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AN INVESTIGATION INTO THE TECHNIQUES OF DIRECT DRILLING SEEDS INTO UNDISTURBED, SPRAYED PASTURE.

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An investigation into the techniques of direct drilling seeds into undisturbed sprayed pasture

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ABSTRACT

Methods of evaluating the techniques and equipment used for direct drilling of seeds into untilled soils were reviewed and developed. Field tests were used to highlight seedling establishment problems and were complimented by a tillage bin technique which sought to isolate variables such as climate, soil type and soil moisture regime. The tillage bin technique involved collecting half-tonne undisturbed blocks of turf in open ended steel bins using a special turf cutting machine. These tillage bins were subjected to a common climate and moisture supply by placing them beneath transparent rain canopies and applying water artificially. Drilling utilized a support bed on which several bins were placed end to end and which was straddled by a moving gantry and tool testing apparatus operating on rails alongside. This facility allowed close visual appraisal to be made of the action of coulters and seed deposition and was operated at speeds which were infinitely variable, within limits. Seed metering was precisely controlled and selected coulter forces and soil physical properties were measured with the apparatus. Turf blocks, in their tillage bins, were returned to the rain protection canopies after drilling for plant response studies.

Soil cover over the seed appeared to be important in promoting seedling emergence. Field covering devices were evaluated and a bar harrow was developed and adopted as a standard covering procedure. The importance of covering the seed appeared to be more pronounced with large seeds such as maize and barley than with smaller seeds such as lucerne. A strong relationship between visual scoring of the amount and type of cover, and seedling emergence data was established. This favoured covering media with a predominance of unbroken dead pasture mulch, compared with loose soil and rubble.

The performances of a range of drill coulters operating at slow speeds in association with the bar harrow, were compared in terms of plant responses under soil moisture stress. An experimental chisel coulter was developed to obviate the noted shortcomings of some of these existing coulters. In contrast to the "V" shaped grooves left by most coulters, the chisel confined most of its soil disturbance to sub surface layers, with a narrow opening at the surface.

With all coulters, seed germination appeared to be less affected by coulter design than seedling emergence because of sub surface mortality of seedlings. In this respect clear seedling emergence responses favoured the

chisel coulter. Maximum wheat seedling emergence with the chisel coulter assembly was 77%, which was significantly greater than hoe and triple disc coulters with 27% and 26% respectively. As the initial soil moisture level was raised in other experiments the magnitude of these differences decreased but the order of ranking remained. A 22% comparative decrease in initial soil moisture content was necessary to reduce the performance of the chisel coulter to a similar level to that of the hoe and triple disc coulters.

Difficulty was experienced in accurately monitoring in-groove soil moisture regimes, but irrigation responses and gravimetric determinations of sub samples suggested that the ability of grooves to retain available soil moisture was a critical factor in the plant emergence responses.

Soil temperatures appeared not to be greatly affected by coulter type in these experiments although the in-groove minimum temperature with the chisel coulter was significantly higher than the hoe and triple disc coulters in one experiment.

Observation of the modes of action of coulters showed that the chisel and hoe coulters produced some upward soil heaving while the triple disc appeared to operate with a downward and outward wedging action in the soil. An increase in soil density under the groove resulted from passage of the triple disc coulter but no effect on density was seen with the chisel or hoe coulters. The down forces required for 38 mm penetration of all coulters tested, appeared also to be closely related to their modes of action and relatively insensitive to soil moisture content in the stress range. In this respect the triple disc required 1.4 times more force than the dished disc coulter and from 2.3 to 4.6 times more force than a range of 4 other coulters.

Field tests of the wear rates of chisel coulters constructed of various steel based materials, with and without hardening treatments, suggested a number of preferred treatments but could not establish any difference in wear rate from coulters operating in the tractor wheel marks compared with those operating in unmarked soil.

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DEFINITIONS

1. Unless defined in Appendix 13 or otherwise explained in the text, all references to agricultural machines or components thereof have the meaning stated in British Standard 2648: 1963, "Glossary of Terms Relating to Agricultural Machinery and Implements".

2. GENERAL INTRODUCTION

Direct-drilling is a term used to identify the practice where seeds are introduced, by mechanical means, into an untilled seedbed, the vegetation of which has been reduced to a non-competitive stage by harvest, herbicide application, natural mortality or drought. In the context of this investigation the term is not intended to include drilling into untilled ground supporting a competitive vegetative canopy. Such a practice is usually referred to as overdrilling or sod seeding. Because of the presence of a competitive cover at the time of drilling, it requires additional functions from the machinery employed, in comparison with direct drilling, and may affect the micro-environment of the seed in a different manner. The practice of direct drilling appears to have the potential to play an important roll in crop and pasture establishment through savings in energy, soil structural loss, soil loss through erosion, and soil moisture.

Numerous authors have reported equal or better crop yield and/or plant emergence counts with direct drilling, as compared with conventionally tilled seedbeds (1,2,3,4,5,6,7,8,9,10,11). Neverthe-less there are other reports of apparent deficiences as far as direct drilling is concerned (9,12,13,14,15,16).

In New Zealand, direct drilling was first reported in 1958 (17). For a number of years, direct drilling on a farm scale relied on, at best, modified conventional seed drills. Until 1969 no New Zealand manufacturer had undertaken specialist production of a seed drilling machine for this specific purpose. As a consequence, conventional drills had to be modified and adapted to the task and this was achieved with only limited success. For instance, few were robust enough to withstand the more vigorous treatment when working in untilled seed-beds, and few conventional drills displayed sufficient vertical coulter movement to accomodate ground contour changes. A number of low cost drilling machines based on either disc harrows or coil tine cultivators were also marketed. While they had obvious advantages in terms of cost individual vertical drill coulter movement was usually restricted or absent, resulting in uneven depth and seed placement.

A disc coulter assembly intended specifically for direct drilling was developed in the United Kingdom in 1964 (18). It led to the New Zealand manufacture of a special direct drilling seed drill featuring a similar coulter assembly.

Despite the growing interest in machinery aspects by commercial organisations little published work nationally or internationally, had been directed specifically at answering the questions "What soil physical conditions best suit seeds sown into untilled seedbeds?" and "What mechanical designs of seed drill coulters and ancillary equipment best fulfill these demands?" There is an absence of quantitative data on which to base designs and only few critical comparisons of machines measured in terms of plant responses under specified and monitored condition.

Observations of crops during the emergence phase in Wagga Wagga (Australia), Takapau, Manawatu and other areas of New Zealand suggested that crop emergence and/or germination failure may have been associated with several factors, including dessication, mechanical soil impedence, soil-seed contact, bird and insect damage, and low soil nitrogen levels (19,20,21). The dearth of information concerning seed germination in, and seedling emergence from untilled seedbeds, together with a lack of published data underlying the mechanical design and functional characteristics of seed drill coulters for this purpose, has been overshadowed by a relative abundance of information on herbicide-plant interrelationships in the supression of resident vegetation prior to direct drilling. Such has been the apparent "hit-and-miss" development of direct drilling coulters and covering devices that this appeared to have become a "weak link" in the chain of narrow tolerance requirements for successful seedling emergence by the technique.

The investigation reported herein has had a four-fold purpose.

a. To develop a technique to permit close study and quantification of the action and effects of direct drilling coulters and covering devices operating under controlled conditions.

b. To identify factors limiting seedling emergence from untilled soil under soil moisture stress.

c. To compare known mechanical devices with respect to their abilities to create physical conditions within untilled seedbeds which might favour seedling emergence.

d. To design where necessary, experimental mechanical devices which might improve on the performance of existing designs.

3 DEVELOPMENT OF EXPERIMENTAL APPARATUS AND TECHNIQUES

3.1 INTRODUCTION AND REVIEW

3.1.1 Seed germination requirements

The requirements for germination of seed have been extensively researched and summarised by Mayer and Poljakoff-Mayber (22), who also noted several differences in moisture and temperature requirements between species. While the physical conditions of a cultivated seedbed and sowing technique which might fulfill these requirements have been commonly assumed to include good soil-seed contact, air, temperature and moisture status of the soil, it is by no means certain that all such assumptions can be safely extrapolated to untilled soils.

Lillard and Jones (23) had earlier noted that the physical factors which constituted the main considerations in the immediate seed environmental zone and in the water management zone between the crop rows were soil moisture, temperature, air and mechanical relationships in the seedling zone, together with surface detention, air porosity and surface structure maintenance in the water management zone. They pointed out however that data was not available for similar seedbed characterization under no-tillage (or direct drilling) conditions.

3.1.2 Seedling emergence under direct drilled conditions

In the early years of direct drilling research there was apparently some acceptability of reduced emergence of seedlings when compared with drilling into conventional seed beds. Triplett and Van Doren (12) recorded seedling emergence percentages of 65% in silt loam and 82% in silty clay loams to clays, when corn was direct drilled, as compared with 85% and 87% respectively for drilling into a conventional seedbed. The drilling machines were described as having used "hollow" coulters that were sometimes preceded by a disc. On the basis of these results the authors felt justified in stating that "any corn planter that would place the seeds at the proper depth and cover them would probably be satisfactory". Hood et al (3) claimed that similar emergence counts to ploughing and conventional sowing had been recorded using a coulter system which produced a vertical slit 12.5mm wide and allowed seed and fertilizer to be introduced to the soil at a depth of from 25 to 50mm. The design featured a 200mm diameter flat pre-disc followed by what was described as a knife coulter. The disc was to cut trash and also act as a depth control, while the knife was to open the slit.

3.1.3 Failure of techniques and machines

Several workers noted that there were apparent shortcomings in some methods of sowing (24). In many cases though, little insight into the causes of failure was given. In New Zealand, experience has apparently been limited to a small range of drill coulters, but Matthews (25) stated in 1972 that manufacturers had been slow to produce precision equipment specifically designed to drill seed into a dead sod with minimal destruction of the sod. The experience of Leonard (26) in New Zealand had been limited to a modified light commercial hoe coulter and a triple disc coulter, but he felt that experience and further developments in machines were necessary if direct drilling was to be extended into drier cropping regions. This view apparently echoed the previous limitations noted by Hunt in the dry areas of Scotland (13).

3.1.4 Reasons for direct drilling failure

Some authors attempted to pinpoint more closely the areas of failure in direct drilling techniques. For example, Kahnt (16) claimed that failures arising from drilling with triple disc coulters, occurred:

" a. when maize or field beans were drilled,
b. when they were used on dry or consolidated soils,
c. when they were used on leys with insufficient kill of grass"

He claimed also that the "Rotaseeder" (which featured rotary coulters) had failed:-

" a. when the rotavated strips were narrower than 30mm
b. when drilling was done at high speed
c. when it was used in wet, consolidated or uneven soil surfaces."

This author also quoted trials by Schwerdtl where winter wheat sown in 1967, 1968, and 1969 with triple disc coulters yielded 33%, 15% and 100% respectively, compared with a single blanket rotary cultivation to 30-80mm depth with simultaneous broadcasting of seed into the disturbed soil.

The inadequate performance of triple disc coulters was linked with their tendency to leave seeds uncovered and also the difficulty of controlling depth, according to Baeumer (15). He felt that this had been one of the main causes for the failure of direct drilled crops in German trials between 1966 and 1969. The shortcomings were apparently more pronounced on soils with little tilth and during seasonal dry periods.

3.1.5 Groove formation and covering

Evans (27) noted that one difficulty of using sod-seeders for sowing into dead turf was that the coulters made a wide slit in the soil which often did not close up again properly, or may have opened in dry weather. He also claimed that this had "interfered with proper establishment of the sown seeds". Plate 1 illustrates a similar effect in a "Te Arakura silt loam".

A dry period following sowing using a pre-disc and hoe coulter assembly, allowed the slits to re-open, according to Blackmore (28). He observed that where chemical spraying prior to drilling had been done, the slit re-opening had been less than when it was applied just prior to drilling. This, he attributed to loss of elasticity of the turf by the earlier spraying. Blackmore (loc cit) felt that the distance between the rows was also important and cited examples where 75mm spacing apparently opened only half as much as for 150mm spacing.

These views were also supported by Taylor (29) who felt that in addition to rapid dessication and poor germination, a wide slit often left seed exposed to birds and allowed substantial weed germination. He observed varied success with dished disc coulters, their greatest failing being with deep sowing on turf or heavy soil where the flap that was produced restricted seedling emergence. The dished disc coulter apparently also suffered with excess speed, according to Hood et al (3), who observed that the higher the speed the greater was the tendency for the sides of the groove to be disturbed and for the groove to be left open.

Plates 2 and 3 illustrate respectively, a flap created by a dished disc coulter in moist soil and the tortured path of a ryegrass shoot in attempting to emerge from this environment.

Plate 1: Exposed barley seed visible in the groove created by a hoe coulter in moist silt loam. (with acknowledgement to L.W. Blackmore)

Plate 2: Dished disc coulters creating soil flaps in moist soil

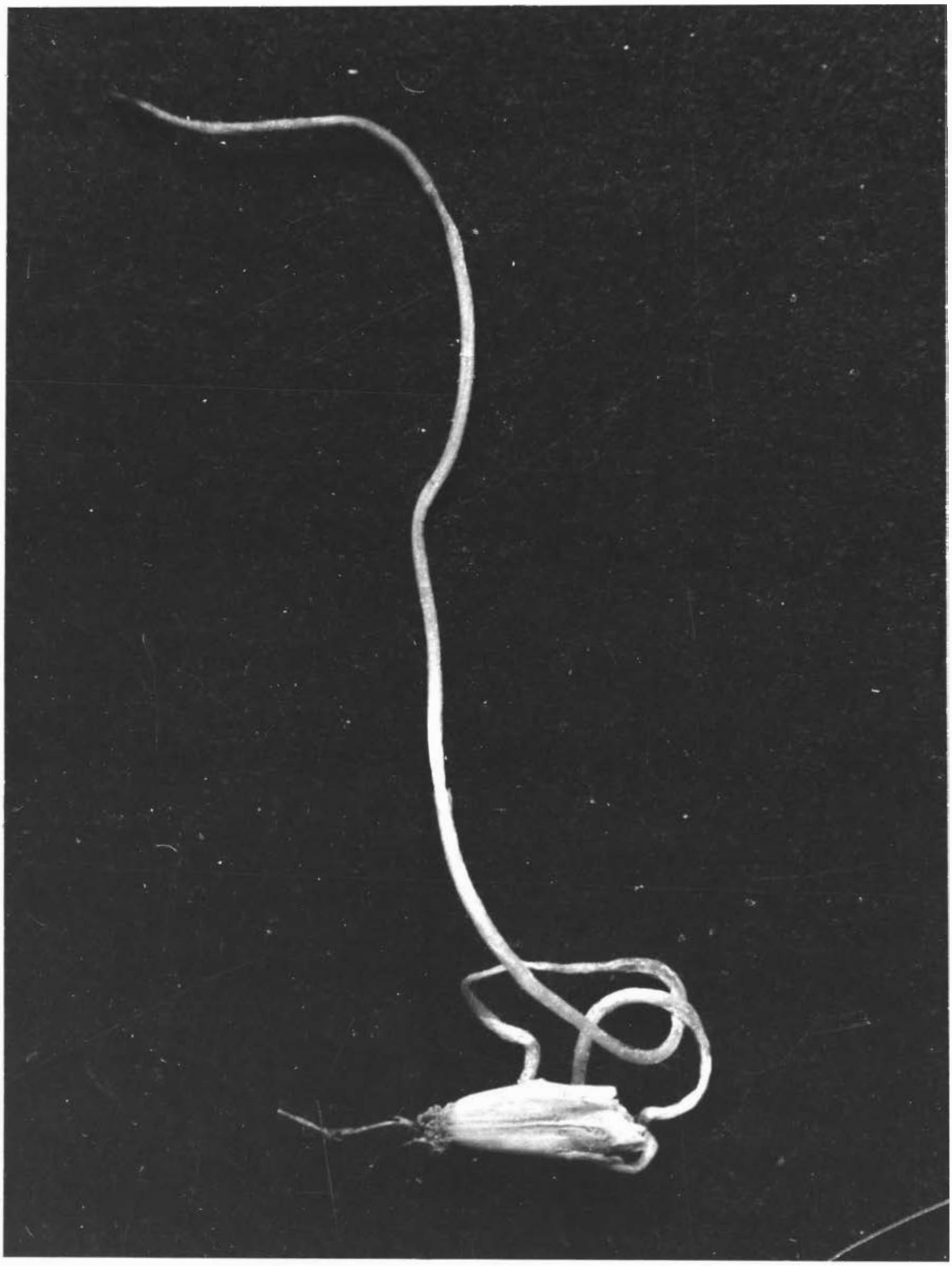


Plate 3: The growth formation of a ryegrass shoot under a soil flap

A number of observations by the author of plant emergence arising from the use of a range of drill couters in New Zealand during a succession of dry periods suggested that study of coulter performance during moisture stress would be important. This reasoning was further strengthened in that little apparent differences between drill coulter performance could be observed when the weather following drilling had been moist and favourable.

Varying amounts of loosening and shattering of the soil occurred as a result of the passage of different drill coulters. The type of cover provided for the seed was similarly variable according to the type of covering operation (if any) which was used after drilling, and to the physical condition of the bounding regions of the seed groove from whence most of the covering material was derived. The condition of the vegetative cover, although sprayed and dead, appeared to influence these factors to some extent, as did the interval between spraying and drilling. Longer intervals (in excess of 10 days, and depending on the intervening weather) seemed to favour at least partial break down of the root system of the dead plants with the result that soil stability in and around the seed groove was reduced. This tended to result in more shattering of the groove and adjacent soil. Perhaps the most noteworthy observation was that irrespective of the differences in the extent of soil shattering, seeds appeared to germinate and emerge more quickly and more vigorously where a flap of dead turf-covered soil covered the seed.

3.1.6 Desirable drill and coulter features

It is apparent that few of the shortcomings of drilling techniques noted in the literature were compared quantitatively, although observation and opinions formulated from them may have assisted in other more positive statements concerning drill coulter design preferences. In the early trial work of Jones *et al* (30) seed was planted by removing small soil cores, dropping seed in the holes, filling the holes with pulverized moist soil and firming the soil with the thumb. While later reported work has usually departed from this seemingly laborious method of sowing, Denize (5) reported that a hand operated rice seeder developed at Okayama Agricultural Experimental Station, punched out a plug of soil to form a hole into which seed was fed simultaneously.

Blackmore (17) specified the desired type of furrow as consisting of a "V" shaped, continuous, plant free track of comparatively shallow and even depth. In relation to these specifications, he felt that seed drills should have independent coulter action, good penetrating ability, self regulating depth control, furrow openers capable of producing wide "V" shaped furrows, and self covering devices. The preference of Blackmore for wide "V" shaped furrows was apparently related to competition suppression where herbicides were not used or were ineffective.

Other authors (18,31,32) preferred the "V" shape, even with effective competition control by herbicides. The first author, cited above, outlined the design criteria adopted for the development of a drill to be equipped with either triple disc coulters, or what was described as "disc and knife coulters".

These were:

"a. combined seed and fertilizer drill
b. row spacing of 150-175mm
c. superior trash control and cutting ability
d. positive seed insertion with firm seed-soil contact
e. seed-soil contact to be maintained under very hard or wet soil conditions
f. wear of the soil working elements must not interfere with efficient trash cutting or seed deposition, or increase load requirement
g. long life of soil-working elements under hard working conditions
h. good seed handling characteristics for small or large seeds without injury to seeds at any seeding rates
i. good contour following by coulters
j. power requirement within current tractor range
k. working rate at least equal to conventional drilling rates
l. simple operation
m. reasonable price
n. low maintenance requirement
o. large adjustable hopper."

A smaller force requirement (for both tractor pull and coulter loading) when the coulters were at 65-75mm depth, together with superior trash handling ability, suggested that preference be given to the triple disc coulter for further development.

Lillard and Jones (23) and Jones et al (30) felt that maize planter requirements should include:-

"a. assisting tools in front of the planter opener, to ensure uniform penetration, provide limited subsurface tillage in the immediate seedling environment zone, and remove enough dead sod from the surface to minimise impedence to plant emergence,

b. a press wheel to firm the maize seed into the soil and a coverer to completely close the slit opened by the opener, so as to eliminate air pockets in the vicinity of the seed, and

c. a press wheel to firm the soil over the seed."

Several authors (33,34,35) briefly described machines used in experiments, without venturing opinions as to their suitability.

3.1.7 Experiments comparing drill performance

Few experiments have been designed to quantitatively compare different methods of introducing seed into untilled soil under controlled conditions. Nor have the effectiveness of alternative mechanical devices in modifying the soil conditions in the immediate vicinity of the seed been compared.

In a comprehensive summary of work relating to minimum cultivation and direct drilling, under the separate headings of "general", "cereals", "maize", "sorghum" and "rice", Johnson (36) listed 456 titles (and in some cases, summaries) of contributing authors. Only a small number of these were related to the drilling method, and only three quoted data relevant to the drilling technique, per se. Scharbau (37) in a review of European work, noted that although workers in United Kingdom, Holland, Sweden, Belgium, France, Switzerland, Italy, West Germany, Hungary, Czechoslavakia, Poland and Rumania had investigated aspects of direct drilling, the main physical aspects which had received attention were studies of root development.

The majority of quantitative comparisons were reported between 1963 and 1969 and little work has been done since. Furthermore, all of the comparative data reported during this period appear to have been with maize, and most have been more concerned with final yield data than with the development of the plants through the germination and emergence phases.

The first comparison between two machines, expressed in terms of seedling emergence appears to be that reported by Triplett et al (38). They compared two maize planters, one of which featured a pre-disc to cut the surface residue, and a hollow coulter through which seed and fertilizer were dropped through separate openings. Small wings operated below the soil surface to fracture the soil and apparently facilitate separation of seed and fertilizer. The other maize planter consisted of a 350mm wide flat sweep working below the soil surface, followed by three wheels of a rotary hoe to "manipulate" the soil in front of a conventional maize planter with what they described as a sword-type opener. Various amounts of surface residue were involved, ranging from no residue to a condition where normal residues were increased by the addition of residues from another source. Under rainfall conditions which the authors considered to be "not limiting", after 30 days the only significant differences in seedling emergence were with the wide sweep coulter where 83% emergence resulted from "no residue", compared with 71% with "double residue". Both the "no residue" and "normal residue" conditions using this latter machine were better than all conditions with the first listed machine. The authors noted that this appeared to be because a high proportion of seeds had germinated but failed to emerge in the latter case which was thought to have reflected surface sealing, although it was also noted that these seeds had been place approximately 25mm deeper than in the other treatments. These results were partly confirmed by Lillard and Jones (23) who compared three versions of "no-till" (direct drilling) maize planters, each involving different degrees of disturbance of the soil in the seedling zone and the dead mulch cover immediately above the seed. None of their designs appeared to be specifically concerned with subsurface soil disturbance beneath an undisturbed surface mulch and the authors again noted that air and temperature conditions during the germination period were favourable. These authors were apparently less concerned with seedling emergence than germination.

In summary, they stated that the germination percentages appeared to be influenced by the extent of soil disturbance around the seed as well as mulch removal above it. The highest germination of 83% occurred with a planting arrangement which removed the mulch from just over the seed and subtilled an 150mm strip 64mm deep along the row. The other planting procedures which gave either less or more disturbance in the seedling zone, all apparently showed lower germination.

3.1.8 Identification of important soil physical parameters

Lillard and Jones (loc cit) generalized that under no-tillage conditions prepared by chemical kill of the vegetation, the following conditions could be expected, compared with conventional cultivation:-

"a. higher bulk density, but more stable soil structure
b. about 2.8°C lower average maximum temperatures, and 2.3 - 3.4°C less fluctuations between day and night averages, with little difference in daily minima.
c. more available water in the root zone throughout the season
d. a more rapid rate of plant growth, and generally as high or higher grain and stover yields
e. superb erosion control and water use efficiency".

The work of Moschler et al (39) supported some of the above observations, and their measurements had shown that more soil moisture was present under sod-planted (or direct drilled) maize than under that sown conventionally, and that this difference was more pronounced in the first half of the growing season. They felt that protection from soil drying in the early stages of growth was especially important.

A number of other experiments comparing the amount of mulch present at sowing have been reported in terms of terminal yield of the crop. While these figures could not be strictly interpolated to reflect seedling emergence performance, they were felt by the authors concerned to be in part a function of the soil environment created by direct drilling. Triplett et al (40) compared various levels of trash cover over a "Wooster silt loam" and found that grain yields fell significantly below those of tillage treatments when the mulch was removed, but that where it remained, or was artificially increased, the opposite effect resulted. In support of this, he found that not only had soil moisture increased with the amount of cover, but so too had infiltration after the plots had been treated for three years. Shear (33) also quoted corn yield results which indicated that significant increases were gained in two successive years out of three from retaining rye as a mulch, compared with removing it at the time of drilling.

Residues from 6270kg/ha (100 bu/ac) maize crops were claimed by Larsen (41) to be capable of reducing temperatures in the top 100mm of soil 1.2°C, equivalent to about 0.4°C / tonne of residue. They supported the contention that infiltration may be increased and erosion decreased by no-tillage residues on a good grass sod, but felt that infiltration may be reduced on land previously under row crops.

3.1.9 Monitoring in-groove conditions

The data relevant to soil physical conditions as a function of the drilling technique all appear to reflect the general soil body and not the specific micro-environment within the groove. Perhaps the lack of more detailed measurements arises from the difficulty of obtaining realistic data in the groove, but it may also reflect a lack of appreciation of the potential differences between intra row and inter row soil conditions under direct drilling. For example, while the energy interchange at the undisturbed soil surface might be expected to produce steep temperature and moisture depth gradients (42), the stresses at the corresponding boundary layer within the groove are largely unknown and possibly more variable and extreme. Because of this recourse to data obtained from the more stable and predictable inter row soil may have been preferred by previous authors.

Attempts to more closely monitor intra row conditions have been one of the more noteworthy aspects of this investigation.

3.1.10 The physical effects of coulters travelling through soil

There appeared to be no published data relating specifically to the interelationship of physical properties of the soil and the passage of specific designs of direct drilling coulters. It is doubtful if data relating to soil flow from the passage of tools in vegetation-free soils has much relevance when dealing with soils in which the physical strength is largely attributable to pasture root systems, but the action of a tine advancing through the ground has been described by several workers (43,44). The last quoted of these authors noted that at that time, only the briefest mention had been made in the literature of factors affecting soil strength and cohesion but that the presence of roots and state of aggregation were important variables in this respect.

Although the work of Willatt and Willis (45), in characterising the shape of grooves left by a chisel plough might be expected to approximate the action of some direct drilling coulters, they also avoided the use of soil with vegetative cover, except in one instance. Apparently no similar work which might have relevance to direct drilling, has been reported for disc coulters or other designs of furrow openers.

3.2 OVERCOMING THE DISADVANTAGES OF FIELD EXPERIMENTS

The limitations of field experiments were largely overcome by testing drill coulters in undisturbed soil which was protected from the weather. To achieve this and to also permit more precise mechanical control and measurement than was possible with field or plot drills a system was developed where undisturbed blocks of turf-covered soil were collected in steel bins using a special turf-cutting machine. Each bin and block was transported to a site where it was covered by a transparent canopy to allow a moisture stress to develop in the soil. Removal to an indoor tillage bin facility comprising an elevated bed, straddled by a mobile gantry and tool-testing apparatus, was followed by the drilling operation. This used drill coulters mounted on a special frame. Penetrative forces were derived by adding weights to the coulters and the seed was metered precisely at infinitely variable drilling speeds (within limits). After drilling, each tillage bin was replaced under the rain protection canopies, to be subjected to further controlled moisture stress during the seed germination and seedling emergence phases.

The apparatus and system which were first described by the author in 1969 (46,47), involved the development of a turf cutter, portable tillage bins, special transportation equipment, support bed, moving gantry, tool testing apparatus, and rain canopies.

In an extensive review of literature centering on minimum and zero cultivation, (36), it appeared that all comparative studies had involved field trials and that no attempts had been made to control or isolate any climatic or soil variables relating to moisture availability. It was clear that the shortcomings of drill coulter design in offering protection for the implanted seed from drying, would best be highlighted in soil moisture stress conditions. In the Manawatu area no reliance on continuing dry weather could be assumed (see Appendix 1). Even if field trials had been feasible, comparison between the effects of soil type and parent vegetative cover would have required a number of sites, each with its own characteristic weather. In fact one of the more noteworthy advantages of the tillage bin system described herein would be to allow comparison of the effects of different soils collected from remote sites but tested under a common, partially controlled climate.

Nevertheless a number of field experiments were undertaken to help highlight field problems which required controlled investigation by the tillage bin method.

3.2.1. Field equipment

The difficulty of control and access, lack of precision, and reliance on springs for coulter penetration with tractor drawn field sowing drills precluded their use for critical studies of the mechanical operation of groove forming components. Plot drills were also not considered as most appeared to feature coulter mounting systems unsuited to this type of work, and lacked sufficient robustness for direct drilling.

Although studies relating to the physical effects of tines moving through the soil had earlier been noted as having limited relevance to direct drilling, the nature of the work and measurements was not unlike that required in this study. In this respect several authors (43,44,45) had seen advantages in using tillage bins. Although none of their tillage-bin studies used undisturbed and/or pasture covered soil as the test medium, the small scale tillage-bin systems used by Gupta and Pandya (48), Fox and Bockop (49) and Bufton et al (50) displayed a number of potential advantages which may have been applicable to studies involving direct drilling.

3.3 DETAILS OF TECHNIQUES AND EQUIPMENT

3.3.1 Turf block collection

The turf block collection apparatus consists of a rectangular stirrup shaped cutter which is direct-mounted by category one three-point-linkage on a 60 drawbar horsepower wheeled tractor. A steel bin (measuring 2.00m long, 680mm wide (inside measure) and 210mm deep) is temporarily connected to the rear of the cutter by hooks and is pulled through the soil by forward movement of the tractor (Plate 4).

Turf cutter

The basic mounting frame of the turf cutter is a short (1.83m) "Ferguson" propriety tool-bar, beneath which is attached a strengthening sub frame. Two vertical blades are bolted to cast steel legs which protrude downwards from the main frame. Each blade is 400mm long by 110mm wide and constructed of 6.4mm steel plate. Welded to the inside base of each of these blades is a horizontal cutting blade, measuring 670mm (in the transverse horizontal plane), 150mm (in the longitudinal horizontal plane). The leading edge of the horizontal blade precedes the corresponding edges of the vertical blades by 38mm. This design was thought to be desirable in helping the machine attain a planing attitude during the cutting operation. The horizontal blade is hollow in construction. Its upper surface is of 3.2mm thick steel plate which extends forward to form the leading cutting edge. A narrower 3.2mm thick plate extends across the full width of the machine and is welded to the underside of the upper plate 70mm back from the leading edge. This under-plate is also welded along its back edge to the upper plate, but is separated from it at this point by a 4.8mm thick spacing strip. In operation, the horizontal blade is arranged so that the under surface is essentially horizontal in attitude. Thus, the upper surface is slightly inclined and the blade is provided with some relief underneath for a distance of 70mm back from the leading edge.

Plate 4: The turf cutter with a tillage bin attached

Plate 5: Water discharge from the hollow turf cutter blade

Twenty small holes are drilled horizontally through the spacing strip between the two layers that make up the back of the horizontal blade. These holes discharge water from the hollow blade (see "lubrication"). Two 4.8mm i.d. copper tubes supply water to the blade. Each tube is brazed to the trailing edge of each of the two vertical blades and passes into the horizontal hollow blade at the rear-most part of its junction with the vertical blades.

Protection

To protect the copper supply tubes from damage when tillage bins are being connected to,or disconnected from the turf cutter, a number of design features are incorporated.

a. On the outer rear edge of each vertical blade (near the base) are welded short horizontal protrusions onto which the tillage bin hooks grip during sampling. Slightly forward of these protrusions are two buffer strips which prevent inadvertent damage to the copper pipes during connection of an empty bin to the turf cutter.

b. The rear edges of the vertical blades slope forward slightly from a height of 90mm above the horizontal blade. Thus the pipes (which are attached to the rear edge of each vertical blade) are protected by this recess at the critical point of their entry and sealing into the horizontal blade.

c. Because the rear end of each bin is elevated approximately 150mm during the connection phase and early passage of the apparatus into the soil, the leading vertical edges of the bins are chamfered back at 15^{o} from the vertical to provide clearance for this angulation between bin and cutter without endangering the copper pipes.

Despite these design features, caution was required in all sampling operations to minimise the likelihood of accidental damage to the copper supply pipes.

Water supply

Water is supplied to the turf cutter blade from a 55 litre reservoir mounted on the frame of the cutter. A conventional boom spraying pump, regulator and flow-control system is used for pressurisation. Delivery on the pressure side of the system is by clear plastic hoses and a copper manifold. The transparency of the two final supply hoses allows a visual check to be made of delivery.

Tillage bins

Details of the bins can be seen in plate 4.

6.4mm thick plate steel is used in the basic construction of the retangular open ended tillage bins. Symetrically located and spaced 1.0m apart on the top edges, are four lifting rings which match a special frame carried by the front-end-loader of a tractor.

Two rounded hooks are welded to the lower leading edges of the sides of each bin. The inside gripping face of each of these hooks is vertical. Although a slight backward rake would have assisted their grip in the matching protrusions on the cutter, such a rake was found to make disconnection of the filled bins from the cutter difficult.

A liner of 1mm stainless steel veneer covers the inside base surface of each bin. Location of this veneer is facilitated by wrapping it around and under the leading horizontal edge of the bin for a short distance. Thus all soil flow through the bins (during both filling and emptying) is required to be from front to back to avoid sliding the veneer out from the bin.

Each tillage bin has two 50mm diameter holes cut in the base, and the stainless steel veneer has fifty two small diameter holes symetrically punched through it. These holes form the entry passage for water applied to the base of the soil during its storage. The holes are punched through the veneer rather than drilled to ensure that this portion is slightly raised above the base of the bin (by the indentation marks) and thus facilitates ready and even movement of water to the bottom of the turf block.

Soil disturbance

Lateral soil disturbance was minimised during collection of turf blocks by bevelling the leading edges of the vertical blades of the cutter on the outside only, and providing 6.5mm cutting relief on each side, compared with the inside width of the tillage bins. Although the hook attachment protrusions (near the base of the cutter) project a further 13mm outside the nominal cutting region, their restricted size appeared to create little additional disturbance. In any case the extra soil disturbance that these protrusions might have created was limited to the soil alongside the lower-most portion of the blocks and was therefore considered to be unimportant.

Vertical soil disturbance, or heaving, was minimised by adjusting the overall pitch of the horizontal portion of the cutting blade so that it attained a planing attitude just beyond the required cutting depth. Depth wheels prevented further downward movement and ensured a consistant operating depth, despite minor pitching of the tractor as its wheels traversed small surface undulations (51). The 250mm diameter depth wheels, which are mounted on two pairs of legs protruding down from the sub-frame, are adjustable for depth and are of plane steel construction. Each has a scraping device attached to prevent adhesion of soil, with its obvious effect on their effective diameters.

Top link movement from draught-control sensing spring depression on the tractor was prevented by wedging this component with a special block. This further assisted in maintaining an even and predictable pitch.

The specific recovery ratio, measured for each of the three dimensions of the rectangular turf blocks, was found to average 1.00 for blocks extracted from an established ryegrass/white clover pasture on a heavy silt loam. This compared favourably with specific recovery ratios obtained by the author for undisturbed vertical soil cores (52).

Lubrication

Although some doubt was expressed about the necessity for lubricants during the collection of undisturbed soil samples of various shapes (52,53), some form of lubrication was found to be necessary for the collection of turf blocks. Without lubrication, soil/metal friction on the horizontal surfaces of the bins was often sufficient to induce compression and shortening of the blocks and in extreme cases, buckling, together with greatly increased draught.

Expense and the inadequacy of available facilities prevented "Teflon" coating of bins, and the recommendation of Stace and

Balm (54) and Palm and Sykes (55) of special oils, silicone grease and cooking fats were thought not to be applicable in this instance. Instead, the base of each tillage bin (with its veneer of stainless steel) was supplied with water at approximately 550-650 kPa. The twenty holes in the trailing edge of the horizontal cutting blade delivered water to both the upper and lower surfaces of the base of the bin by discharging into the space between the cutter and bin. It was felt that water pressure and size of the discharge holes were not critical factors, so long as the holes were free from blockage and sufficient water was discharged in the restricted space to form a slurry on which the undersides of the turf block and bin could both slip at a forward sampling speed of approximately 0.8 km/h. The resulting localized slurry on the underside of the soil block soon drained and was considered to have no appreciable effect on the moisture content or physical properties of that portion of the block required for direct drilling treatments.

Lubrication beneath the bin was primarily to reduce draught, which although difficult to measure accurately under a variety of soil conditions, was generally in excess of 10-13 kN.

Vegetation

Long pasture hampered the turf block collection procedure, but it was found to be little trouble to ensure that the pasture prior to turf block extraction was closely grazed or mown. It is possible that provision of flat vertical disc coulters ahead of the vertical cutting blades would have assisted in this regard. However experience with similar devices on mole ploughs had apparently not been entirely satisfactory (51).

Soil Cohesion

There was little doubt that successful collection of soil blocks by this machine was dependent on supplementation of the inherent strength of the surface layers of the soil by fibrous pasture root systems. Although no specific tests were undertaken, the collection apparatus would not be expected to satisfactorily collect soil blocks under vegetative canopies other than turf, unless they too supported a vigorous and fibrous root system.

3.3.2 Turf block extraction procedure

The following procedural steps were used for collection of a turf block in a tillage bin.

With a spade, a shallow wedge-shaped slice was cut from the soil for a little more than the full width of the machine. (Plate 6). This provided a vertical soil-face for the leading edge of the horizontal blade to initiate its soil entry. Because of the minimal pitch of this blade it was found to slide along without penetrating if the cutter was simply lowered onto the turfed surface and drawn forward.

The tractor was driven to a position which allowed the cutter to be lowered into this wedge shaped trench.

A bin was connected to the cutter by engaging the hooks in their respective protrusions. (Plate 7). A cylindrical wooden roller was positioned under the bin just behind its mid point to elevate the rear end (Plate 8).

Water supply and discharge was checked by engaging the tractor p.t.o. and activating the pressure system for a few seconds.

The tractor was moved forward until the cutter was seen to satisfactorily enter the vertical face of the wedge shaped trench. A second operator was usually required to stand on the front floor of the bin to ensure that the hooks remained totally engaged in their protrusions on the cutter during this critical entry stage. Forward movement was continued until about 200-300mm of the front of the bin was seen to be underground and the operators were satisfied that the hooks had remained engaged. (Plate 9)

The pre-pressurized water system was reactivated and the second operator left his position in the tray. The tractor continued in its uniform forward motion until the bin had been drawn into a depth where the sides were parallel with the ground surface throughout their lengths at the predetermined sampling depth. In all trials undertaken by the author an extraction depth of 200mm was standandized (Plate 10).

The tractor and water supply were simultaneously stopped. During the bin-entry and travel phases, care was taken to ensure that the pitch of the cutter had been correctly adjusted and kept to a minumum by observing the amount of surface heaving taking place

Plate 6: Turf block extraction procedure; (1) cutting lead-in channel

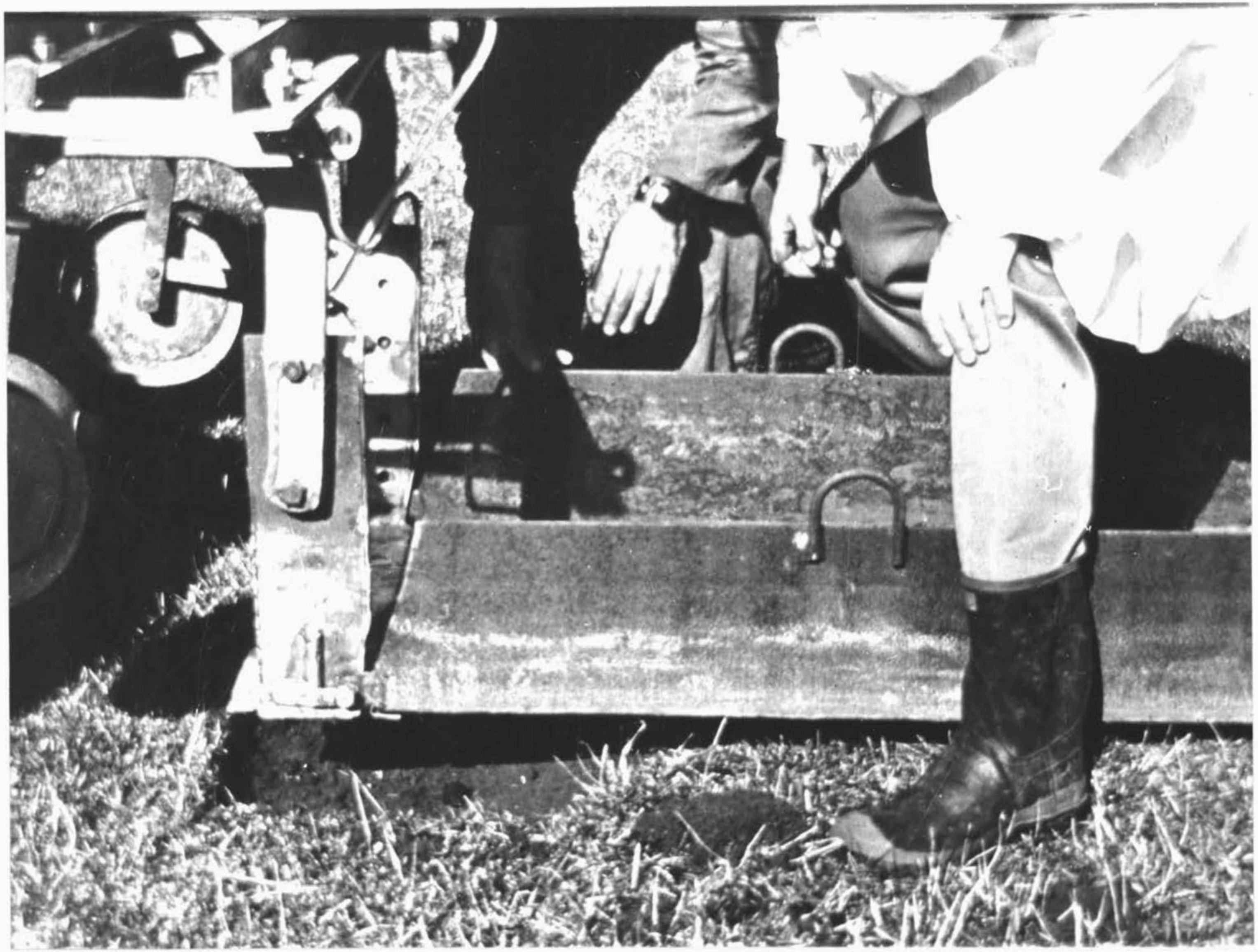


Plate 7: Turf block extraction procedure: (2) connection of tillage bin

as soil flowed over the horizontal blade. Normally, when pitch was optimally adjusted, the machine would require from 5m to 10m forward travel to reach full and even depth.

There appeared to be no critical forward operating speed, but all turf blocks collected for the experiments reported herein, were taken at the slowest satisfactory forward and p.t.o. speeds possible - viz 0.8 km/h.

A spade was used to cut each end of the block in situ about 50-60mm out from the end of the bin to its full depth. (Plate 11).

The tractor hydraulic system was raised, lifting the cutter and front of the attached bin clear of the ground surface, whereupon a length of timber was slipped under the bin. The tractor hydraulics were lowered until the weight of the front of the bin was born by the timer resting on the undisturbed soil adjacent to the formed hole. Lowering was continued until the cutter detached from the bin hooks.

The tractor was moved forward a short distance and the cutter again raised clear of the ground.

The bin was finally removed from the ground by uplifting it with the tractor front-end-loader which attached by a special frame to the four rings on the top of the bin. Attachment was facilitated by two pipe rods which each passed through two matching pairs of loops on the frame and bin. Once uplifted, the 500kg tillage bin and turf block could be rotated in a horizontal plane through a ball race swivel in the lifting frame attachment to the loader (Plate 12).

Final trimming of the soil block was achieved with a sharp knife using a straight-edge and leaving about 25mm of soil overhanging on each end. This overhang was to ensure a close fit of successive bins when they were placed end to end on the support bed of the tool-testing apparatus (as described later). To reduce the possibility of crumbling during transportation, the trimmed ends were undercut with the knife near their base. Where extended travel was anticipated (bins were transported up to 50km) two boards were clamped against the trimmed soil ends to further deter crumbling.

Up to eleven trimmed turf blocks in their tillage bins were lifted onto a special low transport trailer by the front-end-loader.

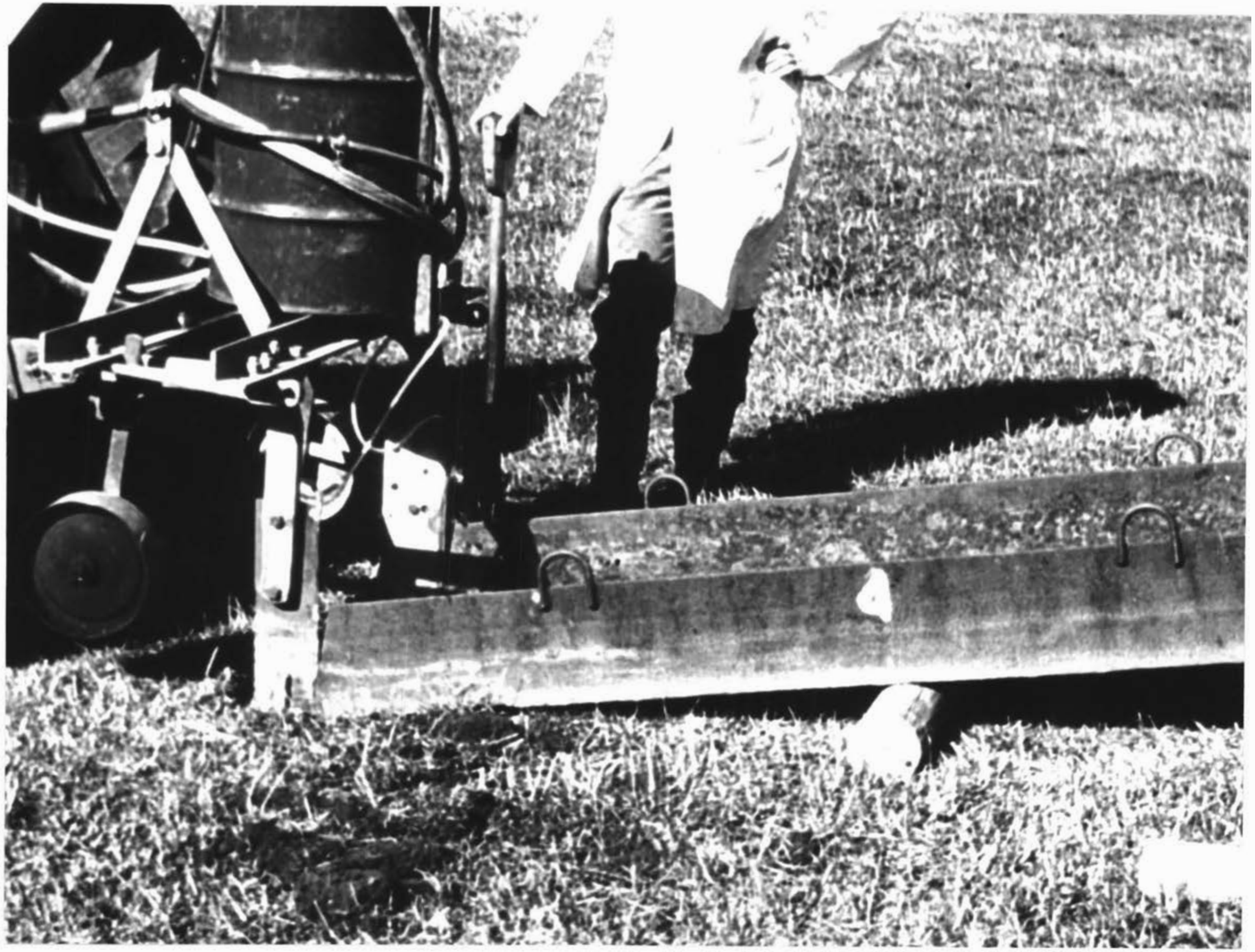


Plate 8:   Turf block extraction procedure; (3) elevation of rear of tillage bin

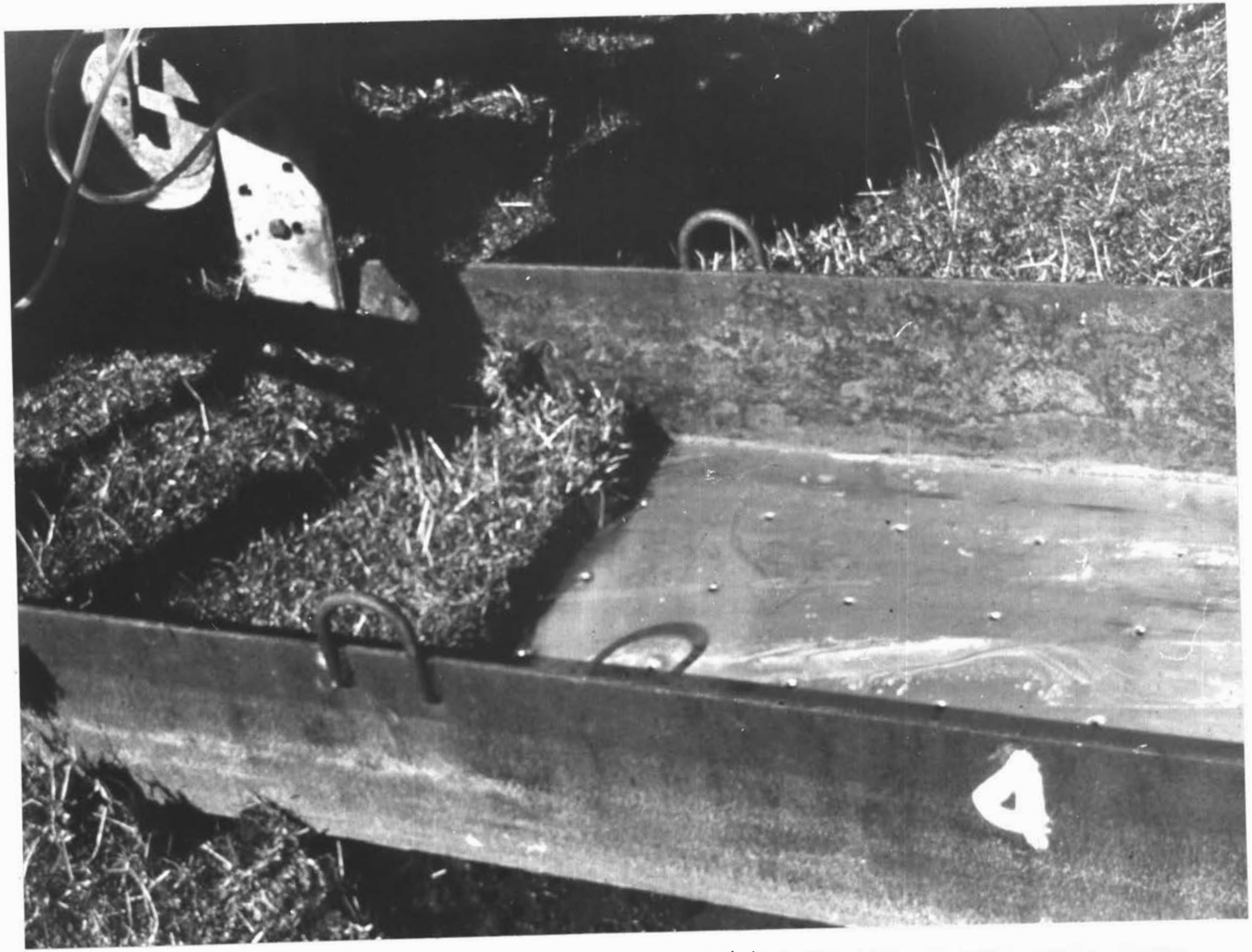


Plate 9: Turf block extraction procedure; (4) initiation of turf cutter travel

Plate 10: Turf block extraction procedure; (5) tillage bin at full depth (note the four lifting rings)

Plate 11: Turf block extraction procedure; (6) severing the turf block ends

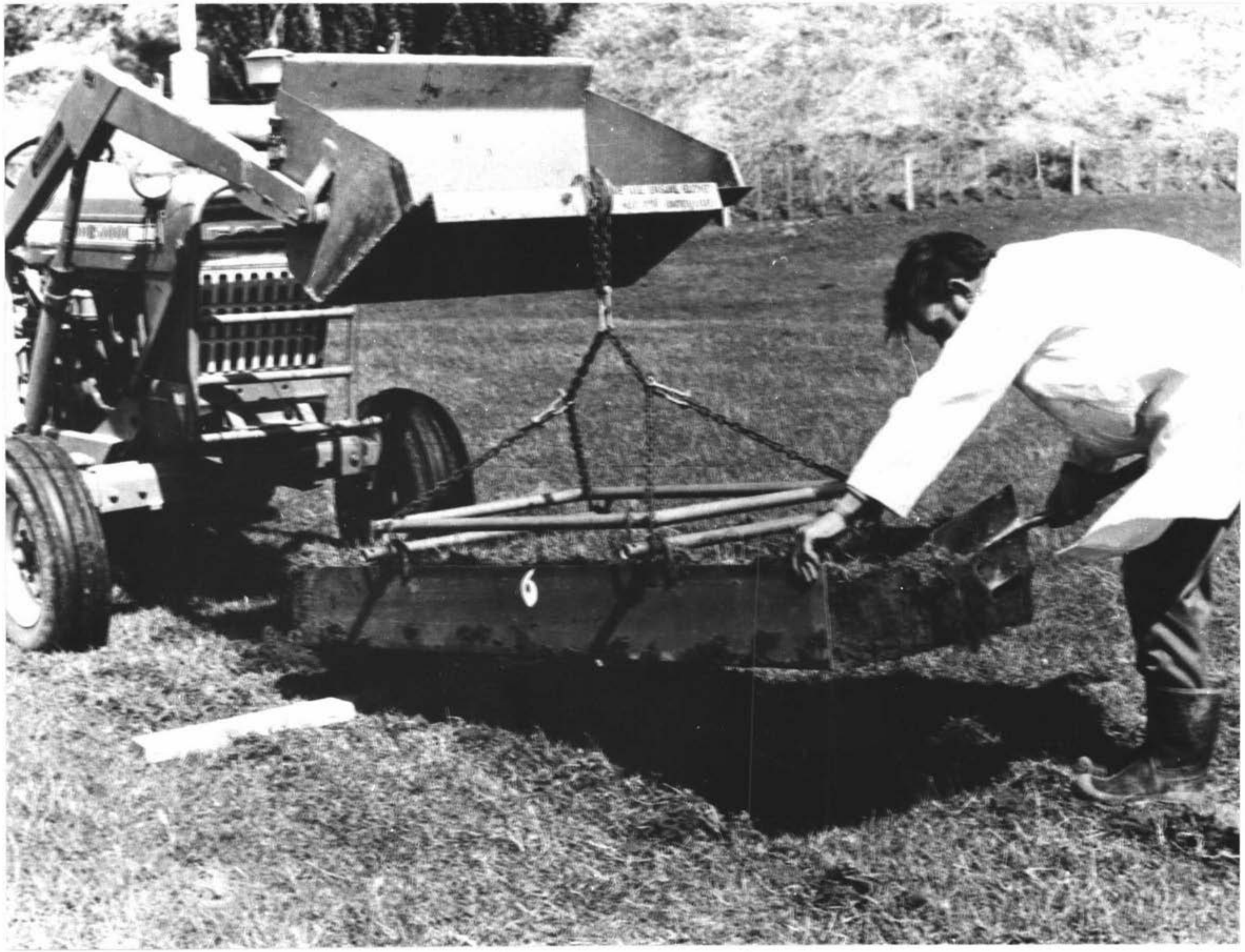


Plate 12: Turf block extraction procedure; (7) uplifting turf block and tillage bin

The tractor, equipped with a vacuum brake system, was coupled to the trailer and the completely self contained extraction and transporting unit, weighing approximately 10 tonnes, was thus removed from the sampling site to the preparation and storage site.

3.3.3 Turf block quality and site selection

During the extraction of turf blocks for use in this study care was taken to avoid areas containing atypical vegetative cover or such undesirable features as holes or humps. Every effort was made, however, to allow random choice of sites. In fact, because of the largely indeterminate distance of forward travel needed to bring the cutter and bins to the required depth, a biased choice of individual turf block sites would be unlikely anyway. Besides, the choice of site and direction was governed to some extent by the topography, the position of extraction of the last block, the tractor wheel marks and the number and position of previously discarded blocks.

A block was discarded when it was observed that during the cutting process excessive heaving had taken place, with the probability that the specific recovery ratio would be reduced substantially. In extreme cases heaving became so excessive that the whole turf block buckled and collapsed. In other instances, traction may have been insufficient and a small amount of weight transfer to the tractor rear wheels through momentarily induced support of the cutter on the hydraulic lift arms induced excessive heaving and even buckling. A discrete amount of such tractive assistance could be achieved with careful manipulation, and appeared not to seriously affect the blocks, but the preferred method of assisting traction (which was always marginal), was to attach another vehicle to the front of the tractor operating the cutter.

The rate of discard of turf blocks from all causes was usually less than 15%.

Care was always exercised in avoiding the passage of vehicles over areas to be sampled.

The procedure outlined above was repeated for the collection of each block, which took two men from 15-30 minutes to complete.

Attempts were made to lower successive bins into the holes left by the preceding blocks, attach these to the cutter and thus continuously extract from an area at the required depth, rather than manually cut a new shallow trench at the commencement of each extraction. While this proved possible on a few occasions, there was a noticably increased tendency for these blocks to buckle during formation. An explanation for this tendency seems to lie in the fact that when starting from surface level the bin gradually increased in depth. By the time the soil/metal friction became critical (assuming that the absolute soil/metal friction increased with depth) the turf block was to some extent being prevented from buckling by the "pull" of that part of the continuous slice which had already passed through the bin. In this respect the fibrous root system of pasture plants appeared to play a major role in giving the soil slice an appreciable tensile strength as well as compressive strength.

In contrast, when initiating the passage of a block through the bin at full depth, the first 2m of travel (and friction) was unassisted by "pull" and thus the block stability relied entirely on the compressive strength of the soil under the influence of "push" from the front. This reasoning was further strengthened by the observation that the majority of turf blocks which buckled from this cause, did so before the soil slice had reached the end of the bin. If a full-depth slice did manage to pass through the end of the bin, little trouble was then experienced with collection of that block.

3.3.4 Emptying of bins

Where bins were required to be emptied (either for discard purposes or where turf blocks were being returned to their holes at the completion of an experiment), the process for emptying was a simple one.

The bin was placed a short distance from the end of a hole by the tractor. It was left in a position in line with the hole and with the hooks closest to it.

The front-end loader was repositioned above the front two lifting rings of the bin (with the tractor straddling the bin) and a chain was passed through the two rings and attached to the loader. Simultaneous lifting of the bin from the front end and forward movement of the tractor usually resulted in the turf block sliding out from the rear end of the bin into the hole from whence it or a similar block had previously been collected.

3.3.5 Preparation, storage and climate control of turf blocks

Preparation

The trimmed exposed ends of each turf block were carefully and manually cleaned of loose material with a wire brush (plate 13)

Each block was positioned so that one end rested above an elongated metal trough of molten paraffin wax, heated from below by a portable gas burner. Wax was liberally brushed on to completely seal the ends of the exposed profile. In this manner an attempt was made to ensure that the drying or wetting front which later advanced through a block would closely parallel the horizontal surfaces of the block. Observation of unsealed blocks under a drying regime suggested that moisture loss from the ends induced preferential dehydration of the vegetation for a distance of up to 300mm from each end.

Storage

Ten water tight trays were positioned on a level site. Each was large enough to accomodate a tillage bin. The trays were constructed of 1mm galvanized sheet and measured 2.4m x 910mm x 150mm high. Each had a drain plug in one corner. Their purpose was to allow the turf blocks to be wetted from beneath when required. To this end, two strips of chicken netting were laid under each tillage bin in the trays to ensure even movement of water under the bins and thence to the two primary inlet holes cut in them. Three wooden frames, which were covered with ultra-violet-light-resistant clear p.v.c. between layers of netting, straddled the trays and bins. These rain canopies were elevated 760mm at the rear and 460mm at the front above the turfed surface of the in-place bins. Their ends and sides, although covered with netting for bird protection were essentially open so that air movement was restricted as little as possible.

The rain canopy frames could be raised to an upright position individually through a rope and pulley double purchase system. Plate 14 illustrates placement of a prepared tillage bin under a raised canopy.

In all experiments involving the turf blocks, replication of treatments for post drilling growth studies involved

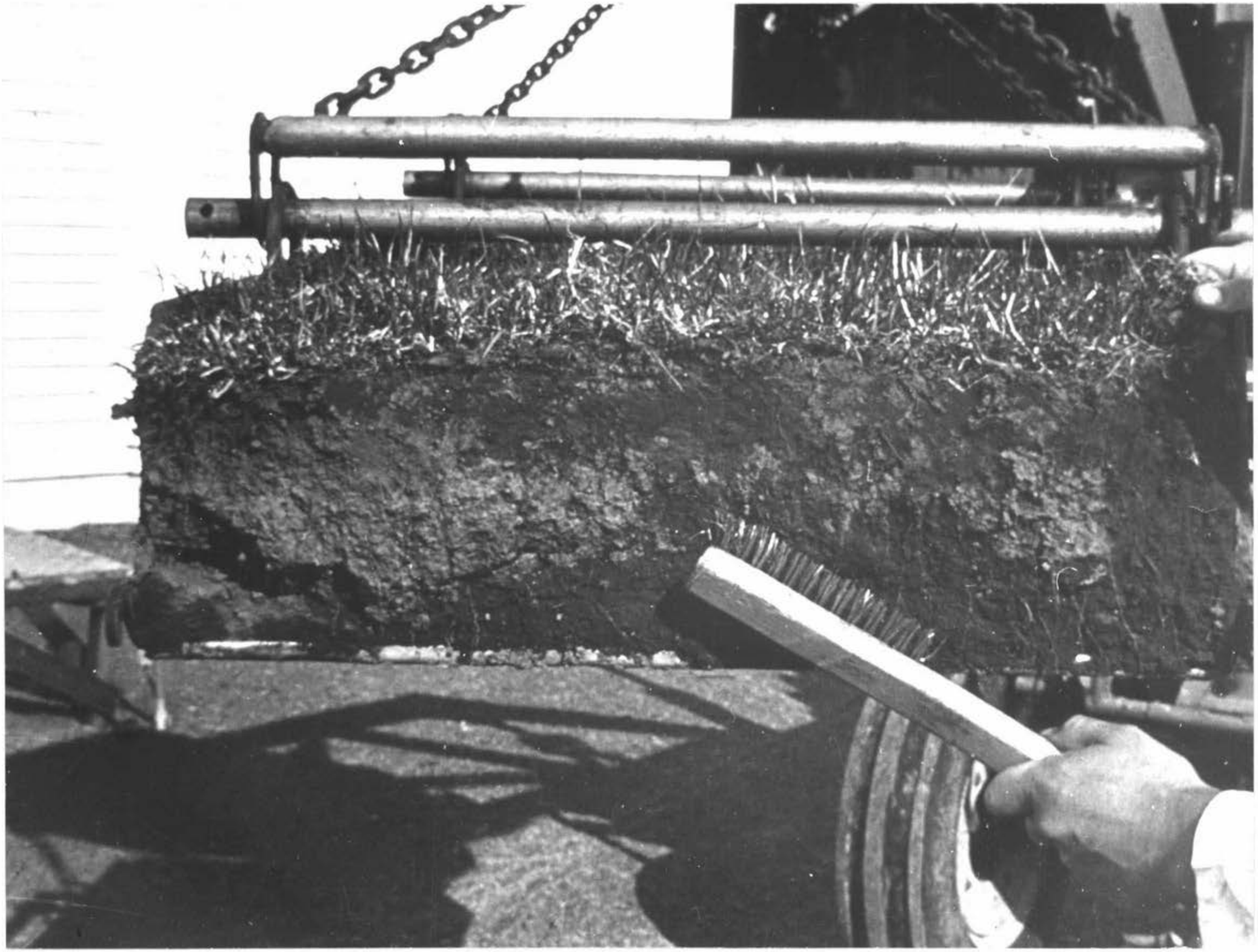


Plate 13: Removal of loose soil from the turf block ends with a wire brush

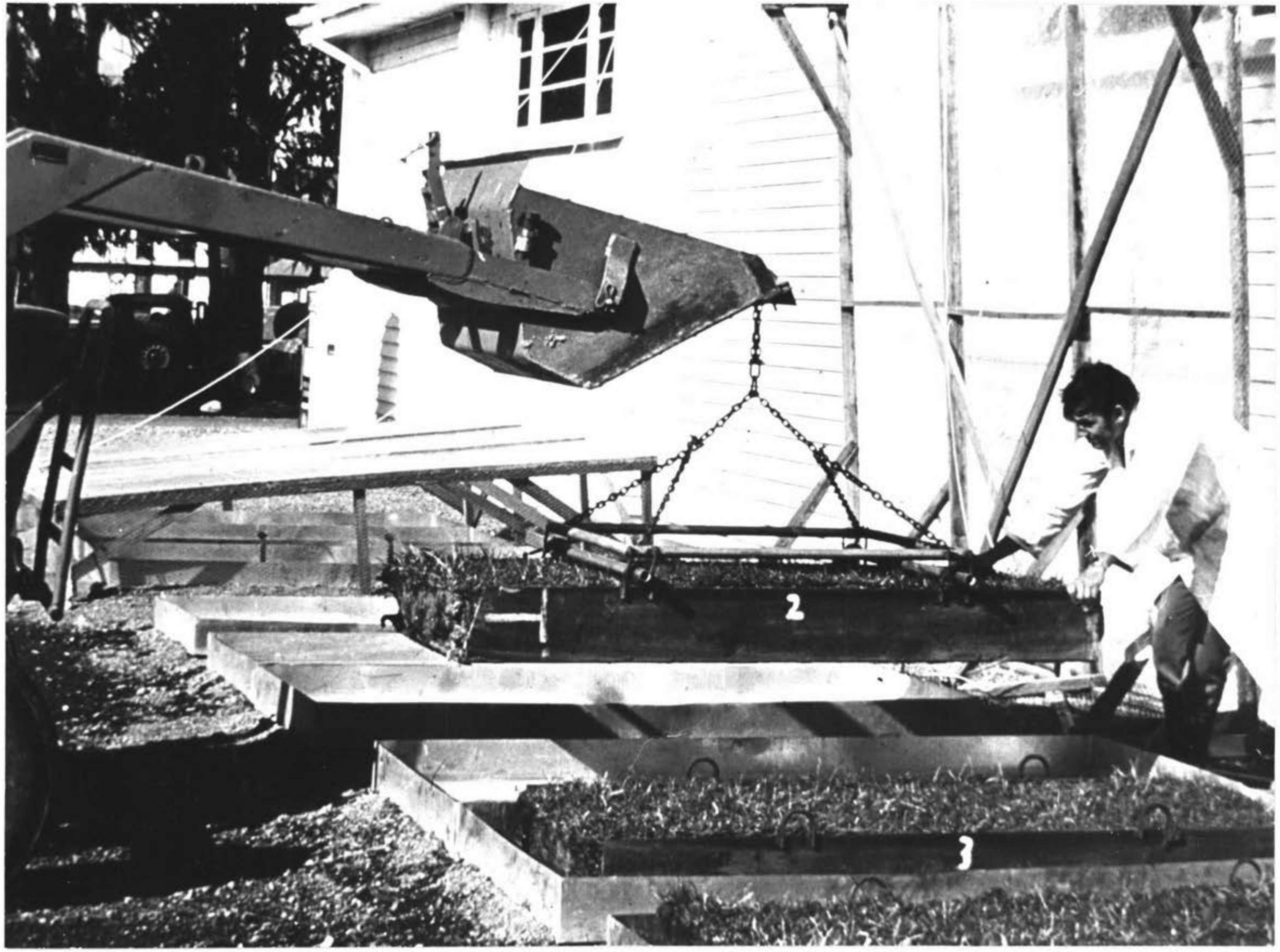


Plate 14: Placement of a prepared tillage bin into its tray, with the rain canopy in the raised position

randomising the order in which blocks were placed in their respective trays under the canopies. In this manner, canopy 1, with its three turf blocks randomly distributed within it, became replicate one, and so on. Although canopy 3 contained four tillage bins, one of these was discarded during the drilling treatments after serving as the "lead-in" block on the tillage bin/support bed system. The soil moisture content of this "lead-in" block was kept the same as the treatment blocks as the physical behaviour of the coulters in the soil could be expected to be in part influenced by soil moisture levels.

Normally, eleven tillage bins were filled prior to an experiment. The eleventh bin (a shorter one, 1.22m long) was not placed under the rain canopies as it served only to form the final area on the support bed into which the drill-coulters under test could "run-out" without bursting the end of the last turf block. For this function, soil moisture content was not considered to be important.

While turf blocks were undergoing pre-drilling drying, they were kept cut to simulate intermittent grazing. No return of herbage was undertaken, nor was fertilizer applied (even though pre-drilling storage often lasted some months) because it was unlikely that sufficient surface moisture would be applied to effectively take the nutrients into solution.

Climate control

No attempt was made to control environmental factors such as relative humidity or wind speed, but some effects on temperature and radiation were unavoidable with the design of the rain canopies. Even with total protection from rain and dew, soil moisture stress was only partially controlled as soils dried under the influence of the other climatic factors prevailing at the time. Thus during the cooler winter months, the development of a moisture stress was a more lengthy process than in warmer months.

Radiation and air temperature could be expected to be affected because of the interception by the p.v.c. sheeting, but location of the site adjacent to an expansive white painted wall, facing roughly north, presumably helped to partially offset this by diffuse reflection. In any case, as most measurements of plant response were confined to the germination and early emergence phases and none of the species used was light sensitive to germination, intensity of radiation per se., was not expected to be a dominant factor.

Air temperature fluctuations beneath the canopies showed some divergence from ambient conditions. In general, during the cooler winter months maximum temperatures were reduced while minimum temperatures were increased (table 1; see also appendix 2). In periods of high radiation and humidity, maximum daytime temperatures were, on occasions increased substantially. However, only when such increases became excessive was this considered important. In one experiment, young wheat plants wilted, apparently from the effects of excessive transpirational demands when soil moisture was limited. A spot check during this period of hot weather indicated that the unshaded air temperature beneath the canopy was 35°C while the unshaded air temperature at the same elevation outside was 26.8°C.

TABLE 1

A comparison of ambient and beneath-rain-canopy temperature data during winter months.

Position of mercury thermometer	Air temperature Max.	Air temperature Min.
Suspended, unshaded, under rain canopy at turf block ground level	20.0°C	6.1°C
Suspended, unshaded, alongside canopy at turf block ground level (i.e. ambient)	24.4°C	3.0°C

The major control exercised over the environment was the artificially applied moisture supply to the soil blocks. This was undertaken in one of two ways.

a. Sprinkler from above. A measured amount of water was applied as evenly as possible from a watering can. The application was usually split several times to avoid run-off. In early work some attempt was made to equate the amount added in this way with the apparent deficit indicated by measurement of soil moisture in the top 40mm of each block although this was later abandoned as impractical.

b. Ground water from below. Water was added to each of the trays to a predetermined depth. As a base line, to bring each soil block to a common moisture level, the trays were filled to capacity with water as soon as the bins were positioned in them. They were left to saturate for 12-24 hours after which the water was drained from the trays. Thereafter it was assumed that with similar vegetative cover and soil type and identical pre-drilling treatments, the drying of all blocks would be at essentially the same rate.

   Where water was required to be added from time to time to reduce the moisture stress (due to overdrying), a known and constant level of water was placed in all trays (usually to a depth of from 25mm to 75mm) and left to be completely uptaken by the turf blocks.

Wetting from below in the manner described was used prior to drilling as it was felt that it would more closely simulate conditions approaching a field moisture stress than wetting from above. This was because the moisture gradients through the turf block profiles could be safely assumed to be unidirectional. Where blocks were wetted from above, there was no reason to assume that the wetting front would extend to the full depth of the soil profile, unless an excessive amount of water was applied. Under continuing surface evapotranspiration, moisture gradients would probably have been set up both above and below the terminal position of this wetting front. Nevertheless watering applied as a post-drilling treatment was usually by sprinkler from above as it had the function of simulating rainfall.

To observe how closely the moisture regime of blocks resembled that of the field soil from whence they were extracted; and also to test the effects of shielding from rain and chemically suppressing the vegetation, the following unreplicated pilot trial was undertaken in December 1969. (see appendix No 3)

Three tillage bins were extracted from randomly selected sites on a "Manawatu fine sandy loam" soil.

Tillage bin No.1 was immediately sprayed with paraquat at a rate of 2.8 litres per hectare. The exposed soil ends were coated with paraffin wax and the bin was placed under a rain canopy.

Tillage bin No.2 was treated identically to No.1 except that it was not protected from rain.

Tillage bin No.3 was neither sprayed, nor protected from rain, but had the exposed soil ends coated with paraffin wax.

An area equivalent to a fourth tillage bin was pegged out on the undisturbed parent pasture adjacent to where the other three blocks had been extracted. This area was only about 1 kilometre distant from the final location of the extracted tillage bins and was thus regarded as being indicative of what would have happened to the soil left *in situ*. Rainfall on this area and the unprotected tillage bins was assumed to be very similar.

Gravimetric soil moisture content determinations at 0-50mm depth gave the results shown in table 2, 10 days after extraction of the blocks, during which time some rain had fallen.

TABLE 2

The effects on soil moisture content of extracting and treating turf blocks

Bin number	Soil Moisture Content (% wet basis)
1	10.5%
2	20.4
3	19.0
4	21.9

This pilot experiment, although unreplicated, suggested several points of information which helped determine future treatment of turf blocks.

As expected, the rain canopies appeared to have been effective in intercepting rainfall with the result that soil moisture content was reduced because of evapotranspiration. (comparison of bins 1 and 2)

Killing of the parent vegetation appeared to have little or no effect in reducing moisture loss compared with the evapotranspiration of the living sward (comparison of bins 2 and 3)
Removal of soil from the parent site may have marginally reduced the moisture content of the surface soil layer (comparison of bins 3 and 4), possibly due to the elimination of ground moisture supply.

On the basis of the comparison between bins 1 and 2, and to a lesser extent the other listed comparisons, it was felt to be realistic to remove turf blocks in their tillage bins from the field and expect them to behave in most respects as if they were in situ.

3.4 DRILLING OF TURF BLOCKS AND TESTING OF DRILL COULTER PERFORMANCE

3.4.1. Description of support bed, moving gantry and tool testing apparatus

Support bed

The elevated support bed is shown in Plate 15. It is constructed of 150mm x 75mm "I" section steel. Measuring 10.0m long and elevated at bench height on eight symmetrically placed legs, it is constructed in two equal sections to allow for ease of dismantling. The purpose of its elevation above ground level was to facilitate convenient manipulation and adjustment of drill coulters and the tool testing apparatus, and also to allow possible insertion into the soil of moisture or soil stress monitoring devices from beneath the bins. Conversion to a deeper conventional pre-filled tillage bin arrangement would also be possible because of the elevation. The two main structural beams are spaced 610mm apart so that each tillage bin is supported on approximately half the width of the webb on either side. This leaves about 40mm clearance on either side of the tillage bins for passage of the moving gantry.

Attached alongside each of the two main beams is a runner, constructed of 120mm x 75mm "I" section steel. These runners bear only the weight of the moving gantry. The upper horizontal surface of their webbs is flush with that of the main beams. Between the runner and beam on each side, the roller chain drives for the gantry are located. Each chain is supported by a light gauge open steel channel lined on the bottom with extruded p.v.c. strip to reduce wear. Immediately below these channels are corresponding enclosed chain-return channels constructed of R.H.S. steel and also lined with p.v.c. strip.

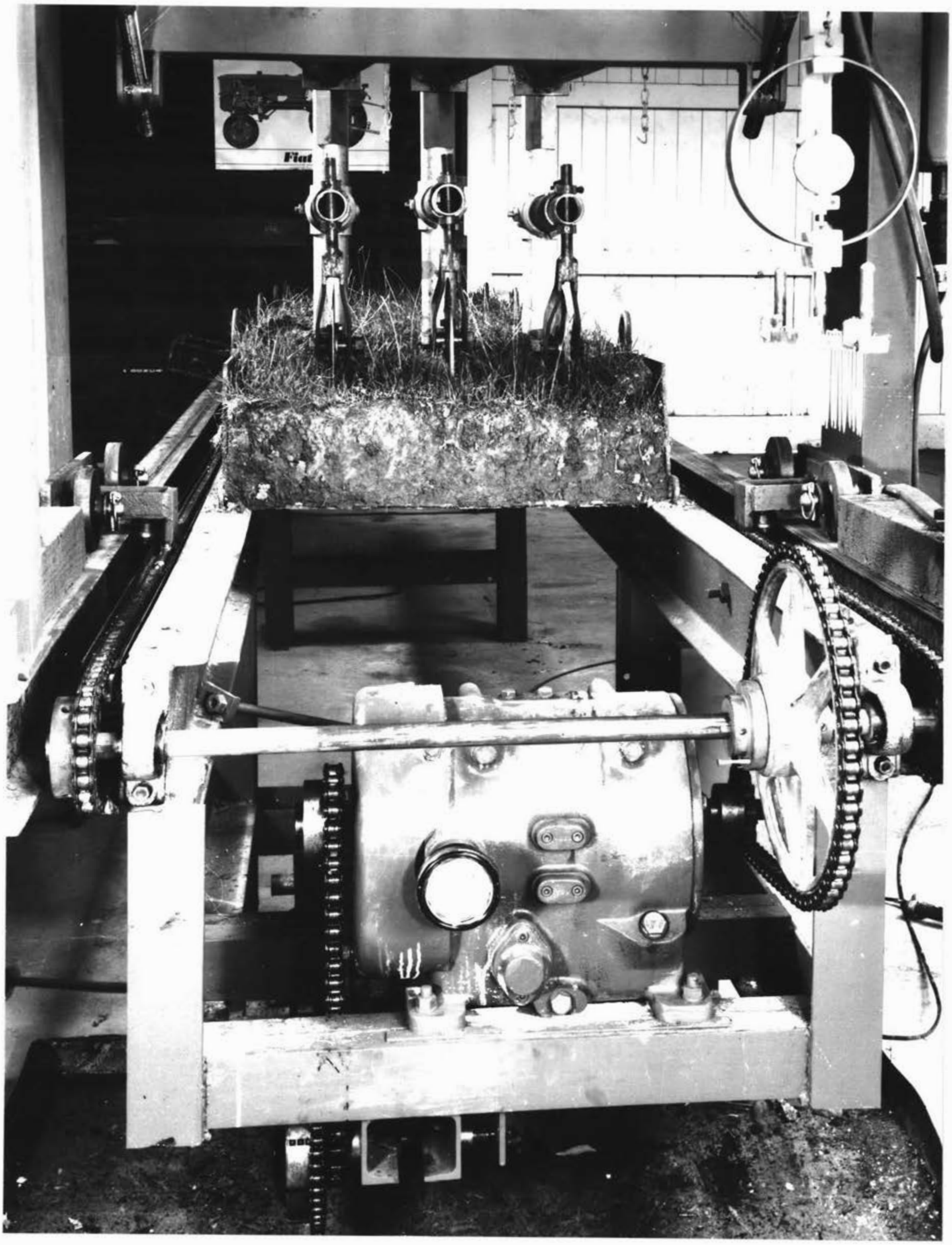


Plate 15: End view of the tillage bin support bed, showing; lower centre- drive mechanism; top right- multipoint penetrometer

Drive chains

A common axle mounted on sealed roller bearings at the drive end of the support bed, carries a keyed 114mm dia. drive sprocket on each side. Corresponding idler sprockets are located at the other end of the bed. These idler sprockets are mounted individually on sealed roller bearings rigidly located by small "U" frames. Each "U" frame has a 25.4mm dia. threaded shaft welded to it. These shafts pass horizontally through clearance holes drilled in the cross member on the ends of the main beams. The threaded shafts lie parallel to the main beams and an adjustment nut is provided on each to allow individual tensioning of the main continuous drive chains. Tensioning in this manner minimises skewing of the gantry which might otherwise arise from uneven draught demand across its width during the testing of various tillage tools.

The main roller drive chains are of standard 19.0mm pitch with a static tensile strength of 29kN. Each is attached to the base of the gantry with a special pinned bracket. On one side a short turn buckle is located to provide fine adjustment so that the direction of travel of the gantry can be adjusted parallel to the drive chains and support runners.

It is probable that other methods of linear drive for the gantry would have been preferable to the long chains. Despite the tensioning facilities provided, smooth travel of the gantry under small draught loads was difficult to achieve. It is thought that a more satisfactory (but possibly more expensive) recourse may have been to use a rack and pinion system but this may have required the drive motor and transmission to be located on the gantry itself. The decision to use a chain and sprocket drive was in part to avoid cluttering the gantry with unnecessary components to the detriment of its most important function - that of providing a conveniently adjustable mounting base for drill coulters under test.

Motivation

The desirable performance criteria which dictated the design of the transmission and primary drive, were: -

Speed:	infinitely variable from 0-8km/h
Direction;	full range of speeds in forward and reverse
Drought;	up to 4.5 kN at 2.0km/h

Drive to a hydrostatic transmission is provided by a 7 h.p. three-phase electric motor, using 12.7mm pitch roller chain. A 100mm dia. sprocket connects the electric motor to a 180mm dia. procket on a motorcycle clutch. Output from the clutch is from a 90mm dia. sprocket to a 130mm sprocket on the input shaft of the hydrostatic transmission,* using 19.0mm pitch roller chain (plate 15).

Although the hydrostatic drive was capable of infinite transmission ratio sequences in both forward and reverse directions, it is a common limitation of the design of such devices that at very small oil flow rates and heavy torque demand, oil displacement is restricted, and often not reliable. Thus, to provide a speed range of 0-8km/h but maintain precision at very slow speeds it was necessary to provide one stepwise speed change on the output side of the hydrostatic transmission assembly. Although the relevant components are not shown in plate 15, the stepwise change is provided in the following manner.

Two identically sized chain sprockets (75mm dia.) are mounted side by side on the output shaft of the hydrostatic transmission assembly. The outer sprocket is keyed to the shaft while the inner sprocket is free to rotate on the shaft but can be locked to the outer sprocket with a mild steel shear-pin. Mounted on the main drive axle of the support bed, and in line with these two sprockets, are two further sprockets of 110mm and 340mm dia. respectively. The larger of these sprockets is coupled to a flange mounted alongside, which itself is keyed to the axle. The pin used to couple these two components is designed to operate as the main shear pin safety release in the event of overload.

The smaller of the two sprockets can also be coupled to the larger one by the use of another mild steel shear-pin.

In operation, one of the sprocket coupling pins was removed, allowing only one pair of sprockets to drive while the fourth sprocket idled alongside. As most drill coulter testing was performed at very slow speeds, the slower alternative combination of sprocket drives was used predominantly in this study.

* Carter Gears Ltd., Model F14

Lubrication

Because the duty cycle of the tool testing apparatus was expected to be low compared with the design specifications of the components used, no permanent lubrication was allowed for except where bearings were sealed. Instead all chains, idlers and the motorcyle clutch were lubricated by flushing, and the main linear drive chain was not lubricated at all because of dust and dirt accumulation in the upper support channel.

Clutch

Some trouble was experienced in the actuation of the multiplate motorcycle clutch. This component was originally designed to be oil immersed but was used in this instance as a dry clutch. The silver-steel thrust rod sustained considerable end wear and had to be adjusted frequently. Design improvements could have been incorporated here. Nevertheless, for the duration of this project the clutch performed adequately. Its function was to allow positive engagement and disengagement of the drive to the gantry without the necessity to build up speed through normal use of the hydrostatic transmission adjustment. It also enabled remote stop-start operations to be carried out, thus allowing the operator to closely observe the action of a drill coulter during the tests. The remote clutch operation was achieved by using a long Bowden cable connected to a portable foot operated control. This control could be positioned on the floor anywhere convenient to the operator and was able to be locked in the disengaged position. Provided the Bowden cable lay flat upon the floor with no sharp bends, it proved capable of adequate clutch operation in spite of its substantial length(which was able to be adjusted with a turnbuckle in the sheath). Design improvements in the form of a rocking foot plate, operating over the full length of the support bed on both sides would probably have improved clutch engagement and disengagement, but would also have sacrificed convenience and versatility because of the awkward postural position often required of the operator or observer.

Overload

A mechanical stop at either end of both gantry runners provides a safety stop in the event of overshooting. As mentioned previously, the main axle drive flange shear pin provides release against excessive torque demand and was found to be particularly useful in positioning tillage bins against each other. The possibility of pressing the overhang of one turf block too firmly against the other and thus bursting up part or one or both soil profiles was frequently avoided through shearing of the appropriate pin.

Gantry

An inverted stirrup shaped gantry straddles the support bed, and is shown in plate 16. Constructed of 200mm x 75mm channel section steel, it is bolted at the base of both sides to vertical plates which carry the axles of four 108mm dia. cast iron wheels. These wheels are positioned in pairs above and below the runners attached alongside the support bed. Longitudinal spacing of the wheel centres is 300mm and vertical spacing is determined by the thickness of the runner and is adjustable within limits (lower left, plate 16)

To the inside basal area of each of the gantry legs, small horizontal projections are bolted, (plate 15). These have two functions. They each carry the vertical axle of a small steel roller which bears against the inner edge of the runner to locate the gantry laterally, and they are also the members to which the main drive chains are attached.

Tool testing apparatus

The support bed and moving gantry, have potential functions for a wide range of research work involving both implement design and growth studies. In the study reported herein the design of the tool testing apparatus was specifically for evaluation and development of direct drilling coulters and techniques. Although it could be expected that its use for other research undertaken would not demand substantial modifications to the basic support bed, drive and gantry components, description of the tool testing apparatus must be regarded as being specific to this study alone.

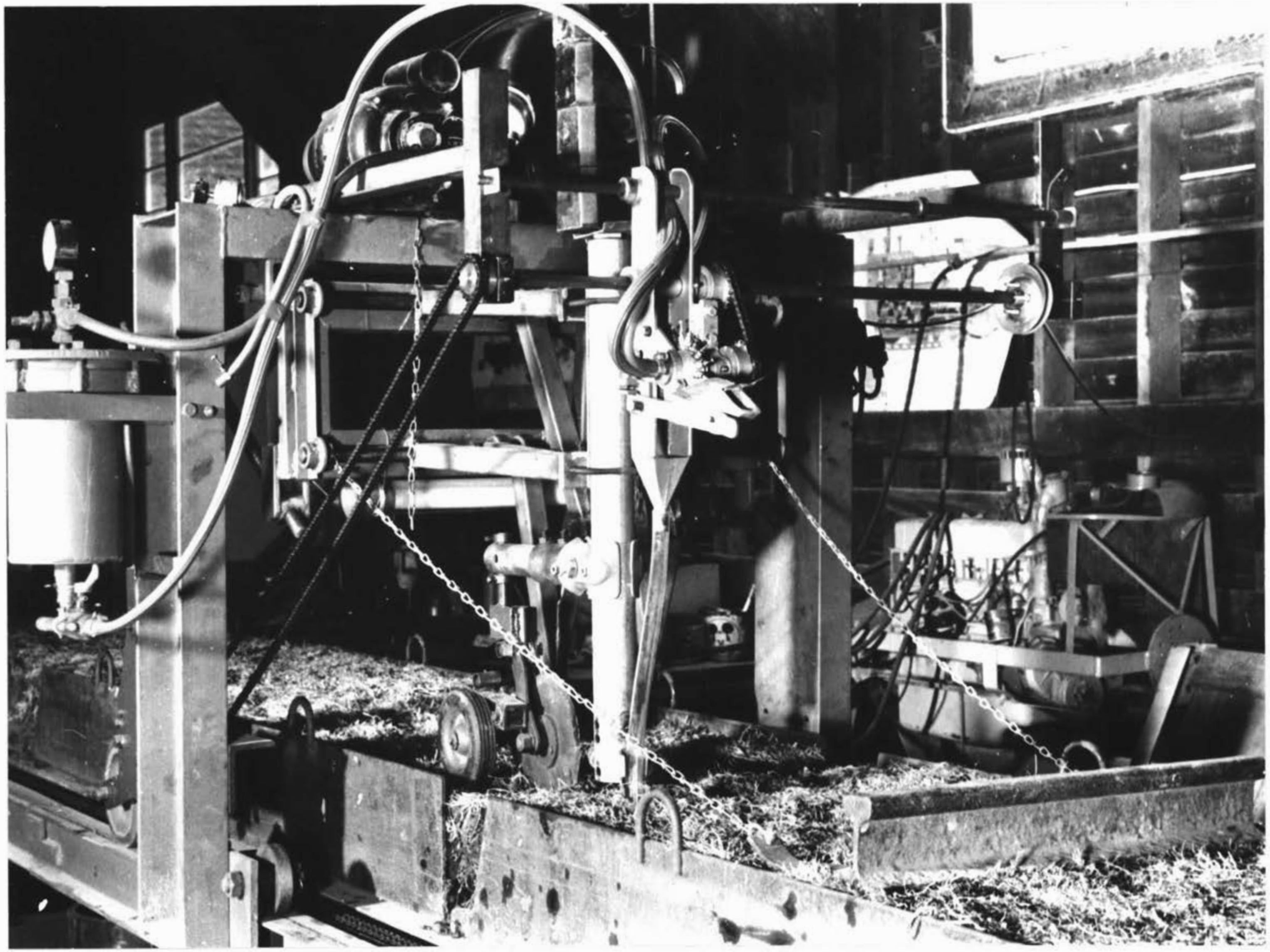


Plate 16: Gantry and tool testing apparatus, showing; centre- parallelogram trailing arms attached to sub frame; upper centre- vacuum seeder, coulter support column & penetration weights; left- vacuum accumulator; lower centre- hoe coulter & pre disc under test; lower right- bar covering harrow section

The specific requirements of the tool testing apparatus, in addition to those provided by the basic components already described, were as follows:-

a. pivotal attachment of drill coulters, giving them the ability to follow ground contour

b. facility to alter inter-row spacing.

c. low frictional interference from attachment points in the mounting and trailing arm geometry

d. facility to adjust and minimise the effects on coulter performance of the vertical components of draught

e. ability to maintain drill coulter pitch, irrespective of ground contour

f. facility to interchange drill coulter assemblies - both between types and between rows with any one type of coulter

g. facility to alter the breast angle (angle of attack in relation to the direction of travel) of individual drill coulters

h. ability to pre-set drill coulter pitch conveniently, rapidly and repeatable

i. ability to measure and isolate penetration forces and to ensure that these remained constant irrespective of ground contour

j. facility to accurately meter seeds singly and to record the number sown in any one run over any distance in any one turf block

k. clear visibility and access to essential working components

l. facility to cover the sown seed in a manner typical of that used in field practice

m. facility to examine and measure some of the physical conditions of grooves formed during testing.

It was considered that anything less than three rows of sown seed would be likely to reduce agonomic sampling accuracy. On the other hand a pronounced guard-row or edge effect was not expected, since studies were to be restricted to the seed germination and seedling emergence phases. By this time, root elongation and aerial spread would not be expected to have reached a competitive stage. These assumptions were later supported from the results obtained, and appeared to justify the decision to conduct all experiments with three rows per block, and with a nominal inter-row spacing of 150mm. In fact, this spacing left the outer rows 190mm distant from the edge of the tillage bin. This was felt to be desirable in avoiding any possible influence from the narrow zone of disturbed soil alongside the edge of the bin. Closer spacing (for example 100mm) and four rows would have been feasible, but 150mm spacing more closely paralleled field practice at that time, and it was desirable to see if the physical disturbance of soil by coulters affected adjacent rows.

Fulfilment of the requirements listed above was a major consideration of this project and was achieved in the following manner.

(<u>Requirements a-e</u>)

A rectangular subframe is mounted within the gantry (plate 16). To the trailing faces of this frame six bearing blocks are welded; three on each of the cross members. Symmetrically spaced, they form the bearers for two 25.4mm diameter shafts which are locked in position with grub screws in each of the outer blocks.

Three pairs of trailing arms are pivotally attached to the shafts. Each arm is triangular in shape (with an external base width of 150mm and perpendicular measurement of 380mm). A horizontal stirrup-shaped bracket is welded to the apex of each triangular trailing arm. The vertical faces of these brackets (which are used to pivotally mount the drill coulter support columns) are machined and aligned perpendicular to the pivot shafts on the sub-frame. In this manner all drill coulter support columns (which form the base on which the seed boot and drill coulter assemblies are attached) can be interchanged between rows and between themselves without altering their essential geometry.

The corresponding attachment points on the drill coulter support columns are spaced vertically, 240mm apart. Identical spacing between the cross shafts of the sub-frame ensure that each pair of trailing arms remain parallel at all attitudes.

Each pair of trailing arms, with their drill coulter support column is therefore free to move vertically, approximately 300mm above or below the horizontal position.

During testing, the operating height of the drill coulter support columns was adjusted to ensure that the trailing arms were essentially horizontal in attitude. By so doing, almost all vertical components of draught were considered to be eliminated.

Row spacing was determined by sliding each pair of trailing arms laterally on the cross shafts until the required spacings were achieved. Grub-screwed collars on either side of the trailing arm pivot bearings were used to lock them in this position.

The use of brush lubrication on all pivots minimised friction between pivoting components although the more expensive recourse to roller bearings would no doubt have further reduced this.

(Requirements f & g)

Each drill coulter to be tested was adapted or constructed to attach to the end of an upright support column constructed of nominal 50mm i.d. water pipe. This column is clamped rigidly (using "U" bolts) against a bracket formed from a length of 38mm x 38mm angle section steel. Two small machined and drilled lugs project from the leading edge of this bracket, and mate with the stirrup shaped brackets on the ends of the trailing arms. By loosening the "U" bolt clamps, the support column could be moved up or down to maintain the trailing arms in their horizontal positions and could also be rotated about a vertical axis to alter the breast angle of the drill coulters.

(Requirement h)

To facilitate adjustment of coulter pitch, the subframe to which the trailing arms are attached is hinged at its top, and is supported by a pair of threaded adjustment shafts.

When the subframe was in the vertical position these two threaded shafts formed the hypotenuse of two right angled triangles, the perpendiculars of which were the vertical members of the subframe and the bases of which were two angle-section brackets which projected horizontally from the top of the gantry. By altering the effective length of the threaded shafts the angle which the subframe made to the vertical was altered. Thus the pitch of the drill coulter support columns (and hence the coulters themselves) was conveniently controlled.

(Requirement i)

Of the two principle resultant force components involved in operation of any one drill coulter assembly, the vertical component (coulter penetration force) was felt to be more important in these tests than the horizontal longitudinal component (draught). Dixon (56) suggested that the effects on localized soil compaction and smearing within the groove were related to the coulter penetration force required to attain operating depth, while Hughes (57) had measured draught forces on a 16 row field drill which suggested that with the three coulters on test, all were within the capabilities of 50 dbhp conventional wheeled tractors. Draught measurements were therefore felt to be of minor interest only, although these could be performed with slight modifications to the tillage bin and tool testing apparatus.

Penetration of coulters into the soil using the compressive force of resilient materials such as springs was not considered desirable because of the dynamic nature of the force in relation to spring length as coulters followed ground contour. One of the important variables resulting from any change in design of drill coulters, was expected to be the force required for soil penetration. Use of springs therefore, would have made measurement of this difficult.

The chosen method of using weights had potential disadvantages too. Where soil-surface undulations required the drill coulters to rise and fall through any appreciable distance, acceleration of the mass above the coulters was required. The greater the movement and the greater the forward speed, the greater the accelerating forces required and thus the greater the temporary penetration of the coulter into the ground. It was also possible that at other times the inertia of the rising, or even stationary mass may have momentarily reduced the penetration force in the event of a drill coulter falling into a small hollow. However, as forces of this nature are dominated by dependence on speed ($F = MV^2$) it was felt that the disadvantages of using weights as the source of penetration could be greatly minimised by adopting slow speeds. In fact all indoor tests using this apparatus were conducted at very low speeds and so the problem never eventuated.

The speed of travel of the tool testing apparatus was set at 1m per minute for these tests. While undoubtedly such a speed was well below those used in field practice, it was chosen for two reasons.

a. It allowed detailed observations to be made of the mode of action of each drill coulter and of seed delivery and implantation. Such direct observation has hitherto not been possible with field machines

b. It was felt that a study could be made of a number of basic forces and patterns of soil disturbance which would be largely independent of forward speed. Clearly, before the basic information obtained from these tests could be fully interpreted in a field situation, independent and complimentary studies would have to be made of other inter-related variables including forward speed, soil moisture content, soil type, vegetative cover, and the time interval between spraying and drilling. Such tests are all possible utilizing the tool testing apparatus which is capable of 8km/h.

To maintain constant depth of drill coulter penetration, special depth restricting wheels were used. Once the nett force required to achieve the full penetration depth had been established for any one coulter and soil, it became the usual practice to adjust the depth wheels so that they contacted the soil surface, and then to increase the weight by about 20% to allow for natural heterogeneity of soil resistance. The depth wheels operate on the undisturbed soil surface ahead and to either side of the drill coulter. If investigations into the effects of speed were to be undertaken, it is conceivable that a major part of the problem with weights could be eliminated by further increasing the gross weight to, say, 50% above that required for penetration alone. Any effect on consolidation by the depth wheels would be expected to be minimal, especially with dry turf covered soils.

The design of the weight racks for each drill coulter support column is simple but flexible. A short length of nominal 38mm i.d. water pipe is welded at right angles to a short length of flat steel drilled with three equally spaced 9.5mm dia. holes. Three lengths of 9.5mm dia. steel rod are each fitted with a flange, 130mm from one end. The shorter end of one of these rods was inserted in the centre hole of the drilled steel plate, which in turn had its pipe projection inserted into the open top end of the tubular drill coulter support column. Cast iron weights, (centre drilled) were slipped onto the rod to provide the penetration forces. Increments of weight addition were:-

major	4.5kg
minor	0.9kg

Each rod allowed a maximum weight of 27kg to be added. Where forces in excess of this were required, three such rods were fitted to the drilled steel plate. At least one drill coulter that was tested required additional weights in the form of 25kg cast iron roller rings.

(Requirement j)

Precise and accurate seed metering and monitoring was considered an essential part of any study likely to involve counts of the number of plants emerging.

A vacuum operated seeder was used. (centre picture, plate 16) This was a modified version of a unit described by Copp (58; also personal communication, 1970). The original unit operated on a principle where a vacuum applied to a series of blunted hypodermic needles, picked up single seeds. A cylindrical rotating chamber was equipped with 16 such needles mounted radially. As each needle, with a seed attached, passed through a discharge chamber, reversal of the vacuum to a positive pressure propelled the seed into the collection tube, and at the same time purged the needle of dust and impurities. Two major problems arose in the early testing of this equipment and were overcome by the following modifications.

a. With many elongated seed varieties, such as barley, two or more seeds were sometimes picked up by a single needle.. Almost invariably one of these seeds was held with more force than the others. This appeared to be particularly so when individuals of the multiple seed group were all held in the end-on position. Leakage of vacuum from around the first-held seed appeared to attract others to the general area and was often sufficient to uplift them as the needle left the seed reservoir. Modifications to overcome this problem included the use of smaller diameter needles, and the provision of a device for removing excess seeds. The latter device comprised a key-hole shaped opening cut into a thin sheet of metal which partially covered the seed reservoir. The needles were obliged to pass through the neck and eye of this opening. Clearance between the neck and the needles was 1.25mm. The open ends of the needles, (with seeds attached) passed through the centre of the eye which permitted sufficient clearance to comfortably allow one wheat or barley seed through along its longitudinal axis, but would not allow more than one seed through at any one time or any seed through "cross-wise". Thus, in operation, all seeds were caused to rotate on their needles to reorientate themselves in order to pass through the eye hole lengthwise. In so doing most additional seeds were dislodged from the needle altogether. The dimensions of the wiping device could be simply modified for different seed varieties.

The key-hole shaped wiping device had some limitations. Its operation was based on the ability of the needle (which had a cross sectional suction area of $0.386mm^2$) to hold the seed while it was being reorientated to pass through the hole. The potential force exerted by a vacuum of 400-600mm mercury operating at the end of the needles was 2.3gf per needle. While this might appear to be adequate in relation to an average individual wheat seed weight of 0.035g, vacuum loss around the contact area of the seed probably accounted for a substantial reduction in the actual available holding force. With groups of seeds, when one or more was dislodged by the device, successful retention of the remaining seed depended upon the ability of the seed/needle contact to quickly make up any leakage caused through dislodgement. In some cases, seeds being dislodged also moved the remaining seed sufficiently to dislodge it. Obviously there was an element of chance associated with the effectiveness of the wiping device and for this reason there were a small proportion of seed stations which received either no seed, or multiple ejections. As a check, during drill coulter testing, clear p.v.c. tubes were used for seed delivery to the coulter.

With very slow drilling speeds and special lighting it was possible for an operator to count the number of seeds passing through the tube and thereby record the precise number of seeds sown in a tillage bin or part thereof.

b. In the seed ejection/delivery chamber of the seeder, precision was lost in the original design because seeds were blown off the needles. The velocity and direction of their initial trajectory was largely a matter of chance and was a function of the orientation of the seed on the needle and the extent of leakage around it. As a result, it was possible that in some cases a seed with high initial velocity and a more direct trajectory could overtake the previous seed, which may either have dropped off the needle at a relatively slow speed or been subjected to bounce from the side walls of the delivery chamber and tube.

In extreme cases, seed was seen to bounce out of the delivery chamber altogether.

Accordingly a small ejection plate was fitted to the modified seeder. This device was located at an angle within the delivery chamber and consisted of a narrow slit (2.5mm) through which the needles passed. Its angle was such that as the needle withdrew from the chamber the seed was mechanically wiped from the needle end. Unlike the original design of Copp (loc.cit.), the vacuum in the needle remained throughout its passage into and out of this modified ejection/delivery chamber. A momentary change to positive pressure, to purge trash from the needles before they re-entered the seed reservoir, occurred as soon as the seeds had been wiped from them.

With the modifications described above, the seed metering device performed satisfactorily for its intended purpose. Repeatability tests showed a 95% potential for metering the precise number of wheat seeds intended, so long as no blockages occurred.

Vacuum supply to the seeder was from a milking machine vacuum pump operating through a 5 litre accumulator. Although the vacuum was held at about 500-635mm mercury, tests indicated that the critical level was about 400mm mercury for Kopara wheat seeds. The exhaust of the vacuum pump was partially restricted and the back pressure thus created was led directly to the seeder as the source of purge for the needles. The 1 h.p. electric motor and vacuum pump were mounted on top of the gantry away from more critical components.

One seeder is common to all coulter positions. It has a metering drive shaft of square section steel which passes unpinned, through the seeder from one side of the gantry to the other. It is supported at either end on bearings attached to adjustable brackets projecting rearward from the top of the gantry. A support rod stretches across the gantry directly above, and parallel to the square section drive shaft. It passes snugly through another transverse hole in the top casting of the seeder and thereby holds the seeder upright. Thus the seeder could be moved sideways to a position behind any one of the drill coulters being tested where it could be locked in position by collars on the support rod.

The drive to the seeder was arranged so that the rate of metering was strictly related to the forward speed of the gantry. A solid rubber tyred wheel was mounted on the forward left-hand side of the gantry so that it could be pressed firmly on the runner on that side (lower left, plate 16). A modified plough levelling-lever assembly, mounted on a bracket from the gantry upright, was used to raise the wheel (for disengagement of the seeder) or to bring it to bear firmly on the gantry runner. The wheel could be lifted high enough to clear the stops at the ends of the runner.

9.5mm pitch roller chain was used to drive the shaft of the seeder from the wheel. Chain tension was automatically adjusted when the wheel was screwed down into the operating position. With a 140mm diameter sprocket on the wheel and a 57mm diameter driven sprocket on the shaft, nominal seed spacing with 16 needles per revolution of the seeder was 20mm.

(Requirement k)

Visibility of the operation of coulters and their associated components was a design priority. The bench height and unobstructed access to the soil surface and coulters, together with the provision of special lighting on the gantry itself made visual observation both convenient and meaningful. Speeds as slow as 100mm per minute allowed close observations of soil movement and seed placement to be made although shattering effects on the soil by coulters could be expected to be less at this speed than at higher operating speeds.

(Requirement l)

In all tests using the tillage bin and tool testing apparatus, cover of the grooves was facilitated by drawing along behind the gantry, a section of a bar harrow developed as a result of field tests (59). It was felt that a single pass with the section of harrow simulated field operations and was more likely to produce results which could be extrapolated to paddock conditions. Nevertheless, in using the same covering technique and equipment in all field experiments an effort was made to compare the physical conditions of the seed grooves thus formed (and covered) with those of the indoor tests.

(Requirement m)

Specific details of measuring techniques relating to the turf blocks at the time of drilling are contained within section 3.5 which also deals with recording and measuring techniques related to the turf blocks while in the storage or observation periods, pre and post-drilling.

3.4.2 Procedure:

Bin matching

Three tillage bins to be used as treatment plots were laid end to end on the support bed (plate 17). Preceding the first of these bins was an identical "lead-in" bin. A "run-out" bin was also placed after the last one. The "lead-in" and "run-out" bins remained common even when treatment bins were interchanged (see below)

To ensure continuity of the soil surface throughout the combined length of the five turf blocks, it was often necessary to shim either or both ends of individual bins so that the soil surfaces of adjacent ends were flush. After placement of the "lead-in" bin on the support bed, the first treatment tillage bin was placed a few mm from it, the appropriate end was shimmed to the required elevation, and the moving gantry was used to slowly slide the tillage bin along the support bed until its waxed end mated firmly with its counterpart on the preceeding bin. Care was taken to have the hook ends of one bin facing the tail end of its neighbour as the combined unsupported overhang of soil from two hook ends facing each other would possibly have resulted in breakage of the soil block through the profile. The matching procedure was repeated throughout the length of the support bed until all tillage bins were positioned in line, giving an overall test soil surface length of 9.9m.

Drill coulter testing

The first of the three drill coulters to be tested in an experiment was positioned with the gantry at the furthermost end of the "lead-in" bin. Weights were added as required and the gantry was moved forward very slowly. All final adjustments (for example, operating depth, penetration force, pitch, seeder operation, and pre-disc alignment) were required to be made in approximately 1.5m of forward travel before the coulter entered the first treatment tillage bin.

As the coulter travelled the full course of the three treatment tillage bins, a direct count of the number of seeds sown per row per bin was made by observing the individual seed fall through the specially illuminated clear plastic delivery tube and recording with a hand counter.

At the conclusion of run one (which finished with the coulter having cleared the last treatment bin and coming to rest in the "run-out" bin) the coulter and seeder drive wheel were raised and the moving gantry returned to the initiation point. The coulter assembly was disconnected from its pair of trailing arms and reconnected to the adjacent pair, 150mm across the bin. The vacuum seeder was similarly repositioned and the drilling procedure recommenced. The second and third runs differed from the first run only in that the starting point used as little of the "lead-in" bin as possible. This was to ensure that when the next three tillage bins were substituted for the first three (with a change in drill coulter type), there would be at least one clear run in the "lead-in" bin in which to make the final adjustments to the coulter as before. The fact that with the second and third treatments at least one run (other than the first run in each treatment) therefore occupied an already disturbed groove in the "lead-in" bin, was considered to be inconsequential, as it was also for the "run-out" bin.

No adjustments to the coulters were made during a treatment run except for emergency purposes, so that each run was uninterrupted and at a constant speed.

Plate 17: Placement of a tillage bin on the support bed

Covering and sealing

The covering operation, using a section of the bar harrow, was performed separately, after each completed drilling treatment.

Each bin was then returned to a position beneath a rain canopy and the disturbed waxed end portions, through which the drilled coulters passed during the treatments, were rewaxed.

3.5 MEASURING TECHNIQUES RELATING TO PRE- AND POST- DRILLED TURF BLOCKS

The important physical variables relating to seed germination, seedling emergence, and the associated environment were expected to be:-

soil matric potential or soil moisture content within the groove
soil temperature within the groove
the type and amount of cover over the seed, and
compaction in the bounding areas of the groove.

Attempts were made to monitor or assess the above listed variables.

Other factors, which may have had some influence on germination and emergence, but which were not assessed were:-

soil-seed contact
aeration within the grooves
soil structural or bulk density changes within the grooves
presence of pests within the grooves
nutrient status within the grooves, and
light intensity within the grooves.

As indicative of the suitability of the groove for seed germination and seedling emergence, the following plant measurements were made:-

the proportion of seeds which failed to germinate
the proportion of seeds which germinated (as judged by the appearance of a shoot or radical from the ruptured seed coat) but had failed to emerge at that stage of inspection
the proportion of seedlings which emerged (as indicated by a visual count of living shoots showing above the ground surface).

In addition, counts were taken of the proportion of abnormal seeds or seedlings (as indicated by twisted or malformed subterranean or aerial tissue - including broken seed).

These four parameters were collectively referred to as "seed fate" counts.

Techniques and equipment associated with measurement of the above were as follows:

3.5.1 Physical measurements

Soil moisture content and matric potential

In a review of the methods for measuring soil moisture content Holmes *et al* (60), observed that gravimetric methods still formed the basis of comparison for all direct and indirect methods. It was apparent that few of the other methods could be applied to this study because of the limitations of site, within 40mm of the soil surface in a sometimes unstable micro environment, and the anticipated steep and variable depth gradients close to the "dry" end of the available water range (42).

Gamma-ray attenuation methods, according to Holmes *et al* (*loc cit*) had the disadvantage of requiring columns of coil to be removed to the laboratory. It was felt that attempts to remove small sub-samples of soil from the recently disturbed area of the seed grooves would be likely to induce errors brought about by crumbling and handling difficulties. Electrical resistance blocks had a number of points in their favour, including suitability for operation in the "dry" end of the field water range. However from the comments of Cox and Filby (61) it was felt that their inherent inaccuracy, compounded by size limitations for in-groove implantation, meant that these devices would not be suitable.

Holmes *et al* (*loc cit*) further reviewed methods for measuring soil water potential. Apart from the electrical resistance methods (which were applicable for both moisture content and potential) it appeared that suction tables and membranes were limited in this case as they required samples to be brought to the laboratory. Pressure equipment had a similar disadvantage, while tensiometers were unsuited to the dry soil range.

Psychrometers apparently had the potential of being a rapid method but early designs required special equipment and procedures as well as scrupulous cleanliness, according to Holmes et al (loc cit). Nevertheless developments in recent years suggested that this method of measuring soil vapour pressure might be applicable to this study (62). Information supplied by the manufacturer (pers.comm.)* claimed that the readings of the dew-point thermocouples in their psychrometer bulbs (μ v), and those of the temperature correction thermocouples alongside (mv) were interelated, and that the negative water potential was given by:

$$\text{negative water potential (bar)} = \frac{\mu v}{0.32 mv} + 152.75$$

Three methods were employed at different stages of the project. These were:

a. Direct measurement

(i) gravimetric soil moisture content (wet basis)

(ii) soil vapour pressure from psychrometric readings

b. Indirect measurement

(i) gravimetric inert-seed dry matter analysis

a. (i) For pre-drilling sampling and between-groove sampling after drilling, soil samples were collected with a 38mm diameter x 38mm deep vertical core sampler. For in-groove determinations a 300mm long, curved bottom scoop was used to gather a length of seed groove together with some of the adjacent soil. Plate 18 shows successive scoop divots left after use of this device. The radius of curvature of the scoop is 75mm. Each side wall of the scoop is turned out through 90° at its top and narrow strips of wood (ski shaped at one end) are attached to the underneath of these flaps on either side. The whole device has one end blanked off, to which is attached a handle, and the leading edge at the other, open end is sharpened.

In practice, the sharpened edge of the scoop was inserted into the vertical exposed and waxed end of the turf block so that it surrounded the cross sectional area of a groove. It was pushed into the turf block parallel to the ground surface with the wooden strips lying upon the ground to control depth. When the scoop had travelled 300mm, the soil section was cut with

*Wescor Inc, U.S.A.

Plate 18: The waxing of divots left by the scoop sampler

a knife and uplifted so that a sample of groove and adjoining soil was removed for gravimetric determination of moisture content. The dimensions of the scoop were decided arbitrarily and were not considered to be critical, but in practice they appeared to adequately gather samples from grooves exhibiting a wide zone of shattering, and also to gather all seeds and seedlings for seed fate counts (see below).

While repetitive destructive sampling in this manner was confined to the post-drilling period, there were limitations to the number of such samples that could be extracted from any one turf block before its action might have been expected to influence the micro-environment of the remaining portions of the grooves. To minimise this influence, the hole from which a scoop sample was extracted was immediately coated with molten paraffin wax to seal it against moisture intercharge with the atmosphere.

a. (ii) A number of soil psychrometers were obtained together with a psychrometric microvoltmeter. The sensor of each psychrometer, being 38mm long and 6.4mm in diameter was considered to be of suitable size for direct insertion into a formed groove, in a similar manner to seeds. Lying horizontally in the groove, and with the connecting cables buried at "groove" depth for at least 300mm alongside, it was hoped to be able to gather direct readings of soil matric potential within the groove. The connecting cables were buried to avoid the influence of temperature gradients within the wires themselves, while the horizontal attitude of the sensing device was expected to further assist in this respect. Upon insertion, the soil immediately adjacent to the sensing bulb was formed into a slurry by addition of a small amount of water. Economics precluded the use of a large number of these sensing devices, but one per groove (with three grooves per plot) was felt to be adequate. Difficulty with the psychrometers in relation to the relatively shallow depth of sensing (maximum, 38mm) and the physical variability of the grooves led to the eventual abandonment of them as in-groove sensors. However they were still used as monitors for establishing pre-drilling matric potential in the turf blocks as a whole.

b. (i) In that one of the effects of a changing soil matric potential was expected to be an interchange of moisture with implanted seeds, inert seeds were sown in some experiments and harvested with the scoop in order that their dry matter content could be established.

In early experiments seed was killed by fumigation with the herbicide 24D for several weeks, but later work used oven heating to 150°C for 2 hours followed by several weeks exposure to the atmosphere to re-establish an equilibrium moisture content. It was noted (42) that oven killing may alter the permeability of the seedcoat, but this was not thought to be critical as the data sought was of comparative uptake of water rather than absolute uptake figures.

Soil temperature within the groove

Thermocouples of copper/constantan were implanted in the area alongside the seeds. In early experiments (prior to acquisition of the soil psychrometers, which had their own thermocouples inbuilt for temperature correction purposes), separate water-sealed thermocouples were implanted. These were collectively read on a single pen recorder in association with a sequential switching device. In this manner a maximum of 25 separate thermocouples could be monitored on a time scale according to the setting of the switching device.

After a number of experiments had shown no pronounced temperature variations which could be linked to the response of the seeds and/or seedlings, some later experiments omitted temperature measurement altogether .

Type and amount of cover over the seed

The type and amount of cover was arbitrarily divided into 4 descriptive ranges which were scored by visual assessment. These were:-

Grade I	negligible loose soil or rubble cover
Grade II	complete loose soil or rubble cover
Grade III	intermittent sod or mulch cover
Grade IV	complete sod or mulch cover

Each represented a visual appraisal of the cover resulting from a particular drill coulter and covering device combination. Field experience and experimental evidence indicated that differences in plant response could be expected from seeds germinating and establishing under the various above-listed grades of cover. Further subdivision was felt to be meaningless and would have introduced excessive subjectiveness.

Compaction in the bounding area of the groove:

a. Beneath the seed

Observation in Australia (Rowell, pers.comm) and in New Zealand suggested that bulk density interfaces which appeared to be created under and alongside the seed by passage of some drill coulters could restrict root growth. Graecen (1967, pers.comm) suggested that an interface at an angle of approximately 30° or less from the vertical tended to cause roots to deflect from it rather than penetrate through it, as they could do with greater angles of interface.

Although this suggested that compaction beneath the seed might be an influential variable in relation to root growth, only a limited number of tests of compaction were carried out in this investigation. There were three reasons for this.

(i) The soil used in all tillage bin experiments was a "Manawatu fine sand loam" which, according to Dixon (56) could be expected to minimise the affects of localized compaction and creation of bulk density interfaces.

(ii) Even if root growth had been restricted by compaction at the interface between the groove and the undisturbed soil, this may have played only a minor role in preventing shoots from emerging in the first place.

(iii) The measuring procedure, to be meaningful, was time consuming. It was not considered practical to undertake it at the same time as drilling and preparing of the tillage bins for plant growth studies. Rather, it was felt that this area of study would support a separate and extensive investigation beyond the scope of the present project.

Penetrometer

Nevertheless, the multipoint penetrometer which was used to assess localized compaction (plate 15) was developed by the author and used for support information in some experiments. It is shown in Figure 1.

The literature revealed no multipoint penetrometer designs which appeared to be suitable for insertion in a pattern that was to be largely two-dimensional because of the shape of the soil groove. Barley and Greacen (63) had shown a clear preference for tapered needle ends where results of soil resistance to the needles were to be indicative of the ability of plant roots to force their way through the same soil. Their work however involved deeper needle penetration than was envisaged here. It was therefore felt (R.D. Northey, pers. comm.) that in very shallow depths of penetration (max 7mm), soil/metal friction on the taper of a pointed needle would possibly be the dominant resistance force, because even 1.5mm dia. needles with a 5^{o} taper would not have penetrated much deeper than the shoulder of the taper.

Description of multipoint penetrometer

The penetrometer needle support bars, metering frame and support frame are labelled A, B, and C respectively in Fig 1 (after Dixon 56) and are also illustrated in plate 15.

Support bars

Two horizontal brass bars (measuring 13mm x 13mm x300mm long) are bolted together along their longest sides. Twenty five semi-cylindrical slots are milled across the mating edge of one bar. Each of these semicylindrical slots has the function of locating and seating one of the penetrometer needles which are vertically orientated, and spaced 10mm apart.

Along the mating face of the matching bar is a longitudinal 5mm deep groove stretching for 260mm along the bar. Slightly deepened rectangular slots are milled across this face (at right angles to the groove). These slots are so spaced and sized that their extremities correspond to the needle seats in the opposite bar. Small press plates fit snugly into these slots in the longitudinal groove. When the two main bars are bolted together each of these press plates bears (at its ends) against a pair of penetrometer needles in their seats. A small grub screw tightens against the centre of each press plate and thereby clamps two penetrometer

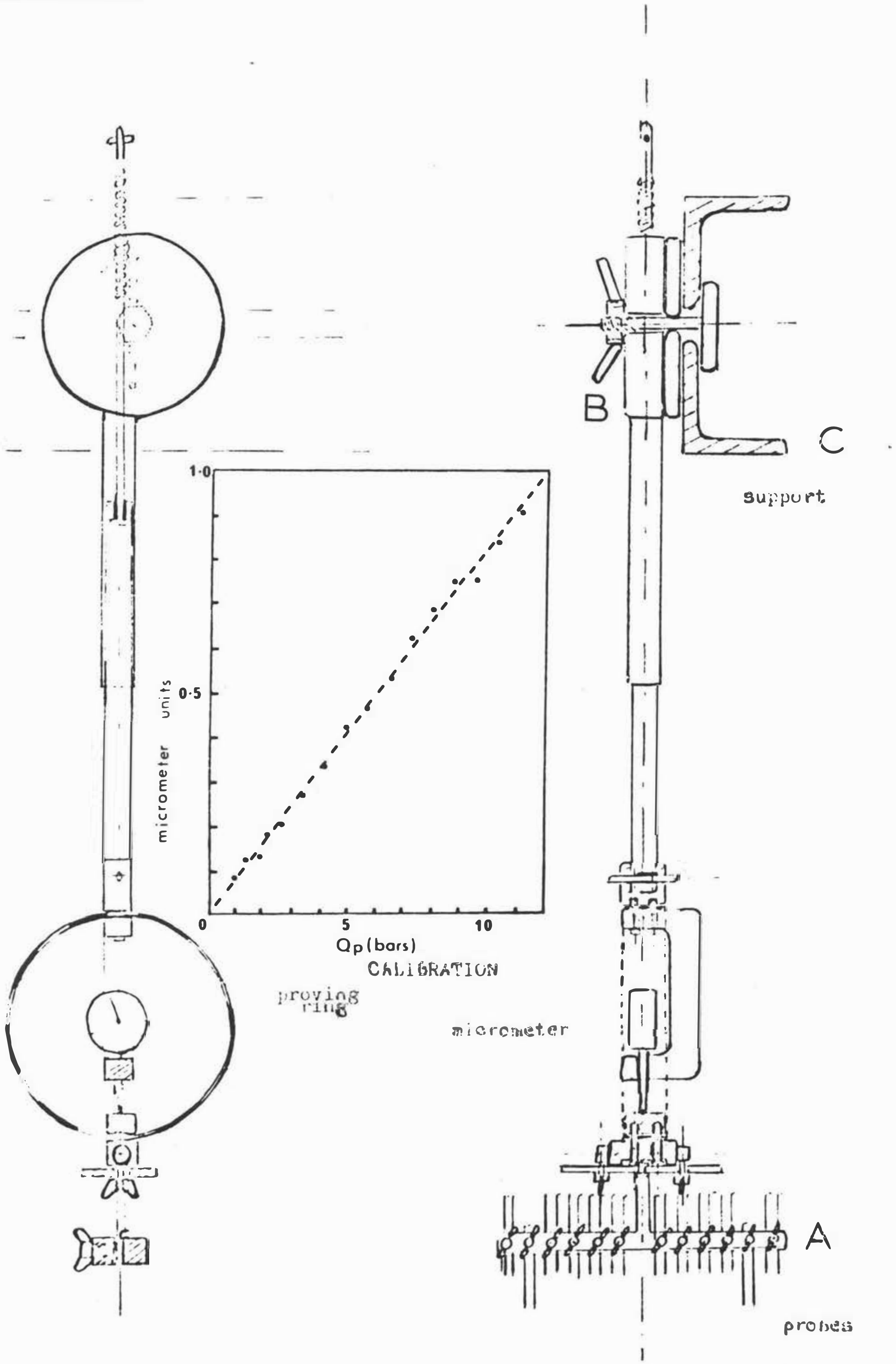


Figure 1 The multipoint penetrometer (from Dixon, 56)

needles in their seat simultaneously.

In this manner 12 pairs of needles are located and clamped along the length of the two mating bars. To avoid the central mounting bracket, which is attached to one of the main bars, the pair of needles either side of it are spaced 20mm apart as compared with the 10mm spacing of all other needles. Provision is made for a single centrally located needle to fit within the mounting bracket but in practice this was seldom used. Thus, each needle is able to be adjusted independently for height in relation to the bar or ground surface before being clamped in pairs.

One of the needle-support bars is centrally mounted on an adjustable clamp which itself attaches to the lower mounting bracket of a proving ring. The adjustable clamp allows 10° angulation about a vertical axis in either direction to assist in aligning the bars and needles with drilled soil grooves which may not be strictly parallel to the penetrometer mounting.

Metering frame

The top end of the proving ring is attached to a 30.5mm x 30.5mm square shaft, the other end of which fits snugly within a hollow square guide. At the top of this hollow guide is a threaded bush which locates a 12.7mm diameter threaded shaft. The lower end of this threaded shaft is attached to the top end of the male square shaft by a simple removable double-thrust bearing plate. Thus by rotating the threaded shaft, the square male shaft can be withdrawn or extended within its female guide.

Support frame

The female guide of the metering frame is welded to a circular steel plate. This plate faces a circular backing plate of the same diameter, and the two are clamped together by a single horizontal bolt passing through their centres. The backing plate has two holes, drilled and tapped on a horizontal diameter. It backs against a horizontal slotted bar which runs the full width across the tillage bin support bed. Two bolts tightening in the tapped holes in the circular backing plate, clamp this plate in any lateral position against the slotted bar.

The slotted bar is located either end by clamping devices with lock into two angle section steel vertical supports which are 1.0m high and originate from the moving gantry runners. At the lower ends of these vertical supports, further horizontal clamping devices locate them on the gantry runners.

Hence, the entire penetrometer support frame could be moved fore and aft along the runners. Removable attachments on the moving gantry were used to shift it to any desired position, whereupon thumb screws were tightened to lock it firmly to the runners. The penetrometer metering frame (containing the threaded shaft) was positioned laterally by moving the circular backing plate across its slotted bar. It could also be angled laterally by rotating the front circular plate against its backing counterpart (this allowed the penetrometer needles to be driven into the angled side wall of a soil groove if desired). It could also be raised or lowered in relation to the ground surface by sliding the slotted bar up and down the vertical legs of the support frame. The needle support bars could be angled to a limited extent in the horizontal plane by the small adjustment provided on the proving ring bracket.

The needles themselves were pushed into the soil uniformly by revolving the metering screw at a constant rate. This latter function was considered to be important and was achieved by temporarily coupling a small hand-held slow speed electric motor to the top of the threaded shaft. Both components were equipped with matching bayonet couplings for this purpose. By instantly connecting the drive (which revolved at 18r.p.m.), and holding it in place for a known number of revolutions, and then quickly removing it, a nominal distance of needle penetration was achieved at a constant feed-in rate. Because of the various required positions and angles of attack of the needles, a permanently mounted power source was thought to be impractical. Nevertheless care was required in connecting and disconnecting the drive to avoid bumping the support bar or anything connected to it as the proving ring system of recording the penetration forces was found to be very sensitive. Although this form of motivation gave a known and constant feed-down rate of the proving ring, deflection of the ring itself was a function of ground resistance to the needles. The net feed-in rate of the needles was therefore not known with precision using this device.

The pitch of the metering thread was 1 thread/mm. Calibration of the micrometer sensor in the proving ring showed a linear relationship between deflection and force (Fig.1).

Procedure

In practice the bar was positioned on its adjustable frame so that the needles were at the desired angle for entry into the soil and approximately 20mm from its surface. Two pairs of needles on either end of the bars were unclamped and allowed to fall. They took up positions conforming to the minor surface irreglarities of the soil face. Once in position each pair of needles was clamped so that any further downward movement of the bar resulted in entry of these four needles into the soil. By using symetrically placed pairs of needles the distribution of force on the bar was kept approximately uniform across its width. This was an important feature as the position of force application was centrally located on the bar.

Each needle was 85mm long which allowed accomodation of quite severe surface irregularities.

After entry, the force recuired was recorded and the four needles were withdrawn unclamped and raised out of the way. Without changing the position of the bars, the next two pairs of needles were lowered onto the ground surface and the procedure was repeated. Thus, for any one major station of the penetrometer, six separate force readings were taken, each using 4 needles, and each needle entry being 10mm from its neighbours. By changing the position of the penetrometer along the soil groove, further readings could be obtained. This largely offset the inherent variability associated with penetrometer readings using fine needles in natural soils.

Once the full preselected penetration depth was achieved in any one test, a "settling" period (arbitrarily timed at 60 seconds) was allowed before the proving ring deflection was recorded. This "settling" appeared to be due to plastic flow of soil from around the needles under the influence of the terminal force stored in the resilient proving ring. Use of a non-resilient displacement sensing device would probably have helped in this regard but was felt to be unwarranted in this particular study as it would have involved expensive and sensitive strain gauge transducers and recording equipment.

b. Above the seed

No attempt was made to measure the extent of compaction above the seed, as the development of the bar harrow had sought to avoid compressive forces being applied to this area (see later).

Soil-seed contact

No attempt was made to quantify soil-seed contact in this study although indirect assessments of this aspect were made by Dixon (56) in a study involving a number of the drill coulters tested in this study. In Dixon's tests, a measured length of the groove was cleaned of all loose soil with a domestic vacuum cleaner. The quantity of soil thus collected in relation to the volume of the cavity created was thought to give some indication of available loose soil which may or may not have been influential in promoting good soil-seed contact.

Obviously other factors such as the shape of the groove could also be expected to play an important role. Dixon (loc cit) gave descriptions of the cross sectional shape of typical grooves, to help define them. These are presented in Fig. 4 in the Results section.

3.5.2 Plant response measurements (seed fate counts)

The proportion of seeds which failed to germinate

The proportion of seeds which germinated by failed to emerge

The proportion of seedlings which emerged

The proportion of abnormal seeds or seedlings

Later experiments took account of the above parameters. In such measurements, the scoop described above was used to collect a number of samples from the sown grooves (the same samples were also used for gravimetric moisture content measurements)

Each sample was carefully broken open, separated and seived by hand in the laboratory and seeds and/or seedlings placed in one of the four groups listed according to their development at that point in time. Because of the reliance on visual assessment for this critical measurement, the species of seed sown in all such experiments was limited to reasonably large, optically distinct seeds, such as wheat. The seedling emergence counts determined the number of living single tillers appearing above a horizontal plane containing the ground surface. This arbitrary definition of emergence was felt to be necessary because with some grooves it was possible to see the shoots before they had actually grown sufficiently to appear above the adjacent undisturbed ground surface. Open grooves, in this manner allowed such shoots to take on green colouration and begin their aerial functions often several days before being counted as emerged.

In addition to the scoop sample counts, whole-plot seedling emergence counts were made (including individual recordings of each row). When considering emergence counts in isolation, these whole-plot figures were considered to be more representative than the corresponding figures derived from scoop sampling, and were therefore used in preference.

3.5.3 <u>Field studies</u>

Studies were also undertaken on field sites for a number of reasons.

a. Where large areas were required that were more appropriate for the development ofancillary equipment (such as the covering bar harrow).

b. For field assessment of equipment that was first designed using the tillage bin and tool testing apparatus.

c. To enable time and area variables to be introduced when investigating such factors as the wear rate of drill coulters.

Accordingly, field studies took one of two main forms

Growth studies

Machinery function studies.

<u>Growth studies</u>

Where seedling emergence counts were the main criterion of growth 300mm x 300mm quadrats were placed randomly about each plot. Avoidance of sampling from the bounding area between two drill passes was an obvious priority. With taller growing plants and at later stages of maturity, plant counts within specified lengths of drilled row were preferred to area quadrats for practical reasons.

In most field plots, extensive use was made of the curved bottom scoop, to enable seed-fate counts to be made.

Only rarely was terminal or interim yield of the crop recorded except where this was felt to reflect the vigour of seedlings at an early stage of development.

On occasions representative sample seedlings were separated from the soil and photographed against a grid background. No attempt was made to quantify these photographs and they were used as support information only.

3.6 DEVELOPMENT OF TRACTOR OR VEHICLE OPERATED FIELD EQUIPMENT

Three pieces of field equipment were developed and were essential to the experimental programme. They are listed below.

Bar harrow

Drill coulter field test rig

Trailing arm, seed boot and chisel drill coulter assembly for attachment to a commercially available seed drill*

3.6.1 Bar harrow

As reported by the author in 1970 (59), early observations suggested the need for improved soil or mulch cover over direct drilled seeds. This was thought to be beneficial in enhancing their changes of emergence, especially under a soil moisture stress. Irrespective of the drill coulter used to create the groove in the first place, it was felt to be desirable to devise a simple machine which could, at least provide Grade II cover (i.e. complete loose soil or rubble). Subsequent development of the chisel coulter (described later) further enhanced the action of the bar harrow and provided Grade IV cover (i.e. complete mulch) under favourable conditions.

During the development of the bar harrow, the action of a number of other covering devices was observed, although the screening of such devices was by no means exhaustive.

The important functional requirements of any covering device were felt to be that: -

* P. & D. Duncan Ltd., Model 730 MultiSeeder

a. it must be capable of either generating loose soil, or of utilizing already available loose soil in providing Grade II or III cover

b. it should not destroy intact stubble mulch in providing grade IV cover

c. it must be able to follow ground contour without either scalping or bridging

d. it must not disturb the placement of the seed in the groove

e. it must be able to clear surface trash at least as well as the seed drill itself

f. no restriction to shoot emergence should arise from its use

g. it should be an inexpensive and low draught-requiring adjunct to the main functioning components of the seed drill

The main types of known covering devices evaluated on an observational basis were:-

ring rollers
chain or ring harrows
bar "levellers"
soil groove "scratchers"

Arndt (64) observed that emerging plants moved through soil by weaving their way through voids and by displacing and deforming some soil obstructions. Thus it seemed desirable to provide for the shortest and least resistant path possible to the surface, consistent with the other above listed provisions of a covering medium. From field observations it appeared that shoots largely avoided penetrating unbroken turf and therefore favoured a path up through the groove slit. Furthermore, observation suggested that closure of the grooves by packing or pressing action often had harmful effects in restricting seedling emergence. In any case, the amount of friable loose soil and rubble available on the surface for coverage after passage of a direct drilling machine was usually minimal, so that any covering device which destroyed this by packing, appeared to be undesirable.

Ring rollers, in general appeared to fail in respect of points (a),(c),(f) and to some extent (g) above.

Chain or ring harrows appeared to fail in (b) and to a lesser extent (e). However, the design of the components of chain or

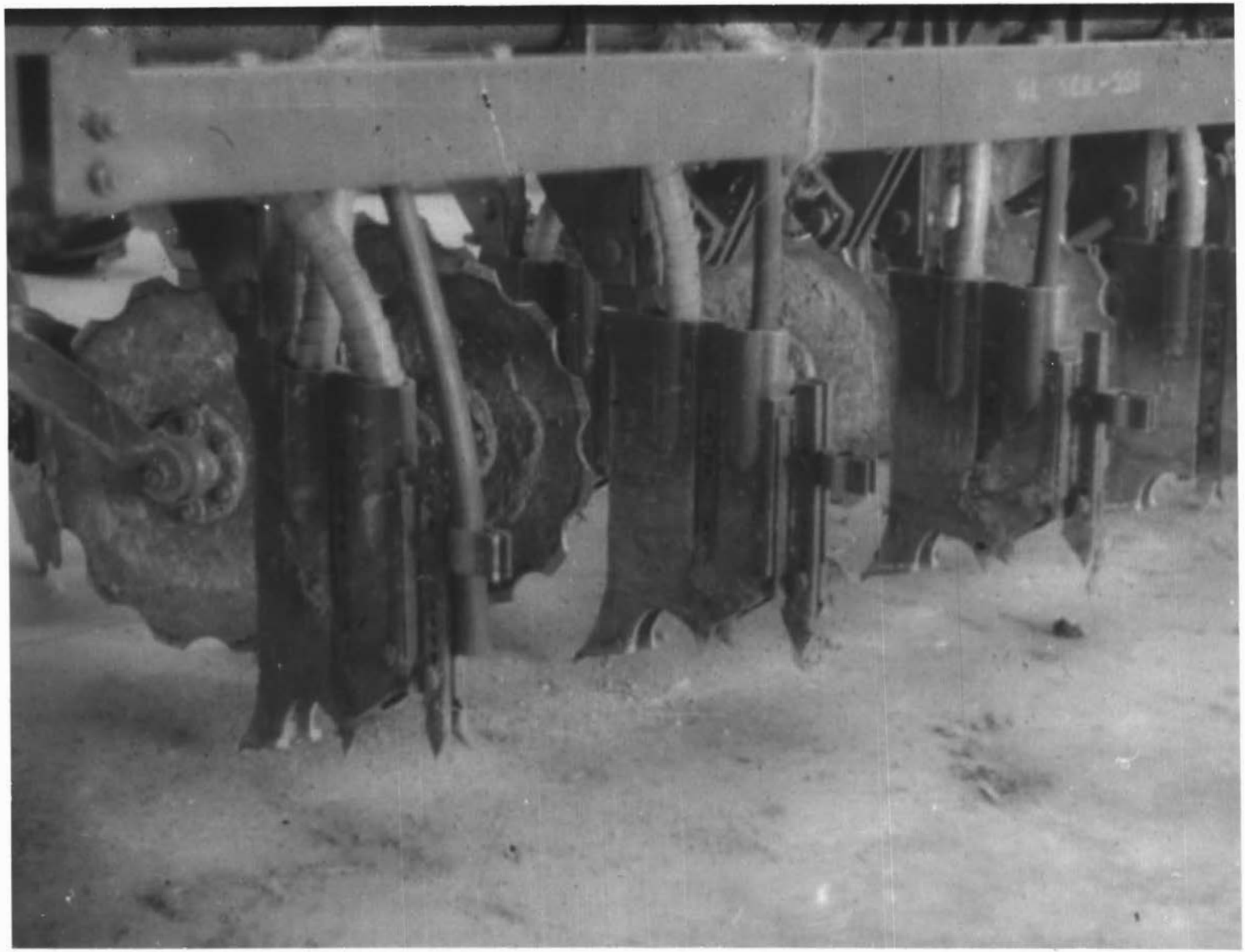


Plate 19: Groove "scratchers" attached to hoe coulter assemblies

ring harrows varied greatly. Accordingly some tended to fail in (a) and (d) as well, so no general recommendation or condemnation could be made of them.

Bar "levellers" tended to fail only in (c) and possibly (g).

Most of the groove "scratchers" consisted of angled projections which were designed to scratch loose soil from the sides of the groove (plate 19). In that this was partly a sub-surface, and partly a surface operation; and that the devices were attached to the back of the drill coulters themselves, their main failing appeared to be in (b). Unfortunately the lack of flexibility in use with a wide range of drill coulters has, in the past, made them unpopular on a practical scale.

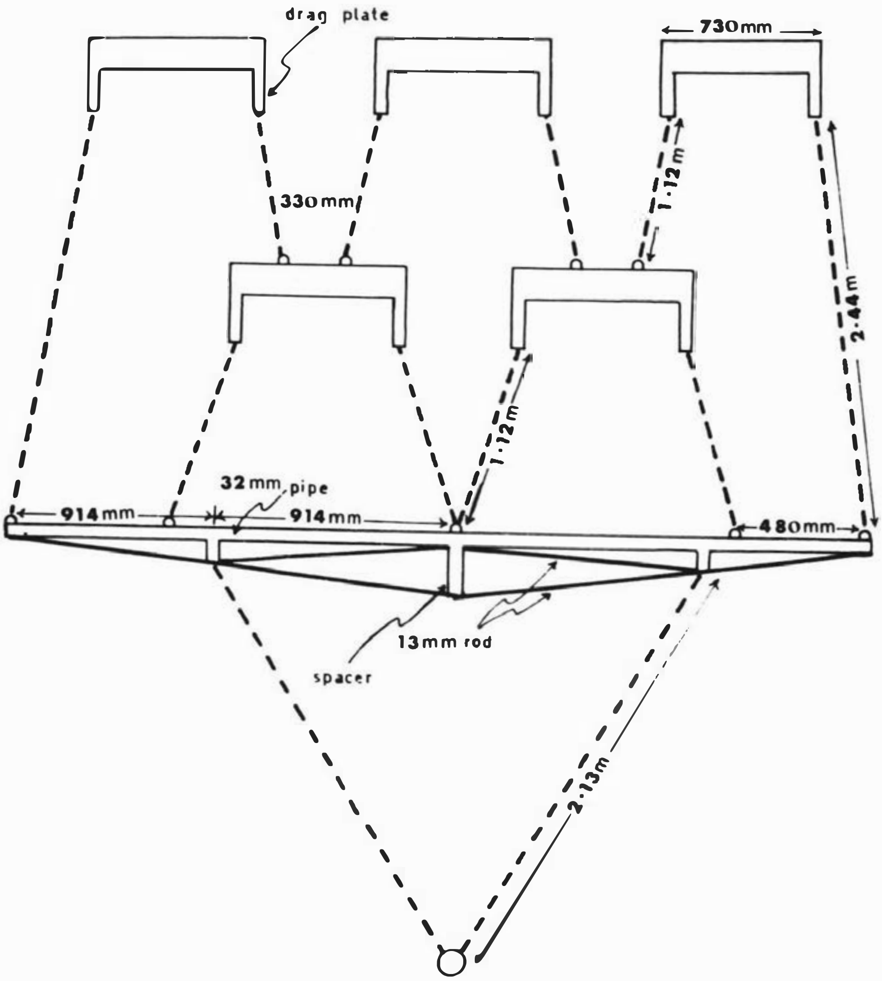
All of the above methods of covering failed in (a) when used with wet plastic soils. No attempt was made to design a device for use under these conditions.

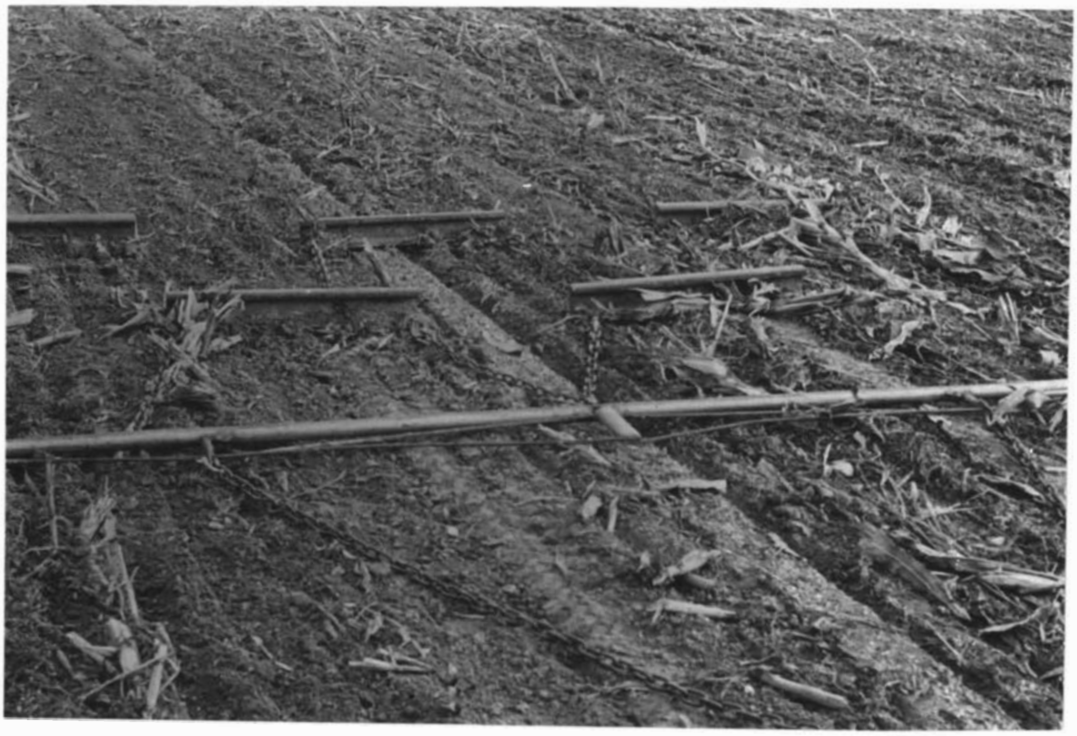
Noting the above criteria, the desirable principles of bar levellers were exhanced by overcoming their inability to follow ground contour. This was achieved by dividing the bars into a number of sections. In this manner a bar harrow was developed which is shown in plates 20 (a) and (b). Results of its effects are given in sections 4.3.1, and 4.3.2.

Operating principles

The operating principles relied on the bars scraping loose soil from the upheaved edges of grooves made by hoe or disc drill coulters, or by a combination of this and a gentle pressing back of the mulch flaps left by chisel coulters. In the former action the wave of loosened soil and rubble was deposited in the open grooves giving effect to Grade II and sometimes Grade III cover. In the latter action the effect was to produce Grade IV cover over the seed. With triple disc coulters operating in all but very friable soils, neither this harrow nor any other form of covering device known to the author proved to be very successful because of the marked absence of loose soil generated by the coulter, except perhaps at high speed.

The dimensions and specifications given in plate 20 (a) are based on a harrow capable of being used with seed drills of up to 2.4m effective width. Chain attachment points facilitate self





Plates 20(a) & 20(b): (a) Bar harrow dimensions, and (b) its operation in maize stubble after passage of dished disc coulter centering and overlap of the individual bar components.

While weight appeared to be necessary to scuff the heaved up sides of some soil grooves the bars rested also on the undisturbed inter-row soil so that the danger of over-compaction in the row was averted. Heavy section railway iron appeared to be an ideal material for the bars but lighter sectioned versions were seen to be adequate under many circumstances.

Experience indicated that it was often desirable to delay harrowing for a short period where soil was damp, so that the heaved up sides could dry a little and crumble instead of smearing. In some other cases it was desirable to treat the whole paddock a second time with the harrow. This was done at relatively high speeds, coupled directly to the tractor and operated in much the same manner as a conventional grass harrow.

No retardation of plant shoot emergence was observed after use of the bar harrow. Field observation and the results of seed fate counts using the scoop sampling technique described, confirmed this. Nevertheless, it is possible that in some heavy and/or damp soil conditions shoot emergence might be retarded by the action of any one of several covering devices, including the bar harrow.

3.6.2 Drill coulter field test rig

On occasions it became necessary to test one, or a small number of drill coulters in a field situation with minimal sacrifice of the versatility of the tillage bin and tool testing apparatus. Such tests were of physical characteristics only (e.g. ability to follow contour, depth control, freedom from trash blockage, smearing tendency and wear rate). No seed or fertilizer metering devices were therefore required.

Difficulty of access to essential components, and of adjustment, made commercial seed drills unsatisfactory for the limited number of these tests that were required.

A small rig was used, onto which three drill coulters could be simultaneously mounted in an identical manner to that of a commercial seed drill. The amount of use to be made of this rig was expected to be limited, so adaptation of other available facilities was preferred to designing a totally new structure. The basic mobile carrier (plate 21) was a 1.0m wide x 2.0m long towed frame equipped

Plate 21: Drill coulter field test rig

with rubber wheels. On the back of this frame was a common pivot bar, to which were attached up to 3 trailing arms of a commercial seed drill. Penetration force was provided by a cantilever and sliding weight system for each individual coulter assembly. At times, the weights totalled in excess of 150kg so a mechanical means of lifting the three drill coulter assemblies was found to be necessary. A triangulated sub-frame was bolted to the mobile carrier and a hand operated winch effectively raised the coulter(s) when required.

The assembly was easily transported and operated by a four-wheeled-drive vehicle. Preliminary drill coulter testing in remote sites, exhibiting particular soil or surface characteristics, was both feasible and rapid with this tool.

3.6.3 Trailing arm, seed boot and chisel drill coulter assembly.

Chisel drill coulter

The ultimate object of much of the research and development work described herein has been to improve the method of sowing seed in a direct drilled situation. The development of a unique chisel drill coulter which gave substantially improved seedling emergence results (see section 4.3) can therefore be regarded as a significant step toward achieving this objective. The functional design of this drill coulter has been a direct result of the greater understanding of the requirements of emerging plants, which accrued from the tillage bin work. Subsequent mechanical improvement to the coulter and assembly has been aimed at improving trash clearance and wear rate, but has at no time been allowed to alter the basic functional design. The order of priority and approach thus adopted is regarded as particularly important in this type of study, and has undoubtedly been largely responsible for the successful implementation of the machine designs and improvements that have resulted from this total investigation.

Functional requirements

As a result of initial observation, and later confirmed by a number of experiments utilizing the tillage bin approach, it was apparent that while cover *per se* was important in preventing dessication of sown seeds, the nature of this cover also played an important part. A substantially unbroken stubble mulch cover (grade IV) was thought to be desirable, according to the comments of a number of authors (3,32). Triplett et al (38), noted also that a plant response advantage had stemmed from sub-surface disturbance. Thus, the chisel drill coulter and its assembly was designed to have the following functions:

a to create a groove with as little bursting and destruction of the overlying vegetation as possible

b. to facilitate subsequent grade IV cover over the seed where a bar harrow followed the drill coulter

c. to avoid closure of the groove in a manner where shoot emergence might be restricted

d. to shatter and physically disturb a localised sub-surface region around the path of the coulter, in order that some loosening of the immediate soil would be achieved

e. to avoid compaction and smearing of the groove (especially in heavy textured soils)

f. to operate at a constant and adjustable depth irrespective of minor surface undulations

g. to deposit seed in the shattered zone of the groove so that it was at a consistent depth, would receive good soil-seed contact and aeration, and be in a position which would promote early root exploration

h. to avoid collection of root and organic material as a result of its passage through the ground

i. to avoid blockage between adjacent drill coulter assemblies from surface trash

j. to be as wear resistant as was feasible

In comparison with other existing drill coulters with which the chisel coulter was compared, it can be considered to have an action similar to a miniature sub-soiler where the area of sub-surface disturbance is considerably in excess of that at the surface. The triple disc, hoe and dished disc coulters, by contrast all form a substantially "V" shaped groove.

The development of the chisel coulter involved construction of a prototype which was used in all tillage bin experiments. Subsequently this basic design was modified to fit to a field drill. These modifications involved the addition of a frontal wing for trash clearance purposes and a reshaped top attachment area. Care was taken not to alter the design or dimensions of the soil-functional components which were responsible for the general shape of the soil groove. The prototype version is not described here.

Figure 4 is a diagramatic representation of the typical cross sections of grooves formed by the chisel coulter in comparison with those formed by the triple disc and hoe coulters at varying soil moisture levels in a silt loam. It was prepared by H.N. Dixon (56).

Full design specifications of the field version of the chisel coulter are given in Provisional Specification No 171357, under the New Zealand Patents Act 1953., in Figs. 2 a,b,c, and d, and plates 22 a,b,and c. With respect to each of the above listed functions the chisel drill coulter assembly displays the following characteristics.

(Requirements a and f)

The vertical shank of the coulter is narrow in width and is preceeded by a front vertical flat pre-disc which together with the chisel coulter makes up the drill coulter assembly. While this pre-disc component is also common to other drill coulter assemblies (e.g. hoe and triple disc) and has the function of initiating the cutting of the turf, in association with the chisel coulter it has been given the additional function of maintaining constant depth of operation. Plate 22(a) shows a pair of circular depth bands attached to the pre-disc in such a manner that penetration beyond this diameter is to all intents and purposes prevented. The axle height of the pre-disc is, however, adjustable within limits in relation to the chisel coulter. In this manner, the operational depth of the latter component can be altered by adjusting the pre-disc position on the drag arm. In so doing, the proportion of the vertical cut which is accomplished by the pre-disc in comparison with the chisel coulter is altered slightly. This is not considered to be important as the major function of the pre-disc is to slice through the top 10-35mm of dead vegetative material at the soil surface and thereby prevent buildup on the leading edge of the chisel coulter itself. Even at the maximum depth of operation of the coulter assembly (38mm in these experiments) the pre-disc did not cut less than 10mm into the soil.

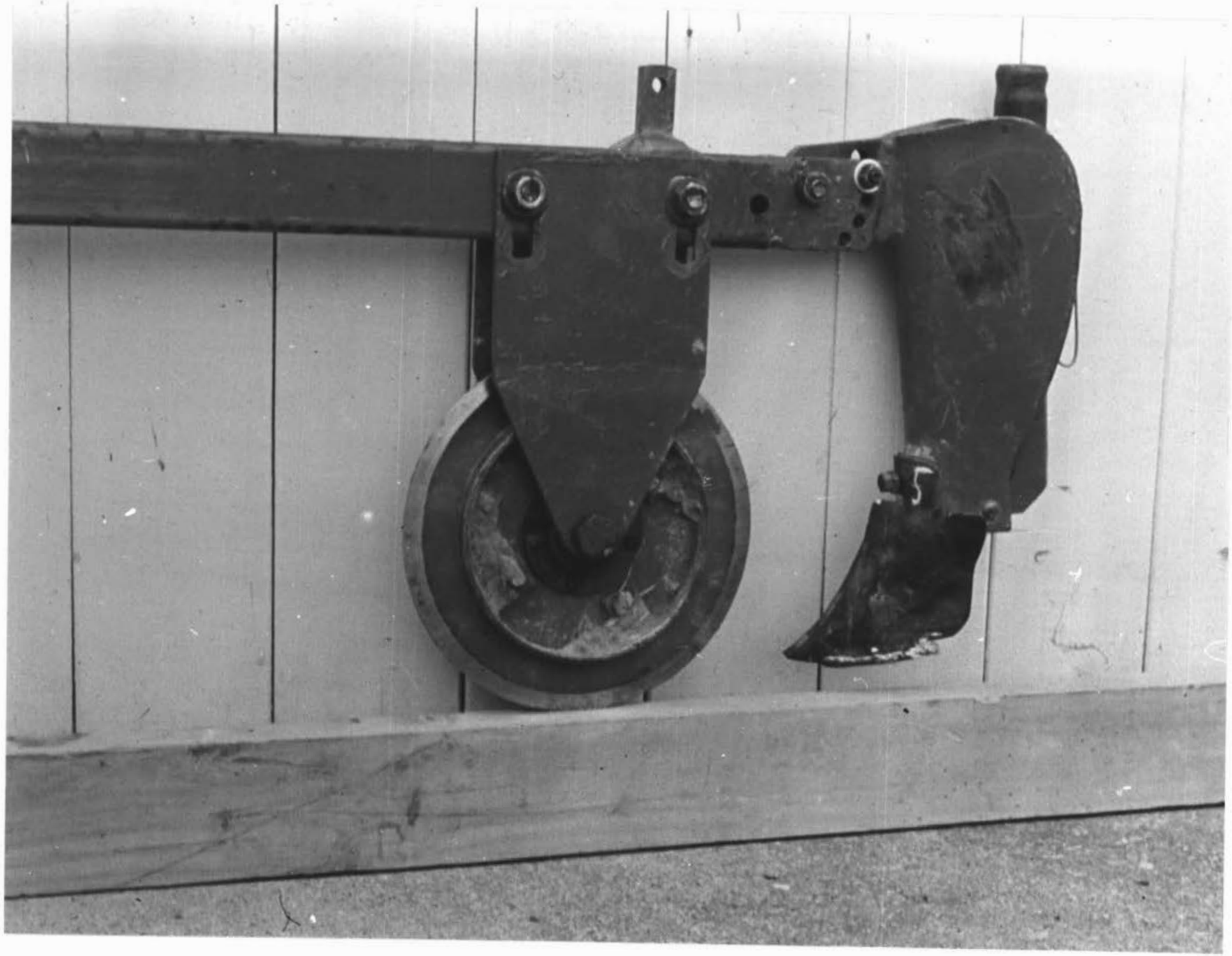


Plate 22(a): Side view of chisel coulter assembly and drag arm

Plate 22(b): Oblique frontal view of the chisel coulter

Plate 22(c): Rear view of the chisel coulter, showing the diverging internal seed delivery tube, and the lateral wings

(Requirements b and c)

The lower wings of the chisel portion of the coulter travel at a slight incline to the horizontal (8-10°), in so doing they create a certain amount of shattering beneath the soil surface. Such shattering is partly achieved through a heaving action which leaves the surface of the soil adjacent to the groove slightly raised. The extent of the surface upheaval, not unexpectedly, decreases with distance from the centre line of the groove. It appeared not to extend as far as the mid point between adjacent coulters in these experiments, although this could be expected to be a function of speed, soil type, and root strength. The nature of this upheaval was such that normally the upper portion of the vertical cut in the groove had some bare soil exposed.

In suitable soil conditions (i.e., at a moisture regime which would normally be adjudged to be suitable for mouldboard ploughing) the groove was usually self sealing with respect to the sides meeting together after passage of the coulter. This provided grade IV cover. In more moist conditions (and especially in heavy textured soils) the groove often remained open as much as 5-6mm, while in dry and friable soils the result was similar to the self sealing state.

In any situation, subsequent passage of the bar harrow had the effect of gently pressing the upheaved portions back from whence they came (at the same time avoiding excessive shoot-restricting compaction, common with the use of rollers). It also scuffed enough loosened surface soil to finally smooth and level that portion of the groove immediately adjacent to the passage of the vertical shank of the coulter.

While in moist heavy soils the grade of cover provided by a combination of the chisel coulter and bar harrow usually fell short of that achieved in more suitable conditions, the dominance of a mulch flap in the covering medium often justified scoring the cover as grade IV. It might be argued that cover *per se* should not be as important in such conditions compared with dry soils, but intense drying conditions following drilling also demanded protection from dessication of the seed and crusting of the groove walls.

The only observed occasions when the chisel coulter assembly, in association with the bar harrow, failed to produce grade IV cover , was where parent root growth had not been sufficient to sustain an unbroken mulch flap over the chisel coulter wings. For example, when drilling into lucerne swards it was not unusual to produce grade III cover (intermittent stubble mulch), depending on whether the coulter had travelled through a lucerne plant or between adjacent plants. Similarly, in ryegrass seed stubble and small grain cereal stubble, the cover could be described as grade II (complete loose soil), rather than grade IV.

(Requirement d)

In turf, the heaving produced by the chisel coulter was not greatly relieved by unrestricted bursting at the soil surface. Thus the action of the wings generated an area of loosened and shattered soil beneath the surface, just below the zone of maximum soil/root-mat strength. Under pasture, this appeared to be generally at 15-25mm depth. It is interesting to observe that in a well consolidated soil, but supporting no vegetation, the lack of soil/root-mat strength allowed bursting to continue to the surface with the result that the final disturbed groove shape closely resembled that which would be left by a more conventional parallel sided coulter of the same width as the chisel coulter wings. The sub-surface tillage beneath a turf mulch was shown to increase the loose soil generation in comparison with the hoe and triple disc drill coulter (56). It is reasonable to suggest that aeration and soil seed contact might also be improved with the chisel coulter because of this greater incidence of loose soil, as well as by more precise seed placement (see below).

(Requirement e)

One of the most serious criticisms of the triple disc coulter has been its tendency to smear and compact the sides of the groove, especially in damp plastic heavy textured soils. In that the chisel coulter was designed with relief along most of its planes of action, or at least is parallel sided, this was felt to be important in reducing the incidence of smearing by this coulter. Any coulter which bursts its way through the soil might be expected to be less likely to create side wall smearing than the essentially wedge shaped triple disc, but in the case of the chisel coulter, special attention was given to this aspect. For example, total relief in the vertical longitudinal plane was achieved through inclination of the chisel wings. Partial relief in the horizontal lateral plane at the wings was achieved by having them substantially parallel sided (the fronts of the wings are bevelled, but the bevel angle is only 44° included angle and is therefore thought likely to smear only in exceptionally plastic soil conditions). There is no horizontal lateral relief at soil surface level on the vertical shank of the coulter - in fact it is slightly tapered. As this is the leading edge of the coulter at soil surface level, there is little option against the taper which is a common feature of most drill coulters (with the exception of the dished disc).

Nevertheless there are likely to be soils and climatic conditions which encourage a certain amount of smearing by any coulter. Dixon (56) was able to show in his limited study that where smearing was associated with soil compaction, the permanence of this increased with moisture content at the time of drilling. It has often been observed that subsequent exposure to drying, tends to "bake" the smeared area into a hard crust. Thus, it is reasoned that any drill coulter which will reduce subsequent drying of the groove, is less likely to encourage "baking" of the smeared groove. Observation suggested that seedling roots were better able to penetrate a moist smeared interface than a dry "baked" previously smeared interface. Dixon (loc cit) showed that compaction resulting from the chisel coulter was similar to that of a hoe coulter, both of which were better than a triple disc coulter, especially in moist soils.

(Requirement g)

Seed deposition with the chisel coulter involves passing the seed down the hollowed vertical shank, which has a deflector so placed to eject the seed at the rear mid point of the inclined wings. In this manner the seed drops into a relieved zero-pressure area, where soil displacement and velocity in the shattered state could be expected to be at a maximum. This is thought to enhance the prospects of soil-seed contact.

The hollowed vertical member of the coulter is not closed at the trailing edge. In fact it diverges slightly in internal width from front to back to discourage seeds from wedging in this passageway.

(Requirements h and i)

Collection of organic debris can be divided into two phases - aerial trash and sub-surface root material.

The former problem is one common to all non-rolling drill coulters. Various combinations of the pre-disc and chisel coulter were observed in operation. As a result a Mark 2 version of the vertical shank of the chisel coulter was constructed. This incorporates an extended leading edge which is shaped to a radius of curvature slightly in excess of that of the pre-disc. It was felt that when the pre-disc was positioned close to this leading edge, the wrapping of trash (which had been cut by the pre-disc) around the chisel coulter shank would be discouraged. As the curvatures of these two closely associated components diverge towards the top, the chances of trash becoming wedged between them is also minimised.

The underside of the protruding leading portion of the coulter is also bevelled downward toward its junction with the front of the chisel wings portion. By this means, unbroken root debris is deflected downwards and shed beneath the moving coulter rather than collected by, or wrapped around it. The horizontal champhering of the leading edge of the chisel wings, also assists this function.

(Requirement j)

It was considered highly undesirable to in any way alter the design or arrangement of the chisel coulter assembly in order to enhance its physical wearing properties, if such alteration was likely to also alter the essential seed placement functions. Rather, experimentation with various ferrous based construction alloys together with arc-weld applied hard surfacing materials was preferred in an effort to extend the useful life of soil engaging components. The wear rates of coulters so treated appeared to compare well with other types of drill coulter assembly. Hard surfacing in this manner also had the advantage that it required only a relatively inexpensive rebuilding operation to bring the coulters back to a serviceable shape, provided that the extent of the wear had not been allowed to proceed too far into the base material.

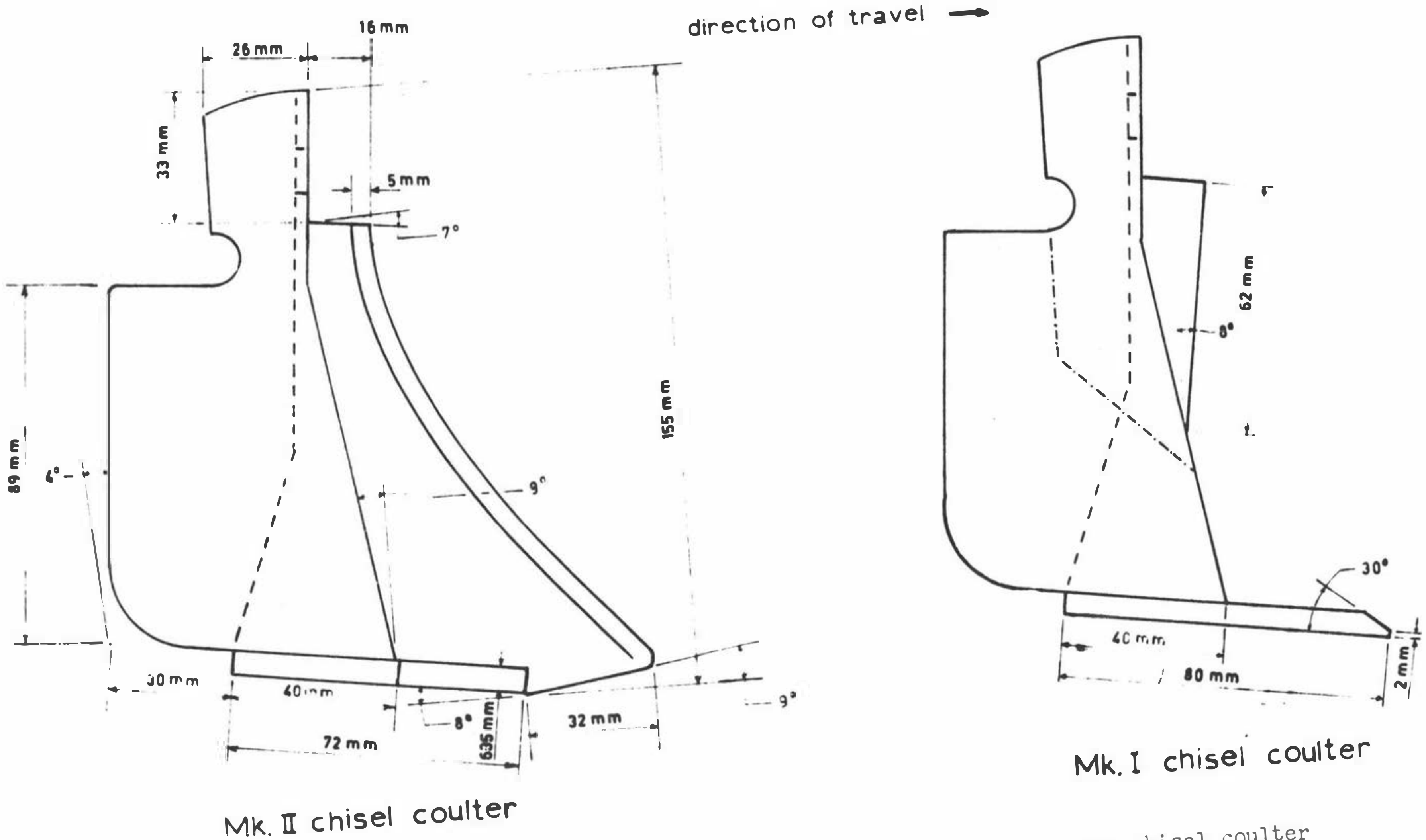


Figure 2(a) Side elevations of the Mk. 1 & Mk. 2 versions of the chisel coulter

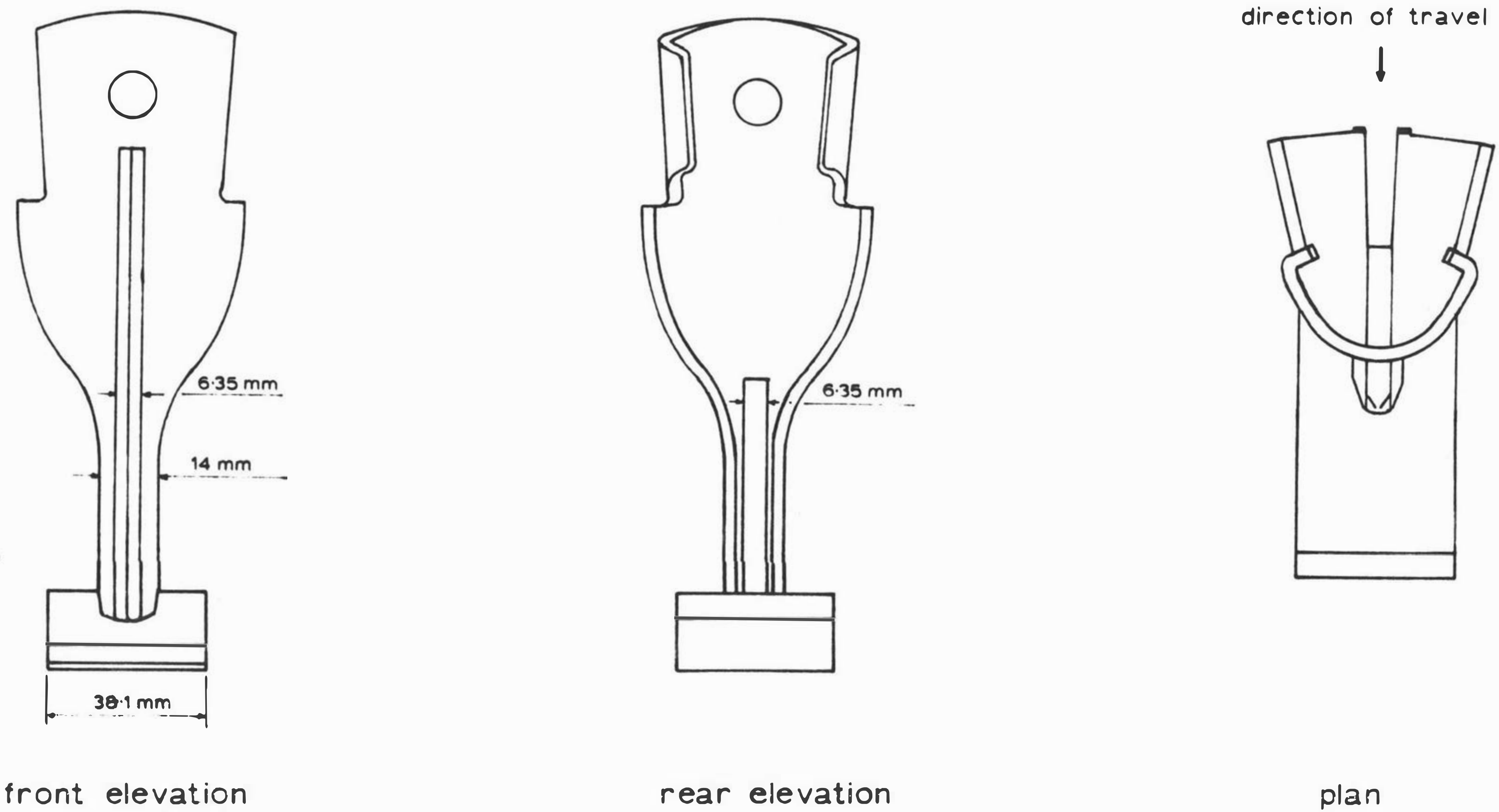


Figure 2 (b) Front & rear elevations, & plan view of Mk. 1 chisel coulter

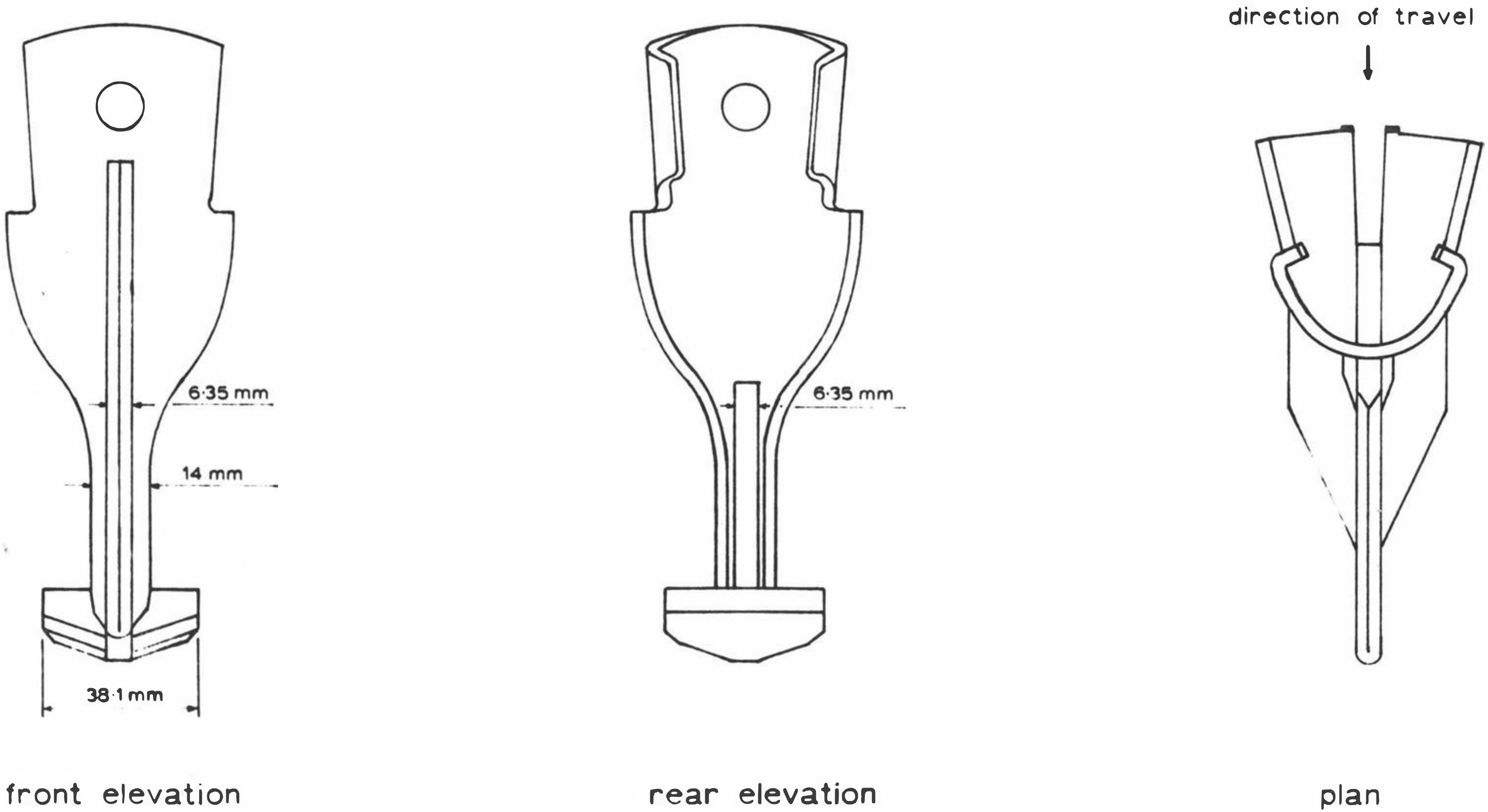


Figure 2 (c) Front & rear elevations, & plan view of Mk. 2 chisel coulter

Trailing arm

Little original design was incorporated in the trailing arm assemblied (Figure 2 (d), plate 22(a)). They are standard commercial components* whose essential features are that the vertical movement is hinged about a forward axle and the attachments for the down-force springs (not shown) are in the same ratio from the forward axle for the short and long versions of the trailing arms. In fact the soil reaction opposing penetration arises from separate components acting on the pre-disc and the chisel coulter respectively. The resultant of these two forces would be expected to lie somewhere between the two components. The exact location of the resultant however, will be governed by such factors as soil resistance, vegetative resistance and the relative depths of operation of the pre-disc and chisel coulter respectively. Thus, the positioning of the spring attachment cannot be expected to always give precisely the same penetration force to the drill coulter assemblies on both the long and short arms under all operating conditions. Nevertheless, as the force component attributable to the coulter alone could be expected to greatly exceed that of the pre-disc, and the resultant line of action of these two will vary continually with natural soil and vegetative heterogeneity, it was unrealistic to do other than position the spring attachment so that it was correct if the total soil reaction had arisen from the coulter component alone. The drawbar height of the seed drill was adjustable to give an essentially horizontal attitude to the trailing arms when the coulter assemblies were at their working depths.

All components not marked with dimensions in Figure 2 (d) are standard components supplied by P. & D. Duncan Ltd.,

Seed boot

Minor modifications were made to various features of the seed boot in order to facilitate attachment and operation of the chisel drill coulter.

a. Angle adjustment. To adjust the angle that the chisel wings made to the horizontal a vernier hole adjustment

*P & D Duncan Ltd.

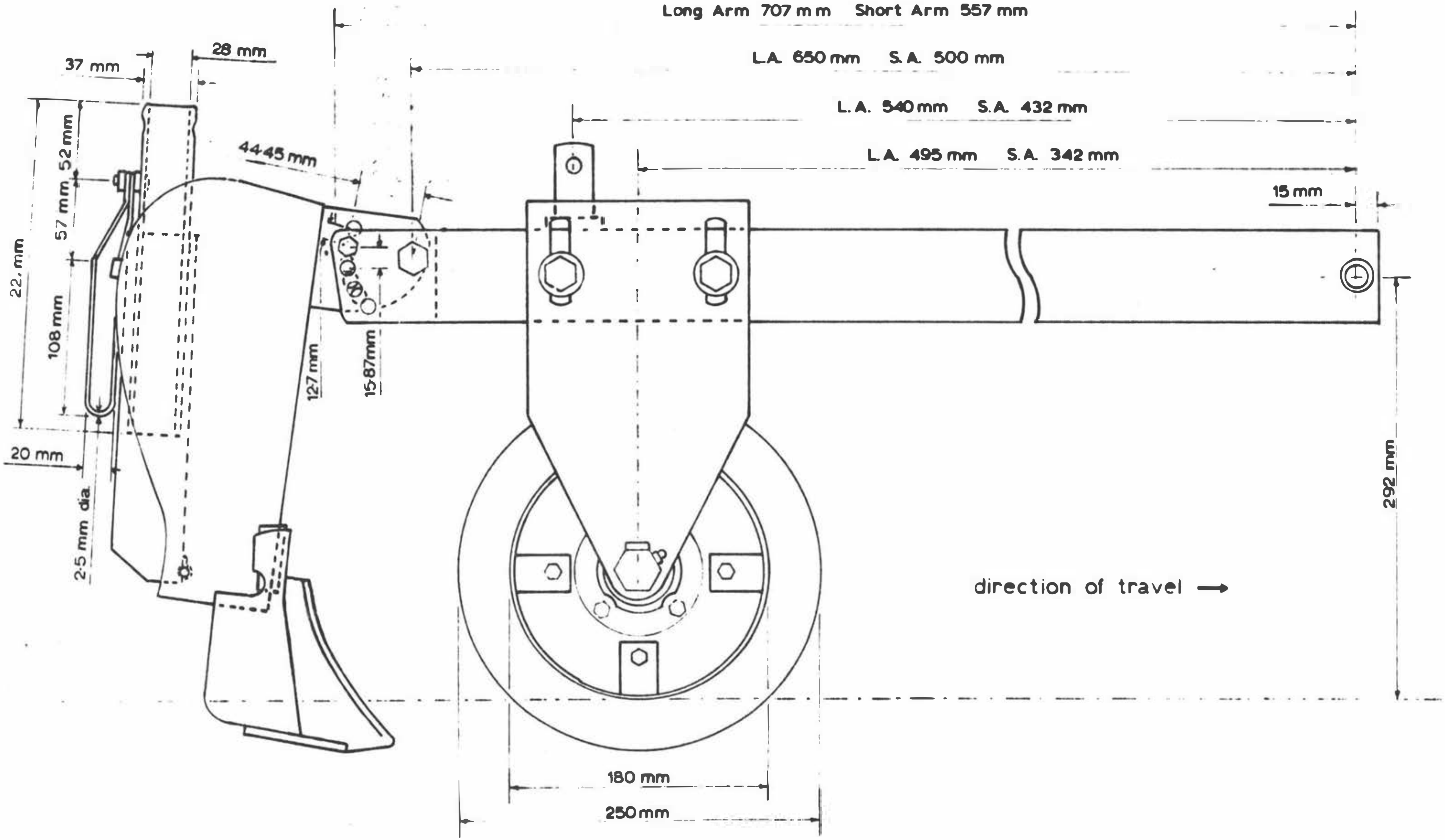


Figure 2(d) Mk. 2 chisel coulter assembly and drag arm was provided at the attachment point of the boot to the trailing arm (long and short arm versions were identical in this respect).

b. Attachment of seed and fertilizer delivery tubes. The rubber seed tube on the seed drill was attached and secured by a spring clip to the upper end of a 37mm o.d. length of alkathene pipe which slid loosely down the front portion of the seed boot. The base of the boot was so shaped that the seed which was dispersed from the alkathene extension was directed into the top hollow shank of the chisel coulter.

A hinged steel tube was a standard attachment to the rear of the seed boot for fertilizer delivery. To extend the height of entry of this tube, a similar extension length of alkathene pipe was attached to the appropriate rubber tube on the drill. Because of the tendency of this rear tube to pull out of the seed boot, a wire slide bracket was attached to limit the amount of upward travel of the extension.

Fertilizer ejection was rearward of the chisel coulter shank. In this way, fertilizer was not specifically directed down the hollow shank of the coulter. Instead it was banded on the ground surface overlying the groove. However, at this point, the groove was usually still partly open, and a proportion of the fertilizer fell directly into the seed placement area. The proportion of fertilizer which fell on top of, and down the groove respectively could be varied by providing for-and-aft adjustment of the position of the fertilizer delivery tube in relation to the coulter. This facility was not provided in the present design but future investigation of fertilizer placement could be important and would warrant modifications to the seed boot accordingly.

3.7. EXPERIMENTAL DESIGNS

3.7.1 Turf block studies

Simple randomised block designs were used in all experiments.

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Site and soil type selection

Sites were chosen which appeared to exhibit a uniform distribution of a particular desirable soil type and vegetative cover. In fact, one of the more noteworthy features of the tillage bin technique developed, was that it allowed the introduction into the experimental system of various soil types or vegetative covers, while retaining other variables (such as climate) substantially constant.

In all tillage bin experiments reported herein the soil type used was classified as a "Manawatu fine sandy loam" and was located on the Massey University No 1 Sheep Farm, and at Flock House School of Instruction, Bulls. A light textured soil was chosen in the hope that changes in moisture regime would be more rapid than might be expected from a heavier textured soil. The parent vegetation was predominantly perennial ryegrass/white clover, with a small proportion of subteranean clover, various flat weed species and occasional plants of paspalum. In that the composition of this parent cover, within limits, was not thought to be a major factor in the experiments conducted, and was subsequently killed anyway, no more precise botanical analysis was considered to be necessary. Steps were taken, however, to ensure that the parent species had been allowed to recover after seasonal drought and to re-establish sufficiently in the bins to ensure that a vigorous root system was present at the time of spraying and drilling.

Sampling procedure and subsequent handling

As described earlier, avoidance of obviously atypical sites for turf block extraction was a high priority. In all other respects however, the collection sites could be considered to be randomly chosen.

Each bin was numbered and the order of extraction was randomised. Furthermore, the order of placement of bins under the rain canopies during the pre-drilling period was further randomised.

The only selection of bins came about at the drilling stage.

The bin exhibiting the most uneven surface conditions or irregular parent vegetation at the time of drilling was put aside as the "lead in" bin. It played no part in the experimental results. The three bins chosen for each treatment were taken separately from each of the three rain protection canopies. In this manner, during the pre-drill period, each of the rain protecting canopies was considered to be a block, within which three tillage bin plots were randomly positioned. After drilling, one bin of each treatment was returned to a rain canopy position but care was taken: -

a. to re-randomise the allocation of individual bins to canopies (blocks), and

b. to randomly orientate the bins so that they were not necessarily replaced with any one end closest to the adjacent white-painted wall.

In this manner the experimental design involving tillage bins is considered to be a randomised block design.

When sampling from or within the sown tillage bins where raising of the rain canopies was involved, care was taken to expose each set of three turf blocks to unrestricted climatic conditions in a repeatable sequence, even when this was for only short periods of time.

3.7.2 Field studies

All field experiments involved randomised block design except where site and machinery movement limitations precluded strict randomisation of plots within blocks. For example, in experiment 2 a single strip was left unharrowed during the normal field drilling of a paddock. Plots pegged across the interface between the "harrowed" and "unharrowed" portions meant that a possible site effect was introduced. This limited the statistical analysis of these results.

4 EXPERIMENTAL OBJECTIVES AND RESULTS

4.1 OBJECTIVES

The objectives of the experiments were in three main catagories.

a. **Field experiments**

Field studies were aimed mainly at gaining an initial insight into seed placement and covering problems and thereby establishing priorities for tillage bin studies (experiments 1 and 2). In one experiment the field study involved mechanical testing of an experimental drill coulter with regard to its resistance to wear (experiment 9).

b. **Pilot tillage bin experiments**

During the development of the tillage bin technique a number of experiments were conducted to test various aspects of the technique, including its sensitivity when screening a range of drill coulter designs. Although some useful data concerning coulter design and plant responses were forthcoming from these experiments, their main objectives were related to methodology (experiments 3,4 and 5).

c. **Main tillage bin experiments**

The main tillage bin experiments had the following objectives:

Identifying soil and/or seedbed physical properties most likely to affect seed germination and seedling emergence in a direct drilled situation.
Identifying and testing the design parameters of direct drilling coulters which were most likely to have direct affects on these soil physical properties.
Recognising those drill coulter design features which would have affects on the direct drilling technique in general or on the design of the field machines which would support them.
(experiments 6,7 and 8).

It must be pointed out that from some of the results of experiments in direct drilling which are reported in the literature, together with those discussed herein it is questionable if it is valid to assume that implantation procedures for seeds in untilled seedbeds should follow the same principles used in cultivated seedbeds. For example, it is commonly assumed that an implanted seed has its water imbibition process enhanced by "good" soil-seed contact and that in physical terms, this favours an amount of loosened friable soil particles in the seed zone. How much friable soil, is something which is difficult to accurately determine as it is likely to be influenced by other factors such as bulk density, soil texture, the moisture regime at the time, seed size, shape etc. No critical assessment of soil-seed contact was undertaken in these experiments as previous attempts to quantify this parameter had not met with a great deal of success and no hypotheses had been extended to suggest what effect this might have had on germination (56).

None of the seed varieties chosen were light-dependent for germination, so this factor was ignored.

Aeration, was expected to be an important soil factor. In the general seedbed it might be expected to be largely dominated by the inherent physical state of the soil prior to drilling under the particular parent vegetation. In that direct drilling, by definition, precludes the opportunity to modify the general state of aeration in the seedbed by cultivation it is left to the drill coulters to bring about what little influence they can in the immediate vicinity of the seed. The same restriction applied in part to soil compaction and bulk density. It was therefore considered appropriate to exclude consideration of the broader seedbed aspects from this study and to concentrate on the seed groove in isolation. In any case the broader questions were felt to be more aptly dealt with in field studies designed to answer the question of whether or not a given soil was in a fit state to be direct drilled (e.g. whether it was heavily pugged, badly drained etc.,) or whether, instead, it should be cultivated.

4.2 RESEARCH PRIORITIES

There appeared to be three general properties of the drilled grooves which could be adequately studied with the experimental equipment developed. These were:-

a. their ability to transmit a sufficient supply of water to the implanted seeds to facilitate imbibition

b. their ability to sustain the germinated sub-terranean seedlings to the emergence stage

c. their subsequent influence on root development and proliferation

Although some initial work had been directed towards the last named area (56) the zone of influence under the seed was not considered in this study except in broad terms in one of the pilot tillage bin experiments (experiment 4 b.).

The experiments which were designed to look at the first two named areas did so by attempting first to identify why seedlings failed to emerge in field experiments, and secondly to find ways of improving the environment of the drill groove (e.g. covering). Subsequently, experiments were conducted into ways of providing better methods of creating the groove and sowing the seed so that the effectiveness of covering (and thereby the micro environment) could be further enhanced. In the presentation of the results of these experiments, the numbering of individual experiments does not necessarily follow a strict time sequence as tillage bin experiments were often conducted simultaneously with field experiments.

4.3 RESULTS

4.3.1 Experiment 1: The effectiveness of bar harrowing (field experiment)

Objective

In spring, 1970, after construction of the bar harrow, an experiment was conducted to test its effectiveness in conjunction with direct drilling hoe coulter assemblies (plate 23). Specifications of experiment 1 are given in appendix .4.

Results

The effects of the bar harrow, used under two contrasting soil conditions, on seedling emergence of choumollier are presented in Table 3.

TABLE 3 The effects of bar harrowing on the seedling emergence of direct drilled choumollier

(plants per square metre)

GROUND CONDITIONS	3 wks post sowing		3½ wks post sowing		4½ weeks post sowing		Means	
	H*	UH*	H	UH	H	UH	H	UH
Rough surface (50-75mm deep hoof marks)	22.3	9.5	26.3	14.2	17.5	12.2	22.0 aA	11.8 bB
Reasonably smooth Surface	12.8	8.2	20.2	18.7	14.9	10.9	15.9 abA	12.3 bA
	* H = bar harrowed UH = unharrowed							

Unlike letters accompanying data denote significant differences. (Capitals, P= 0.01; small letters, P= 0.05)

The results indicate a general increase in plant numbers in all treatments until 3½ weeks and a decline during the following week. Because these trends appeared to be consistent across all treatments comparison of mean plant density figures covering the three sampling dates was felt to be meaningful.

Discussion

The most apparent effect of the use of the bar harrow was to scuff loose soil from the heaved-up sides of the groove and push it back over the seed. The effect of this, however, was most pronounced on the roughened surface where a significant increase in plant density resulted from its use (P = 0.01).

It is possible that this may have been in part a function of poor initial seed placement in the rough ground (which was subsequently improved by harrowing) as compared with better initial seed placement in the smooth ground and which was not significantly improved by harrowing.

It is possibly more interesting to note that under the continuing dry weather that occurred, the initial improvement in seedling emergence with all treatments was soon reversed. This suggests that while cover *per se*, appeared to have had an initial advantage over no cover in the rough conditions, the nature of this cover allowed eventual mortality of seedlings at about the same rate as did no cover although the margin between the two remained throughout.

The author in reporting this experiment earlier (65) also cited data which indicated that a similar experiment conducted in December 1969 had experienced good rain soon after sowing and had shown only a small and insignificant gain in favour of bar harrowing.

Plate 23: The hoe coulter assembly as tested

4.3.2 Experiment 2: The effectiveness of bar harrowing with different seed sizes (field experiment)

Objectives

In order that the initial field results from experiment 1 might be further evaluated with seeds of differing sizes, an experiment was designed with lucerne as an example of a small seed, barley as a medium sized seed, and maize as a large seed. It was felt that from the comments of Kahnt (16) there might be an interaction of seed size and soil covering, possibly because of the inherent vigour of large seeds, offset by the possible difficulty of adequately covering large particulate objects in comparison with smaller objects.

With lucerne and maize a comparison with conventional sowing into a cultivated seedbed was also included.

Specifications of experiment 2 are given in Appendix 5.

Two sampling dates for each crop were used to study the short and longer term seedling emergence trends. The actual dates chosen were dependent on the intervening weather. For example, an attempt was made to record the effects from a dry period before rain had time to have an effect on seedling emergence.

With the lucerne experiment, dry matter yield and soil moisture contents were determined at day 85. Measurements ceased with lucerne on this day, while with maize terminal results were on day 37, and with barley on day 17.

With all three crops, plots were pegged across the border between a harrowed and unharrowed strip. The lucerne and maize plots also straddled the border between a cultivated paddock and an uncultivated strip at one end. Because each of the respective treatment plots was thus not randomised across each of the 5 blocks, a possible site effect was introduced. To minimise this effect, blocks were positioned across obvious topographical changes which might reasonably have been expected to demonstrate changes in soil characteristics. Nevertheless no attempt was made to compute levels of statistical significance for treatment mean differences. Instead, each mean is quoted together with its standard error for comparative purposes.

Results

Tables 4(a), 4(b) and 4(c) present seedling emergence, yield and soil moisture data for lucerne, barley and maize respectively. In the table no comparison among crop species is inferred.

Visual scoring of the cover over the direct drilled grooves with each of the crops was as follows;

Lucerne-	harrowed;	grade II
	unharrowed;	grade I to no cover
Barley-	harrowed;	grade II
	unharrowed;	grade I to no cover
Maize-	harrowed;	grade I
	unharrowed;	no cover

TABLE 4 (a) The effects of cultivation, direct-drilling and bar harrowing on seedling emergence, dry matter yield and soil moisture content of a lucerne crop

		Seedling Emergence (plants/m^2)	SE means ±	Dry Matter Yield (kg/ha)	SE means ±	Soil Moisture content (%w.b.; 0-60 mm)	S.E. means ±
Day 10	C*	91.9	20.5				
	H*	117.7	16.6				
	UH*	86.8	12.0				
Day 85	C	295.8	27.7	2944	162	6.6	0.8
	H	57.4	9.4	2305	390	13.5	2.0
	UH	40.2	13.1	1900	37	10.5	0.01

* C = cultivated, conventional sowing technique (roller drill)
H = direct drilled, bar harrowed
UH = direct drilled, unharrowed

TABLE 4(b) The effects of bar harrowing on seedling emergence of direct drilled barley

	(plants/m^2)	S.E Means ±
Day 8		
H*	204.5	27.1
UH*	21.5	6.2
Day 17		
H	265.5	12.4
UH	295.6	12.4

* H = direct drilled, bar harrowed
UH = direct drilled, unharrowed

TABLE 4 (c) The effects of cultivation, direct-drilling and bar harrowing on the seedling emergence of maize.

		(plants/m^2)	SE Means±
Day 9	C *	6.9	0.3
	H *	4.6	0.3
	UH *	0.3	0.1
Day 35	C	7.3	0.2
	H	2.4	0.2
	UH	0.5	0.1

* C = cultivated, conventional sowing technique (maize planter)
H = direct drilled, bar harrowed
UH = direct drilled, unharrowed

Discussion

a. Lucerne

As shown in Table 4(a), initial trends, in terms of seedling emergence, may have been slightly in favour of the direct-drilled harrowed treatment compared with the direct-drilled unharrowed treatment but no difference was apparent between these and the cultivated treatment. The slight early trend towards lower plant emergence counts in the unharrowed direct drilled treatment, was reduced and perhaps eliminated by day 85. Because no attempt had been made to suppress clover in the direct drilled plots, strong competition from white clover, together with intra specific competition, severely reduced lucerne plant numbers with time. The effect of the competition is shown on day 85 where the cultivated treatment which was free of competition was by this time clearly superior to both direct drilled treatments.

Not unexpectedly, the total dry matter yield favoured the cultivated treatment at day 85. It must be appreciated that the dry matter figures for both of the direct drilled treatments included a white clover component. Lucerne yields alone are therefore likely to have been more in favour of the cultivation treatment than is indicated by the figures given in Table 4(a). It is unlikely that any depression in yield resulted from not harrowing the direct drilled treatments although the yield figure given in Table 4(a) may be misleading as it is reasonable to expect the white clover component of the unharrowed plots to be slightly greater than their harrowed counterparts because of the reduced number of competing lucerne plants.

By day 85, soil moisture content in the top 60 mm appeared to favour both of the direct drilled plots in comparison with the cultivated plots. While this might suggest that there was a potential soil moisture advantage from direct drilling, it is also probable that the greater plant numbers in the cultivated treatments will have induced more moisture loss by transpiration.

These results suggested that soil moisture status was likely to be an important factor in the design of direct drilling and covering equipment.

b. Barley

With barley [table 4 (b)] the experiment was of shorter duration. By day 8 seedling emergence counts appeared to strongly favour the direct drilled harrowed treatment in comparison with the direct drilled unharrowed treatment. A total of 26.7mm rain fell on days 6,7 and 8 but the preceeding period was hot and dry. Thus, the difference in seedling emergence (day 8) is thought to reflect, at least in part, the soil moisture content at the level of the implanted seed up until day 6. Visual observation confirmed that the unharrowed seed grooves with grade I cover had offered little resistance to dessication and bare uncovered seed was often visible. This was further strengthened by the effects of the rain. By day 17, before which a further 20.8mm of rain had fallen, plant numbers had increased substantially and the difference between the two treatments was negligible.

This largely "hit and miss" distribution of rainfall and radiation led to the eventual use of tillage bins and rain-control canopies for many subsequent comparisons of drill coulter performance in relation to dessication of the seed and the soil surrounding it.

c. Maize

With this crop several factors limited the general effectiveness of the direct drilled treatments.

The scheduled sowing date of 4.11.71 coincided with 2.5mm rain, which was sufficient to dampen the surface soil to a stage where plasticity was evident. Accordingly the action of the hoe coulters was to smear the sides of the groove and the bar harrow was largely ineffective in scuffing loose soil back over the seed.

By day 9 [table 4 (c)] the cultivated treatment appeared to have achieved a higher seedling emergence density than both the direct drilled harrowed treatment, and the direct drilled unharrowed treatment. Of perhaps greater interest however was the apparently substantial advantage of the bar harrowed plots over the unharrowed plots in the direct drilled treatments. These differences between treatments were also apparent on day 35.

Summary of species response to harrowing

Because rainfall, as a variable, was not controlled it is difficult to form firm conclusions as to the causes of the apparent trends. Nevertheless it is interesting to note that the increase in seedling emergence due to harrowing following direct drilling was much greater in the case of the large seeds (maize) than the intermediate sized seeds (barley), which in turn showed a greater increase in response to harrowing than did the small seeds (lucerne). It must be appreciated that these figures relate only to the improvement of harrowed over unharrowed and not to the ability of large or small seeds to germinate under moisture stress *per se*. In the latter case it would be reasonable to expect an advantage for maize, as Hunter and Erickson (66) had shown it to be tolerant of dry germination conditions. In the present context, however, soil-seed contact and protection from dessication as a function of covering, appeared to be the dominant factors which more than compensated for any advantage in inherent vigour which the large seeds may have had.

The proportional increase in emerged plants in response to harrowing were as listed: -

Maize showed a maximum increase due to harrowing of x 15.3
Barley " " " " " " " " x 9.5
Lucerne " " " " " " " " x 1.4

All these apparent increases occurred at the first sampling dates.

It is reasonable to suggest from this (together with visual scoring of the cover on the three respective direct drilled grooves) that the smaller seeds had a greater chance of being adequately covered (or at least shaded) by relatively small particles of soil, rubble, or mulch. The possibility of cover resulting from a chance placement of material (such as in the unharrowed plots) is also likely to have been more pronounced with small seeds than the larger species.

4.3.3 Experiment 3: The effectivness of coulter design on seedling emergence (pilot tillage bin experiment)

Objectives

In an attempt to measure the effects of sowing seed into a soil which was experiencing a continuing and partially controlled moisture stress, a pilot experiment was conducted using the tillage bins and the tool testing apparatus.

This experiment was also the first comparative trial using the experimental chisel coulter. As a result of the apparent advantages in barley seedling emergence from bar harrowing under dry soil conditions and to a lesser extent with maize, lucerne and choumollier, it seemed a reasonable proposal to adopt bar harrowing as a standard procedure for all direct drilling treatments hereafter. It was not considered necessary to determine the seedling emergence response from not harrowing grooves formed by either the triple disc or chisel coulters as the method of visually scoring the grooves according to the amount and type of cover was felt to be meaningful. This assumption was strengthened by later work which established a strong correlation between the grade of cover and seedling emergence under soil moisture stress. The experimental chisel coulter was however, observed in operation with and without harrowing and the cover was scored accordingly. Without harrowing the cover produced by this coulter alone was grade III (with a small proportion of seeds sometimes visible), while harrowing usually improved the grade of cover to IV, at least in the light textured soil used in these tillage bin experiments.

A treatment involving unharrowed hoe coulter grooves was included in this experiment to examine the degree of repeatability between the previous field experiment using barley (experiment 2) and the tillage bin technique.

Specification of experiment 3 are given in appendix 6.

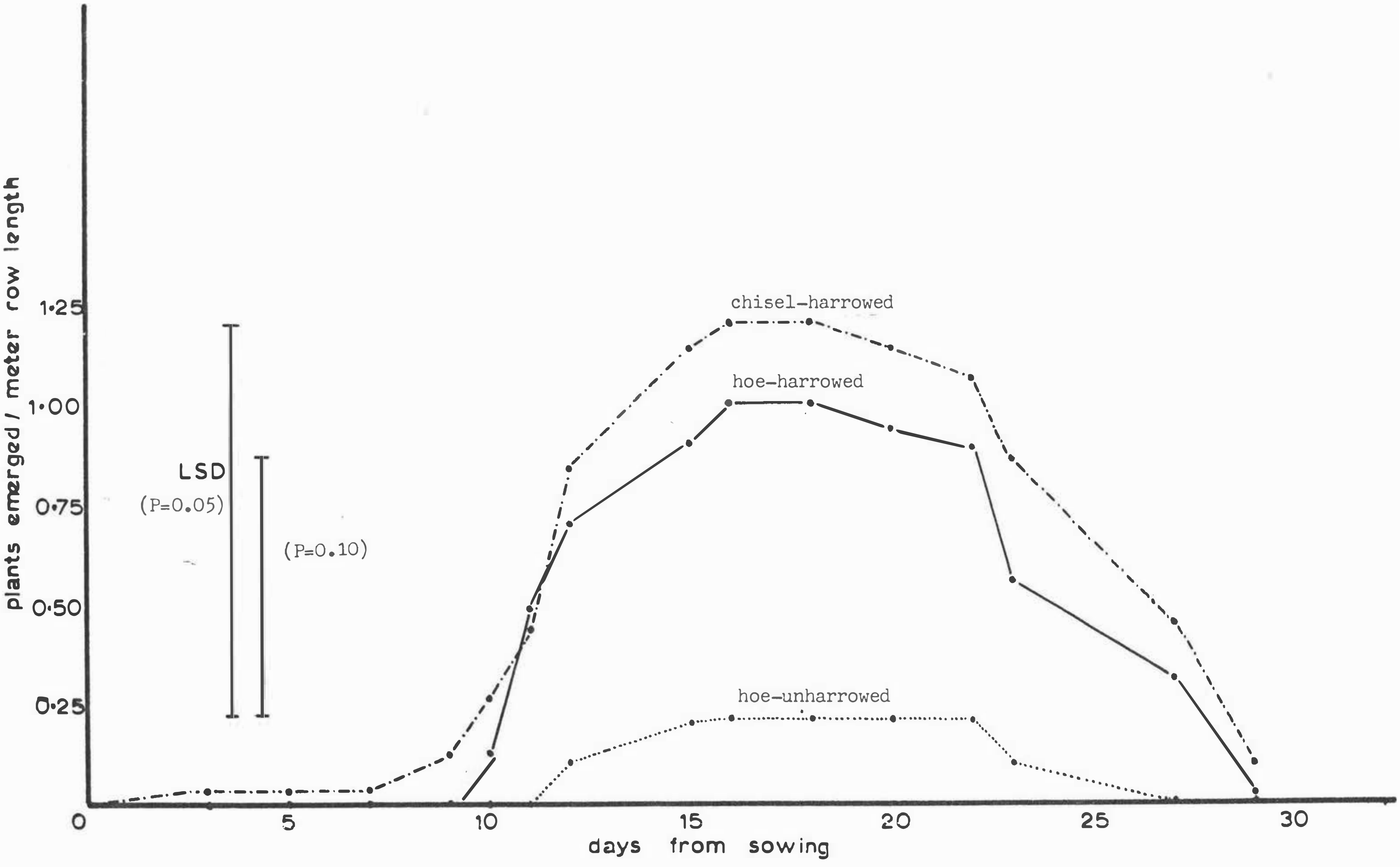


Figure 3 The effects of direct drilling using chisel coulters followed by bar harrowing, and hoe coulters with and without harrowing, on seedling emergence of barley

Results

Fig 3 illustrates the seedling emergence pattern resulting from the hoe and chisel coulter, each followed by the bar harrows, and compared with the hoe coulter with no covering operation.

Discussion

It should be appreciated that the soil moisture stress of these plots was severe and that plant numbers reflect a very low emergence rate in all treatments. Thus, comparisons between treatments is probably not very meaningful in practical terms relating to field establishment of barley crops. Nevertheless a significant ($P=0.05$) increase in emerged plant numbers is evident from the use of the chisel coulter with covering (chisel-harrowed) as compared with the hoe coulter without covering (hoe-unharrowed). There may have been an advantage from covering the seed when using the hoe coulter, although this difference attained significance only at a lower order of probability ($P=0.10$). It might be considered as partial confirmation of the trends in this respect of experiment 2.

Also of interest in this experiment is the clear progressive mortality of plants in all treatments after day 18. From visual observation of wilting it was evident that the persistent and increasing moisture stress had probably reached or exceeded permanent wilting point by that stage. Nevertheless the treatment differences appeared to persist throughout the experiment. This suggests that in-groove moisture loss had been affected by the drill coulter x covering treatments imposed, even at very low soil moisture levels. It is logical to assume that there had originally been sufficient available moisture in the total soil of the tillage bins to initiate a small amount of germination and emergence. Within each tillage bin, the hoe-unharrowed treatment showed consistently less seedling emergence, which suggests that the moisture loss from each treatment at the early stage was indeed a localised effect, and had influenced only the area immediately adjacent to the groove. This, however is in apparent conflict with the simultaneous wilting of plants in both harrowed treatments on day 18 which was earlier than for the unharrowed treatment (day 22). No explanation is offered in respect of this, but it was a prime reason for designing later experiments to use one tillage bin per treatment and thereby eliminate the possibility of a moisture exchange between treatments.

In later stages of this experiment there was also visable evidence of bird damage to young shoots. Although such shoots were still counted in the total, a decision was taken to protect the rain canopies in future by enclosing them with wire mesh.

4.3.4 Experiment 4(a) The effects of coulter design on soil physical properties (pilot tillage bin experiment)

Objectives

It was apparent from experiments 1, 2 and 3 that covering, and coulter design, had an effect on seedling emergence. In an attempt to identify the processes involved more closely, an experiment was designed so that some of the physical parameters of a number of different grooves might be monitored at the same time that seedling emergence counts were being recorded. The physical parameters chosen were; in-groove temperature, in-groove soil moisture regime and seed dry weight.

As in experiment 3, one turf block was utilised as a plot into which three separate drill coulter treatment rows were randomly positioned. While there had been doubt about the interchange of moisture between rows, the limitation of available tillage bin numbers precluded using one bin per treatment at this stage. The seed used was maize. In addition to the rows of drilled viable seed, another three replicate tillage bins were drilled with non-viable seed. All coulter treatments were covered using the bar harrow, and this experiment included for the first time a triple disc coulter as one treatment (plate 24).

There was no attempt in this experiment to positively control the depth of operation of each coulter. Rather, each was arranged to operate as for field conditions with depth therefore becoming a function of the equilibrium established between coulter down-force and ground resistance to penetration.

In the grooves of each plot sown with non-viable seed, two moisture-sealed thermocouples were placed in a similar position to the seed. A total of 18 thermocouples were so placed to record the temperature of the grooves. One additional thermocouple recorded the ambient shade temperature. Each thermocouple reading was traced on a single pen chart recorder through a 25 point automatic scanning switch. Initially the scanning time was $2\frac{1}{2}$ minutes per thermocouple but this was later adjusted to 5 minutes, and then to 10 minutes as the experiment progressed. It could be argued that with such scanning the delay of $47\frac{1}{2}$ minutes (and later up to 250 minutes) between successive readings of the same thermocouple could lead to bias for particular thermocouples monitored

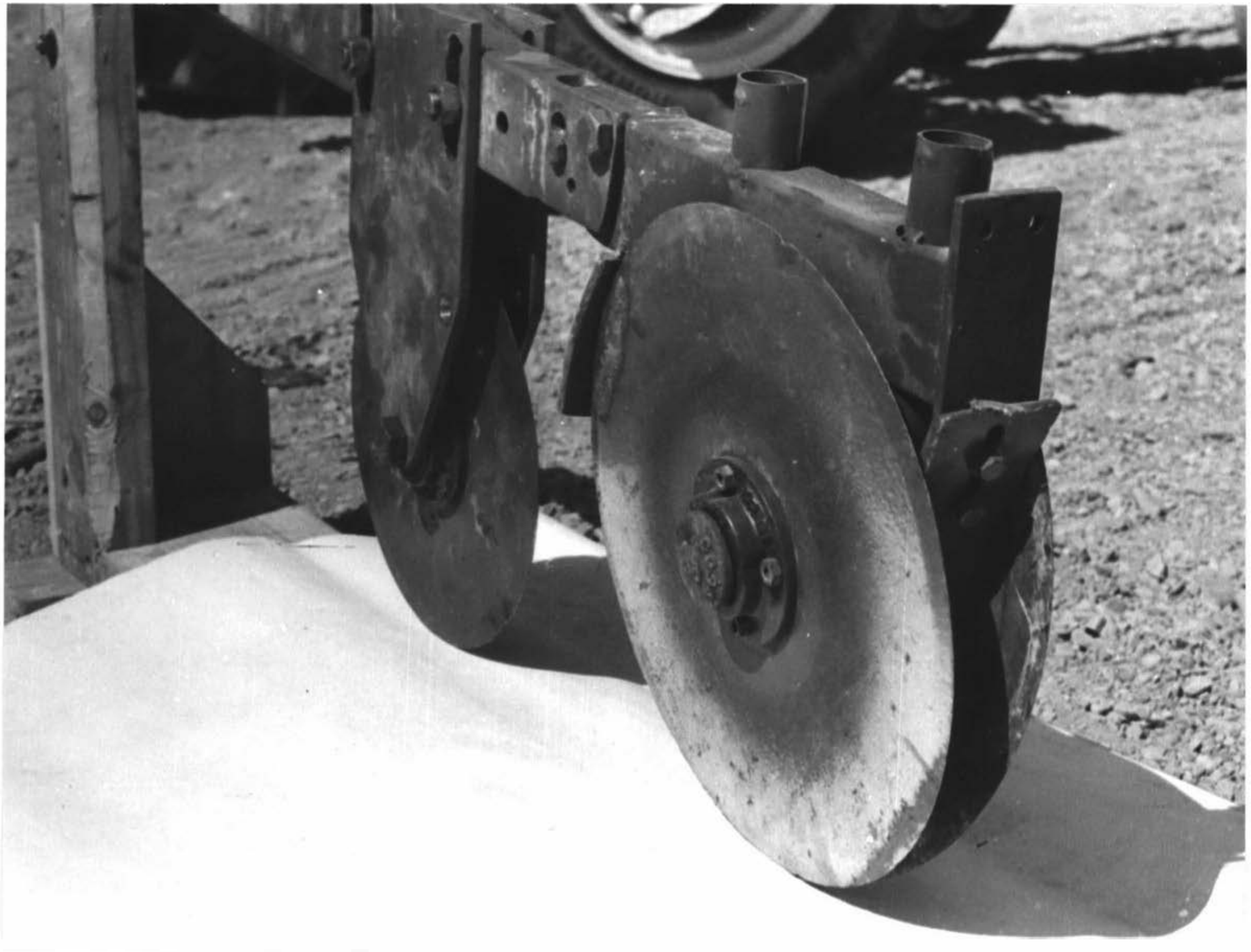


Plate 24: The triple disc coulter assembly as tested

when, for example, the sun was behind a cloud. However by randomly positioning the the thermocouple sequence on the switching device and continuing the monitoring night and day it was felt that over the duration of 25.13 days (which included up to 166 single recordings of each thermocouple) the effect from this could be neglected. In appendix 7 the time scales of the means of each pair of thermocouples are thus adjusted to a common starting point of 0 hours.

At selected periods during the experiment six non-viable seeds were recovered and their dry matter contents determined gravimetrically. In this experiment the method used to recover seeds was to pick them from the grooves with long-nosed pinchers. In that this inevitably caused some soil disturbance (particularly when seeds were difficult to locate) it was not regarded as a very satisfactory method of seed recovery and was replaced by a soil-scooping method in later experiments (see section 3.5.1).

Pre-drilling soil moisture content was determined gravimetrically for each of the six tillage bin plots. In-groove soil moisture content was also determined throughout the experiment from seed grooves containing viable seed.

By checking both seed and soil moisture content it was hoped that (a) the available water, and (b) the uptake of this by the seed might be reflected. Maize seed was chosen because it was large and easily recovered and had shown in experiment 2 to be sensitive to the physical conditions of the groove.

However, a simultaneous pot pilot trial showed no consistent relationship between soil moisture content and the dry matter of non-viable maize seed, nor between this seed and viable seed prior to its germination. The results of this pilot trial are given in table 5.

It was not clear whether the soil or the seed data (or both) was the more unreliable . Despite the lack of relationship between the two, both were continued with as measurements during the main experiment.

At the low temperatures in which this pilot trial was conducted, germination was delayed until 14 days after sowing.

In-groove soil moisture content involved taking 38mm deep x 25mm diam. cores from the soil which bounded and included the groove. The holes were immediately refilled with molten paraffin wax to prevent atmospheric moisture exchange with the holes.

Specifications of experiment 4 are given in appendix 7.

TABLE 5 The effect of soil moisture content on the water uptake by viable and non-viable maize seed.

Days from sowing	Soil moisture content (% w.b.)	D.M.% Viable seed	D.M.% Non-viable seed
0	7.9	15.3	15.3
1	14.2 irrigated	26.0	27.3
3	10.4	31.1	33.1
5	5.4	32.4	28.0
7	5.9	49.4	32.1
14	2.8	16.5	17.0
		r = -.009	r = 0.35

Results and discussion

a. Cover

Visual scoring of the grade of cover resulting from each coulter in association with a section of the bar harrow was as follows:-

triple disc	-	grade I
hoe	-	grade II
chisel	-	grade IV

b. Seedling Emergence

TABLE 6(a) The effects of coulter type and bar harrowing on seedling emergence of direct drilled maize.
(arc-sin transformations in parenthesis).

	triple disc	hoe	chisel	L.S.D. (P=0.05)
Day 8	9.6%	12.9%	9.5%	
10	16.3	24.2	23.2	
14	19.3	27.3	30.4	
16	all plots irrigated			
16	19.3	27.3	30.9	
21	25.4 (15.3)	32.7 (21.4)	31.7 (23.2)	(30.9)

The data shown in Table 6(a) indicate that there were low absolute maximum emergence percent counts for all treatments, and that none of the differences between treatments were significant at the 5% level of probability. However it is noteworthy that there appeared to be a strong replicate effect which favoured replicate 2 with all three coulters. This particular tillage bin apparently began the experiment at a slightly higher moisture content (see appendix 7) and maintained some advantage in this respect throughout the experiment. In contrast, replicates 1 and 3 were apparently too dry throughout, and initiated only a negligible amount of seedling emergence on the final day of sampling (day 21).

Although it is dangerous to form firm conclusions from unreplicated data, the trends of replicate 2 alone might be viewed with some interest and are presented in table 6(b).

From the table it appears that both the hoe and chisel coulters may have sustained a substantially higher emergence percentage than the triple disc coulter. There may even have been a slight advantage of the chisel coulter compared with the hoe coulter. Later work confirmed these results.

TABLE 6(b) The effects of coulter type and bar harrowing on seedling emergence of direct drilled maize.

Replicate 2 only

	triple disc	hoe	chisel
Day 8	28.9%	38.6%	28.6%
10	48.9	72.7	69.6
14	57.8	81.8	91.1
16		all plots irrigated	
16	57.8	81.8	92.9
21	57.8	81.8	92.9

It is also of interest to observe from Table 6(a) that both the triple disc and hoe coulter grooves appeared to respond more in terms of emergence to sprinkle irrigation than the chisel coulter. An explanation for this effect would seem to lie in the more open nature of the grooves with the first two named coulters which were seen to encourage water infiltration. The more-or-less-sealed, and slightly heaved nature of the chisel groove was seen to shed water from the groove area when precipitation was limited, as was the situation in this case

c. In-groove soil moisture content

Data for soil moisture content was incomplete because of sampling difficulties. However possibly the data of most interest is that relating to replicate 2 alone, which is presented in table 7.

TABLE 7 The effects of coulter type on in-groove soil moisture content following direct drilling and bar harrowing

Replicate 2 only

	triple disc	hoe	chisel
Day 10	9.5% w.b.	6.6% w.b.	7.7% w.b.
25	3.6	3.8	3.6

As for table 6 (b) it would be dangerous to conclude much from the restricted data relating to soil moisture. It is of interest however that there appeared to be no clear relationship between this data and the seedling emergence data of replicate 2 in table 6 (b). In fact, the triple disc coulter may have had an initial advantage in terms of available moisture but this appeared not to be reflected in seedling emergence; nor was the advantage sustained to the later reading of soil moisture at day 25.

All plants appeared to wilt in replicate 2 on day 25 by which time in-groove soil moisture content was very similar in the three treatments (ranging from 3.6 - 3.8%). Thus it would seem that in this particular soil, permanent wilting point for maize seedlings was close to 3.7% moisture content. Some of the later experiments which utilized the same soil type had due regard for this soil moisture content.

d. Seed dry matter

TABLE 8 The effects of coulter type and bar harrowing on the dry matter content of direct drilled non-viable maize seed (arc-sin transformations in parenthesis)

	triple disc	hoe	chisel	L.S.D. (P = 0.05)
Day 2	75.9% w.b	74.6% w.b	76.8% w.b	
4	73.8	72.5	74.5	
10	81.5	79.3	81.9	
16	All plots irrigated			
21	61.2 (37.7)	69.4 (44.0)	69.0 (43.6)	(14.8)

As shown in table 8 there were no significant differences in seed dry matter percentages between coulter treatments at day 21. Not unexpectedly, the effect of irrigation was to lower the dry matter content of seed in all treatments after day 16. In contrast to soil moisture and seedling emergence data there appeared to be no noticeable replicate effect favouring replicate 2 with seed dry matter data. This casts some doubt on the reliability of either or both sets of data. Later work confirmed the unreliability of seed dry matter as an indicator of the seed groove environment.

e. In-groove temperature

TABLE 9 The effects of coulter type on in-groove temperature following direct drilling and bar harrowing

	triple disc	hoe	chisel	LSD (P=0.05)	Ambient
Experiment means	18.9°C	19.4°C	18.7°C		15.7°C
Mean maxima (top 10 readings)	25.0	23.3	23.7	4.3	21.9
Mean minima (bottom 10 readings)	13.7	14.1	13.6	3.0	9.9
Range	11.3	9.3	10.1	6.0	11.9

Table 9 presents the in-groove temperature data according to treatments, together with a record of ambient temperature. Diurnal and other temperature fluctuations were regarded as common to all treatments.

"Experiment means" represent the overall means of 990 separate readings per treatment over 25.13 days. It was felt that these mean readings might reflect effects on in-groove temperature of, for example soil moisture loss and/or direct radiation. Statistical analyses of these means was felt to be meaningless because of the natural diurnal variability of readings. Even with n = 166 the differences shown between the treatment means are considered to be negligible. In order that extremes of temperature might be compared, the data was scanned to obtain the top and bottom 10 consecutive pairs of ambient temperature readings. In selecting 2 consecutive ambient readings it was felt that this would have covered one complete cycle of the switching device. Where pairs of ambient readings showed a greater than 5°C difference they were discarded, but the order of paired readings outside this arbitrary rejection criterion, was determined on the average of the two readings. Comparison was then made of the treatment readings coinciding with the later of the two ambient readings (i.e. treatment readings contained within the time boundaries of the two ambient readings). These data were statistically analysed.

The data of table 9 shows that there were only very small differences in mean temperatures. There were no significant differences in mean maxima or mean minima of the selected temperature readings; nor the range of temperature in the groove between the three coulter treatments compared. Not unexpectedly, all coulters tended to increase the in-groove temperatures above ambient.

It would be easy to conclude from the above data that the physical parameters of the groove which were studied were not greatly influenced by the three drill coulter treatments. Such a conclusion however, would be in contrast to the evidence from a number of subsequent experiments, and also to parts of experiment 3. The only explanation put forward to account for the apparent failure of this experiment to expose differences is that the initial soil moisture content of replicates 1 and 3, at least, imposed too much initial stress on germination. It is possible also that maize seed may not have been a satisfactory indicator, and that the method of in-groove soil moisture content sampling left much to be desired as far as representativeness was concerned.

Accordingly, later experiments used wheat and barley as the seed species and explored different (and sometimes direct) methods of in-groove soil moisture measurement.

Limited conclusions only, have therefore been drawn from this experiment.

Experiment 4 (b): The effects of coulter passage on soil compaction (pilot tillage bin experiment)

Objective

During the drilling of individual grooves in Experiment 4 (a), a check was made of the effect that each of the drill coulters had on the resistance to penetration of the soil at the bottom of the groove. Six vertical penetrometer readings were taken at a site within each groove. A separate tillage bin was used for these readings as such sampling was a destructive process.

The data were recorded as newtons force rather than units of stress as their comparative values only were of interest. In any case it would be unrealistic to state absolute values of stress in these experiments as the probe design was not one which was known to have a close correlation with root penetration ability.

With triple disc, an additional probe reading was taken at an oblique angle to determine if the side walls of this groove had sustained any increase in soil strength. Such measurements were not possible with the hoe and chisel coulters because there was no clear interface on the side walls.

Results

The penetrometer and coulter penetration force data are presented in Table 10 (also appendix 7).

TABLE 10 Soil penetrometer resistance and drill coulter penetration force as affected by direct drilling coulter type

	undisturbed (vertical probe)	triple disc (vertical probe)	hoe (vertical probe)	chisel (vertical probe)	triple disc (oblique probe)
Penetrometer Resistance	7.42 N	7.61 N	6.14 N	5.94 N	5.24 N
Coulter Penetration force required	-	774	196	89	
			r = 0.75		

Discussion

From table 10 there appeared to be a moderate relationship between vertical probe readings (soil "strength") and the force (weight) required to obtain full penetration of the coulters during the drilling operations (r=0.75). The triple disc coulter had produced more localised compaction at the base of its groove than it had on the sides, or than had either of the other two drill coulters at their bases. Such an effect is thought to arise from the wedging action of the components of the triple disc coulter, as no apparent soil surface heaving took place which would otherwise be expected to relieve the soil from the compaction effects of coulter penetration and forward travel. The triple disc coulter required almost 4 times the penetration force of the hoe and 8½ times that of chisel which would suggest that a considerable amount of extra energy was thus being transferred to the soil by this coulter. Unless the plastic flow of soil which results, is internally absorbed over an appreciable distance by the surrounding soil or is relieved by surface heaving, localised compaction is inevitable.

Both of the non-rolling drill coulters (viz. hoe and chisel) created substantial surface heaving and sub-surface shattering (even though with the chisel coulter the soil/vegetative mat remained unbroken). The result was that soil resistance to penetration was apparently reduced in the immediate vicinity of the bottom of these grooves. It was somewhat puzzling to find a similar bulk density reduction along the walls of the triple disc groove and this suggests that most of the compressive force imparted to the soil by this coulter was in a near vertical direction. However it must be appreciated that the soil was of a light texture and was at approximately 7.7% moisture content. The smearing effects commonly observed with the triple disc coulter have usually occurred in heavy and/or damp soil conditions.

H.N. Dixon (56) demonstrated a relationship between soil moisture content and the formation of high bulk density layers by the triple disc coulter, but revealed no similar relationship with the hoe or chisel coulters.

He illustrated the principal characteristics of the grooves formed by the triple disc, hoe and chisel coulters operating in a silt loam at various soil moisture contents. Although the extent and severity of compaction zones could be expected to vary with soil type, the general shape of the grooves formed by the same coulters in the lighter textured soils used in these experiments were not unlike those illustrated by Dixon in Figure 4. They are presented here for illustrative purposes.

In the figure the letters denoted the following soil characteristics or zones, according to Dixon (loc cit.)

h - heaving of soil
d - sod displaced during coulter passage
l - loosening and cracking of the soil
c - zone of compaction
s - smearing of groove walls

Obviously there is room and a need for intensive research into the effects of various drill coulters on the localised physical properties of soil and its corresponding effect on seedling root development.

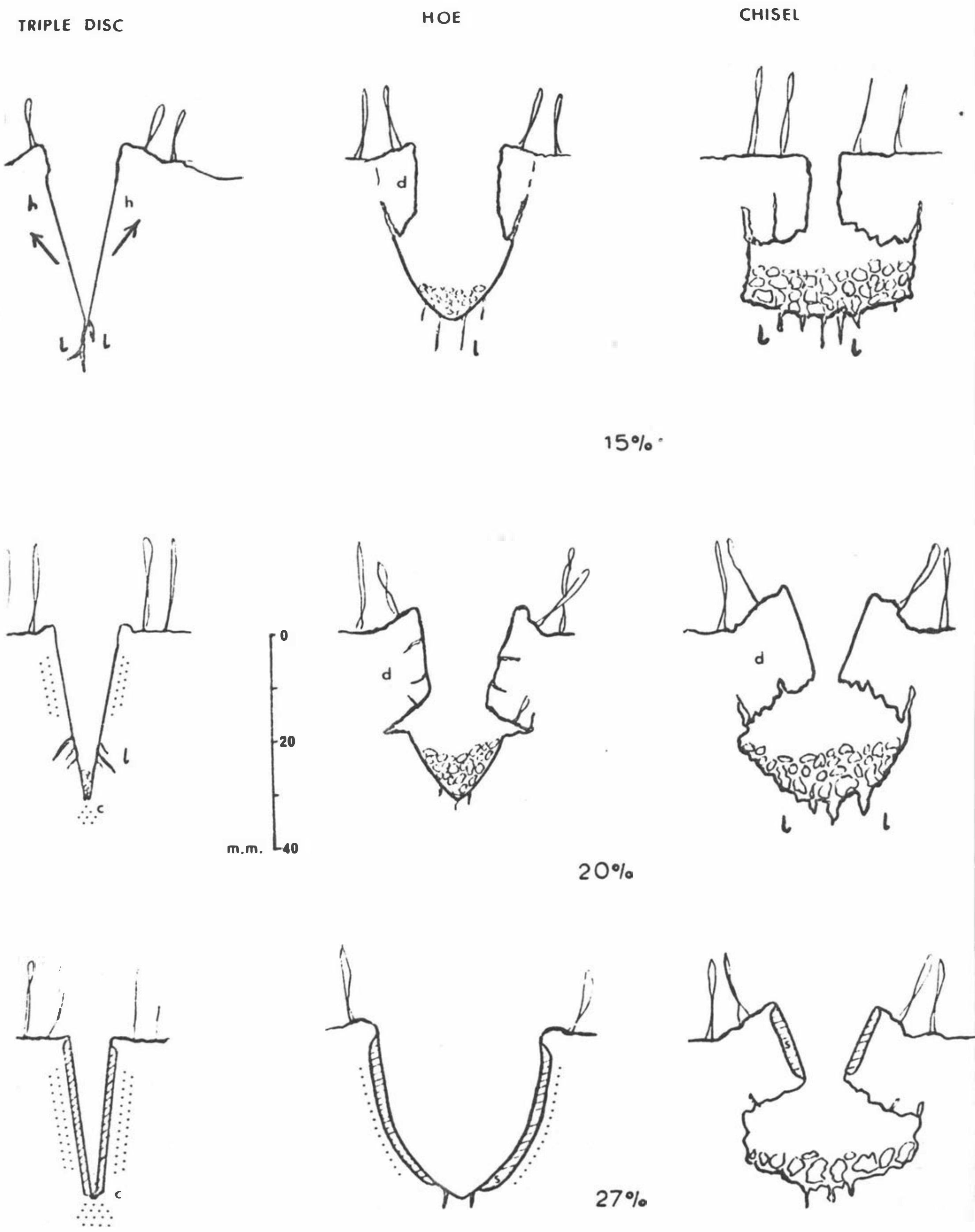


Figure 4 The principal characteristics of direct drilled grooves in a silt loam at moisture contents, 15%, 20% & 27% (from Dixon, 56)

4.3.5 Experiment 5: The effects of a range of drill coulters on selected plant and soil responses (pilot tillage bin experiment)

Objectives

In an attempt to determine if the lack of temperature response to coulter type in experiment 4 was conclusive, and to further explore in-groove moisture content responses to coulter type, it was felt to be desirable to extend the range of coulters to include a wider variety of designs. In this experiment no attempt was made to measure seed dry matter, which was partly bought about by a limitation of the number of available tillage bins in relation to the 6 separate drill coulter designs to be evaluated. This precluded the use of duplicate bins with non-viable seed.

Barley seed was used instead of maize to permit shallower planting and an increased seed number. The purpose of increasing the seed number was to increase the accuracy of emergence counts over a limited length of drilled row.

An attempt was made to control the pre-drilling moisture content of individual soils in their tillage bins so that each would commence the experiment at approximately the same moisture content; viz. approximately 8%. Experience in experiment 4 had highlighted the undesirability of permitting some bins to enter the experiment at substantially higher moisture contents than others, especially when all were under a moisture stress. A record of the pre-drilling moisture status of each turf block is given in appendix 8. From starting points which ranged from 7.8% to 14.3% over all 8 tillage bins, 10 days careful individual manipulation of added water produced little improvement in the range. The major difficulty experienced was due to the time lag between adding water to the trays and when it showed up in 38mm deep core samples at the soil surface, while other unwatered soils had in the meantime continued to dry.

As a result of this, no further attempts were made to manipulate the individual moisture contents of blocks. Rather, care was taken in later experiments to uniformly pre-dry all turf blocks by first bringing all to saturation point immediately after installation in their trays and then allowing all to evapotranspirate under a common drying regime.

During this experiment, in-groove moisture content was determined as in experiment 4. However, as the soil core samples now also removed viable seeds from the rows, continual adjustment of the known seed pool was made after each sampling to facilitate percentage seedling emergence calculations (table 11). As with experiment 4, no attempt was made to positively control the operating depth of individual coulters.

Results and discussion

a. Cover

Visual assessment of the cover produced by each coulter in association with a section of the bar harrow was as follows:-

triple disc	-	no cover to grade I
hoe	-	grade III
chisel	-	grade IV
ski	-	no cover to grade I
dished disc	-	grade I-II
angled-flat-disc	-	grade II

b. Seedling emergence

In common with soil moisture content determinations (see later) the data for three of the treatments (viz. triple disc, hoe and angled flat disc) are staggered one day ahead of the other three treatments. This occurred because the former three treatments were sown a day later than the others but all were subsequently sampled for in-groove moisture content and seedling emergence counts together.

TABLE 11 The effects of coulter type and bar harrowing on seedling emergence of direct drilled barley.

	triple disc	hoe	chisel	ski	dished disc	angled flat disc
Day 5	5.0%	67.3%				32.3%
6			41.3%	30.5%	22.0%	
7	———	all	plots	irrigated		———
8	9.7 a	68.7 d				51.3 bcd
9			44.3 bc	30.0 b	34.3 ab	
12	8.7	60.3				51.0
13			42.7	36.0	31.0	

The maximum emergence for each coulter (table 11) was reached on days 8 and 9 after which a certain amount of pest damage occurred (despite protective measures). In comparing the maxima, the hoe coulter (68.7%) and the angle-flat-disc (51.3%) were not significantly different (P= 0.05) but the hoe was superior to a group containing the chisel (44.3%), dished-disc (34.3%) and the ski coulter (30.0%). The chisel and ski coulters were themselves significantly superior to the triple disc coulter (9.7%).

It is difficult to explain the superiority of hoe over chisel in this experiment as this was not found in experiment 4 using maize seed, although the superiority of both of these coulters over the triple disc coulter was a feature of both experiments. In fact the hoe coulter was superior to all except the angled-flat-disc, which left the seed more or less wedged under a mulch flap in a similar manner to the chisel coulter.

In the light of subsequent experiments which isolated each treatment within a separate tillage bin it was not considered to be meaningful to attempt to determine the extent of correlation between maximum seedling emergence data and the grade of cover. This experiment was used to survey a range of coulter designs and select three for more detailed study using a modified tillage bin technique.

c. In-groove soil moisture content.

TABLE 12 The effects of coulter type on in-groove soil moisture content following direct drilling and bar harrowing (% w.b.)

	triple disc	hoe	chisel	ski	dished disc	angled flat disc
Day 5	16.6% a	12.2% a				11.1% a
6			10.3% a	6.8% a	10.1% a	
7		- ——— all		plots	irrigated ———	
8	19.6	14.2				16.7
9			7.9	11.5	11.4	
12	16.5 a	8.5 a				14.3 a
13			10.6 a	11.8 a	11.8 a	

There were no significant differences (P - 0.05) between treatments in terms of the in-groove soil moisture content, either before or after irrigation (table 12).

There appeared to be no consistent relationship between seedling emergence data and in-groove soil moisture content. Some coulters (viz. hoe, dished-disc and angle-flat-disc) showed a reasonably strong positive correlation coefficient (r = 0.88 to 0.96), while the chisel coulter showed a moderately strong negative coefficient (r = - 0.84). The emergence data of the ski and triple disc coulter appeared to be weakly related to soil moisture content (r = 0.48, to 0.54). These figures further strengthen the doubts about the sensitivity of the technique using three treatments in a common tillage bin but may also reflect unreliable soil moisture data. They are therefore not considered to be very indicative of the real situation.

d. In-groove temperature

As with experiment 4 the mean in-groove temperature of all treatments showed no notable difference, although for reasons explained earlier, these were not statistically analysed (table 13).

The maxima, minima and range data (which accounted for the top and bottom 7 readings in this experiment because of its shorter duration in comparison with experiment 4) showed no significant differences. All treatments displayed the same range as the unprotected ambient thermacouple which is also in agreement with experiment 4.

These two experiments indicated that in-groove temperature was generally 4-5^{o}C above ambient but that the range tended to follow ambient variations.

TABLE 13 The effects of coulter type on in-groove temperature following direct drilling and bar harrowing.

	triple disc	hoe	chisel	ski	dished disc	angled flat disc	ambient
Experiment means	20.0°C	19.5°C	20.5°C	20.6°C	20.4°C	20.0°C	16.3°C
Mean maxima (top 7 readings)	23.4 a	23.3 a	25.2 a	25.6 a	26.1 a	24.2 a	21.8
Mean minima (bottom 7 readings)	16.4 a	15.8 a	16.1 a	16.5 a	15.7 a	15.9 a	11.1
Range	7.0 a	7.5 a	9.1 a	9.1 a	10.5 a	8.3 a	10.7

e. Penetration forces

Although no inference is drawn from the data as far as plant vigour or measured soil parameters are concerned, it is noteworthy that the force required to achieve penetration of the respective drill coulters was greater with triple than any other coulter, except dished disc. The figures are listed below.

triple disc	623 N
dished disc	445 N
chisel	267 N
hoe	222 N
ski	178 N
angled-flat-disc	133 N

From observations of their modes of action at the very slow speeds involved, it is suggested that the relief afforded by either surface or subsurface soil heaving with the chisel, hoe and angled-flat-disc coulters, accounted for their relatively low penetration forces. The ski coulter showed no surface heaving, but created only a very narrow groove, which is thought to have offered little resistance to penetration. The triple disc, as noted above, featured a wedging action with little relief from soil heaving, and the dished disc appeared to suffer because a portion of the convex side of the disc tended to resist penetration.

Discussion of technique

Experiments 3, 4 and 5 brought forward several problems which required further development of the tillage bin technique.

a. Because of the restricted test distance over which the drill coulters operated (a total of approximately 3 metres in the three replicates), greater effort was required to reduce the variation in physical conditions of individual drilled grooves. Accordingly, depth restricting wheels were attached to the tool testing apparatus. It had been apparent that those drill coulters which required little comparative penetration force, and which had not been positively restricted for depth (e.g. the angled-flat-disc, hoe and chisel coulter) had varied more in the depths of their operation than those which required substantial down-force (e.g. the dished disc and triple disc). Use of depth restricting wheels appeared to be contrary to usual commercial practice in New Zealand.

b. Additional steel tillage bins and rain canopies were also constructed giving a total of 11 bins which could be filled and used in such a manner that each bin was a plot into which 3 rows of the same drill coulter treatment were placed. Three treatments and three replicates thereby extended the total length of drilled row for any one treatment to approximately 27 metres. Furthermore, by physical separation of each treatment in its tillage bin from others, any possible interchange between different, but adjacent treatment rows, was avoided.

c. All seed was here-after metered by the modified vacuum seeder to avoid the possible disturbance which the technique of post-drilling hand placement had used until this stage.

d. Attention was given to improving the method of in-groove soil moisture content assessment. With vertical cores it was difficult to remove soil for drying from the immediate vicinity of the seed without including a disproportionate amount of loose covering material or undisturbed soil beneath the seed. This was mainly because the vertical cores tended to crumble at the shattered zones close to the seed. Soil psychrometers were used in some of the following experiments. However, because of the subsequent apparent inadequacy of these sensing devices eventual recourse was made to a modified gravemetric method which sampled with a horizontal scoop, a 300mm length of row, and included an area bounding the groove, as well as the groove itself, its seed and the covering medium.

The descriptions given in sections 3.3, 3.4 and 3.5 relate to the system of utilization of tillage bins, their soil moisture determinations and experimental design adopted for experiments 6, 7 and 8.

4.3.6 Experiment 6: Comparison of the performance of selected drill coulters (main tillage bin experiment)

Objectives

Three drill coulters were tested using the emergence response of wheat seeds under moisture stress as an indicator. The triple disc, hoe and chisel coulters were chosen.

The triple disc coulter had become established amongst users as the "normal" direct drilling coulter. It had therefore to be included in any realistic comparative trials.

The hoe coulter was the immediate predecessor of the triple disc in this roll and was included as the control coulter.

The experimental chisel coulter, despite variable results in earlier experiments, had shown sufficient promise, and had a radically different action, which warranted its inclusion as an experimental design.

The three drill coulters chosen exhibited a contrasting range of actions in the soil and produced conditions which yielded an equally contrasting range of grades of cover in association with the bar harrow. The other coulters tested in experiment 5, but not selected for more intensive study displayed poor seed deposition, inconsistent depth regulation or were very speed sensitive.

The turf blocks in all tillage bins were pre-dried to an average soil moisture content of 17.4%.

It was felt that of the parameters monitored in experiments 4 and 5 in-groove moisture content was likely to have the strongest influence on seedling emergence, especially under an initial moisture stress. Soil psychrometers were inserted into the drilled rows alongside viable wheat seeds. Being roughly cylindrical and measuring 6mm in diameter and 38mm long, they were able to be inserted unobtrusively in the groove and were expected to experience much the same water-vapour exchange gradients as the viable seed.

As this experiment progressed, and it became apparent that little reliable information was being obtained from the soil psychrometers, an attempt was made instead to study the plant emergence response to irrigation. On day 22, each turf block, in its tillage bin, had a steel plate driven across it at its mid point so that, to all intents and purposes, one half of the block was physically isolated from the other half. One half was chosen at random for irrigation while the other half continued under moisture stress.

Although counts of seed were made for each whole row during drilling the number of seeds sown in each half row of the split plots was not known because of occasional blockages of the vacuum seeder. Destructive scoop sampling could only be carried out at the end of the experiment, so it was not practical to estimate the seed pool by this method. Although the seedling emergence count at day 22 recorded the numbers of viable plant shoots in each half row of the blocks (as yet unaffected by irrigation) it was not considered sufficiently accurate to estimate the half row seed pools from this data together with the whole row percentage seedling emergence data as this would have assumed, dangerously, that there was no variability of seedling emergence within rows. Thus it was not possible to record seedling emergence percentages for the half rows, except at the single terminal scoop sampling. These data are presented in table 14.

Temperature values were recorded at the time the psychrometers were monitered. As with the psychrometers, they included also readings from one thermocouple placed in the undisturbed soil between the drilled grooves. Because all were recorded during the same sampling, it is felt that they can be compared with more confidence than the temperature readings in experiments 4 and 5 because no scanning was involved. The only delay between individual temperature readings arose from the operator moving between all reading points.

Specifications of experiment 6 are given in appendix 9.

Results and discussion

a. Cover

The visually assessed grade of cover produced by each coulter in combination with the bar harrow was:

triple disc	-	grade II
hoe	-	grade II
chisel	-	grade IV

b. Seedling emergence and seed-fate

Figure 5 illustrates the whole-plot seedling emergence percentage figures for each of the three drill coulters, to day 22 (i.e. prior to irrigation).

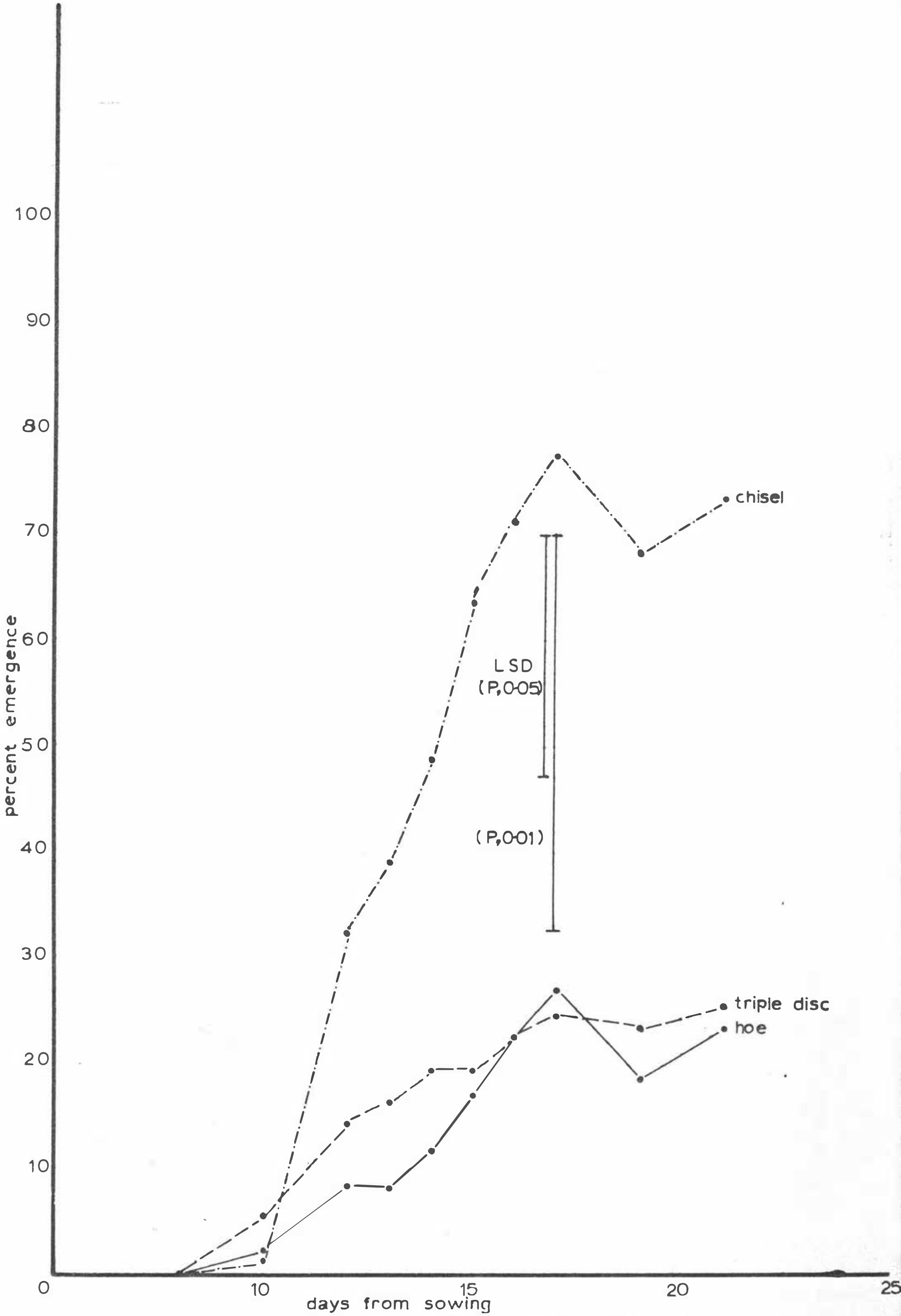


Figure 5 The effects of coulter type and bar harrowing on the seedling emergence of direct drilled wheat

The figure clearly illustrates the significant superiority (P = 0.01) of the chisel coulter in terms of wheat seedling emergence. After day 17 there was practically no change in seedling emergence with all coulters, which was probably due mainly to unavailability of further moisture.

Although there was no significant difference in percentage emergence between the maxima of hoe and triple disc, the latter suggested a slightly more rapid initiation of emergence than did either hoe or chisel. It is possible that this initial advantage arose from the better light regime of these seedlings through not having to penetrate any appreciable amount of soil cover. This relatively exposed position of the seeds might also have led to early desiccation of their seedlings. While the hoe coulter had loose soil cover (grade III), which delayed initial shoot emergence, this cover did not apparently have the same eventual moisture retention properties as did the mulch cover (grade IV) which the chisel coulter promoted.

The effects of irrigation on day 22 are shown in table 14. In the table the seeds or seedlings which were classified as abnormal have not been included in the totals as their numbers were in all cases negligible. The table also confirms the large significant differences in seedling emergence data between coulters in the unirrigated plots.

TABLE 14 The effects of coulter type and bar harrowing on the seed fate of direct drilled wheat, with and without irrigation.

	Percent Ungerminated		Percent Germinated but failed to emerge		Percent Emerged		Increase in Emergence percent due to Irrigation
	Dry	Irrigated	Dry	Irrigated	Dry	Irrigated	
triple disc	18.8% a	4.6% d	56.0% g	16.8% k	20.2% q	75.2% v	+55.0 x
hoe	17.2 a	0.9 d	43.1 gh	6.2 k	38.3 q	92.2 v	+53.9 x
chisel	2.5 a	2.7 d	16.9 h	6.6 k	77.6 r	85.9 v	+ 8.3 y

Columns showing unlike letters in a group denote significant differences (P = 0.05)

In response to irrigation on day 22 both the hoe and triple disc coulters showed notable improvements in seedling emergence. Of more importance however, was the significantly small response with the chisel coulter. This (together with figure 5) suggests that a high proportion of its seeds had already germinated under the non-irrigated conditions, whereas the hoe and triple disc coulters had a significant percentage of seeds ungerminated or unemerged at day 22. Scoop samples were not taken until the end of this experiment. Therefore, the proportions of the seeds or seedlings which were in the "ungerminated" and "germinated-but-failed-to-emerge" categories at day 22 are not known. Irrigation may have increased either seed germination and/or recovery of subterranean shoots. The relatively large (and in one case, significant) terminal counts of the "germinated-but-failed-to-emerge" category for the "dry" hoe and triple disc treatments in comparison with chisel however, suggest that emergence may have been at least as sensitive to coulter design as germination.

In table 14 the difference in percent "ungerminated" between the hoe (irrigated) and triple disc (irrigated) treatments was almost significant ($P = 0.05$). From examination of the physical appearance of these two grooves, the hoe appeared to have produced more complete soil-seed contact because of the greater amount of loose soil around and over the seeds. The triple disc coulter left the seeds more or less wedged between well defined near-vertical sides and substantially exposed to the atmosphere. It is possible however that in this position, transferrence of soil moisture to the triple disc seeds will have, in fact, been initially more effective than with the hoe because of the direct contact of the seeds (however small in area) with the "undisturbed" water-bearing medium, compared with embodiment in a looser medium less able to conduct water to the seeds from its source in the surrounding undisturbed soil. If such was the case, however, it would be reasonable to expect a similar germination retardation to have occurred with the chisel, as its seed too, lay in a shattered area of soil. Perhaps the real answer lies in a combination of pre and post germination soil conditions.

Plates 25 (a) and 25 (b) illustrate typical whole wheat plants from the three treatments. In plate 25 (a), which shows plants taken from the unirrigated plots, it is noteworthy that even though the plants sown by the hoe coulter and triple disc coulter appear to be stunted when

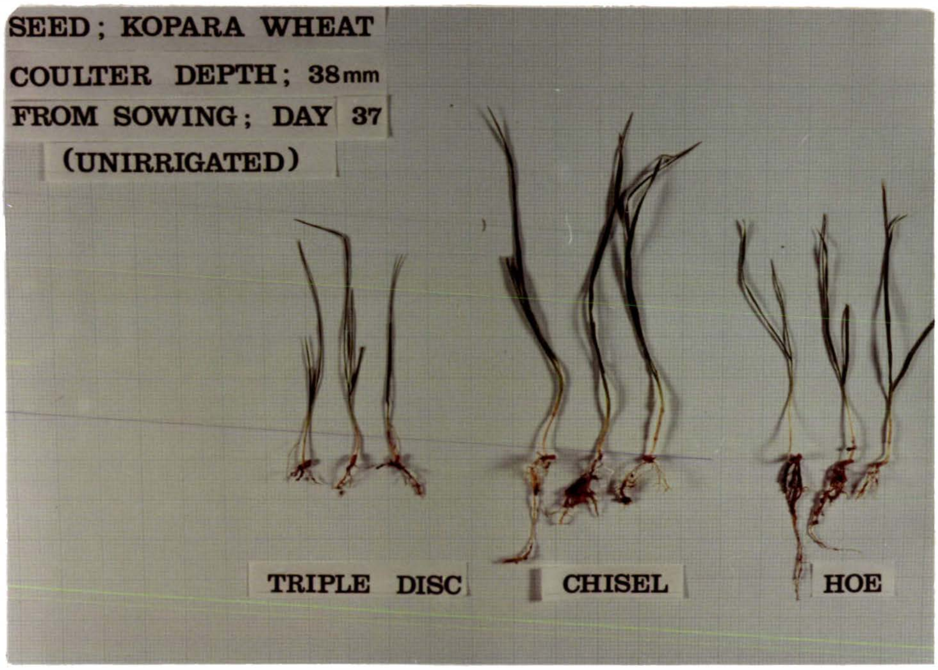


Plate 25(a): Typical direct drilled wheat seedlings (unirrigated)

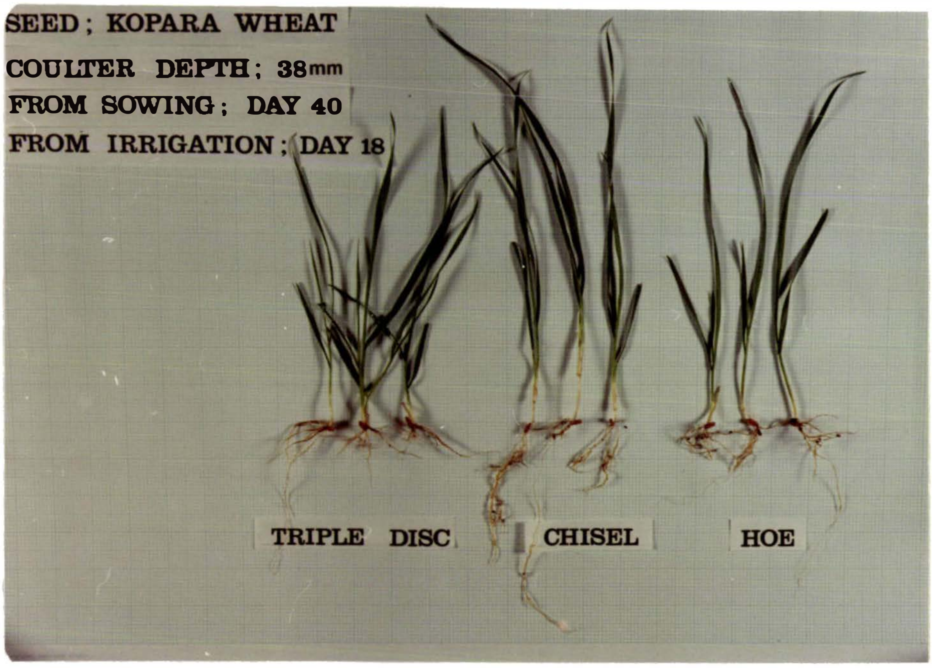


Plate 25(b): Typical direct drilled wheat seedlings (irrigated) compared with those from the chisel grooves, the root systems of the hoe coulter treatment appear to have suffered little by comparison with the chisel. Perhaps this reflected less physical impedence to root exploration in the relatively shattered soil within the grooves of these two coulters compared with the triple disc.

Although irrigation [plate 25 (b)] had clearly promoted vigour in all treatments, some retardation of root development is still evident in plants recovered from triple disc grooves.

It must also be appreciated that in using the tool testing apparatus, a slow speed of operation was chosen. With greater forward speed, more soil "throw" could be expected with any drill coulter and the difference in occurrence of shattered and non shattered soil areas would be likely to become less well defined between coulters.

c. Relationship of cover and emergence

A comparison of maximum seedling emergence data for the unirrigated plots with the grade of cover produced by each coulter in association with a section of the bar harrow suggested that the two factors were strongly related (r = 0.97).

d. Soil moisture content and matric potential

On day 37 the mean undisturbed soil moisture content (w.b.) of the chisel coulter was 7.2%, compared with 6.1% for triple disc and 5.2% for the hoe coulter. This corresponded in part with the plant emergence trends, although analysis of variance narrowly failed to expose these differences as significant at the 5% level of probability. No in-groove gravimetric determinations were carried out in this experiment.

The psychrometer data were of doubtful value. Figure 6 illustrates the apparent matric potential data derived from psychrometers placed in the grooves and the undisturbed soil alongside.

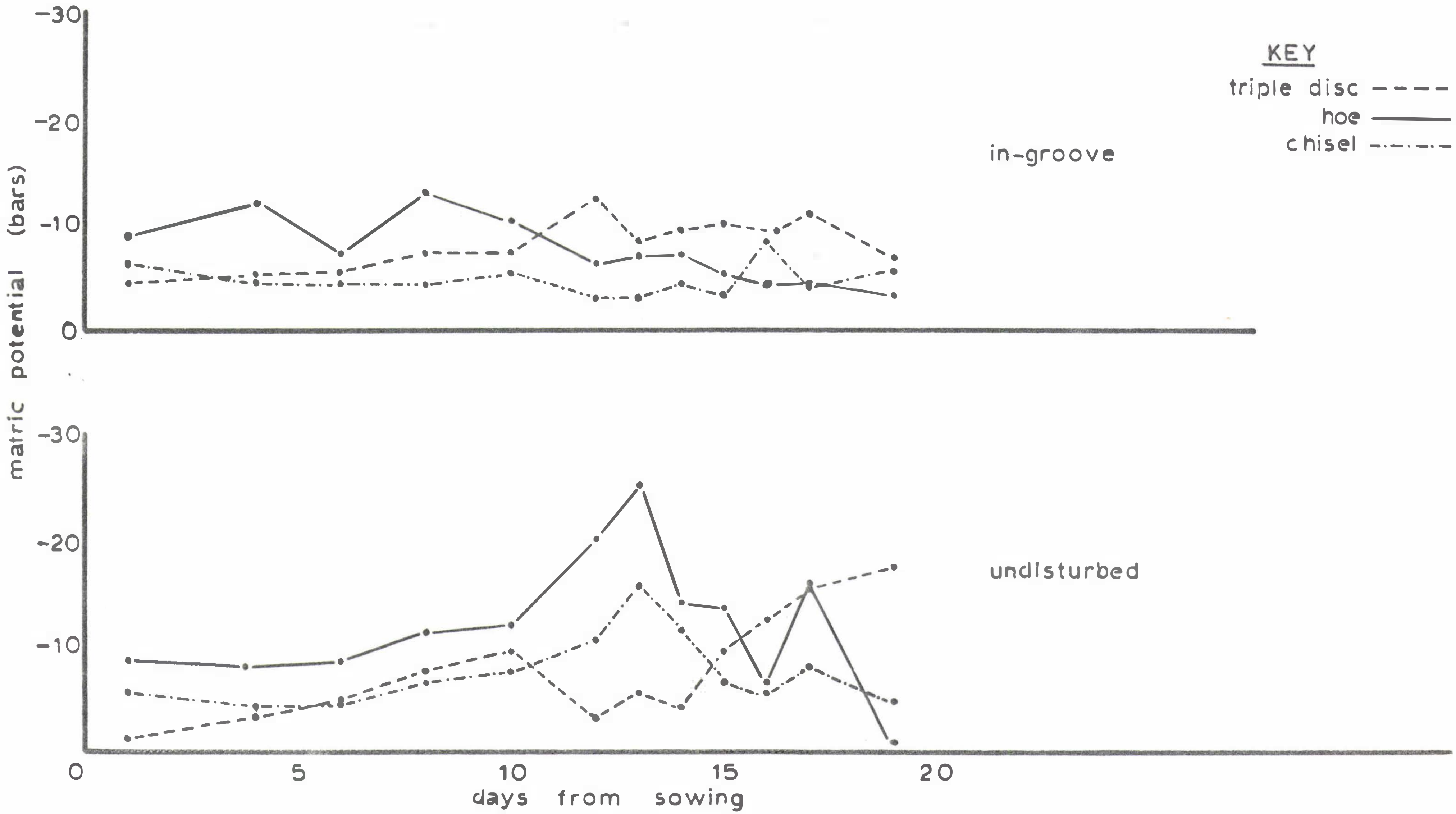


Figure 6 The effects of coulter type on in-groove and undisturbed soil moisture contents following direct drilling and bar harrowing

It is difficult to distinguish any strong trends between or within treatments or sampling sites, although most of the readings in the undisturbed sites increased in negative potential with time until about day 12 after which the readings appeared to become erratic, with some actually indicating gains in soil moisture under continuing induced drying condition. It is perhaps noteworthy that from about day 12 onwards, the general soil temperatures had also increased substantially, compared with the preceeding period (Fig. 7). These higher temperatures may have affected the accuracy of the psychrometers in an unpredictable manner. Comparison of matric potential and simultaneous temperature readings produced scattered correlation coefficients.
(Triple disc $r = +0.70$ hoe, $r = -0.67$, chisel $r = -0.29$).

Thus it was felt that no reliance could be placed on the data supplied by the soil psychrometers other than from their direct readings of temperature. Whether the inconsistency experienced with these devices was a design failing, or a factor of instability of micro environment, was not established although J.P. Kerr (1973 pers. comm) reported more consistent readings at greater soil depths at *in situ* localities nearby.

e. Soil Temperature

Table 15 lists temperature data for 19 days of the experiment.

Figure 7 shows the temperature trends with time.

From the table, comparison of in-groove mean temperatures with those of the undisturbed soil in the corresponding treatment, revealed only small differences. With the triple disc and hoe coulters, the in-groove temperature was elevated 0.5°C above that of the undisturbed soil, while with chisel it was depressed by the same amount. This meant approximately 1°C depression of mean in-groove chisel temperature compared with both the triple disc and hoe coulters.

Statistical comparison of overall means was again felt to be meaningless as the natural diurnal variability would be expected to dictate the computations of least significant differences rather than treatment effects.

Statistical analysis of maxima, minima and range data was felt to be more meaningful. Even so, comparison of the range of the temperatures is not as meaningful as in experiments 4 & 5 because of the reduced amount of data. Maximum and minimum temperatures were taken for one day each only (days 14 and 2 respectively) because of the limited number of available readings.

TABLE 15 The effects of coulter type on in-groove and undisturbed soil temperature following direct drilling and bar harrowing

	In-Groove				Undisturbed			
	triple disc	hoe	chisel	LSD (P=0.05)	triple disc	hoe	chisel	LSD (P=0.05)
Experiment means	13.3°C	13.2°C	12.3°C		12.8°C	12.7°C	12.8	
Maximum (day 14)	19.1	19.3	16.6	4.8	17.6	17.5	17.4	2.3
Minimum (day 2)	5.6	5.5	6.2	0.6	5.7	5.6	6.1	0.6
Range	13.5	13.7	10.5	5.3	11.8	12.2	11.3	2.6

There were no significant differences between treatments with regard to in-groove maxima, undisturbed maxima, in-groove range or undisturbed range, but the in-groove minimum temperature of the chisel coulter treatment was significantly higher ($P = 0.05$) than either the hoe or triple disc coulters. The undisturbed minimum for the chisel coulter treatment was also slightly higher than the other two treatments, but these differences fell just short of significance.

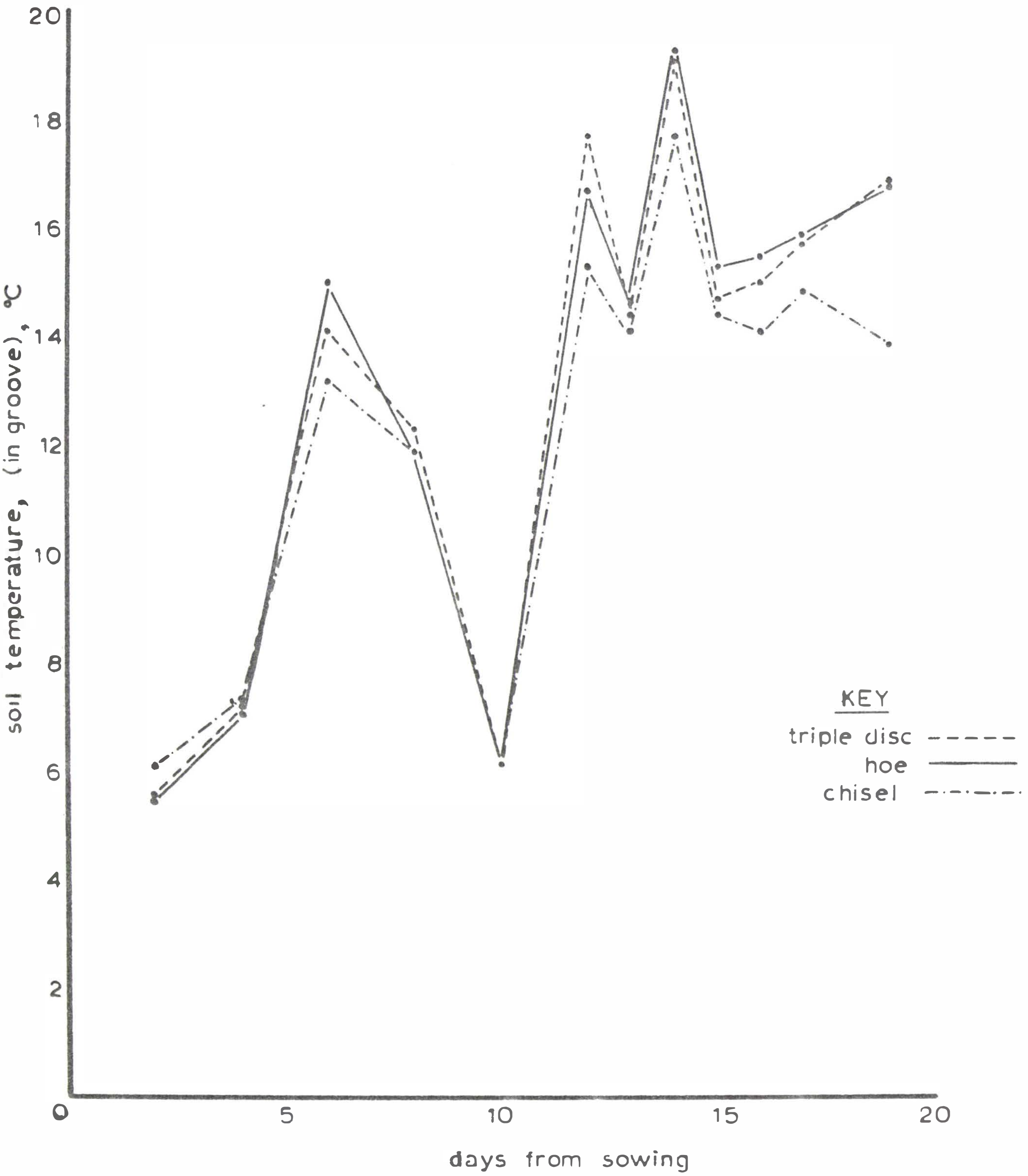


Figure 7 The effects of coulter type on in-groove soil temperature following direct drilling and bar harrowing

f. Physical effect of drill coulters

The net penetration forces for the three drill coulters on test were

Triple disc	941 N
Hoe	226 N
Chisel	177 N

The force application to the triple disc coulter induced vertical cracking of the turf block to its full depth (approx. 200 mm). There was only limited evidence of such cracking with the hoe coulter, and none with the chisel coulter. The hoe and chisel coulters appeared to have promoted some degree of lateral internal soil shattering which was evident when the "undisturbed" soil was sliced with a knife to insert the psychrometer leads. The area bounding the chisel coulter groove was loose and fluffy when inserting the knife, making it difficult to cut a slice, while the area adjacent to the hoe coulter groove showed a similar effect but on a reduced scale. The soil adjacent to the triple disc groove was easily cut and was substantially undisturbed, but not compacted.

The "dry" light textured soil used in this experiment, because of its low shear strength, would be expected to show a considerable response to shattering forces applied to and within it.

4.3.7 Experiment 7: Comparison of the performance of selected drill coulters (main tillage bin experiment)

Objectives

Data from experiment 6 could be interpreted more readily if the changes in germination rate and seedling life between drilling and emergence were known. Therefore an experiment was designed to examine these factors using sequential scoop harvests of seeds and seedlings.

This experiment was also used to re-test the usefulness of sequential recovery of ungerminated, viable seeds and determination of their dry matter contents.

The number of scoop samples was limited by individual plot size. Soil temperature and soil moisture content were not measured. All turf blocks were pre dried to an average soil moisture content of 18.2%

Three rows of each of the treatments; triple disc, hoe and chisel coulter were drilled into each plot and the number of seeds sown, noted. Whole-plot seedling emergence counts were recorded at each scoop sampling date and these were compared with the corresponding seedling emergence figures derived from individual scoop samples. The potential seed pool per row of each plot was reduced by the number of seeds harvested at each sampling, and the pool was therefore adjusted when calculating the whole plot emergence percentages.

Seed dry matter was determined only until germination became evident (day 6). It is possible that non-viable seed would have been more useful although the experience of experiment 4 made this by no means certain. In any case there was no non-viable wheat seed available at that time, and obtaining sufficient would have involved considerable delay, as the preferred method of oven-killing required considerable time for the seed to re-establish equilibrium moisture content with the atmosphere.

Specifications and raw data for experiment 7 are given in appendix 10.

During the laying down of the experiment a malfunction of the chisel coulter occurred during one entire row length of two turf blocks. This resulted in two of the total of 9 rows for that treatment being severely torn and broken at the surface of the soil. These two ("rogue") rows gave the appearance of being similar to rows created by the hoe coulter.

Accordingly, the readings for these two rows are omitted from the results for that coulter, but it was interesting to note the similarity of these results with the figures for the hoe coulter obtained during the same experiment.

Results and discussion

a. Cover

The visually assessed cover promoted by each coulter in association with a section of the bar harrow was as follows:-

triple disc	- grade II
hoe	- grade III
chisel (normal)	- grade IV
chisel ("rogue")	- grade III

b. Seedling emergence and seed fate

Figure 8 illustrates the whole-plot seedling emergence percentages of the three drill coulters. An apparent plateau came into effect with all coulters at about the same time. Maximum counts indicated that the chisel (70.1%) was significantly greater ($P = 0.05$) than the triple disc coulter (32.2%), but that the difference between the chisel and hoe coulters was only significant at the 10% level of probability. Also the hoe coulter was not significantly superior to the triple disc coulter. Although the magnitude of these differences is reduced in comparison with those for experiment 6 (Fig 5) the order of ranking is the same. The slightly higher initial soil moisture level of this experiment may have resulted in the better comparative performance of the hoe coulter than occurred in experiment 6.

With the limitation of three replicates, only large differences would be expected to be significant at the normally accepted levels of probability. Nevertheless, when the above results are regarded along with those of experiment 6 it is probable that the differences recorded here are real.

The previous evidence of a delay in initial seedling emergence with the chisel coulter does not appear to have been repeated in this experiment.

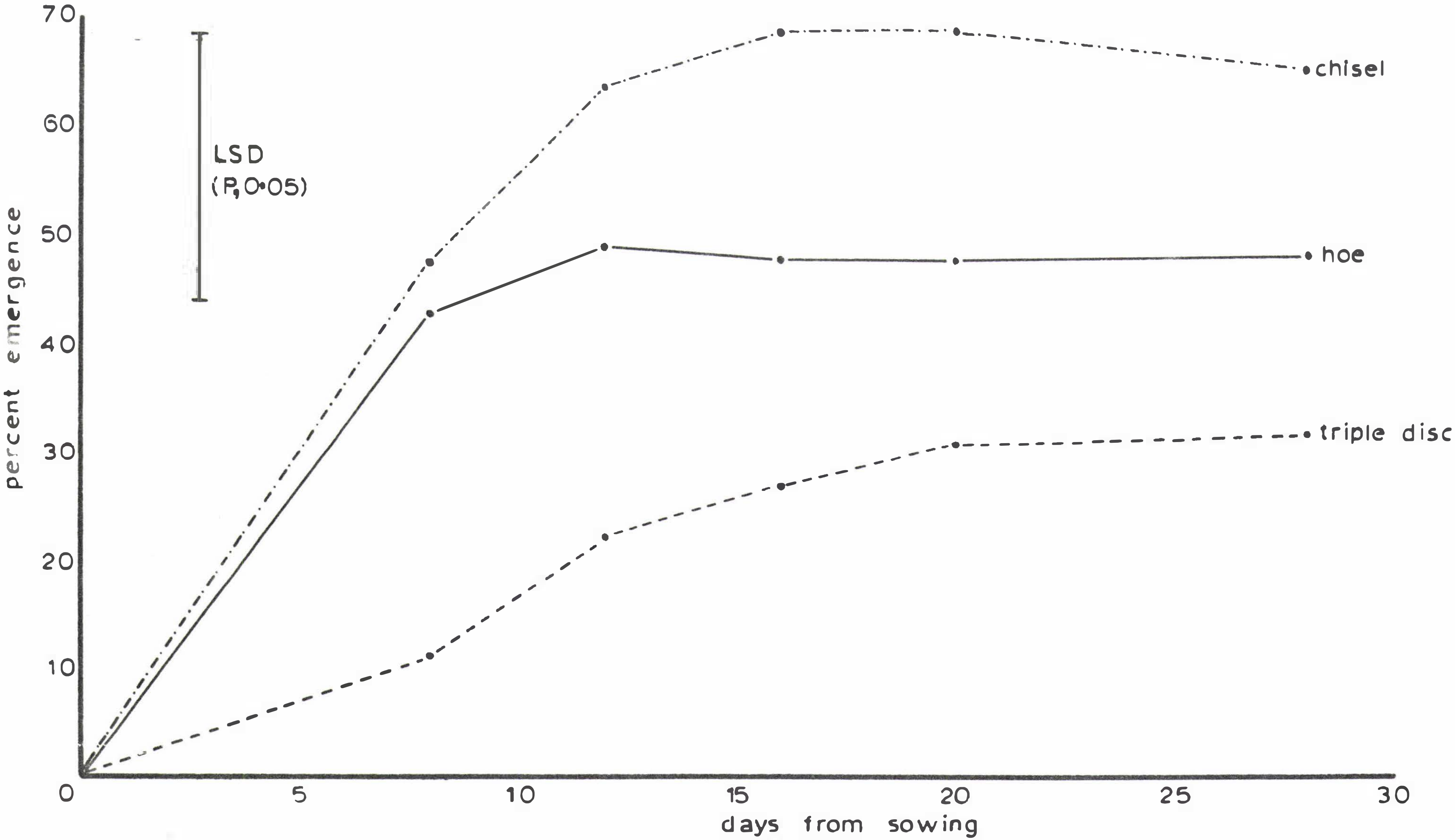


Figure 8 The effects of coulter type & bar harrowing on the seedling emergence of direct drilled wheat

The observation that the two "rogue" rows noted with the chisel coulter more nearly resembled the grooves of the hoe coulter was strengthened by comparing the maximum seedling emergence counts for these two rows with the mean for the hoe treatment. The "rogue" chisel coulter figure of 41.9% compared well with 49.6% for the hoe, and confirms that the decision to omit these two rows from the general analysis was justified. It also strengthens the value of the physical appearance of the groove as an indicator of its likely seedling emergence-promoting capabilities in any one soil type with which a worker has had experience.

c. Relationship of cover and emergence

A comparison of maximum seedling emergence data with the grade of cover produced by each coulter in association with a section of the bar harrow indicated a reasonably strong relationship (r = 0.86). This confirms a similar strong relationship noted in experiment 6.

No analysis was made of the "rogue" chisel coulter rows in this respect because of the limited number of rows involved.

Comparison of whole-plot emergence counts and emergence counts from scoop samples

As noted earlier, there was not always a strong relationship between these two readings. Because of the smaller potential sampling error, the whole-plot counts are regarded as the more reliable figures. Table 16 compares the respective figures and correlation coefficients for each treatment.

TABLE 16 The effects of coulter type plus bar harrowing, and method of sampling on seedling emergence counts of direct drilled wheat

	Coulter Type:	triple disc		hoe		chisel	
	Sampling Method:	Whole-plot	Scoop	Whole-plot	scoop	whole-plot	scoop
Day 8		11.0%	2.4%	42.9%	38.9%	47.5%	51.6%
12		22.0	2.0	48.8	39.8	63.8	50.9
16		26.6	17.4	47.2	51.6	68.5	57.1
20		30.7	41.0	47.2	90.4	68.5	79.5
28		31.7	56.7	48.0	78.8	65.0	85.7
r=		0.82		0.32		0.46	

No particular relevance is attached to the correlation coefficient (r = 0.82) of the triple disc treatment in comparison with the other two treatments, although it could be argued that this reflected a more even treatment effect over the whole plot, with correspondingly less sampling error when using the scoop. Subsequent trials did not substantiate this argument however.

d. Seed fate counts

Figure 9 is a family of cumulative graphs for each of the three drill coulters, depicting various categories of seed fate. These were, "ungerminated", "germinated-but-failed-to-emerge", and "emerged". A category of "abnormal" (i.e. twisted development and broken seed) is omitted from figure 9 because it comprised only a negligible proportion of the total seed pool.

Notwithstanding some inconsistencies which are attributed to sampling error of the scoop procedure, the graphs illustrate the relative proportions of the various categories with time. Perhaps most noteworthy is the apparent confirmation that with the triple disc coulter a large component of "germinated-but-failed-to-emerge" appeared to persist throughout the experiment (an effect first noted in experiment 6). While the "ungerminated" component appeared also to be more pronounced with this coulter than either of the other two treatments, it did appear to tend towards a plateau at an early date (day 4, if the reading for day 12 is ignored as atypical). The "germinated-but-failed-to-emerge" category was still enlarging at this stage and showed little sign of reducing before about day 16.

Statistical analysis of arc-sin transformed data was restricted to one sampling date. It seemed logical to select a sampling date from Figure 9 at which the seedling emergence figures of all treatments had started to plateau. Beyond this the "ungerminated" and "germinated-but-failed-to-emerge" proportions might change with time, but the "emerged" percentage remained largely static. In this instance, day 20 appeared to be an appropriate date for statistical analysis.

The levels of significance exhibited at this sampling, might reasonably be regarded as typical of other sampling dates, as a scan of the raw data suggested that while the variability within treatments and replicates was quite large it was reasonably consistent throughout.

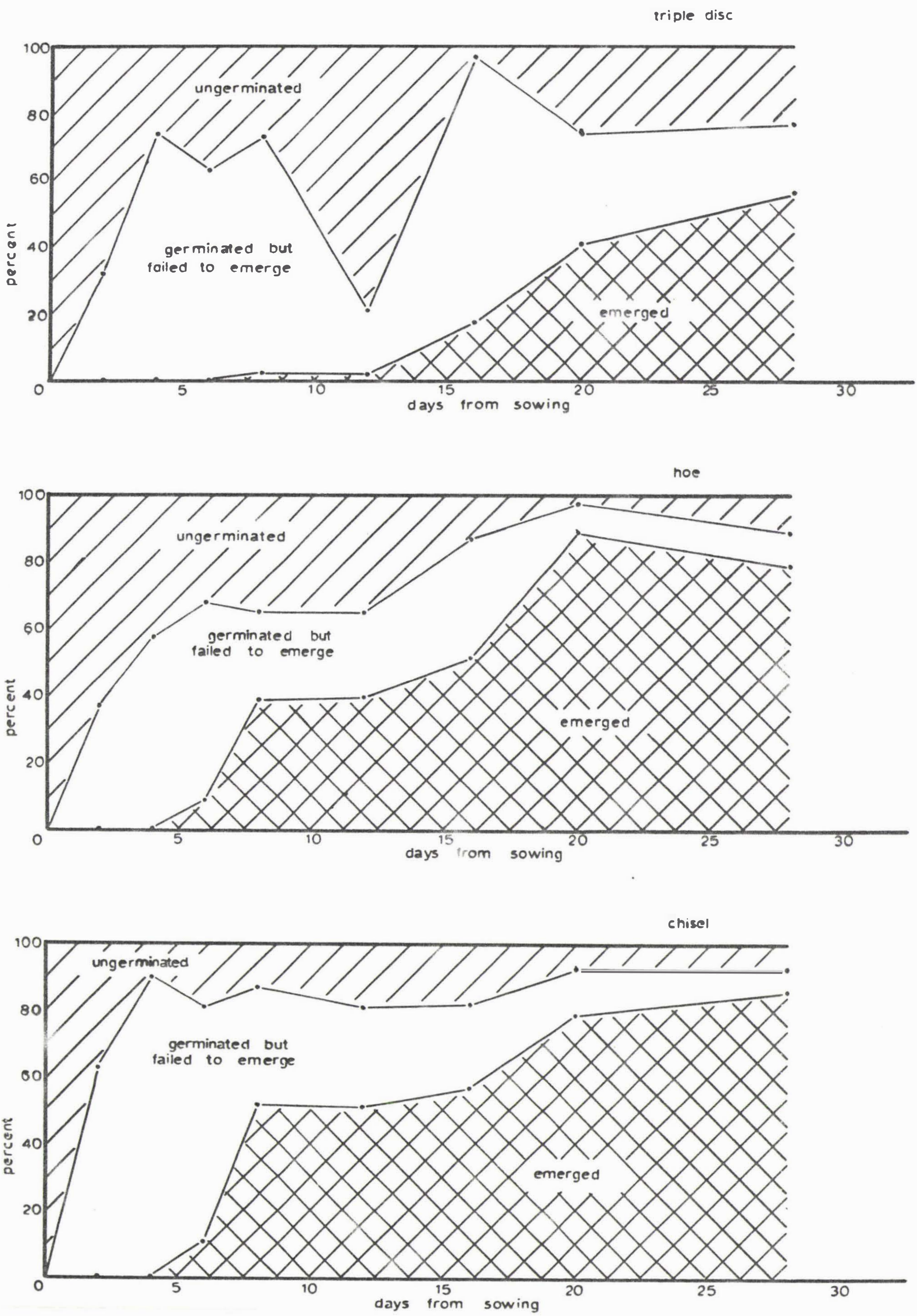


Figure 9 The effects of coulter type on the fate of wheat seeds following direct drilling and bar harrowing

Within the comparison on day 20 there were no significant differences ($P = 0.05$) between any treatments in the percentages of "ungerminated" seed.

The "germinated-but-failed-to-emerge" figures revealed no significant difference between the chisel and hoe coulter treatments, but both were significantly lower than the triple disc treatment.

Not unexpectedly, similar inverse significant differences were also apparent in the percentage "emerged" figures.

The family of curves shows a predictable fall off of the relative proportion of ungerminated seed with time, in both the hoe and chisel coulter treatments. The triple disc treatment displayed some irregularity in this respect, but as mentioned earlier little importance is attached to this as it was probably due to sampling error.

All coulter treatments showed larger proportions of "germinated-but-failed-to-emerge" seeds than "ungerminated" seeds at later readings. This might suggest that the soil environment in this experiment was not totally restrictive to germinating seeds, nor to the emergence of their shoots, but that it was sufficiently restrictive to require considerable periods of time before seedling emergence took place. In the case of the triple disc treatments, the environment may have been more restrictive, but was reduced in its effect in the final week.

e. Dry matter content of ungerminated seeds.

Because living seed was harvested for these measurements the measurements were ceased at day 6, by which time some seeds had shown evidience of germination. The number of seeds per treatment sampling varied between 39 and 48 depending on the chance number recovered from the seed-fate scoop samplings.

Treatment means are shown in Table 17.

TABLE 17 The effects of coulter type and bar harrowing on the dry matter content of ungerminated direct drilled wheat seeds. (arc-sin transformations in parenthesis, P=0.05)

	triple disc	hoe	chisel	LSD
Day 2	63.4% (39.4)	68.2% (43.1)	64.9% (40.5)	(6.0)
4	59.9 (36.9)	77.0 (50.4)	67.9 (43.4)	(14.6)
6	65.7 (40.5)	73.7 (43.4)	74.9 (48.5)	(14.9)
As sown = 90.8%				

On days 2 and 6 there were no significant differences between treatments. However on day 4 the triple disc coulter appeared to have a lower dry matter content than either the hoe or chisel coulter. The comparison with hoe was almost significant at the 5% level of probability. If this was a real effect it is difficult to explain why the trends did not persist to day 6. Because of the high level of variability with these readings no firm conclusions can be drawn from them.

f. Herbage dry matter yield.

A terminal harvest (day 28) of 20 living shoots from each replicate (severed at ground level) was taken in an attempt to establish whether or not differences in seedling growth had become apparent by that stage.

Table 18 compares the dry matter yields of the three treatments, both on a per plant basis and on an area basis, taking into account the number of emerged plants per unit area. Although the hoe coulter appeared to produce bigger plants than either of the other two treatments, when adjusted to a per hectare basis, there were no significant differences. Nevertheless the suggested superiority of plant yield from the hoe and chisel coulters compared with the triple disc supports the established superiority of at least the chisel coulter in terms of plant emergence reported earlier.

TABLE 18 The effects of coulter type and bar harrowing on dry matter production of direct drilled wheat seedlings

	triple disc	hoe	chisel	LSD
Dry weight/plant	0.088g	0.13g	0.094	
Dry weight of plants resulting from 100 seeds*	28.2 g	67.1 g	61.4 g	
Computed dry weight/ha	631 kg/ha	1503 kg/ha	1375 kg/ha	1225.9

* computed from whole-plot emergence data

g. Penetration forces

As with experiment 6, the net approximate force which was required to achieve satisfactory operating depth of the coulters, was greatest with the triple-disc coulter, while little difference existed between the hoe and chisel coulters.

The forces required were

triple disc	747.0 N
hoe	356.0 N
chisel	400.0 N

The triple disc coulter required almost twice the penetration of the chisel coulter and more than twice that required by the hoe coulter. These figures are not in complete agreement with those of experiment 6 and their range is considerably reduced. No explanation is put forward to account for these apparent effects, as the soil moisture content of turf blocks in this experiment were slightly greater than in experiment 6. This might account for the reduction in force required by the triple disc coulter, but it is difficult to visualise by what means, damper soil would increase the forces required by both the hoe and chisel coulters. At a moisture content of 18.2% (w.b.) such a soil would be unlikely to gain any more strength from adhesion due to moisture films than the same soil at 17.4% (as it was in experiment 6).

4.3.8 Experiment 8: The effects of soil moisture content on the performance of drill coulters (main tillage bin experiment)

Objectives

This experiment set out to establish an arbitrary bias against the experimental chisel coulter to determine its tolerance of adverse conditions compared with triple disc and hoe coulters. Pre-drilling soil moisture stress was manipulated within the individual tillage bins until the three turf blocks to be used with the chisel coulter averaged 15.3% soil moisture content compared with 19.7% for the hoe and triple disc coulters.

Thus, clearly the soil conditions for the chisel coulter were less favourable than for the hoe or triple-disc coulters. Because all soils were under an appreciable moisture stress anyway, the deficit with the chisel treatments could be considered to be quite a marked disadvantage. In this way it was hoped to gain some idea of the additional moisture stress in which the chisel coulter could operate with comparable results to other coulter types.

The experimental procedure followed the same pattern as the previous two experiments, except that in each tillage bin, only one row of viable wheat seed was drilled while the other two rows contained proven dead seed and were sequentially harvested with the scoop, for seed dry-matter determinations. At other intervals, scoop samples were also taken in live seed rows for seed-fate analysis. It was not possible to strictly randomise the order of the viable and non-viable rows in each tillage bin at the time of drilling, as the tool testing apparatus was required to travel the entire length of the 3 replicate bins for any one treatment, without stopping. However, the order was randomly determined for each treatment. Furthermore, as in other experiments, replacement of the bins under their respective rain canopies followed a procedure which not only allowed random positioning of each treatment within the replicate, but also allowed each bin an equal chance of being placed in one or two positions, 180^{o} from each other.

Specifications of experiment 8 are given in appendix 11.

Results and discussion

a. Cover

The visually assessed grade of cover produced by each coulter in association with the bar harrow was:

triple disc	-	grade I
hoe	-	grade III
chisel	-	grade IV

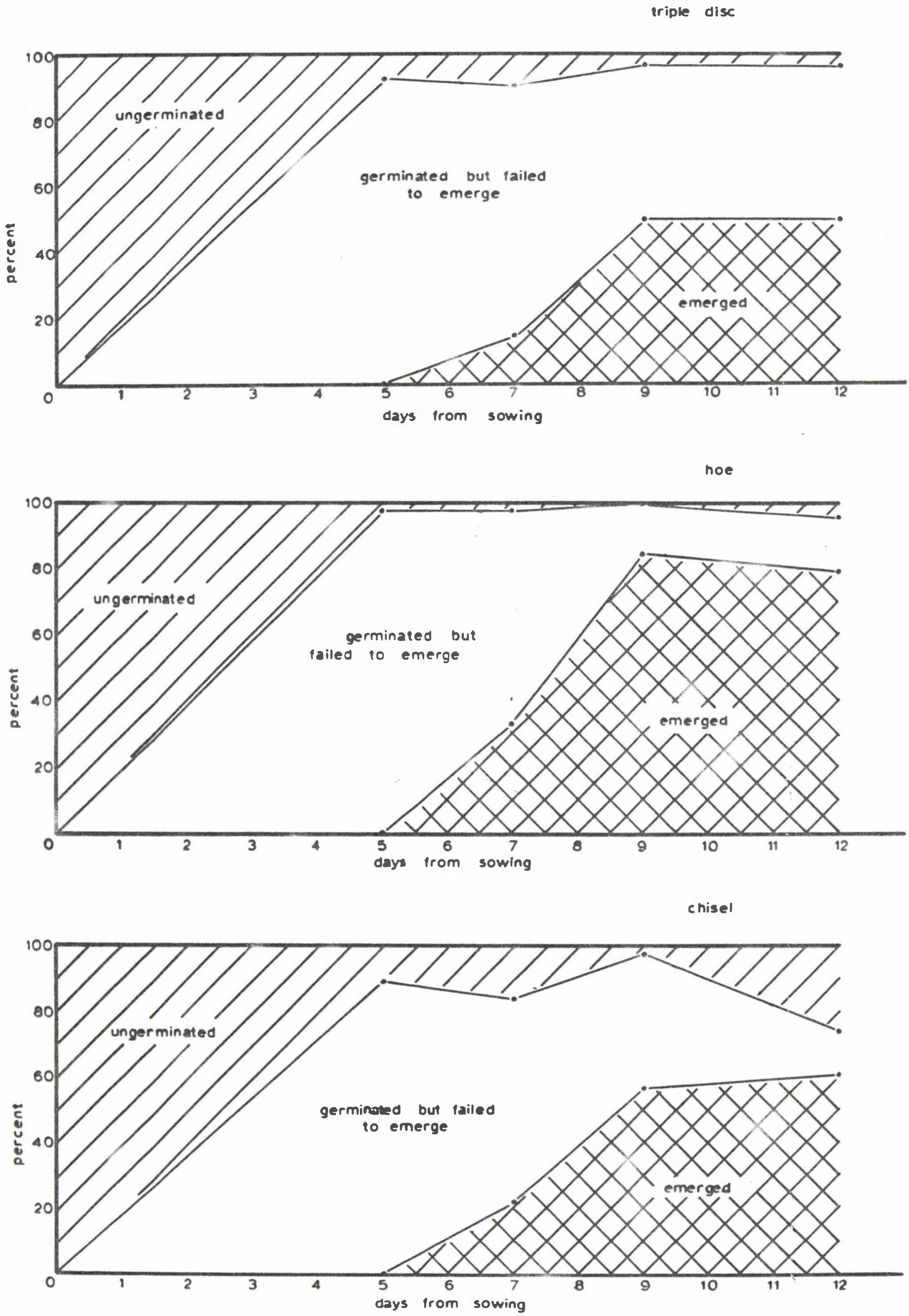
b. <u>Seedling emergence and seed fate</u>

Figure 10 represents a family of cumulative curves illustrating the porportions of the various categories involved in seed fate counts for each treatment. Any apparent negative relationship between "days from sowing" and, for example, "ungerminated" is attributed to sampling error. The category of "abnormal" has been omitted from the graphs because its contribution was negligible.

Statistical analysis of arc-sin transformed data was restricted to day 9.

Despite some apparent differences in Figure 10 none of these were significant. Not surprisingly, the overall trend is for a decrease in the proportion of "ungerminated" seeds with time. This is not "mirrored" precisely by an increase in the proportion of "emerged" seedlings. The sensitive area, as in experiments 6 and 7, therefore appears to be the "germinated-but-failed-to-emerge" category.

It appears that even with an initial disadvantage of a 22.3% decrease in soil moisture content, the chisel coulter was able to sustain a seedling emergence performance little different from either triple disc or hoe.



<u>Figure 10</u> The effects of coulter type on the fate of wheat seeds following direct drilling and bar harrowing

c. Soil moisture content

At regular intervals, scoop samples were taken from rows containing non viable seed. From these the seed and soil were separated and the dry matter determined separately from each of the two components. As in experiment 7 the procedure of sequential sampling could not be described as strictly randomised. The position of each sequential scoop site was determined by the preceding site in one of two rows. Although the sites in each of the two rows worked progressively in from the ends of each bin sample (the first scoopful was discarded) there was a four-way choice at each sampling (viz. 2 x ends of the bin, plus 2 x rows). Scoop samples were considered to be large in size in comparison with the shallow core samples usually involved in moisture determinations. It was considered therefore, that soil from the scoop samples may have been representative of the average moisture content in the locality immediately adjacent to the seed.

Figure 11 shows the treatment soil moisture contents with time, with least significant differences ($P = 0.05$) calculated for days 9, 16 and 21.

The graphs show a tendency of all treatments to converge with time after an initial unstable period, which was possibly related to the prevailing weather. The comparison between the grooves of hoe and triple disc (which both began the experiment at the same moisture content) reveals no significant differences at each of three sampling dates. The groove of the chisel coulter, (which began at a moisture disadvantage in comparison with the hoe and triple disc coulters) maintained its margin below these two treatments until day 16 after which it fell at a reduced rate and eventually merged with them. The initial difference between triple disc and chisel (which was significant at day 9) was reduced by about half at day 7 and remained at this level until day 16. By day 21 the deficit of chisel below both hoe and triple disc had been reduced by two thirds. Although the restrictions of replication precluded many of these differences from attaining statistical significance, the fact that by day 21 all treatments simultaneously showed signs of seedling wilting suggests that these trends were real.

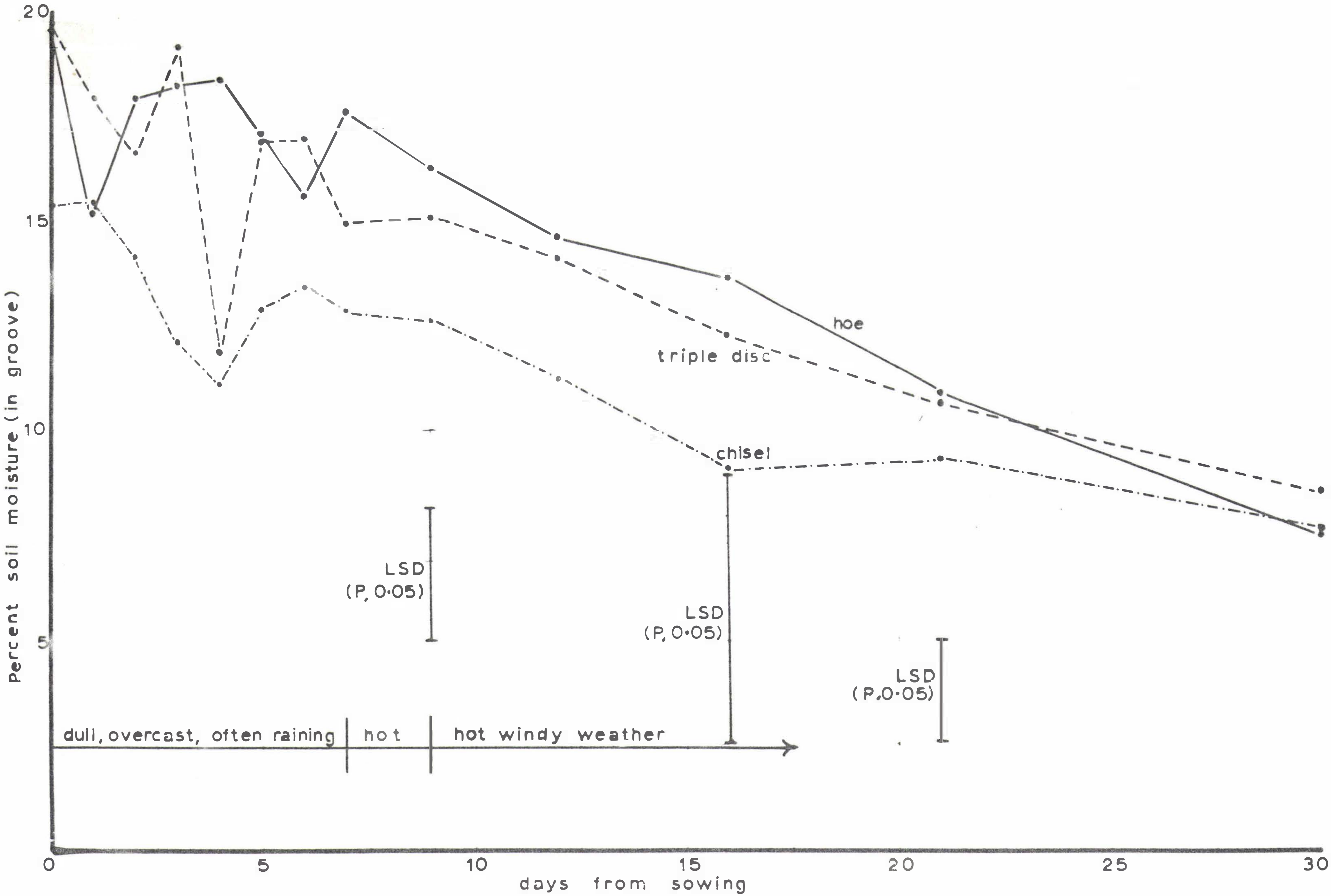


Figure 11 The effect of coulter type on in-groove soil moisture content following direct drilling and bar harrowing

d. Non-viable seed dry matter content

The sampling procedure and site selection for this was identical to that for soil moisture content determinations. The trends over the period 0-12 days are shown in Figure 12. In this instance, seeds in all three treatments began the experiment at a common dry-matter content of 88.3%. During scoop sampling, the number of seeds recovered for gravimetric determination varied from 4 to 19 with an average number per sampling of 12. While it could be argued that this sample size variation is likely to have led to error, the majority of sample sizes lay close to the mean (as instanced by the coefficient of variation of sample size = 22%). Of greater doubt however is the effect of the pretreatment of the seeds which were killed by exposure to 24D vapour for three weeks. This apparently rendered the seeds liable to early decomposition as the counts had to be ceased on day 12 because of visual evidence of rotting seed. No significant differences were apparent on day 9, which displayed the widest variation between treatments. Thus as in previous experiments, little importance can be attached to the absolute values shown on the curves.

e. Inter-relationships

There appeared to be no consistent relationships between soil moisture content and seed dry matter content, although the time lag for imbibition and establishment of equilibrium moisture content within the seed would be expected to make comparisons difficult. No analysis of the relationship between seedling emergence data and either seed dry matter content or soil moisture data were made because of the indeterminate time lag involved in the emergence data.

f. Herbage dry matter yields

At two sampling dates a section of one row of each plot was harvested by cutting the shoots at ground level. Dry weights of these plants, were determined, and the dry weight per plant figure was adjusted according to the terminal emergence percentage figure for that plot, and thereby converted to an equivalent dry matter weight per unit area. (kg/ha).

The number of plants per sampling varied between 5 and 26. Table 19 lists this derived data for two sampling dates.

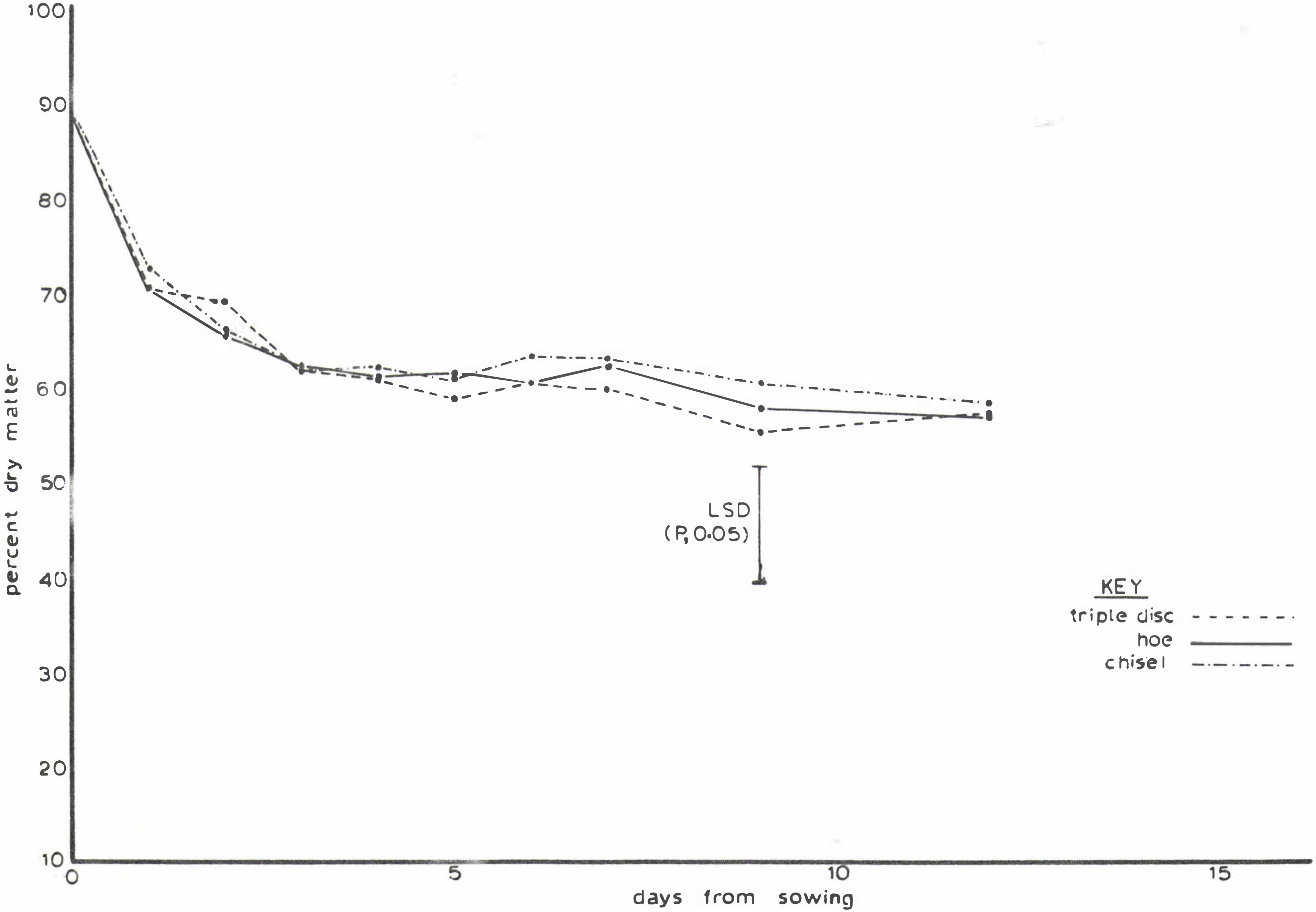


Figure 12 The effects of coulter type on the dry matter content of ungerminated wheat seeds following direct drilling and bar harrowing

TABLE 19 The effects of coulter type and bar harrowing on dry matter yield of direct drilled wheat seedlings

	triple disc	hoe	chisel	significance (P=0.05)
Day 33	233.3 kg/ha	333.6 kg/ha	358.1 kg/ha	NS
Day 50	211.8	390.2	170.5	NS

In comparing the interactions of sampling date and drill coulter type, although none of the differences above (Table 19) were significant (P=0.05) it is possible that the hoe coulter may have allowed plants to become sufficiently well established to withstand the increasing soil moisture stress while plants from both the triple disc and chisel coulters treatments appeared to have been affected by these deteriorating growth conditions. Even then the gain in dry matter per hectare between sampling dates with the hoe coulter is considered to be minimal (17%) for plants at this early growth stage, compared with what might be expected under an adequate moisture regime.

At the earlier sampling however, (day 33), and despite a common soil moisture content of approximately 7% for the three treatments, the plants sown with the chisel and hoe coulters gave the appearance of being slightly more vigorous than those sown with the triple disc coulter.

Plates 26 (a), (b), (c) and (d) illustrate the relative development of typical seedlings with time in the early stages of all three treatments.

Of particular note is the early extended root systems of seedlings sown by both the chisel and hoe coulters and the apparently stunted roots from the triple disc coulter. This effect persisted through to day 12 (by which time the soil moisture regimes in the triple disc, hoe and chisel coulter treatments were 15.0%, 14.5%, and 11.2% respectively), and had also reflected itself in the corresponding shoot developments. Although no further photographs were taken after day 12 (at which time scoop harvests ceased) it is possible that some of these shoot development trends were maintained until at least day 33.

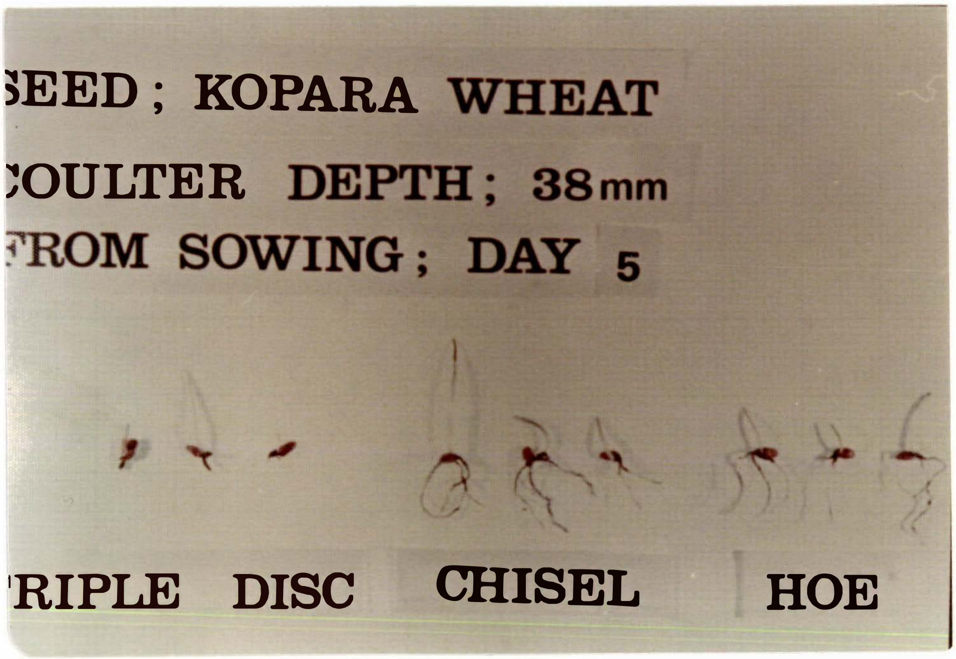


Plate 26(a): Typical direct drilled wheat seedlings (day 5)

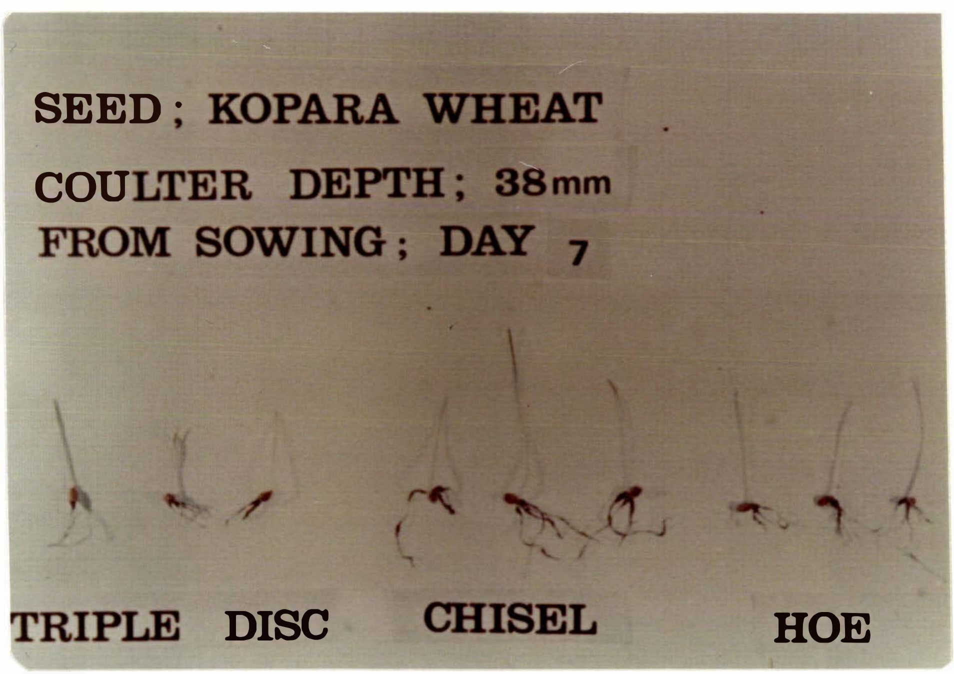


Plate 26(b): Typical direct drilled wheat seedlings (day 7)

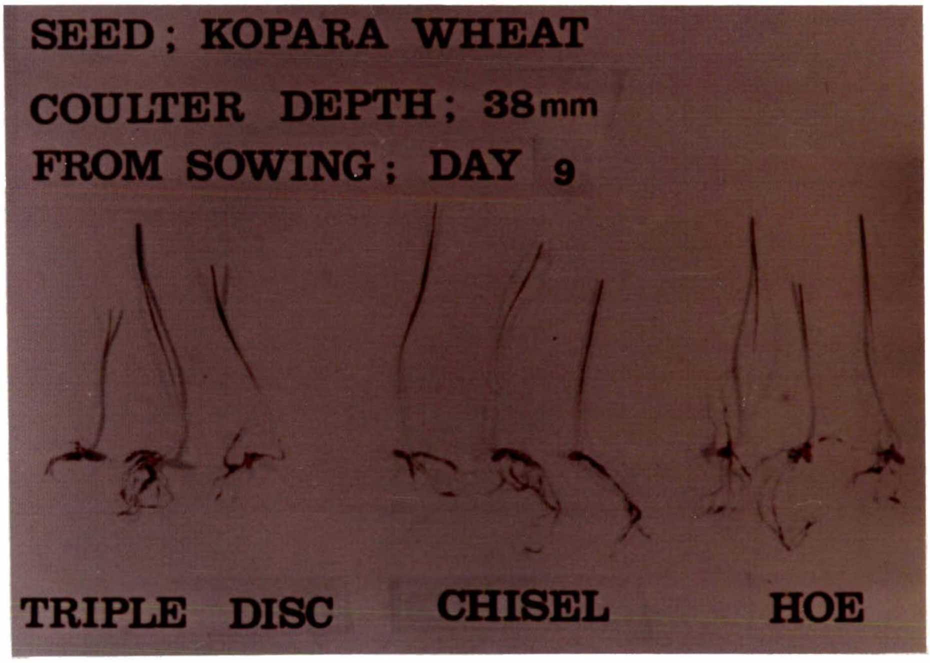


Plate 26(c): Typical direct drilled wheat seedlings (day 9)

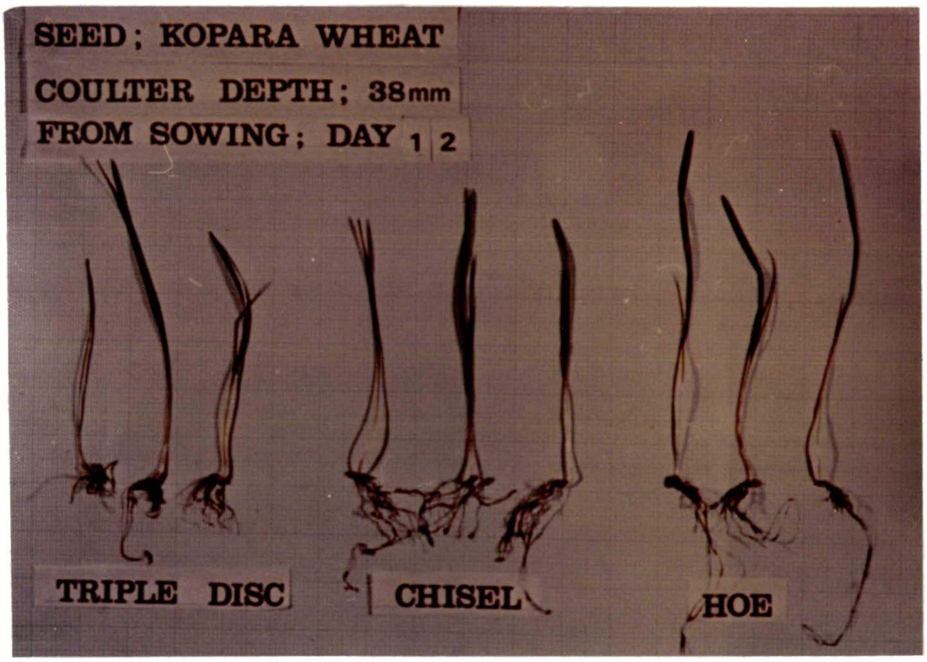


Plate 26(d): Typical direct drilled wheat seedlings (day 12)

3. Penetration forces

The net forces required to achieve full penetration of each coulter assembly were as follows

triple disc	912 N
hoe	225 N
chisel	225 N

Comparison of these figures with the corresponding figures in experiments 6 and 7 confirms the relatively high resistance of the triple disc assembly to penetration - even though in this instance, the chisel coulter assembly, was operating in a drier soil

4.3.9 Experiment 9: Comparison of the wear rates of chisel coulters (field experiment)

Objectives

All tillage bin experiments had tested a special prototype version of the chisel coulter assembly. Because of the promising results of this coulter under moisture stress, it was felt to be pertinent to construct a field version, which could be attached to an appropriate direct drilling machine. Special emphasis was placed on adherence to the functional specifications of the prototype device.

Accordingly, the Mark 1 and Mark 2 versions of the coulter and their associated pre-discs were produced. Visual appraisal of the groove and cover produced by these field versions suggested that to all intents and purposes the groove was identical to that formed by the prototype. The reliability of such visual appraisal was shown to have been of a high order in experiments 6 and 7. With extended field use, however two problems appeared, neither of which was concerned with the shape or cover of the groove, at least in the short term.

Because the coulters were non-rolling devices they were subject to considerable wear at the pressure points of ground entry. In addition, and for the same reason, banks of adjacent coulter-assemblies tended to block when operating in lying trash.

No attempt was made to overcome the latter problem in the course of this investigation (although it had a high priority later), but comparisons of wear resistant materials were made in order to reduce the former problem. This was felt to be pertinent to the investigation, in that excessive wear could alter the critical shape of the drill coulter. In extreme cases the "horizontal" wings were worn away completely, so that the coulter resembled in shape, a suffolk or knife coulter.

The method of test was to randomly distribute the variously hard-surfaced chisel coulters amongst the 16 positions on a "Duncan 730 Multiseeder" seed drill, taking care to avoid positioning more than one example of each treatment within the tractor wheel tracks. The drill was then operated in a variety of agricultural soils. At intervals, coulters were removed and checked for wear. The soils consisted of grassed swards, predominantly on silt loams. Care was taken to avoid soils of either high clay content or high sand content. Because of the number of treatments, the tests occupied two different operational periods and therefore cannot be strictly compared between these periods.

Measurements.

Attempts had been made earlier to measure certain critical dimensions of the coulters as indicative of wear. However it soon became apparent that the areas which exhibited the most wear were difficult to define by dimensions alone, so that recourse to a gravimetric assessment was made. Each coulter was weighted prior to attachment to the drill and the loss of weight was recorded after work. A portion of the coulters were not designed for soil engagement (attachment areas etc). The proportional change in weight of the soil engaging components alone was measured to increase the sensitivity of the tests. All tests were performed at a nominal planting depth of 25mm. At this depth dissection of one coulter established that approximately 33% of its weight was involved in soil engagement. Accordingly a figure of 0.33 of total coulter weight was used as the base weight for the soil engaging portion of all coulters tested.

At the times of removal and reweighing, the total number of hectares covered in the intervening period was also recorded, so that a figure of weight loss per hectare (soil engaging portion) could be established. Coulters were removed when visual appraisal had determined that wear was at an advanced stage.

Table 20 lists the treatments. The group 1 trial period tested treatments A,B,C,D,E and the control, while group 2 comparisons involved F,G,H,I,J and K treatments.

TABLE 20 Hardness treatments applied to direct drilling chisel coulters

Treatment No.	Number of coulters tested	Base material for construction of the coulter wings	Preparation weld onto which hard facing was applied	Hard facing material	Hardness Value*
A	3	T_1 steel	Nil	"EMF Hard-craft 250"	228
B	3	T_1 steel	Nil	"EMF Tool-craft	639
C	3	T_1 steel	Nil	"Lincoln Abrasoweld"	466
D	2	T_1 steel	Nil	"Hislop Faceweld No. 1"	550
E	2	T_1 steel	"EMF Hard-craft 250"	"EMF Tool-craft"	672
F	2	Spring steel	"Phillips 565"	"Phillips 700"	557
G	3	Mild steel	"Phillips 565"	"Phillips 700"	666
H	3	Mild steel	"Phillips 565"	"Phillips 850"	666
I	2	Spring steel	"Phillips 565"	"Vidalloy 10"	985
J	3	Mild steel	"Phillips 565"	"Vidalloy 10"	1084
K	3	Mild steel	"Phillips 565"	"Tube Arc"	795
Control	2	T_1 steel	No hard surfacing at all		349

* Vickers Pyramid Hardness Values obtained from tests by D.S.I.R. (A.G. Ellis, pers. comm.)

Results and discussion

Table 21 lists the data for both trial periods

According to statistical analysis of variance (studentised range test, P = 0.05), none of the treatments in group 2 were significantly different. On the visual appearance of the individual coulter wings, it is difficult to reconcile this with apparent wear rates. Treatments I, J, and K appeared to be distinctly superior to all other treatments. This was probably due to the insensitivity of this form of weight testing as the sole measurement of wear and to inadequate replication. Removal of the wings for weighing in isolation was not practical.

Although group 1 treatments were also limited in replication, treatments C and D were significantly more resistant to wear (P = 0.05) than the control treatment. This was not surprising since the hardness values of these three treatments were also much higher, but treatments E and B (which had the highest and second highest hardness values respectively) appeared not to have performed as well as C and D. This is reflected in the correlation coefficients for both groups which showed only a weak relationship between wear rates and hardness values.

Plate 27 illustrates the comparative wear of the wing portions of the coulters (which were severed from the coulter for illustrative purposes) within group 1.

TABLE 21 The effects of hard surfacing treatments on the wear rates of chisel coulters

	Number of coulters tested	Average number of hectares per test	Percentage weight loss per hectare (soil engaging portions)
Group 1.			
Treatment A	3	15.4	1.10 abc
B	3	15.4	0.78 abc
C	3	15.4	0.47 a
D	2	15.4	0.56 ab
E	2	15.4	0.83 abc
Control	3	15.4	1.35 c
Correlation co-efficient of weight loss vs hardness r = 0.43			
Group 2.			
Treatment F	2	35.2	1.22 a
G	3	34.2	1.26 a
H	3	36.8	0.73 a
I	2	36.8	0.32 a
J	3	35.0	0.43 a
K	3	36.8	0.47 a
Correlation coefficient of weight loss vs hardness r = 0.46			

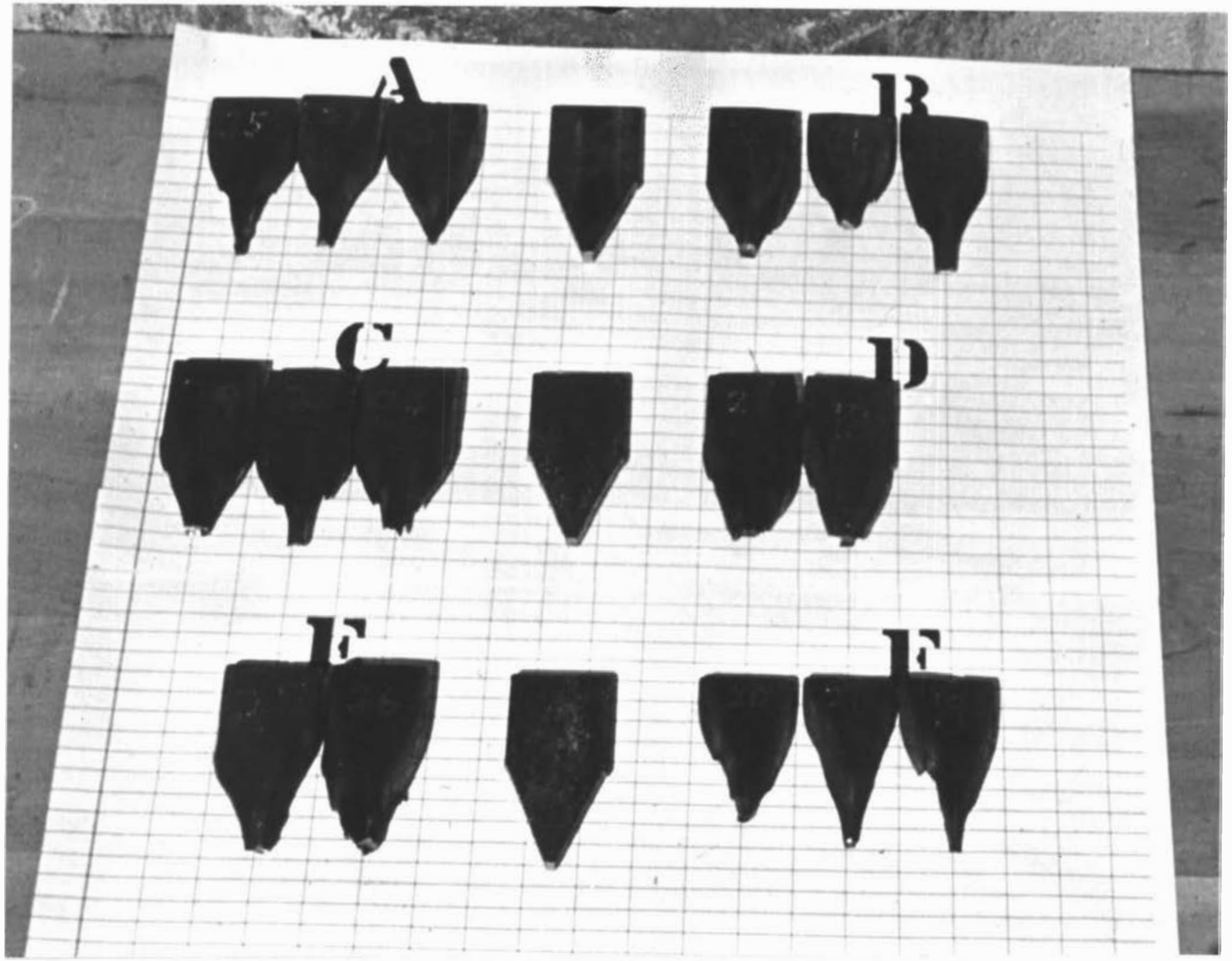


Plate 27: Comparative wear rates of chisel coulter wings. The three separated central wings are the original unworn shape

Although no strict comparison is possible between group 1 and group 2 results, it is reasonable to expect the control treatment to display the highest wear rate of all treatments. As none of the group 2 treatments exceeded, in wear rate, the control treatment of group 1 it is probable that the two groups had sustained similar wearing conditions. In fact, each test consisted of a number of different soils at different localities with varying moisture contents and with different parent vegetations. Thus each group could have been expected to have undergone a similar variety of wear promoting conditions, and comparison of results between groups may be possible.

From a practical viewpoint, this is of little consequence as the most wear resistant treatment in group 1 (viz. C & D), and those of group 2 (viz. I, J and K) all appeared to be superior to the other treatments. Which of the treatments subsequently appealed as a commercial proposition, would depend on a number of factors such as cost and availability, but consideration of their merits and demerits in these terms was beyond the scope of this investigation.

All chisel drill coulters were subsequently treated in an identical manner to treatment J.

<u>Effect of tractor wheel marks</u>

With group 2 tests, an effort was made to determine if tracking behind the tractor wheels had any effect on the wear rate of individual coulters. A total of 6 coulters was found to be tracking thus. Comparison of their individual wear rates with others of the same treatment which were not in wheel tracks, was not able to establish any clear trend, as indicated in table 22.

TABLE 22 The effects of position in relation to tractor wheel marks on the wear rate of chisel coulters

Treatment	Number of coulters in wheel marks	% wt. loss/ha in wheel marks	Number of coulters outside wheel marks	% wt. loss/ha outside wheel marks	Effect on weight loss of wheel marks
G	1	0.93	2	1.50	Reduction
H	1	1.00	2	0.59	Increase
I	1	0.30	1	0.33	Nil
J	2	0.45	1	0.41	Nil
K	1	0.71	2	0.34	Increase

It could be argued that tractor wheel marks would have been expected to provide a more consolidated and therefore, presumably more wear-promoting medium in which increased wear rates might have been expected. However, in a substantially stable, well structured and settled soil, as is commonly found under undisturbed pasture, the effects of external compaction forces could be expected to be minimal. Besides, in many conditions the draught of the drilling machine was sufficient to promote some wheel slip from the driving wheels of the tractor, with the effect that physical disturbance and loosening of the track areas often occurred.

5. SUMMARY AND DISCUSSION

This study was initiated against a background which offered little published information about comparative drill coulter designs or performances, but a relative abundance of opinion, observation and "trial and error". Clearly, a high priority was to develop an experimental technique which could both monitor plant response during germination and establishment, as well as measure the critical mechanical and physical inputs which manipulate the soil during the process of seed sowing. In realistically studying the biological factors, the system was required to control variables, such as soil moisture content, depth and spacing of seed implantation, and freedom from predators etc. From the mechanical viewpoint, the system was required to facilitate close study of the action of seed sowing machines through precise control of speed, geometry of components, measurement of soil strength and coulter penetration forces. In addition the system had to permit close visual appraisal to be made of hitherto little reported factors such as the path and direction of seed fall to and from the drill coulters, and the completeness and nature of cover over the seed.

It is therefore appropriate that a considerable proportion of this study revolved around the development of a tillage bin and tool testing apparatus together with equipment and methods for extracting undisturbed blocks of turf-covered soil and the preservation and manipulation of soil moisture content using rain protection canopies and water trays. Encumbent in the tool testing apparatus was a precision spacing seeder, a multipoint penetrometer, and means by which drill coulter assemblies could be interchanged while retaining the essential geometry which normally characterizes their action on a field drilling machine.

With this unique facility, a range of known and experimental drill coulter assemblies was compared. From this initial study, the short-comings of existing drill coulters were noted and a number of experimental designs were constructed and evaluated. The most promising assembly was called a chisel coulter and consisted of a vertical flat pre-disc followed by a sharpened hollow vertical tool which had slightly angled lateral wings welded to its base in such a manner that soil disturbance and manipulation was almost totally confined to sub-surface soil layers, and the dead surface turf mulch was left largely intact as a buffer against in-groove drying. The chisel coulter was further compared with two selected commercially available designs (triple disc and hoe coulters) in a series of experiments which sought to establish and examine their effectiveness in terms of seedling emergence responses under soil moisture stress.

This technique, together with a limited number of field trials established the importance of covering the sown seed. The extent and nature of cover was visually scored according to its appearance and completeness and was shown to have a strong correlation with seedling emergence data in dry conditions. This was felt to form a possible guide to the writing of design specifications for seed sowing and covering equipment. In this regard scuffing devices appeared preferable to pressing devices. Accordingly, a bar covering harrow was developed, which was shown to promote notable improvements in the seedling emergence percentages of field sown choumollier, barley, lucerne and maize (experiments 1 and 2).

Experiments 3, 4 and 5 had as their main function, to develop the experimental techniques which utilized tillage bins and the tool testing apparatus. As such, there were some limitations to the comparative coulter performance data forthcoming which was mainly attributable to the method of treatment isolation and replication with the tillage bins. Nevertheless, the advantage of covering the grooves made by hoe or chisel coulters was clearly demonstrated. Experiments 6, 7 and 8 indicated highly significant and repeatable responses of wheat seedling emergence to a combination of drill coulter design and bar harrowing, at least at very slow speeds. The chisel coulter design was significantly superior to both the triple disc and hoe coulters under severe moisture stress but had its advantage over the hoe coulter reduced when the soil moisture content was raised. The hoe and triple disc treatments failed to differ significantly at severe soil moisture stress, although the hoe coulter may have had a small but insignificant, advantage over triple disc at the higher soil moisture content. Only when the pre-sowing soil moisture content was deliberately decreased by 22.3% in the case of the chisel coulter, in comparison with the triple disc and hoe coulters, was a situation developed where plant emergence counts showed no significant differences between the three treatments.

The study was not able to precisely identify all casual processes responsible for these plant responses to coulter design and covering, but irrigation responses and soil moisture data suggested the strong possibility that moisture retention by individual seed grooves (as a function of coulter design and bar harrowing action) had been a dominant factor. In fact, the difficulty of adequately monitoring in-groove soil moisture conditions was a feature of the experiments. The performance of the hoe and triple disc coulters responded significantly more to irrigation than did the chisel coulter. In the case of the triple disc, and to a lesser extent the hoe, these responses were seen to reflect the number of seedlings which had not emerged prior to irrigation, rather than the number of seeds which had remained ungerminated. With the chisel coulter the relative lack of response to irrigation was because most of its seedlings had already emerged prior to irrigation.

The fate of individual seeds was studied, to gain an insight into the manner by which plants apparently failed to emerge under moisture stress. There appeared to be a critical sub-surface development phase between germination and emergence which may have accounted for the relative failure of seeds sown with the triple disc coulter to emerge in the first place, and also to respond to subsequent irrigation. The relatively large proportion of seeds in the "germinated-but-failed-to-emerge" catagory with the triple disc, was significant in comparison with the chisel coulter, and also appeared to contrast (though not always significantly) with the hoe coulter - even though the final plant emergence counts of these last two named coulters, were often similar. Germination, *per se.*, did not appear to be the dominant performance factor of any coulter. The chisel coulter appeared to promote comparable germination to the other coulters, but a stronger sub-surface survival rate led to its eventual considerable superiority, in terms of numbers of emerged seedlings.

In-groove soil temperature, and that of the undisturbed soil between the grooves was monitored. The minimum in-groove temperature of the chisel coulter was slightly and significantly higher than that of triple disc and hoe coulters in one experiment. No other in-groove or undisturbed significant differences appeared when comparing minima, maxima, or ranges of temperature fluctuations in this or other experiments.

Dry matter percentage of recovered seeds appeared not to be a reliable indicator of in-groove soil moisture regime and no satisfactory correlations could be established between these two factors. Comparisons among treatments revealed an almost significantly lower seed dry matter content with triple disc as compared with hoe in one experiment, and this may strengthen the impression gained, that water imbibition by seeds with the triple disc coulter was not one of its failings.

Dry matter yield of young shoots, on a corrected plant population basis, revealed no significant differences between treatments in the two experiments in which this was determined, although visual and photographic evidence suggested that root development had been restricted in seedlings sown with the triple disc coulter, and may have been strongest with the chisel coulter.

In considering the mechanics of the actions of each of the drill coulters tested, penetration of the respective drill coulters into the ground appeared to be closely related to their modes of action and were relatively insensitive to soil moisture content in the stress range. A moderate positive correlation existed between the external force required for ground penetration of the triple disc, hoe and chisel coulter assemblies and the subsequent soil bulk density immediately below the coulter path (as measured by resistance to penetrometer probes). The triple disc coulter commonly required 1.5 to 4 times more external force for penetration than did the hoe or chisel coulters, which were roughly the same except in one situtation. The ski and angle-flat-disc coulters each required less force than the hoe and chisel, while the dished disc coulter lay between these two and the triple disc. At no instance was soil bulk density increased as a result of passage of the hoe or chisel coulter, whereas a slight increase was recorded by triple disc in one experiment.

Care would be required in interpreting the results of these experiments as wholly applicable to field practice. The purpose of such an intensive and perhaps restrictive study has been to lay a possible foundation for realistic appraisal of direct drilling equipment. Nevertheless observation and subsequent field trials have confirmed the potential of the experimental chisel coulter described, and the shortcomings of the triple disc and to a lesser extent the hoe coulter in dry soil conditions, and at slow speeds.

Field tests (experiment 9) of chisel coulters, to investigate their wear rates as a function of the materials used in their construction or hard-surfacing, suggested a number of suitable alloy materials for protection. There appeared to be no measurable effect on wear rate from coulters which travelled in the tractor wheel tracks as compared with those in unmarked soil.

It is evident that the potential of direct drilling will not be fully realised except in favourable weather and soil conditions which might mask otherwise sub-optimal seed drill design or performance, unless research effort is directed toward the critical phases of seed germination and seedling emergence. An untilled seedbed is not as "forgiving", with respect to the adequacy of seed placement and cover, as is cultivated ground, but it often possesses greater potential to promote the establishing plant. It is necessary that machine design schedules should have as a high priority, methods of utilizing, rather than destroying this potential.

6.

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m. Drill coulter assembly

An assembly attached to a seed boot and/or trailing arm which features two or more different drill coulters or one drill coulter in combination with a flat pre-disc.

APPENDIX 1

Meteorological Data - Station E05465 - Massey University

Rainfall - mm

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Rain days												
1961	12	11	13							9	10	6
1962	8	4	15							17	12	13
1963	5	11	9							8	20	16
1964	14	5	15							13	11	15
1965	14	14	22							17	15	19
1966	11	12	7							13	16	18
1967	12	10	9							9	14	16
1968	8	5	7							12	12	24
1969	14	8	4							10	7	13
1970	6	7	14							21	8	6
Means	10.4	8.7	11.5							14.3	12.5	13.2
Monthly Rainfall, mm.												
1961	172*	53*	89*	71*	59	76	115	100	140	20	30	25
1962	123	30	80	91	42	150	132	122	50	151	87	72
1963	35	107	49	69	95	76	88	40	115	19	131	91
1964	95	57	97	26	59	76	158	120	108	94	46	174
1965	113	90	227	56	50	48	115	62	66	101	114	133
1966	109	139	49	105	60	83	144	49	48	36	76	217
1967	87	98	69	58	78	43	44	185	32	67	99	156
1968	59	50	-	121	136	161	77	68	69	129	49	145
1969	81	70	27	63	107	71	38	70	33	43	36	92
1970	27	6	89	25	103	122	111	68	167	90	53	74
Means**	81	72	86	68	79	91	102	89	83	75	72	118

* records from D.S.I.R., Palmerston North

** Means are from Massey records only.

APPENDIX 2

Ambient and Comparative Temperature Data, beneath rain canopies
Temperature checks (Winter Months).

Equipment: Maximum-minimum thermometer.

Date	Ambient, °C		Canopy, °C	
	Maximum	Minimum	Maximum	Minimum
26.6.70	30.0	3.3	24.0	7.0
28.6.70	31.7	5.0	26.0	8.0
1.7.70	21.1	2.2	17.0	5.5
28.7.70	18.9	4.4	16.0	6.5
29.7.70	20.0	0.0	17.0	3.5
Means	24.4	3.0	20.0	6.1

APPENDIX 3

Comparative Soil Moisture Contents of Tillage Bin Turf Blocks and Parent Soils in Situ.

Turf block extracted 8/12/69

Sampled for moisture content 18/12/69

Depth of moisture content sampling 0-50mm

Method of moisture content sampling, gravimetric (50mm diam. plugs)

Tillage Bin No.	Soil Plug	% Moisture (wet basis)	Mean for Turf Block
1	1	11.02	
(sprayed, waxed, covered from rain)	2	11.59	
	3	8.93	
	4	10.30	10.46
2	1	20.31	
(sprayed, waxed, exposed to rain)	2	22.31	
	3	17.88	
	4	21.26	20.46
3	1	18.44	
(unsprayed, exposed to rain)	2	19.65	
	3	17.07	
	4	20.66	18.96
4	1	19.28	
(in situ, exposed to rain)	2	25.59	
	3	22.08	
	4	20.73	21.92

APPENDIX 4.

Specifications of Experiment No. 1.

Type of experiment	:	Field trial
Location	:	Massey University Tuapaka Farm
Drill-coulter assembly	:	Flat pre-disc followed by "Duncan hoe coulter
Depth control	:	No positive control - spring force versus ground resistance
Sowing depth	:	Nominally, 20mm
Row spacing	:	150 mm
Operating speed	:	6.4 km/h
Type of field drill	:	"Duncan 700 Seedliner"
Condition of parent vegetation	:	Sparse, drought affected, then sprayed
Condition of soil	:	Surface variable - some heavy pugging by cattle during winter. Low moisture content at time of drilling
Soil type	:	"Ohakea silt loam"
Environmental conditions at sowing	:	Dry
Environmental conditions during experiment	:	Remained dry - little rain
Herbicide, rate and application	:	Blanket sprayed at 2.8 l/ha paraquat and 1.4 l/ha dicamba 4 days prior to drilling - single application
Harrowing and delay	:	bar harrows attached to drill
Class of cover over seed	:	Bar harrowed - grade II Unharrowed - grade I to "no cover"
Seeding rate	:	Unknown, but common to both treatments
Seed metering	:	Plate seeder
Fertilizer sown with seed	:	Unknown, but common to both treatments
Experimental design	:	Randomised block, 4 replications

APPENDIX 5.

(a) Specifications of Experiment No. 2.

Sowing date	lucerne 3/11/69 barley 9/11/69 maize 4/11/69
Species	Lucerne - "Wairau" Barley - "Carlsberg" Maize - "Wisconsin 415"
Germination potential	Unknown but common to all treatments within each species
Type of Experiment	Field trial
Location	Kimbolton Road, Fielding
Drill-Coulter assemblies	Direct drilling all species: "Duncan hoe coulter - no pre-disc for barley and maize Clean-seed-bed: lucerne, V ring roller drill maize, double disc.
Depth Control	All coulters: no positive control; spring or weight versus ground resistance.
Sowing depth	Lucerne: nominally 13mm barley : " 25mm maize : " 40mm
Row Spacing	Lucerne: - clean-seed-bed 75mm Lucerne - direct drilled - 150mm but cross drilled at 30° Barley: - direct drilled 150mm Maize: - all treatment 750mm
Operating speed	Lucerne, barley and maize direct drilled 6.4 km/h Lucerne, clean-seed-bed 6.4 km/h Maize " " " 4.5 km/h
Type of Field Drill	Lucerne, maize and barley direct drilling: "Duncan 700 seedliner" Lucerne clean-seed-bed "Grasslands" roller drill Maize clean-seed-bed "Duncan 410 maize planter"
Condition of parent vegetation	Mature sheep pasture, sprayed.
Condition of soil	Lucerne - favourable, slightly dry and friable Barley - as for lucerne Maize - moist and plastic.
Soil type	"Ohakea silt loam"
Environmental conditions at sowing	- Lucerne and barley - dry - Maize - light rain

Environmental Conditions During Experiment - little effective rain for 11 days
- high radiation, giving drying conditions.

Herbicide, rate and application: all blanket sprayed:

Lucerne: direct drilled, split dressings, 2 days apart, 2.8 1/ha and 2.1 1/ha paraquat last application same day as drilling

Clean-seed-bed: 5.6 1/ha "Balan", p.p.s.i. 1 day prior to drilling

Barley : 4.9 1/ha paraquat + 1.4 1/ha dicamba 4 days prior to drilling

Maize : direct drilled: Split dressings 1 day apart 2.8 1/ha and 2.1 1/ha paraquat + 1.4 1/ha dicamba with first dressing.

Harrowing and delay: Lucerne : bar harrowing delayed until after cross drilling

Barley : Nil, bar harrows attached to drill

Maize : Nil: " " " " " (moist soil conditions would have favoured some delay)

Class of cover over seed: Bar harrowed: Lucerne - Grade II
Barley - Grade II
Maize - Grade I

Unharrowed: Lucerne and barley - "no cover" to Grade I
Maize - "no cover".

Cultivation: Lucerne and maize. - Primary: mouldboard ploughing
Secondary: roller, disc harrows, leveller (multiple).

Seeding rate: Lucerne : 12 kg/ha

Barley : 100 kg/ha

Maize : Clean-seed-bed: 182,000 seeds/ha, Nominally 165mm intra-row spacing
Direct drilled: 171,000 seeds/ha Nominally 140mm intra-row spacing (widest possible with drill).

Seed Metering: Lucerne clean-seed-bed; overshot fluted roller
direct drilled; plate seeder

Barley undershot fluted roller

Maize clean-seed-bed; plate seeder; direct drilled undershot fluted roller

Fertilizer sown with seed:	Lucerne, nil; 200 kg/ha broadcast 3 days after sowing. Barley; 200 kg/ha Superphosphate Maize: 150 kg/ha 10:18:8 "Ammophos"
Experimental design	Not randomised, 5 replicates.

(b) Rainfall - Feilding trial area 1969/70
mm per rain-day

November 1969		January 1970	
4th	2.5mm	3rd	30.5
15	10.2	7	3.6
16	12.7	8	11.2
17	3.8	10	0.5
18	2.5	11	4.8
19	5.6	15	5.1
20	12.7	29	1.3
23	11.4	30	10.2
25	5.6		67.2
26	13.2		
27	12.7		
28	1.3		
	94.2		

December	
3rd	18.8
4	19.3
8	7.1
20	2.5
26	2.8
31	2.5
	53.0

APPENDIX 5

(c) Direct drilled and conventionally sown lucerne, plant emergence counts

All counts = 3 x 0.0929 m^2 quadrats randomly placed per plot.

Plants/m^2

Sampling / Rep.	Day 10 13/11/69 Cultiv.*	D.D-Harr*	D.D-Unh*	Day 85 27/1/70 Cultiv.	D.D-Harr.	D.D.-Unhar.
1	154.2	96.9	50.2	218.9	46.6	75.3
2	111.2	161.5	114.8	261.9	82.5	57.4
3	50.2	93.3	111.2	358.8	57.4	43.1
4	43.1	82.5	75.3	279.9	28.7	25.1
5	100.5	154.3	82.5	359.6	71.8	0.0
Means	91.9	117.7	86.8	295.8	57.4	40.2
S.E.Means	±20. 5	16.6	12.0	27.7	9.4	13.1

Lucerne Dry Matter Yields

Measurements = 3 x 0.0929M^2 quadrats of all treatment (Reps 1 and 2); cultivation and DD-Harr. treatments (Rep 4.)

Kg/ha D.M.

Rep	Cultiv.	D.D-Harr.	D.D.-Unhar.
1	2705.2	3054.5	1862.2
2	2873.6	1743.1	1936.8
4	3251.3	2118.0	No reading
Means	2943.5	2305.2	1899.5
S.E. Means ±	161.6	390.0	37.3

* Cultiv = Cultivated-clean-seed-bed

D.D.-Harr. = Direct-drilled-bar-harrowed

D.D.-Unhar. = Direct-drilled - unharrowed.

APPENDIX 5

(d) Direct drilled and cultivated lucerne plots, soil moisture status

All measurements 25mm diam. x 600 mm cores   Reps 1 and 2 only.

Coring position - between rows, randomly placed.

Percentage Moisture Content - Wet Basis

Rep. \ Sampling	Day 85 27/1/70 Cultiv	D.D.-Harr*	D.D.-Unhar.*
1	5.8	15.5	10.6
2	7.4	11.5	10.4
Means	6.6	13.5	10.5
S.E. Means ±	0.8	2.0	0.09

(e) Direct drilled barley, plant emergence counts

All counts = 3 x 0.0929 M^2 quadrats randomly placed per plot

Plants/M^2

Rep. \ Sampling	Day 8 17/11/69 D.D. Harr*	D.D.-Unhar*	Day 17 4/12/69 D.D.Harr	D.D.-Unharr
1	222.5	17.9	229.6	315.7
2	279.9	39.5	290.6	269.1
3	168.6	10.8	265.5	312.2
4	122.0	7.2	294.2	319.3
5	229.6	32.3	247.5	261.9
Means	204.5	21.5	265.5	295.6
S.E.Means ±	27.1	6.2	12.4	12.4

*D.D-Harr. = Direct drilled, bar harrowed

D.D. Unhar. = Direct drilled, no harrowing

APPENDIX 5

(f) Direct drilled and conventionally sown maize, plant emergence counts

All counts = 5 x 0.91m row length
(0.91 m row at 0.76 m inter-row spacing = 0.69 m^2)
Plants/m^2

Sampling / Rep.	Day 9 13/11/69 Cultiv.*	D.D.-Harr*	D.D.-Unhar*	Day 37 11/12/69 Cultiv.	D.D.Harr.	D.D.unhar.
1	6.7	3.8	0.0	7.2	2.9	0.6
2	6.7	4.6	0.0	6.7	2.3	0.9
3	6.1	4.6	0.6	7.8	1.7	0.6
4	7.0	4.1	0.6	7.8	2.3	0.3
5	7.8	5.8	0.3	7.0	2.9	0.3
Means	6.9	4.6	0.3	7.3	2.4	0.5
S.E. Means	0.3	0.3	0.1	0.2	0.2	0.1

* Cultiv = clean seed bed cultivated, sown with standard maize planter

D.D. Harr. = direct drilled, bar harrowed

D.D. Unharv. = direct drilled, no harrowing

APPENDIX 6

(a) Specification of Experiment No. 3.

Sowing date	7/12/69
Species	"Zephyr" barley
Germination potential	99.0% (M.A.F. Seed Testing Station)
Type of Experiment	Tillage bin study
Location	Massey University Agricultural Mechanisation Hall.
Drill-Coulter Assemblies	"Duncan" hoe coulter with vertical pre-disc; prototype chisel-coulter with vertical pre-disc.
Depth Control	no positive depth restriction
Sowing Depth	Nominally 25mm
Row Spacing	150 mm
Operating Speed	0.5 Km/h
Type of Drill	Tillage bin and tool testing apparatus
Condition of parent vegetation	Short dense pasture : sprayed
Condition of Soil	Considerable moisture stress
Soil Type	"Manawatu fine sandy loam"
Environmental condition at sowing	dry, under rain canopies
Environmental Condition during trial	dry under rain canopies
Herbicide, rate and application	Blanket sprayed, single application 5.6 l/ha paraquat + 1.4 l/ha dicamba, 2 days prior to drilling.
Harrowing and delay	Immediate. Simulated bar harrow action using a small piece of timber scraped along the grooves by hand.
Class of cover over seed	Hoe open - "no cover", to Grade I Hoe closed - Grade II to Grade III Chisel closed - Grade IV
Seeding rate	Nominal intra-row spacing, 20mm
Seed metering	Hand placement of individual seeds with long-nosed pinchers after formation of the grooves.
Fertilizer sown with seed	Nil
Experimental design	Randomised block. Each drill treatment was randomised within each sample bin. 3 replicates.

APPENDIX 6 (b)

Direct drilled barley, plant emergence counts

Treatment and Rep / Time	Rep 1 Hoe* open	Rep 1 Hoe* closed	Rep 1 Chisel* closed	Rep 2 Hoe Open	Rep 2 Hoe closed	Rep 2 Chisel closed	Rep 3 Hoe open	Rep 3 Hoe closed	Rep 3 Chisel closed
	VISIBLE PLANTS PER M LENGTH OF ROW								
Day 3	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
5	0.0	0.0	0.07	0.0	0.05	0.1	0.0	0.0	0.0
7	0.0	0.0	0.07	0.0	0.05	0.1	0.0	0.0	0.0
9	0.0	0.0	0.3	0.0	0.05	0.1	0.0	0.0	0.0
10	0.0	0.4	0.5	0.0	0.05	0.3	0.0	0.04	0.0
11	0.0	1.0	0.8	0.04	0.09	0.4	0.0	0.4	0.1
12	0.05	1.3	1.1	0.2	0.2	0.8	0.08	0.7	0.6
15	0.05	1.6	1.3	0.4	0.4	1.1	0.1	0.9	1.0
16	0.05	1.6	1.4	0.4	0.4	1.1	0.2	1.0	1.1
18	0.05	1.6	1.4	0.4	0.4	1.1	0.2	1.0	1.1
20	0.05	1.6	1.3	0.4	0.4	1.1	0.2	0.9	1.0
22	0.05	1.5	1.2	0.4	0.3	1.1	0.2	0.9	0.9
23	0.05	1.0	1.1	0.2	0.2	0.9	0.08	0.5	0.6
27	0.05	0.9	0.9	0.0	0.0	0.3	0.0	0.08	0.2
29	0.0	0.1	0.2	0.0	0.0	0.06	0.0	0.0	0.04

* Hoe-open = hoe coulter assembly, groove left unharrowed
Hoe-closed = " " " " closed by simulated bar harrowing
Chisel " = chisel " " " " " " " "

APPENDIX 7

(a) Specifications of Experiments No. 4(a) and 4(b)

Sowing date	2/11/70
Species	"Wisconsin 415" maize
Germination potential	93% (M.A.F. Seed Testing Station
Type of Experiment	Tillage bin study
Location	Massey University, Agricultural Mechanisation Hall
Drill-coulter Assemblies	"Duncan" triple disc "Duncan" hoe with vertical pre-disc experimental chisel with vertical pre-disc
Depth control	No positive depth restriction.
Sowing depth	Nominally 38 mm
Row Spacing	150 mm
Operating speed	70 m/hr
Type of drill	Tillage bin and tool testing aparatus
Condition of parent vegetation	Short dense pasture, paspalum (*Paspalum dilatatum*) and subterranean clover (*Trifolium subterraneum*) dominant
Condition of soil	Considerable moisture stress
Soil type	Manawatu fine sandy loam
Environmental conditions at sowing	Dry, under rain canopies
Environmental conditions during trial	" " " " all plots irrigated by sprinkle from above with 12 mm water at 345.36 hours.
Herbicide, rate and application	blanket sprayed, single application 4.2 l/ha paraquat + 1.4 l ha dicamba applied 20/10/70
Class of cover over seed	Triple disc - "no cover" to gra I. Hoe Grade III Chisel Grade IV
Seeding rate	
Seeding rate	Nominal inter-row spacing 36mm

<u>Seed metering</u>	Hand placement of individual seeds with long-nosed pinchers after formation of the grooves.
<u>Fertilizer sown with seed</u>	Nil
<u>Experimental design</u>	Randomised block. Each drill treatment was randomised within each sample bin 3 replicates
<u>Penetrometer operation</u>	
depth of penetration	5 mm (6 turns of screw)
probe ends	square faced
recovery time	60 seconds before reading
<u>Drill-coulter penetration force</u>	Triple disc: 774 N Hoe : 196 N Chisel : 89 N

APPENDIX 7

(b) Direct Drilled Maize, Emergence Counts. (Percentage)

Treatment / Reading	Potential Seed Germination - 93%									
	Triple Disc			Hoe			Chisel			LSD
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	
Day 8	0.0	28.9	0.0	0.0	38.6	0.0	0.0	28.6	0.0	
10	0.0	48.9	0.0	0.0	72.7	0.0	0.0	69.6	0.0	
14	0.0	57.8	0.0	0.0	81.8	0.0	0.0	91.1	0.0	
16	ALL PLOTS IRRIGATED									
16	0.0	57.8	0.0	0.0	81.8	0.0	0.0	92.9	0.0	
21	11.4	57.8	7.1	16.3	81.8	0.0	2.1	92.9	0.0	
Means		25.4			32.7			31.7		
Arc-sin means		(15.3)			(21.4)			(23.2)		(30.9) (41.8)

APPENDIX 7

(c) Direct Drilling, In-groove Soil Moisture Content

Arc-sin means in parenthesis

Treatment / Reading	25 mm cores, 38 mm deep - % Wet basis									
	Triple Disc			Hoe			Chisel			LSD
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	
245.52 hrs	3.3	9.5	NR	3.2	6.6	NR	4.2	7.7	NR	(2.78)
Means		6.4	(3.67)		4.9	(2.81)		6.0	(3.42)	(6.43)
603.28	NR	3.6	NR	NR	3.8	NR	NR	3.6	NR	
Means		3.6			3.8			3.6		

	ALL TREATMENTS (viable seed)			ALL TREATMENTS (non viable seed)		
Initial Moisture Content	8.8	10.1	6.0	5.8	5.0	8.7

MEAN OF SIX SAMPLE BLOCKS PRIOR TO SOWING = 7.7%

APPENDIX 7

(d) Direct Drilled Maize Seed, Dry Matter Percentage

All readings = total of six seeds

Reading \ Treatment	Triple Disc			Hoe			Chisel		
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3
1 (42.64 hrs)	77.7	75.5	74.4	75.3	74.7	73.6	78.1	77.1	75.3
		$\bar{x}$ =	75.9		$\bar{x}$ =	74.6		$\bar{x}$ =	76.8
			Aa			Aa			Aa
2 (105.04 hrs)	76.6	72.5	72.3	75.5	72.5	69.6	78.3	75.5	69.7
		$\bar{x}$ =	73.8		$\bar{x}$ =	72.5		$\bar{x}$ =	74.5
			Aa			Aa			Aa
3 (237.20 hrs)	82.9	79.6	81.9	76.8	81.7	79.4	86.1	81.9	77.8
		$\bar{x}$ =	81.5		$\bar{x}$ =	79.3		$\bar{x}$ =	81.9
			Aa			Aa			Aa
(345.36 hrs)	ALL PLOTS IRRIGATED								
4 (507.60 hrs)	59.4	58.4	65.7	71.6	65.4	71.3	71.3	70.6	65.0
		$\bar{x}$ =	61.2		$\bar{x}$ =	69.4		$\bar{x}$	69.0

LSD =14.8 (5%), 24.6 (1%)

APPENDIX 7

(e) Direct Drilling, In-groove Temperature (^{o}C)

All readings = mean of two diodes per groove

Treatment / Cumulative Time	Triple Disc			Hoe			Chisel			Ambient
Hrs.	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	
0	15.19	15.93	16.66	14.95	15.19	16.42	16.42	14.70	15.68	21.07
1.04	17.64	18.87	18.87	16.66	16.42	18.38	19.36	16.91	17.15	18.13
2.08	18.13	19.36	19.36	17.40	17.64	19.60	20.09	17.89	17.89	15.19
3.12	17.89	18.38	19.11	17.40	17.64	19.36	17.89	17.89	18.38	18.13
4.16	18.38	18.87	18.87	18.13	17.89	19.11	19.36	18.38	18.13	14.70
5.20	17.64	17.64	17.64	17.64	17.40	18.13	17.40	17.89	17.89	14.21
6.24	17.15	17.15	16.66	16.91	17.15	17.15	16.91	17.40	17.40	14.21
7.28	16.66	16.66	16.17	16.42	16.66	16.91	16.17	16.91	17.15	14.21
8.32	16.17	16.17	16.42	16.42	16.42	16.17	15.68	16.91	16.66	13.72
9.36	16.17	16.17	15.68	16.17	15.44	16.42	15.68	20.56	16.42	14.21
10.40	15.93	15.68	15.19	15.93	16.17	16.17	15.44	16.17	16.17	13.23
11.44	15.44	15.68	15.19	15.93	15.93	15.68	15.19	15.68	15.93	13.23
12.48	15.19	15.44	14.70	15.44	15.93	15.68	14.70	15.68	15.68	13.23
13.52	14.95	14.95	14.46	15.44	15.44	15.19	14.70	15.19	15.19	12.74
14.56	14.70	14.95	14.21	15.19	15.44	14.95	14.46	15.19	15.19	13.23
15.60	14.70	14.70	14.21	14.95	15.19	14.95	14.46	14.95	14.95	13.72
16.64	14.70	14.95	14.70	14.95	15.19	15.19	14.70	14.95	14.95	15.19
15.68	15.19	15.68	15.68	15.44	15.68	15.93	15.44	15.19	15.44	16.17
19.76	15.68	16.17	16.42	15.93	15.93	16.66	16.17	15.68	15.93	18.13
21.84	16.91	17.64	19.11	16.66	16.91	18.87	17.64	16.91	17.40	18.13
23.92	18.13	19.60	20.83	18.13	18.13	20.58	19.11	18.62	19.11	18.13
26.00	18.87	19.11	18.87	18.87	18.38	19.11	19.36	18.87	18.87	16.66
28.08	18.38	18.87	18.62	18.38	18.13	19.11	18.87	18.62	18.87	16.17
30.16	17.89	18.38	17.40	18.13	17.89	18.13	18.38	18.38	18.13	13.72
32.24	16.91	16.91	16.17	16.91	16.91	16.91	16.42	17.15	17.15	13.72
34.32	16.17	16.42	15.68	16.42	16.42	16.17	15.68	16.42	16.42	13.72
36.40	15.68	15.93	15.19	15.93	16.17	15.68	15.44	15.93	15.93	13.23
38.48	15.44	15.44	14.70	15.93	15.93	15.44	14.95	15.44	15.44	13.23
40.56	14.70	15.19	14.46	15.44	15.19	14.95	14.46	15.19	14.95	12.74
42.64	14.70	14.95	14.95	15.19	15.19	15.44	14.46	14.95	14.95	15.68
44.72	15.93	16.42	17.89	15.93	16.17	17.64	16.42	15.68	16.42	18.62
46.80	18.13	18.62	19.36	17.89	17.89	19.11	19.11	17.89	18.13	18.13
48.88	18.62	18.38	16.91	18.38	17.89	17.64	18.62	17.89	17.40	13.23

	Triple Disc			Hoe			Chisel			Ambient
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	
50.96	16.66	16.91	16.42	16.91	16.66	16.91	16.42	16.91	16.91	13.72
53.04	16.42	16.42	15.93	16.66	16.42	16.42	16.17	16.66	16.42	12.74
55.12	15.93	15.93	14.95	16.17	16.42	15.68	15.44	15.93	15.93	12.25
57.20	15.19	15.19	14.21	15.44	15.44	15.19	14.17	15.19	14.95	12.25
59.28	14.70	14.70	13.72	14.95	14.95	14.46	13.97	14.70	14.70	11.76
61.36	14.21	14.21	12.99	14.46	14.70	13.97	13.48	14.21	13.97	11.27
63.44	13.72	13.72	12.50	13.97	14.21	13.48	12.99	13.72	13.48	11.27
65.52	13.23	12.99	12.25	13.72	13.48	12.99	12.50	13.23	12.99	11.76
67.60	12.99	12.99	12.74	13.23	13.23	13.23	12.74	12.99	13.23	13.23
71.76	13.48	13.72	14.21	13.72	13.72	14.21	13.48	13.48	13.72	14.70
75.92	16.42	17.64	16.66	15.93	16.42	16.66	18.38	16.42	16.17	13.23
80.08	15.93	15.19	13.72	15.68	14.95	14.46	15.19	14.95	14.46	9.80
84.24	13.72	12.74	11.52	13.48	13.23	12.50	12.50	12.99	12.74	9.31
88.40	12.01	11.76	10.54	12.50	12.25	11.27	11.03	11.76	11.27	8.82
92.56	11.27	10.78	10.29	11.52	11.27	10.78	10.29	11.03	10.78	12.25
96.72	12.50	13.23	13.48	12.50	12.74	13.48	13.48	12.25	12.25	16.66
100.88	16.42	18.13	26.46	15.44	17.40	23.77	17.89	18.13	22.05	21.56
105.04	25.73	23.77	22.30	22.79	21.56	21.32	26.71	22.54	21.81	15.19
109.20	20.58	18.62	16.17	19.60	18.38	16.91	18.62	18.87	17.64	12.25
113.36	16.91	15.68	13.72	16.66	16.17	14.46	14.95	15.93	14.95	9.31
117.52	14.46	13.23	11.52	14.46	14.21	12.25	12.25	13.48	12.99	8.82
121.68	12.74	12.50	N.R	12.99	12.74	N. R	11.66	N.R	N. R	N.R
125.84	22.30	26.46	33.08	20.34	22.30	28.91	25.73	22.79	27.20	23.52
130.00	31.36	27.44	27.20	26.22	26.95	26.46	32.59	26.71	26.46	14.70
134.16	23.03	22.05	19.11	21.81	21.07	19.85	20.58	21.56	20.58	11.76
138.32	18.87	17.89	15.44	18.62	18.38	16.42	16.17	17.89	17.15	9.80
142.48	15.68	14.95	12.99	15.93	15.93	14.21	13.72	15.19	14.70	11.76
146.64	14.46	14.46	19.36	14.70	14.95	18.62	13.48	14.95	16.91	25.48
150.80	24.99	28.91	37.49	22.30	24.01	31.85	29.16	24.50	29.65	27.44
154.96	31.36	28.67	27.20	28.42	26.71	27.20	34.30	27.69	26.71	13.72
159.12	23.77	22.79	19.85	22.54	22.05	20.58	20.83	22.30	21.81	12.74
163.28	19.85	19.11	17.15	19.85	20.09	18.13	17.89	19.36	18.38	12.25
167.44	17.64	17.15	16.42	17.89	18.13	16.91	16.42	17.40	16.91	14.21
171.60	17.64	18.13	20.34	17.64	17.89	20.09	17.40	17.40	18.87	24.50
175.76	24.01	23.03	25.48	22.54	21.56	25.24	24.75	21.56	22.54	20.09
179.92	24.75	23.52	22.05	23.28	22.30	22.05	24.99	22.79	22.05	14.70
184.24	20.83	19.85	17.64	19.85	19.36	18.62	18.38	19.60	18.87	12.25
188.08	17.64	16.91	15.19	17.89	17.64	15.93	15.93	17.40	16.42	11.27
192.40	15.68	15.44	15.93	15.93	15.68	15.93	14.21	15.44	15.68	15.68

	Triple Disc			Hoe			Chisel			Ambient
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	
216.40	16.91	18.38	20.83	17.40	17.89	21.07	18.13	17.89	18.38	19.60
220.56	23.03	24.75	26.22	21.56	22.30	N.R	25.73	22.79	N.R	N. R
224.72	16.17	18.13	22.05	16.17	18.13	22.05	16.91	16.17	18.87	18.13
228.88	22.05	23.52	24.50	21.56	20.83	26.22	24.99	21.56	22.30	15.68
233.04	20.09	20.34	18.62	20.09	19.36	19.60	20.09	19.60	19.11	13.72
237.20	17.64	17.64	16.17	17.89	17.64	17.15	17.15	17.40	17.15	19.11
241.36	15.93	15.93	15.44	16.42	16.42	16.42	15.93	16.17	16.17	14.70
245.52	15.44	15.19	14.95	15.93	15.68	15.68	15.19	15.19	15.44	15.68
249.68	15.93	16.17	16.91	16.17	15.93	17.40	16.66	15.93	16.42	16.17
253.84	16.66	16.66	16.42	16.66	16.42	16.91	16.91	16.17	16.66	17.15
258.00	15.93	15.68	15.44	15.93	15.68	15.68	15.19	15.68	15.93	13.72
262.16	15.19	14.70	13.97	15.44	15.19	14.70	22.30	14.95	14.95	11.27
266.32	13.72	13.48	12.25	13.97	13.97	12.99	12.99	13.72	13.48	12.25
270.48	13.23	13.72	17.15	13.48	13.72	17.89	13.23	13.97	15.68	23.03
274.64	26.71	27.20	35.53	22.05	23.03	31.36	28.91	24.01	28.91	27.44
278.80	32.10	26.71	26.46	28.42	25.24	24.99	32.83	26.71	26.22	13.72
282.96	23.77	21.32	19.11	21.56	20.83	19.11	20.34	21.56	20.58	12.25
287.14	19.60	17.89	16.17	18.62	18.87	16.42	16.91	18.13	17.89	12.74
291.28	17.40	16.66	15.93	17.15	17.15	16.42	15.93	16.66	16.66	14.70
295.44	18.38	19.36	23.03	17.89	18.38	22.79	18.38	18.38	20.58	22.54
299.60	25.97	26.22	28.91	23.77	23.28	29.16	27.69	24.26	26.22	21.07
303.76	26.71	24.99	24.01	25.73	23.52	24.50	26.95	24.50	24.26	17.15
307.92	22.54	21.81	20.58	21.81	21.56	21.07	21.32	21.56	21.32	15.68
312.08	19.85	19.36	18.38	19.85	20.09	19.11	19.11	19.36	19.36	15.68
316.24	18.38	17.89	17.89	18.62	18.62	18.62	17.89	18.13	18.38	16.17
320.40	18.62	19.85	22.54	18.62	19.11	23.52	19.11	18.87	20.58	24.99
324.56	29.40	30.38	35.28	27.20	26.22	35.53	32.59	25.97	29.40	22.54
328.72	28.67	26.22	24.26	27.20	24.75	24.75	26.95	24.99	24.75	15.19
332.88	22.79	21.81	19.60	22.05	21.81	20.09	20.58	21.32	20.83	18.62
337.04	19.36	18.62	16.91	19.11	19.36	17.40	17.64	18.87	18.38	13.23
341.20	17.15	16.66	16.42	17.15	17.64	17.15	16.17	17.15	17.15	N.R
345.36	25.24	29.40	29.65	22.30	24.26	28.42	26.22	25.24	25.97	28.91
349.52	28.42	31.61	29.16	28.42	27.69	29.40	29.65	29.40	27.69	20.09
353.68	25.24	26.22	22.54	25.24	25.24	23.03	24.01	25.97	23.77	16.17
357.84	21.56	22.79	19.85	21.81	23.03	20.58	20.58	22.54	20.83	15.68
362.00	19.60	20.34	17.64	20.09	20.83	18.87	18.87	20.83	19.11	14.70
366.16	17.89	19.60	18.38	18.62	17.40	19.60	17.89	19.36	18.38	20.09
370.32	20.34	25.97	25.24	21.81	23.52	28.67	23.52	22.79	24.01	21.56
374.48	24.75	26.22	24.50	25.48	24.50	25.97	24.75	25.24	24.50	17.15
378.64	21.81	22.30	20.34	22.30	22.30	21.32	21.56	22.30	21.81	15.68

	Triple Disc			Hoe			Chisel			Ambient
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	
382.80	19.36	19.85	18.38	20.09	20.58	19.36	19.11	20.34	19.36	15.19
386.96	18.13	18.38	16.91	18.62	19.11	18.13	17.89	18.62	17.89	17.15
391.12	17.64	20.58	21.32	18.62	19.36	22.05	18.38	19.60	19.85	23.52
395.28	24.01	29.40	31.61	22.79	25.73	32.34	27.69	25.97	27.20	21.56
399.44	25.97	26.95	24.26	26.71	25.24	25.48	26.46	25.97	24.99	15.68
403.60	21.81	21.81	19.85	22.30	22.05	21.07	20.83	21.81	21.56	14.21
407.76	19.11	18.62	16.66	19.60	19.85	18.13	18.38	19.11	18.38	11.76
411.92	16.17	16.42	15.44	16.91	17.40	16.42	15.68	16.66	16.42	16.17
416.08	15.44	18.62	18.62	16.66	17.15	17.64	16.42	16.91	16.91	14.21
420.24	16.42	20.58	18.87	17.40	17.64	20.34	17.64	18.13	17.89	16.66
424.40	19.60	20.09	18.13	20.34	19.85	19.36	19.85	20.09	19.36	12.74
428.56	16.91	17.15	15.93	17.64	17.89	16.91	16.66	17.89	17.40	12.74
432.72	15.68	16.17	14.95	16.66	16.91	15.93	15.68	16.42	15.93	12.25
436.88	14.70	15.68	15.68	15.44	16.17	16.42	14.95	15.68	15.68	16.17
441.04	16.66	20.83	20.58	17.40	18.87	21.07	18.38	18.38	18.62	16.17
445.20	19.11	19.11	16.66	19.60	18.62	17.64	20.58	18.13	17.40	11.27
449.36	16.42	15.68	13.48	16.66	16.42	14.46	15.93	15.68	14.70	9.80
453.52	13.97	13.23	11.27	14.21	14.21	12.01	12.74	13.48	12.74	8.33
457.68	12.01	11.27	9.56	12.50	12.50	10.54	11.27	12.01	11.03	8.82
461.84	11.03	11.52	12.50	11.52	12.01	12.74	10.54	11.76	11.52	17.64
466.00	15.44	19.11	18.87	15.68	16.42	17.89	16.91	16.17	16.17	17.64
470.16	19.11	21.56	22.05	19.60	18.87	21.32	21.32	19.11	19.36	13.72
474.32	20.83	16.66	14.95	17.64	17.15	15.19	16.91	17.15	16.17	8.33
478.48	14.95	13.48	12.25	14.70	14.21	13.48	13.48	14.21	13.72	7.84
482.64	12.74	11.52	9.80	12.74	12.99	10.78	11.27	12.50	11.76	9.31
486.80	11.52	12.25	12.74	12.01	12.50	14.95	11.27	12.25	12.25	18.62
490.96	17.15	21.56	24.26	18.13	18.13	24.01	20.34	18.13	20.09	23.52
495.12	22.54	24.26	24.26	23.77	21.56	23.52	27.20	22.30	22.30	14.21
499.28	20.34	18.87	16.66	19.11	18.13	16.91	18.38	18.87	18.13	10.29
503.44	17.15	15.68	14.21	16.66	15.93	14.46	15.19	15.93	15.68	9.80
507.60	14.70	13.23	12.50	14.46	14.46	12.74	12.99	13.97	13.48	12.25
511.76	13.48	18.13	21.56	14.21	14.95	24.01	13.48	16.17	18.38	25.97
515.92	24.99	30.14	36.02	25.73	24.99	35.04	31.12	25.24	27.93	25.97
520.08	27.69	29.16	26.46	28.91	26.46	26.71	31.36	26.46	26.46	16.66
524.24	24.26	22.79	20.83	23.52	22.30	21.07	22.54	22.05	22.05	13.23
528.40	20.83	19.11	17.15	20.34	19.85	26.71	18.38	19.11	18.62	12.25
532.56	18.13	16.66	15.44	17.89	17.89	16.17	16.17	16.91	17.15	16.17
536.72	17.15	20.83	24.50	17.89	18.62	24.26	18.13	18.62	20.83	25.48

	Triple Disc			Hoe			Chisel			Ambient
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	
540.88	24.99	29.16	32.59	25.48	25.73	32.10	30.63	25.24	27.20	24.99
545.04	28.18	25.48	23.77	27.69	24.75	23.28	28.91	24.75	24.26	13.72
549.20	23.28	20.34	18.62	21.32	20.58	18.87	19.85	20.58	20.09	12.25
553.36	19.36	17.15	15.68	18.62	18.38	16.17	16.66	17.89	17.64	11.27
557.52	16.66	15.68	15.44	16.42	16.66	16.17	14.95	16.42	16.42	19.60
561.68	19.36	24.75	34.06	20.83	21.32	30.14	23.03	21.32	24.75	29.40
565.84	30.14	34.30	36.26	31.61	28.91	37.24	37.49	29.16	30.87	24.50
570.00	28.91	27.69	24.75	28.91	25.97	25.24	28.18	26.22	25.97	15.19
574.16	24.01	21.81	19.36	23.03	22.54	20.09	21.07	22.05	21.81	12.25
578.32	20.09	18.13	16.17	19.60	19.36	17.40	17.40	18.87	18.62	12.74
582.48	17.89	17.15	18.62	17.64	18.38	19.11	16.91	17.64	18.13	21.56
586.64	23.03	32.10	40.92	23.77	25.48	37.00	27.20	24.50	29.62	26.46
590.80	30.63	33.32	31.36	32.10	28.42	33.08	34.30	28.42	29.16	17.15
594.96	25.97	25.24	22.30	25.73	24.26	23.28	23.77	24.01	23.77	13.72
599.12	21.81	20.34	17.64	21.32	21.07	17.89	19.11	20.34	20.09	12.25
603.28	18.62	18.13	15.93	18.62	18.62	16.91	16.91	17.89	17.64	13.23
	n=166	n=166	n=165	n=166	n=166	n=164	n=166	n=165	n=164	n=163
$\bar{X}$	18.85	18.88	19.01	18.69	18.57	20.91	18.85	18.58	18.69	15.68
Treatment $\bar{X}$		18.91			19.39			18.71		

(f) Range Analysis of In-groove Temperature (^{o}C), Direct Drilling

Maxima

Cumulative hrs	Mean Ambient (2 readings)	Triple Disc Rep 1	Triple Disc Rep 2	Triple Disc Rep 3	Hoe Rep 1	Hoe Rep 2	Hoe Rep 3	Chisel Rep 1	Chisel Rep 2	Chisel Rep 3
1.04	19.60	17.64	18.87	16.87	16.65	16.42	18.38	19.36	16.91	17.15
100.88	19.11	16.42	18.13	26.46	15.44	17.40	23.77	17.89	18.13	22.05
150.80	26.46	24.99	28.91	37.49	22.30	24.01	31.85	29.16	24.50	29.65
175.76	22.28	24.01	23.03	25.48	22.54	21.56	25.24	24.75	21.56	22.54
241.36	16.91	15.93	15.93	15.44	16.42	16.42	16.42	15.93	16.17	16.17
274.64	25.24	26.71	27.20	35.53	22.05	23.03	31.36	28.91	24.01	28.91
299.60	21.81	25.97	26.22	28.91	23.77	23.28	29.16	27.69	24.26	26.22
324.56	23.77	29.40	30.38	35.28	27.20	26.22	35.53	32.59	25.97	29.40
370.32	20.83	20.34	25.97	25.24	21.81	23.52	28.67	23.52	22.79	24.01
395.28	22.54	24.01	29.40	31.61	22.79	25.73	32.34	27.69	25.97	27.20
Means	21.86	22.54	24.40	28.03	21.10	21.76	27.27	24.75	22.02	24.33
Treatment means	21.86			24.99			23.34			23.70

LSD = 4.28 (5%), 7.10 (1%)

Minima

Cumulative hrs	Mean Ambient (2 readings)	Triple Disc Rep 1	Triple Disc Rep 2	Triple Disc Rep 3	Hoe Rep 1	Hoe Rep 2	Hoe Rep 3	Chisel Rep 1	Chisel Rep 2	Chisel Rep 3
84.24	9.56	13.72	12.74	11.52	13.48	13.23	12.50	12.50	12.99	12.74
88.40	9.07	12.01	11.76	10.54	12.50	12.25	11.27	11.03	11.76	11.27
92.56	10.54	11.27	10.78	10.29	11.52	11.27	10.78	10.29	11.03	10.78
113.36	10.78	16.91	15.68	13.72	16.66	16.17	14.46	14.95	15.93	14.93
117.52	9.07	14.46	13.23	11.52	14.46	14.21	12.25	12.25	13.48	12.99
138.32	10.78	18.87	17.89	15.44	18.62	18.38	16.42	16.17	17.89	17.15
142.48	10.78	15.68	14.95	12.99	15.93	15.93	14.21	13.72	15.19	14.70
453.52	9.07	13.97	13.23	11.27	14.21	14.21	12.01	12.74	13.48	12.74
457.68	8.58	12.01	11.27	9.56	12.50	12.50	10.54	11.27	12.01	11.03
474.32	11.03	20.83	16.66	14.95	17.64	17.15	15.19	16.91	17.15	16.17
Means	9.93	14.97	13.82	12.18	14.75	14.53	12.96	13.18	14.09	13.45
Treatment means	9.93			13.66			14.08			13.57

LSD = 1.81 (5%), 3.00 (1%)

	Mean Ambient	Triple Disc Rep 1	Triple Disc Rep 2	Triple Disc Rep 3	Hoe Rep 1	Hoe Rep 2	Hoe Rep 3	Chisel Rep 1	Chisel Rep 2	Chisel Rep 3
Ranges	11.93	7.57	10.58	15.85	6.35	7.23	14.31	11.57	7.93	10.88
Treatment means				11.33			9.26			10.13

LSD = 5.98 (5%), 9.91 (1%)

APPENDIX 7

(g) Penetrometer Resistance, Direct Drilled Grooves and Undisturbed Turf

Site \ Treatments	Absolute Readings - Newtons (N) Triple disc (vert)	Triple disc (oblq)	Hoe (vert)	Chisel (vert)	Undis-turbed (vert)	Comparative Readings - % Triple disc (vert)	Triple disc (oblq)	Hoe (vert)	Chisel (vert)	Undis-turbed (vert
1	6.63	4.80	5.15	6.63	6.55	101.3	73.3	78.7	101.3	100.0
2	7.33	5.24	6.20	4.98	7.51	97.7	69.8	82.6	66.6	100.0
3	8.64	5.94	6.46	4.98	6.98	123.8	85.0	92.5	71.3	100.0
4	7.24	NR	5.94	6.98	7.51	96.5	NR	79.1	93.0	100.0
5	8.03	4.28	6.20	4.98	8.03	100.0	53.3	77.2	62.0	100.0
6	7.77	5.94	6.90	6.20	7.94	97.8	74.7	86.8	78.0	100.0
$\bar{x}$	7.61	5.24	6.14	5.94	7.42	102.9	71.2	82.8	78.7	100.0

DRILL COULTER PENETRATION FORCE (N)

Triple Disc	Hoe	Chisel
774	196	89

APPENDIX 8

(a) Specification of Experiment No. 5.

Sowing date:	chisel, ski, dished disc, 22/2/71
	triple disc, hoe, angled-flat-disc, 23/2/71
Species:	"Black barley"
Germination potential:	93% (M.A.F. Seed Testing Station)
Type of Experiment:	Tillage bin study
Location:	Massey University, Agricultural Mechanisation Hall
Drill-Coulter Assemblies:	"Duncan" triple-disc
:	"Duncan" hoe with vertical pre-disc
:	experimental chisel with vertical pre-disc
:	"Clough" experimental ski
:	dished-disc
:	angled-flat-disc
Depth Control:	Ski; by design; has flat wings which slide on the ground surface
	All other coulters: no positive control. Weight versus ground resistance equilibrium
Sowing depth:	nominally 25 mm
Row spacing:	150 mm
Operating Speed:	70 m/hr
Type of drill:	Tillage bin and tool testing apparatus
Condition of parent vegetation:	short dense pasture, paspalum (*Paspalum dilatatum*) and subterranean clover (*Trifolium subterraneum*) dominant.
Condition of soil:	considerable moisture stress. Mean soil moisture content at time of drilling, approx. 14.1%
Soil type:	"Manawatu fine sandy loam"
Environmental condition at sowing:	dry under rain canopies
Environmental conditions during trial:	dry under rain canopies, all plots irrigated by sprinile from above with 10 mm water on day 7.
Herbicide, rate and application:	blanket sprayed, split application
	1st. 16/2/71 4.2 l/ha paraquat + 1.4 l/ha dicamba
	2nd. 22/2/71 4.2 l/ha paraquat + 1.4 l/ha dicamba
Harrowing and delay:	Immediate. Bar harrow section trailed by tool testing gantry.
Class of cover over seed:	Triple disc - "no cover" to grade I
	Hoe - grade III
	Chisel - grade IV
	Ski - "no cover" to grade I

	Dished disc - grade I to grade II
	Angled flat disc - grade II
Seeding rate:	nominal intra-row spacing 18 mm
Seed metering:	Hand placement of individual seeds into shank of coulter or behind disc during formation of the groove.
Fertilizer sown with seed:	Nil
Experimental Design:	randomised block. Each drill treatment was randomised within each sample bin (block). 3 replications.

APPENDIX 8

(b) Pre-drilling Soil Moisture Status of Turf Blocks

Bin No. / Reading Date	1	2	3	4	5	6	7	8
	Wet basis moisture content % mean of 3 readings per sample							
9/12/71	11.1	14.3	12.4	7.8	12.5	10.1	11.3	11.8
10/2/71	25mm water placed in tray for total uptake by bin 4							
15/2/71	5.2	5.4	6.9	7.9	4.9	5.2	4.7	5.3
16/2/71	25mm water placed in trays for 1½ hours uptake by bins 1,2,3,5,6,7,8							
	" " " " " " 30 mins " " bin 4							
17/2/71	5.1	7.1	5.7	8.6	4.7	9.6	4.9	7.7
18/2/71	25mm water placed in trays for total uptake by bins 1, 3, 5, 7, 8							
	25mm " " " " " 1½ hours " " bin 2							
	25mm " " " " " 1 hour " " bins 4,6							
19/2/71	19.9	17.8	13.6	9.5	13.6	13.9	7.2	17.7
20/2/71	12.5mm water placed in trays for total uptake by bins 4 and 7							

(c) Direct Drilled Barley, Plant Emergence Counts

All counts adjusted for decreasing seeding population through soil core harvesting: Percentage Emergence

Treatments / Reading	Triple Disc			Hoe			Chisel			Ski			Dished disc			Angled flat disc		
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3
Day 5	7.0	6.0	2.0	79.0	61.0	62.0										30.0	41.0	26.0
			$\bar{x}$=5.0			$\bar{x}$=67.3												$\bar{x}$=32.3
6							45.0	44.0	35.0	32.0	32.0	29.0	29.0	18.0	19.0			
									$\bar{x}$=41.3			$\bar{x}$=30.5			$\bar{x}$ = 22.0			
8	9.0	18.0	2.0	79.0	61.0	66.0										51.0	61.0	42.0
			$\bar{x}$=9.7a			$\bar{x}$=68.7d												$\bar{x}$ = 51.3 bcd
9							55.0	53.0	25.0	35.0	35.0	25.0	41.0	33.0	29.0			
									$\bar{x}$=44.3bc			$\bar{x}$=30.0b			$\bar{x}$=34.3ab			
12	6.0	17.0	3.0	69.0	63.0	49.0										49.0	60.0	44.0
			$\bar{x}$=8.7			$\bar{x}$ = 60.5												$\bar{x}$=51.0
13							55.0	51.0	22.0	36.0	36.0	36.0	42.0	31.0	20.0			
									$\bar{x}$=42.7			$\bar{x}$ = 36.0			$\bar{x}$ = 31.0			

All treatments appeared to have shoots removed by unknown pests

APPENDIX 8

(d) In-groove Soil Moisture Content (% Wet Basis) Direct Drilling

All Readings = mean of 3 cores from each groove

Treatment / Reading	Triple disc			Hoe			Chisel			Ski			Dished disc			Angled flat disc			Grand mean of all treatments
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	
Day 5	12.4	19.2	18.2	11.8	11.9	9.9										17.0	5.7	10.8	
			x̄=16.6a			x̄=11.2a												x̄=11.1a	11.0
6							20.1	6.2	4.8	6.6	7.5	6.3	20.2	5.8	4.4				NS
									x̄=10.3a			x̄=6.8a			x̄=10.1a				
8	18.1	22.8	17.9	12.0	18.6	12.1										14.5	18.8	16.8	
			x̄=19.6			x̄=14.2												x̄=16.7	
9							12.2	4.8	6.7	15.3	11.4	7.8	19.4	8.2	6.4				
									x̄=7.9			x̄=11.5			x̄=11.4				
12	15.1	17.1	17.4	10.4	12.3	15.1										13.4	17.0	12.6	
			x̄=16.5a			x̄=8.5a												x̄=14.3 a	12.2
13							16.7	11.0	4.0	17.6	9.9	8.0	18.3	9.3	7.7				NS
									x̄= 10.6a			x̄=11.8a			x̄=11.8a				

<u>APPENDIX 8</u>

(e) In-groove Temperature (°C), Direct Drilling

All readings = 1 diode per groove

Cumulative Time \ Treatment	Triple Disc			Hoe			Chisel			Ski			Dished disc			Angled flat disc			Ambient
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	
4.16	20.09	18.13	19.60	20.09	18.13	19.60	20.09	21.56	22.05	21.56	21.56	22.05	21.07	22.05	22.05	20.58	20.09	20.09	19.11
8.32	19.60	19.11	20.09	19.60	18.13	19.60	20.09	20.58	20.58	20.58	20.58	21.07	19.60	21.07	21.07	19.60	19.60	19.60	17.64
12.48	19.60	19.11	19.60	19.60	17.64	19.11	19.60	20.09	20.09	20.09	19.60	20.58	19.11	20.09	20.09	19.60	19.11	19.11	16.66
16.64	19.11	19.11	19.60	19.11	17.64	19.11	19.11	19.60	19.60	19.60	19.60	19.60	18.62	19.60	19.60	19.11	19.11	19.11	16.66
20.80	18.62	18.62	19.11	18.62	17.64	18.62	18.62	19.11	19.11	19.11	18.13	19.11	17.64	19.11	18.62	18.62	18.62	18.13	13.72
24.96	20.09	20.09	20.09	19.11	19.11	19.60	20.58	21.56	19.11	20.09	21.56	19.11	20.09	21.07	19.11	20.58	20.58	20.09	19.11
29.12	19.60	18.13	19.60	20.09	18.13	19.11	18.62	20.09	20.09	19.60	19.60	20.58	18.62	21.07	21.56	20.09	18.62	18.62	16.66
33.28	18.62	17.64	18.62	19.11	17.64	18.62	18.13	18.13	18.62	18.62	18.13	18.62	17.15	19.60	18.62	18.62	18.13	18.13	14.70
37.44	17.64	17.15	18.13	18.13	17.15	17.64	17.15	17.64	16.64	18.13	17.64	17.64	16.66	18.13	17.64	17.64	17.15	17.15	13.72
41.60	17.15	17.15	18.13	17.15	17.15	17.15	17.64	17.15	16.66	17.15	17.15	16.66	15.68	17.15	16.66	16.66	17.64	17.15	13.23
45.76	19.60	20.09	20.09	19.11	20.09	19.60	20.09	21.56	18.62	20.09	21.07	18.13	20.58	20.09	18.62	19.60	20.58	19.60	17.64
49.92	20.09	20.58	21.56	20.58	21.07	21.07	21.07	21.07	20.09	20.09	21.56	20.09	19.11	21.07	20.58	20.58	21.56	22.05	17.64
54.08	19.60	18.13	19.11	20.58	18.62	19.11	18.62	19.60	20.09	19.11	19.11	20.09	18.13	21.07	20.58	19.60	18.62	19.11	15.19
58.24	18.13	17.64	18.62	18.62	17.15	18.13	17.15	17.64	18.13	18.13	17.64	18.62	17.15	18.62	18.13	18.13	17.64	17.64	12.74
62.40	17.15	16.17	17.15	17.15	16.17	16.66	16.17	16.66	16.66	17.15	16.66	17.15	15.68	17.15	16.66	16.66	16.17	16.17	13.23
66.56	19.66	16.66	17.15	16.66	16.66	16.17	18.13	16.66	16.17	16.66	16.66	16.17	15.68	16.66	15.68	16.66	16.66	16.17	13.72
70.72	22.05	22.54	21.07	21.56	22.54	21.07	25.48	25.48	23.03	22.05	25.48	21.07	21.07	23.03	21.07	23.52	22.05	22.54	22.05
74.88	24.01	21.56	22.05	24.01	22.05	22.05	22.05	26.95	26.95	24.50	25.97	26.95	23.52	25.97	27.93	25.48	22.54	24.01	21.56
79.04	20.58	19.11	19.60	20.58	19.11	19.11	19.11	20.09	21.07	20.09	19.60	21.56	18.62	22.05	21.56	20.58	19.11	20.09	14.21
83.20	18.62	17.64	18.13	18.62	17.15	17.64	17.15	18.13	18.62	18.62	18.13	19.60	17.15	18.62	18.62	18.62	17.64	17.64	11.27
87.36	16.66	16.17	16.66	16.66	15.19	16.17	15.68	16.17	16.66	17.15	16.17	17.15	15.19	16.66	16.17	16.66	16.17	15.68	9.80
91.52	15.68	19.60	18.62	15.68	19.60	17.15	21.07	17.64	15.68	16.17	18.13	15.68	15.19	17.15	14.70	15.68	18.13	18.13	14.70

Cumulative Time	Triple Disc Rep 1	Rep 2	Rep 3	Hoe Rep 1	Rep 2	Rep 3	Chisel Rep 1	Rep 2	Rep 3	Ski Rep 1	Rep 2	Rep 3	Dished Disc Rep 1	Rep 2	Rep 3	Angled flat disc Rep 1	Rep 2	Rep 3	Ambient
95.68	23.03	25.97	24.01	22.05	24.50	22.54	27.93	25.97	24.01	23.52	25.97	23.03	24.01	24.50	23.52	23.03	26.95	25.97	22.05
99.84	24.99	22.05	23.03	24.99	23.03	24.01	22.05	27.44	26.46	24.50	25.48	27.93	24.50	26.95	30.38	26.46	23.03	21.50	21.56
104.00	20.58	19.60	20.58	21.56	19.60	20.09	19.11	20.09	21.56	20.09	19.60	22.54	19.11	22.05	21.56	21.07	19.60	20.58	13.23
108,16	18.62	17.64	18.62	18.62	17.15	18.13	17.15	18.13	18.62	18.62	18.13	19.60	16.66	18.62	18.13	18.13	17.64	17.64	11.76
112.32	16.66	16.17	17.15	16.66	15.68	16.17	16.17	16.17	16.66	17.15	16.17	17.15	15.19	16.66	16.17	16.17	16.17	15.68	11.27
116.48	18.13	22.05	21.07	16.66	23.03	18.62	24.50	19.60	16.17	18.62	21.07	16.66	19.60	19.60	16.17	18.13	22.05	21.07	17.64
120.64	28.42	26.46	26.46	25.97	26.46	25.97	27.93	28.91	29.89	26.95	31.36	27.93	27.93	28.42	29.40	26.95	28.91	28.91	25.97
124.80	20.50	21.56	23.03	24.99	22.05	23.03	22.05	24.50	26.46	24.01	23.52	27.44	23.52	25.97	27.93	24.99	22.54	24.01	17.64
128.96	21.07	19.60	21.07	21.07	19.60	20.09	19.60	20.58	21.56	20.58	20.58	22.54	19.11	21.56	21.56	21.07	20.09	20.58	14.70
133.12	19.11	18.13	19.11	19.11	17.64	18.62	18.13	19.11	19.11	19.11	19.11	20.09	17.64	19.60	18.62	19.11	18.62	18.62	14.21
137.28	17.64	18.13	18.62	17.64	17.64	17.64	19.11	18.13	17.64	18.13	18.13	18.62	16.66	18.13	17.64	17.64	18.62	17.64	13.72
141.44	20.58	22.05	21.07	20.09	22.54	20.58	24.50	22.54	20.58	20.58	22.54	20.09	20.58	21.56	20.58	20.58	22.54	21.07	19.11
145.60	26.95	23.52	24.99	24.99	24.01	24.01	24.01	27.93	28.52	24.99	27.93	26.95	25.48	26.95	29.40	26.95	24.50	25.48	24.01
149.76	22.54	20.58	22.54	23.52	21.56	22.05	21.07	23.03	23.52	22.05	22.05	24.01	21.56	24.50	24.99	23.52	21.56	22.54	17.64
153.92	21.07	20.09	21.07	21.07	19.60	20.58	19.60	21.07	21.07	21.07	20.58	21.56	20.09	21.56	21.07	21.56	20.09	20.09	15.68
158.08	19.60	18.13	19.60	19.60	18.13	18.62	18.13	19.11	19.11	19.60	19.11	19.60	18.13	19.60	19.11	19.60	18.62	18.62	14.70
162.24	23.03	18.13	19.11	23.03	18.13	18.13	19.60	18.62	22.54	23.52	18.62	23.03	22.54	18.62	22.54	23.03	18.62	18.13	16.17
166.40	21.56	21.07	22.05	21.07	21.56	21.56	22.54	23.52	22.54	21.56	23.52	21.55	21.56	22.54	22.54	22.05	22.05	21.56	21.07
170.56	23.03	21.07	23.03	22.54	22.05	22.54	21.56	24.99	23.03	22.05	24.01	22.54	22.05	24.01	24.01	23.52	22.54	23.03	21.56
174.72	21.07	19.60	21.07	21.56	20.09	20.58	20.58	21.56	21.56	21.07	21.07	21.56	20.58	22.05	22.54	21.56	20.58	21.07	17.15
178.88	20.09	18.62	19.60	20.09	18.13	18.62	18.62	19.60	20.09	20.09	19.11	20.58	18.62	20.58	20.58	20.58	18.62	18.62	14.21
183.04	17.64	17.15	18.13	18.13	16.66	17.15	16.66	17.64	17.64	18.13	17.64	18.13	16.66	18.13	17.64	18.13	16.66	17.64	12.74
187.20	16.66	17.15	17.15	16.66	16.66	16.17	18.62	17.15	16.66	17.15	17.64	16.66	15.68	17.15	15.68	16.66	17.15	16.66	12.25
191.36	20.58	19.11	19.60	18.62	19.60	18.62	21.07	21.07	20.09	20.58	22.54	19.60	20.09	21.07	20.09	20.09	19.60	19.60	16.66

	Triple Disc			Hoe			Chisel			Ski			Dished disc			Angled Flat Disc			Ambient
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	
195.52	19.60	18.13	18.62	19.60	18.13	18.13	18.13	19.60	20.58	19.60	19.60	21.07	18.62	20.58	21.56	19.60	18.13	19.11	15.19
199.68	17.15	16.66	17.15	17.64	16.17	16.66	16.17	17.15	17.64	17.64	17.15	18.13	16.17	17.64	17.15	17.64	16.66	16.66	12.74
203.84	15.68	15.68	15.68	16.17	15.19	15.19	15.19	15.68	15.68	16.17	15.68	16.17	14.70	16.17	15.68	16.17	15.19	15.19	11.76
208.00	15.19	15.19	15.68	15.19	14.21	14.70	15.19	15.19	14.70	15.68	15.19	15.19	14.21	15.19	14.70	15.19	14.70	14.70	11.76
212.16	16.17	19.11	18.13	15.68	19.60	16.17	21.07	17.64	15.68	16.17	18.62	15.68	15.68	17.15	15.19	16.17	18.13	18.13	15.19
216.32	27.93	24.50	23.03	27.44	23.52	21.56	24.50	26.46	26.95	24.50	28.42	25.48	25.48	25.48	27.44	25.97	24.99	25.97	23.52
220.48	22.54	19.11	20.09	22.05	20.09	19.60	19.60	22.54	24.01	21.56	21.07	24.99	20.58	23.52	25.48	23.03	19.60	21.07	15.19
224.64	19.60	18.13	19.11	19.60	18.62	19.11	18.13	20.58	20.09	19.60	20.58	20.09	19.11	20.58	21.56	19.60	18.62	19.60	17.15
228.80	18.13	17.15	17.64	18.13	17.15	17.15	16.66	18.13	18.13	17.64	17.64	18.13	17.15	18.62	18.13	18.13	17.15	17.64	13.72
232.96	16.17	15.68	16.17	16.66	15.19	15.68	15.19	15.68	16.17	16.66	15.68	16.66	15.19	16.66	16.17	16.66	15.68	15.68	10.78
237.12	14.70	14.70	15.19	15.19	14.21	14.21	14.70	14.70	14.70	15.19	14.70	15.19	13.72	15.19	14.21	15.19	14.21	14.21	12.25
241.28	15.19	19.11	19.11	15.19	19.60	16.66	21.56	17.15	14.70	15.68	19.11	14.70	15.19	17.15	14.21	15.19	19.11	19.60	15.19
245.44	23.03	24.50	24.01	21.56	24.50	23.03	25.48	25.97	25.48	23.03	28.42	24.99	23.52	25.48	26.95	21.07	25.48	26.95	25.48
249.60	23.52	20.58	21.56	23.52	21.56	22.05	21.07	22.05	24.99	22.54	22.54	25.48	22.54	25.48	27.44	24.01	21.07	23.03	19.60
253.76	20.09	18.62	19.60	20.09	18.62	19.11	18.62	19.60	20.09	19.60	19.11	21.56	18.62	21.07	20.09	20.58	18.62	19.60	13.23
257.92	17.64	17.15	17.64	17.64	16.17	16.66	16.17	17.15	17.15	18.13	16.66	18.62	16.17	17.64	17.15	17.64	16.66	16.66	9.80
262.08	15.19	15.68	16.17	15.68	14.70	14.70	15.68	15.19	15.19	16.17	15.19	15.68	14.21	15.68	14.70	15.68	15.68	14.70	8.82
266.24	22.05	24.99	22.54	19.60	28.42	23.52	27.44	28.91	21.07	21.07	28.91	18.13	20.09	23.03	19.11	19.60	27.44	23.52	20.58
270.40	31.36	26.46	27.93	26.95	29.40	29.40	27.93	35.28	34.30	28.42	32.34	31.36	28.91	29.89	35.28	26.95	28.91	33.32	28.91
274.56	25.48	22.54	24.01	26.46	23.52	24.50	23.03	25.97	26.95	24.50	24.01	27.44	24.01	27.93	28.91	26.46	23.03	25.48	17.15
278.72	22.05	20.58	21.56	22.05	20.09	21.07	20.09	21.56	22.05	22.05	21.07	23.52	20.58	22.05	22.05	22.54	20.58	21.56	13.23
282.88	19.60	18.62	19.60	19.11	17.64	18.13	18.13	18.62	18.62	19.60	18.62	20.09	18.13	19.60	18.62	19.11	18.13	18.13	10.78
287.04	17.64	18.13	18.13	17.15	17.64	17.15	19.60	17.64	16.66	18.13	17.64	17.64	16.17	17.64	16.17	17.15	17.64	17.15	12.74
291.20	25.97	28.42	25.97	24.50	30.87	27.44	29.40	32.34	26.95	25.48	32.34	24.50	25.97	27.93	24.99	24.01	30.38	28.42	25.97
295.36	28.91	25.97	26.95	27.93	27.44	27.93	25.97	33.32	32.34	28.42	32.34	31.85	29.40	31.36	35.77	28.91	26.95	30.88	26.95

	Triple Disc			Hoe			Chisel			Ski			Dished Disc			Angled Flat Disc			Ambient
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	
299.52	24.01	25.54	23.52	24.96	22.54	23.03	22.54	24.01	24.99	24.01	23.03	25.48	24.01	25.97	25.48	24.99	22.54	24.01	17.15
303.68	22.05	21.07	21.56	21.56	20.09	20.58	20.58	21.56	21.56	22.05	21.56	22.54	20.58	22.05	21.56	22.05	20.58	21.07	15.19
307.84	19.60	19.11	19.60	19.60	18.13	18.62	18.62	19.11	19.11	20.09	19.11	20.09	18.62	19.60	19.11	19.60	18.62	18.62	14.70
312.00	18.62	20.09	19.11	18.13	20.58	18.13	21.56	19.11	17.64	19.11	19.11	18.62	17.64	19.11	18.13	18.13	19.11	18.62	16.17
316.16	25.48	24.50	23.52	22.54	24.50	23.52	26.46	26.95	24.50	24.99	26.95	24.01	24.50	25.48	24.50	22.05	25.48	25.97	24.01
320.32	24.99	21.56	23.03	24.01	22.05	22.54	22.05	25.48	26.46	24.50	24.50	27.93	24.01	25.48	29.40	24.01	22.05	24.01	19.11
324.48	20.58	19.60	20.09	20.58	19.11	19.60	19.60	20.09	20.58	20.58	20.09	22.05	20.09	21.07	20.58	21.07	19.60	20.09	14.70
328.64	18.62	18.13	18.62	18.13	17.15	17.64	17.64	18.13	18.13	19.11	18.13	19.11	18.13	18.62	18.13	18.62	17.64	17.64	13.23
332.80	17.15	16.66	17.15	16.66	15.68	16.17	16.66	16.66	16.66	17.64	16.66	17.15	16.66	17.15	16.17	17.15	16.17	16.17	12.74
336.96	17.64	20.09	19.11	16.66	20.58	17.64	22.05	18.62	16.66	17.64	20.58	16.66	17.15	18.62	16.17	16.66	20.09	19.11	16.17
341.12	24.50	23.52	23.03	22.54	23.52	22.54	23.52	25.97	26.46	24.01	26.95	25.48	24.01	24.99	25.97	21.07	24.99	25.97	22.05
345.28	21.56	19.60	20.09	21.07	19.60	19.60	19.60	21.56	22.54	21.56	23.03	23.52	21.07	22.54	23.52	21.07	19.60	20.58	15.19
349.44	18.62	18.13	18.62	18.13	17.15	17.64	18.13	18.62	18.62	19.11	18.62	19.60	18.13	19.11	18.62	18.62	18.13	18.13	13.72
353.60	17.64	17.15	17.64	17.15	16.17	16.66	17.15	17.64	17.15	18.13	17.64	18.13	16.66	17.64	17.15	17.15	16.66	16.66	14.21
357.76	16.66	17.15	17.15	16.17	16.17	16.66	17.15	17.15	16.17	17.15	17.15	16.66	15.68	17.15	16.17	16.66	17.15	16.66	14.70
	n=86	n=86	n=86	n=86	n=86	n=86	n=86	n=86	n=86	n=86	n=86	n=86	n=86	n=86	n=86	n=86	n=86	n=86	n=86
$\bar{x}$ =	20.28	19.61	20.08	19.99	19.35	19.29	20.11	20.86	20.56	20.26	20.82	20.76	19.41	20.93	20.77	19.94	19.93	20.17	16.30

$\bar{X}$=19.99 $\bar{X}$=19.54 $\bar{X}$=20.51 $\bar{X}$=20.61 $\bar{X}$=20.37 $\bar{X}$=20.01

(f) Range analysis of in-groove temperature (^{o}C), Direct Drilling

Hours	Mean Ambient (2 readings)	Triple Disc			Hoe			Chisel			Ski			Dished disc			Angled flat disc		
		Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3
Maximum																			
8.32	18.38	19.60	19.11	20.09	19.60	18.13	19.60	20.09	20.58	20.58	20.58	20.58	21.07	19.60	21.07	21.07	19.60	19.60	19.60
74.88	21.81	24.01	21.56	22.05	24.01	22.05	22.05	22.05	26.95	26.95	24.50	25.97	26.95	23.52	25.97	27.93	25.48	22.54	24.01
99.84	21.81	24.99	22.05	23.03	24.99	23.03	24.01	22.05	27.44	26.46	24.50	25.48	27.93	24.50	26.95	30.38	26.46	23.03	24.50
145.60	21.56	26.95	23.52	24.99	24.99	24.01	24.01	24.01	27.93	28.52	24.99	27.93	26.95	25.48	26.95	29.46	26.95	24.50	25.48
170.56	21.32	23.03	21.07	23.03	22.54	22.05	22.54	21.56	24.99	23.03	22.05	24.01	22.54	22.05	24.01	24.01	23.52	22.54	23.03
295.36	26.46	28.91	25.97	26.95	27.93	27.44	27.93	25.97	33.32	32.34	28.42	32.34	31.85	29.40	31.36	35.77	28.91	26.95	30.38
320.32	21.56	24.99	21.56	23.03	24.01	22.05	22.54	22.05	25.48	26.46	24.50	24.50	27.93	24.01	25.48	29.40	24.01	22.05	24.01
Means	21.84	24.64	22.12	23.31	24.01	22.68	23.24	22.54	26.67	26.33	24.22	25.97	26.46	24.08	25.97	28.29	24.99	23.03	24.43
Treatment Means	21.84			23.36a			23.31a			25.18a			25.55a			26.11a			24.15a
Minimum																			
87.36	10.54	16.66	16.17	16.66	16.66	15.19	16.17	15.68	16.17	16.66	17.15	16.17	17.15	15.19	16.66	16.17	16.66	16.17	15.68
112.32	11.52	16.66	16.17	17.15	16.66	15.68	16.17	16.17	16.17	16.66	17.15	16.17	17.15	15.19	16.66	16.17	16.17	16.17	15.68
208.00	11.76	15.19	15.19	15.68	15.19	14.21	14.70	15.19	15.19	14.70	15.68	15.19	15.19	14.21	15.19	14.70	15.19	14.70	14.70
237.12	11.52	14.70	14.70	15.19	15.19	14.21	14.21	14.70	14.70	14.70	15.19	14.70	15.19	13.72	15.19	14.21	15.19	14.21	14.21
257.92	11.52	17.64	17.15	17.64	17.64	16.17	16.66	16.17	17.15	17.15	18.13	16.66	18.62	16.17	17.64	17.15	17.64	16.66	16.66
262.08	9.31	15.19	15.68	16.17	15.68	14.70	14.70	15.68	15.19	15.19	16.17	15.19	15.68	14.21	15.68	14.70	15.68	15.68	14.70
287.04	11.76	17.64	18.13	18.13	17.15	17.64	17.15	19.60	17.64	16.66	18.13	17.64	17.64	16.17	17.64	16.17	17.15	17.64	17.15
Means	11.13	16.24	16.17	16.66	16.31	15.40	15.68	16.17	16.03	15.95	16.80	15.96	16.66	14.98	16.38	15.61	16.24	15.89	15.54
Treatment Mean	11.13			16.36a			15.80a			16.05a			16.47a			15.66a			15.89a
Range	10.71	8.4	5.95	6.65	7.70	7.22	7.56	6.37	10.64	10.37	7.42	10.01	9.80	9.10	9.59	12.68	8.75	7.14	8.89
Mean	10.71			7.0a			7.49a			9.13a			9.08a			10.46a			8.26a

APPENDIX 9

(a) Specification of Experiment No. 6

Sowing date	9/8/72
Species	"Kopara" wheat
Germination potential	96% (M.A.F. Seed Testing Station)
Type of Experiment	Tillage bin study
Location	Massey University, Agricultural Mechanisation Hall
Drill-coulter Assemblies	"Duncan" triple-disc; "Duncan" hoe with vertical pre-disc; Experimental chisel with vertical pre-disc.
Depth Control	Depth restricting wheels on either side of pre-disc.
Sowing depth	Nominally 38 mm.
Row spacing	150 mm
Operating speed	60 m/hr
Type of drill	Tillage bin and tool testing apparatus
Condition of parent vegetation	Short dense pasture Ruanui Ryegrass (*Lolium perenne*) dominant.
Condition of soil	Considerable moisture stress
Soil type	"Manawatu fine sandy loam"
Environmental conditions at sowing	Dry, under rain canopies
Environmental Conditions during trial	Dry, under rain canopies. Half of all plots irrigated on day 22.
Irrigation	12.5 mm water sprinkled in 3 applications of 4.2 mm each. Applied, day 22.
Herbicide, rate and application	Blanket sprayed, single application 5.6 l/ha paraquat + 1.4 l/ha dicamba. 8/8/72.
Harrowing and delay	Immediate. Bar harrow section trailed by tool testing gantry at 180 m/hr.
Class and cover over seed	Triple disc, grade II Hoe grade II Chisel grade IV No seed was visible after covering in any treatment.

Seeding rate — Nominal intra-row spacing 19 mm

Seed metering — Modified vacuum seeder operating at 571.5 mm mercury. During drilling seed number per drilled row recorded.

Number of seeds sown per row

		Rep 1	Rep 2	Rep 3
Triple disc	LHS	100	93	91
	Mid	91	96	100
	RHS	100	99	98
Hoe	LHS	95	90	86
	Mid	100	96	89
	RHS	104	100	88
Chisel	LHS	94	88	94
	Mid	99	102	94
	RHS	92	91	98

Fertilizer sown with seed — Nil

Experimental design — Randomised block. Each bin represented a treatment plot randomised within one of 3 blocks.
Irrigation treatments = randomised plot.
3 replications

APPENDIX 9 (b)

Seedling Emergence % Direct Drilled Wheat

Time \ Treatment		Triple Disc				Hoe				Chisel			
		Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean
Day	8	0.7	1.0	0.4	0.7	0.0	0.0	0.00	0.00	0.0	0.0	0.0	0.00
	10	3.7	4.4	8.3	5.5	0.4	4.9	1.4	2.2	0.0	1.0	2.5	1.2
	12	16.4	3.1	22.7	14.0	8.4	8.4	8.0	8.3	27.6	31.9	37.8	32.4
	13	20.6	6.2	22.4	16.4	4.5	11.4	8.5	8.1	38.3	33.4	45.8	39.2
	14	22.2	9.4	26.2	19.3	5.8	17.8	12.2	11.9	42.8	48.8	55.1	48.9
	15	20.2	9.0	32.9	20.7	12.7	26.6	12.9	17.4	62.3	65.4	63.9	63.9
	16	18.9	12.6	35.7	22.4	18.1	33.9	14.3	22.1	71.5	71.4	70.7	71.2
	17	24.3	14.4	35.0	24.6	26.6	41.1	15.0	27.6	71.9	79.8	73.8	77.1
	19	25.0	9.4	34.6	23.4	16.9	21.7	17.1	18.6	73.2	58.2	73.8	68.4
	22	29.0	13.9	33.6	25.5	20.6	33.9	15.8	23.4	76.4	67.9	75.9	73.4

Absolute Maxima

Triple Disc				Hoe				Chisel				L.S.D.
Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean	
29.0	14.4	35.7	26.4 (15.34)	26.6	41.1	17.1	28.3 (16.52)	77.9	79.8	75.9	77.9 (51.15)	(15.61) (25.89)

APPENDIX 9 (c)

Seed fate counts - direct drilled wheat

Fate of seed / Treatment		All counts = mean of 3 separate samples per plot				
		% Ungerminated	% Germinated but failed to emerge	% Abnormal	% Emerged	Increase
TRIPLE	Rep 1	7.2	53.7	0.0	39.1	
DISC	Rep 2	8.5	70.9	6.1	14.5	
("DRY"	Rep 3	43.1	43.4	0.0	13.5	
END)	Mean	18.8	56.0	0.3	20.2	20.2
TRIPLE	Rep 1	6.1	13.3	0.0	80.7	
DISC	Rep 2	2.8	23.4	5.6	68.2	
("WET"	Rep 3	4.8	13.7	4.4	76.6	
END)	Mean	4.6	16.8	3.3	75.2	75.2
						+55.0
HOE	Rep 1	10.0	71.0	2.4	16.7	
("DRY"	Rep 2	3.0	40.3	0.0	57.0	
END)	Rep 3	38.5	18.1	2.2	41.2	
	Mean	17.2	43.1	1.5	38.3	38.3
HOE	Rep 1	2.8	18.6	4.8	76.7	
("WET"	Rep 2	0.0	0.0	0.0	100.0	
END)	Rep 3	0.0	0.0	0.0	100.0	
	Mean	0.9	6.2	1.6	92.2	92.2
						+53.9
CHISEL	Rep 1	4.8	25.9	9.1	62.8	
("DRY"	Rep 2	0.0	17.2	2.4	80.4	
END)	Rep 3	2.8	7.5	0.0	89.7	
	Mean	2.5	16.9	3.8	77.6	77.6
CHISEL	Rep 1	1.5	5.8	2.6	90.1	
("WET"	Rep 2	4.5	9.7	9.3	76.5	
END)	Rep 3	2.2	4.4	2.2	91.1	
	Mean	2.7	6.6	4.7	85.9	85.9
						+ 8.3

APPENDIX 9 (d)

Direct drilling, in-groove and undisturbed matric potential (bars)

All treatment readings = mean of 3 psychrometers in 3 grooves per treatment replicate

All undisturbed readings = 1 psychrometer per treatment replicate

Treatment / Time	TRIPLE DISC								HOE							
	In-groove				Undisturbed				In-groove				Undisturbed			
	Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean
2	-7.20	-3.61	-2.51	-4.44	-1.79	-0.89	-1.74	-1.47	-8.70	-6.91	-11.14	-8.95	-8.71	-11.82	-5.82	-8.78
4	-7.76	-4.80	-3.20	-5.25	-2.01	-2.64	-5.36	-3.34	-12.62	-6.64	-16.87	-12.04	-8.13	- 9.32	-7.30	-8.25
6	-7.22	-6.25	-3.57	-5.68	-3.22	-7.83	-4.11	-5.05	-7.68	-7.07	-7.44	-7.40	-9.43	-8.06	-8.44	-8.64
8	-9.19	-9.55	-2.99	-7.24	-6.76	-10.13	-7.04	-7.98	-16.06	-15.74	-7.55	-13.12	-11.48	-13.18	-9.62	-11.43
10	-8.80	-9.79	-3.53	-7.38	-4.04	-19.08	-6.01	-9.71	-19.81	-5.57	-5.43	-10.27	-16.09	-10.89	-9.15	-12.04
12	-18.03	-16.57	-3.36	-12.65	-4.01	+1.66	-7.14	-3.16	-6.03	-8.49	-4.47	-6.33	-30.73	-19.79	-9.92	-20.15
13	-6.83	-14.36	-4.61	-8.60	-8.77	-0.90	-7.54	-5.74	-6.72	-10.25	-4.09	-7.02	-43.83	-20.89	-10.81	-25.18
14	-10.01	-13.19	-5.89	-9.70	-7.37	-0.53	-4.75	-4.22	-9.52	-6.76	-5.65	-7.33	-1.37	-28.25	-12.53	-14.05
15	-12.06	-12.31	-5.99	-10.12	-18.08	-0.74	-9.74	-9.52	-0.48	-11.01	-4.47	-5.32	-0.09	-32.22	-9.03	-13.72
16	-14.93	-6.41	-6.93	-9.42	-23.88	-0.05	-13.52	-12.48	-1.05	-9.49	-4.57	-4.33	-3.04	-14.37	-9.11	-6.81
17	-14.09	-7.60	-11.24	-10.98	-28.24	+1.27	-18.63	-15.20	-0.39	-10.22	-3.89	-4.57	-0.11	-36.71	-10.82	-15.80
19	-7.39	-3.38	-10.18	-6.98	-31.05	-1.63	-20.30	-17.66	-2.46	-6.94	-5.16	-3.21	-2.32	-0.57	-8.49	-1.86

CHISEL

In-groove				Undisturbed			
Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean
-8.33	-5.98	-4.61	-6.31	-5.66	-5.66	-6.01	-5.18
-7.14	-4.92	-2.38	-4.82	-4.76	-4.42	-3.71	-4.30
-7.68	-3.66	-2.64	-4.66	-2.79	-6.69	-4.82	-4.77
-7.10	-3.68	-2.56	-4.45	-4.11	-9.71	-6.47	-6.77
-4.49	-4.82	-7.10	-5.47	-3.81	-6.60	-12.37	-7.59
-5.26	-3.44	-0.74	-3.15	-4.93	-18.69	-6.71	-10.11
-5.04	-2.86	-1.54	-3.15	-6.27	-23.51	-17.87	-15.88
-8.01	-4.84	-0.51	-4.45	-6.71	-27.80	-0.00	-11.50
-7.22	-1.84	-1.23	-3.43	-8.69	-9.13	-1.63	-6.48
-14.57	-9.29	-1.78	-8.54	-9.74	-5.85	-1.15	-5.58
-8.59	-4.06	-0.52	-4.39	-11.71	-11.61	-0.69	-8.00
-10.34	-5.40	-1.93	-5.89	-14.46	-0.87	-1.21	-4.93

APPENDIX 9 (e)

Between direct drilled rows, soil moisture data (day 36)

Treatment \ Reading		Per cent (wet basis)
Triple Disc	Rep 1	6.6
	Rep 2	5.7
	Rep 3	6.0
	Mean	6.1
Hoe	Rep 1	5.4
	Rep 2	5.3
	Rep 3	5.0
	Mean	5.2
Chisel	Rep 1	6.0
	Rep 2	9.2
	Rep 3	6.3
	Mean	7.2

APPENDIX 9 (f)

In-Groove and Undisturbed Soil Temperature (°C), Direct Drilling

All treatment readings = mean of 3 diodes in 3 grooves per treatment replicate

All undisturbed readings = 1 diode per treatment replicate

Treatment / Time	TRIPLE DISC						HOE						CHISEL						
	In-Groove			Undisturbed			In-Groove			Undisturbed			In-Groove			Undisturbed			
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	LSD
Day 2	5.45	5.37	5.96	5.54	5.54	6.04	5.70	5.45	5.45	6.04	5.28	5.54	5.87	5.96	6.63	6.04	6.04	6.29	
4	7.38	7.30	6.88	7.55	7.30	7.05	8.48	6.54	6.12	8.31	6.54	6.29	7.38	7.13	7.38	7.80	7.55	7.05	
6	14.19	14.69	13.60	14.86	14.10	12.84	15.36	14.35	15.44	13.85	14.35	14.10	13.26	13.51	12.76	13.35	13.85	14.10	
8	13.26	13.01	10.66	13.60	12.84	10.32	14.94	10.15	10.32	13.35	10.07	10.07	12.34	12.84	10.41	12.84	13.09	11.08	
10	6.04	6.46	6.04	6.29	6.54	6.29	6.71	6.38	5.62	7.05	6.04	6.04	6.21	6.46	5.79	6.54	7.05	5.79	
12	17.46	18.38	17.38	17.38	16.37	16.62	13.85	16.70	19.56	13.60	16.62	18.13	15.86	16.37	13.43	15.11	16.62	16.12	
13	13.26	14.69	15.28	13.09	14.10	15.11	10.91	15.70	17.12	11.33	15.86	16.37	11.92	15.11	15.28	11.83	15.11	16.62	
14	18.55	22.41	16.45	17.88	18.64	16.12	17.21	19.64	20.90	16.62	18.64	18.13	17.21	17.71	15.03	16.12	19.14	16.87	
15	14.10	15.19	14.69	14.10	14.35	13.85	13.93	15.03	16.96	13.60	14.86	15.86	13.77	14.02	14.86	13.35	13.85	16.87	
16	14.35	16.54	14.10	14.35	15.36	13.60	14.35	15.70	16.45	13.85	15.36	15.61	14.02	14.19	13.93	13.85	14.86	15.36	
17	15.53	16.20	15.44	15.86	15.86	14.61	14.94	16.12	16.70	14.61	15.86	15.61	15.11	14.52	14.94	14.86	15.11	16.12	
19	15.95	19.90	15.03	14.61	16.87	14.35	15.53	15.86	16.28	15.11	15.36	14.86	14.61	13.85	13.09	14.10	14.86	15.11	
Means	12.96	14.17	12.62	12.92	13.15	12.23	12.65	13.13	13.91	12.27	12.90	13.05	12.29	12.63	11.96	12.14	13.09	13.07	
Treatment mean		13.25			12.76			13.23			12.74			12.29			12.76		
Day 14	18.55	22.41	16.45	17.88	18.64	16.62	17.21	19.64	20.90	16.62	18.64	18.13	17.21	17.71	15.03	16.12	19.14	16.87	
Treatment mean (ingroove) max		19.13						19.25						16.55					4.83
																			8.01

APPENDIX 9(f) contd

	TRIPLE DISC						HOE						CHISEL						
	In-Groove			Undisturbed			In-Groove			Undisturbed			In-Groove			Undisturbed			
	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	LSD
Treatment mean (undisturbed) max					17.55						17.80						17.38		2.27 3.57
Day 2	5.45	5.37	5.96	5.54	5.54	6.04	5.70	5.45	5.45	6.04	5.28	5.54	5.87	5.96	6.63	6.04	6.04	6.29	
Treatment mean (in groove) min		5.59						5.53*						6.15*					0.61 1.02
Treatment mean (undisturbed) min					5.71						5.62						6.12		0.63 1.05
Range	13.10	17.04	10.49	12.34	13.10	10.08	11.51	14.19	15.45	10.58	13.36	12.59	11.34	11.75	8.40	10.08	13.10	10.58	
Mean (in groove)		13.54						13.72						10.50					5.31 8.91
Mean (undisturbed)					11.84						12.18						11.25		2.56 4.25

APPENDIX 10

(a) Specification of Experiment No. 7

Sowing date	1/11/72
Species	"Kopara" wheat
Germination potential	96% (M.A.F. Seed Testing Station)
Type of Experiment	Tillage bin study
Location	Massey University, Agricultural Mechanisation Hall
Drill-coulter Assemblies	"Duncan" triple-disc "Duncan" hoe with vertical pre-disc Experimental chisel with vertical pre-disc
Depth Control	Depth restricting wheels on either side of pre-disc
Sowing depth	Nominally 38mm
Row spacing	150mm
Operating speed	90m/h
Type of drill	Tillage bin and tool testing apparatus
Conditions of parent vegetation	Short dense pasture. Ruanui ryegrass (*Lolium perenne*) dominant
Condition of soil	Considerable moisture stress
Soil Type	"Manawatu fine sandy loam"
Environmental condition at sowing	Dry, under rain canopies
Environmental conditions during trial	Dry under rain canopies (no irrigation)
Herbicide, rate and application	Blanket sprayed, single application 5.6 l/ha paraquat + 1.4 l/ha dicamba 1/11/72.
Harrowing and delay	Immediate. Bar harrow section trailed by tool testing gantry at 180m/h
Class and cover over seed	Triple-disc, grade II Hoe - , grade III Chisel - , grade III for two rows (excluded from results) grade IV for main body of trial
Seeding rate	Nominal intra-row spacing 19mm
Seed metering	Modified vacuum seeder operating at 571.5mm mercury. During drilling, seed number per drilled row was recorded.

Number of seeds sown per whole row		Rep 1	Rep 2	Rep 3
Triple-disc	LHS	50,51	51,53	44,45
	MID	50,50	42,49	51,52
	RHS	50,53	51,52	54,44

		Rep 1	Rep 2	Rep 3
Hoe	LHS	39, 56	51, 50	47,41
	MID	51, 52	52, 50	54, 49
	RHS	51, 43	51, 47	50, 49
Chisel	LHS	53, 51	42, 40	47, 49
	MID	57, 50	55, 49	55, 50
	RHS	53, 50	52, 46	50, 50

Fertilizer Sown with Seed — Nil

Experimental design — Randomised block. Each bin represented a treatment plot randomised within one of 3 blocks.

APPENDIX 10

(b) Seedling Emergence Percentage - Direct Drilled Wheat - Whole plot counts (arc-sin means in parenthesis)

Treatment / Time	Triple Disc Rep 1	Rep 2	Rep 3	Mean	Hoe Rep 1	Rep 2	Rep 3	Mean	Chisel Rep 1	Rep 2	Rep 3	Mean	L.S.D.
Day 8	10.5	13.6	8.8	11.0	21.8	58.8	48.1	42.9	48.4*	40.9*	53.1	47.5	
12	20.3	24.7	21.0	22.0	27.7	63.7	54.9	48.8	62.8*	62.0*	66.6	63.8	
16	25.7	28.0	26.2	26.6	24.2	61.2	56.3	47.2	72.0*	64.7*	68.9	68.5	
20	26.4	34.8	31.0	30.7	24.2	61.2	55.9	47.2	72.3*	63.6*	69.6	68.5	
28	28.3	37.4	29.3	31.7	25.0	61.8	57.3	48.0	60.9*	68.4*	65.6	65.0	
Maxima	28.3	37.4	31.0	32.2 (18.8)	27.7	63.7	57.3	49.6 (30.2)	72.3	68.4	69.6	70.1 (44.3)	(16.6) (27.6)

* results from 2 rows of plot only

Supplementary counts of the two abandoned rows of chisel

	Rep 1	Rep 2	Mean
Day 8	30.8	23.2	27.0
12	34.6	32.9	33.6
16	45.2	36.6	40.9
20	46.2	34.1	40.2
28	47.1	35.4	41.3
Maxima	47.1	36.6	41.9

APPENDIX 10

(c) Seed Fate - Direct Drilled Wheat - Percentages of Total Seed Pool

Time \ Treatment		Triple Disc Rep 1	Triple Disc Rep 2	Triple Disc Rep 3	Triple Disc Mean	Hoe Rep 1	Hoe Rep 2	Hoe Rep 3	Hoe Mean	Chisel Rep 1*	Chisel Rep 2*	Chisel Rep 3	Chisel Mean
Day 2	Ungerminated	73.3	53.8	80.0	68.0	73.3	23.5	93.7	63.5	50.0	32.3	26.7	36.3
	Germinated but failed to emerge	26.7	46.2	20.0	32.0	26.7	76.5	6.3	36.5	50.0	67.7	73.3	63.7
	Abnormal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Emerged	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Day 4	Ungerminated	21.4	13.3	42.9	25.9	28.6	7.7	93.3	43.2	14.3	8.3	6.2	9.6
	Germinated but failed to emerge	78.6	86.7	57.1	74.1	71.4	92.3	6.7	56.8	85.7	91.7	93.8	90.4
	Abnormal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Emerged	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Day 6	Ungerminated	25.0	26.7	58.3	36.7	53.3	21.4	26.7	33.8	31.2	26.6	0.0	19.3
	Germinated but failed to emerge	75.0	73.3	41.7	63.3	46.7	50.0	73.3	56.7	68.8	60.0	81.3	70.0
	Abnormal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Emerged	0.0	0.0	0.0	0.0	0.0	28.6	0.0	9.5	0.0	13.4	18.8	10.7
Day 8	Ungerminated	28.6	7.7	35.7	24.0	86.7	7.1	0.0	31.3	0.0	40.0	0.0	13.3
	Germinated but failed to emerge	64.3	84.6	64.3	71.1	6.7	42.4	33.3	27.6	33.3	33.3	38.5	35.0
	Abnormal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Emerged	7.1	0.0	0.0	2.4	0.0	50.0	66.7	38.9	66.7	26.7	61.5	51.6
Day 12	Ungerminated	71.4	76.5	90.0	79.3	13.3	9.1	81.8	34.7	0.0	0.0	35.3	11.8
	Germinated but failed to emerge	28.6	17.6	10.0	18.7	40.0	18.2	18.2	25.5	28.6	38.5	23.5	30.2
	Abnormal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Emerged	0.0	5.9	0.9	2.0	46.7	72.7	0.0	39.8	50.0	61.5	41.2	50.9
Day 16	Ungerminated	9.1	0.0	0.0	3.0	16.7	14.3	7.1	12.7	31.6	0.0	18.2	16.6
	Germinated but failed to emerge	63.6	75.0	100.0	79.5	50.0	14.3	42.9	35.7	15.8	11.8	45.5	24.4
	Abnormal	9.1	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	5.9	0.0	2.0
	Emerged	27.3	25.0	0.0	17.4	33.4	71.4	50.0	51.6	52.6	82.4	36.4	57.1

		Triple Disc				Hoe				Chisel			
		Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean
Day 20	Ungerminated	7.1	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	7.7	2.6
	Germinated but failed to emerge	85.7	28.6	44.4	52.9	10.0	0.0	12.5	7.5	15.4	15.4	7.7	12.8
	Abnormal	0.0	0.0	11.1	3.7	0.0	0.0	6.3	2.1	7.7	7.7	0.0	5.2
	Emerged	7.1	71.4	44.4	41.0	90.0	100.0	81.3	90.4	76.9	76.9	84.6	79.5
Day 28	Ungerminated	11.1	0.0	0.0	3.7	23.1	0.0	6.3	9.8	0.0	0.0	0.0	0.0
	Germinated but failed to emerge	0.0	25.0	33.3	19.4	23.1	0.0	0.3	9.8	7.1	0.0	14.3	7.1
	Abnormal	33.3	18.8	8.3	20.1	0.0	5.0	0.0	1.7	0.0	21.4	0.0	7.1
	Emerged	55.6	56.3	58.3	56.7	53.8	95.0	87.5	78.8	92.9	78.6	85.7	85.7

* Sampling from 2 rows only

APPENDIX 10

(d) Dry Matter Percentage - Direct Drilled Wheat Seeds.

All samples = seeds recovered from seed fate scoop samples (arc-sin transformations in parenthesis)

Treatment \ Time		Day 2	Day 4	Day 6
Triple Disc	Rep 1	60.8	57.1	59.4
	Rep 2	62.7	57.0	66.5
	Rep 3	66.8	65.6	71.2
	Mean	63.4	59.9	65.7
		(39.4)	(36.9)	(40.5)
Hoe	Rep 1	68.1	75.2	76.5
	Rep 2	63.4	81.1	69.4
	Rep 3	73.0	74.6	75.3
	Mean	68.2	77.0	73.7
		(43.1)	(50.4)	(43.4)
Chisel	Rep 1	66.9	60.4	73.4
	Rep 2	64.6	60.7	76.3
	Rep 3	63.1	82.6	74.9
	Means	64.9	67.9	74.9
		(40.5)	(43.4)	(48.5)
LSD		(6.0)	(14.6)	(14.9)
		(9.9)	(24.3)	(24.8)

APPENDIX 10

(a) Shoot Dry-Matter Yields - Direct Drilled Wheat Terminal Figures

		Dry weight per shoot g	Terminal Emergence %	Dry weight of shoots per 100 seeds sown, g.	Dry weight of shoots kg/ha
Triple	Rep 1	0.069	28.3	19.5	437
Disc	Rep 2	0.064	37.4	35.0	784
	Rep 3	0.10	29.3	30.1	674
	Mean	0.088	31.7	28.2	631
Hoe	Rep 1	0.056	25.0	13.9	311
	Rep 2	0.19	61.8	117.4	2630
	Rep 3	0.13	57.3	70.0	1568
	Mean	0.13	48.0	67.1	1503
Chisel	Rep 1	0.083	60.9	50.3	1127
	Rep 2	0.12	68.4	79.0	1776
	Rep 3	0.084	65.6	54.8	1228
	Mean	0.094	65.0	61.4	1375
LSD					1225.9
					2033.2

APPENDIX 11

(a) Specifications of Experiment No. 8

Sowing date	12/11/73
Species	"Kopara" Wheat
Germination Potential	96% (M.A.F. Seed Testing Station)
Type of Experiment	Tillage bin study
Location	Massey University, Agricultural Mechanisation Hall
Drill Coulter Assemblies	"Duncan" triple disc; "Duncan" hoe with vertical pre-disc; Experimental chisel with vertical pre-disc
Depth Control	Depth restricting wheels on either side of pre-disc
Sowing Depth	Nominally 38mm
Row Spacing	150mm
Operating Speed	60 m/h
Condition of Parent Vegetation	Short dense pasture Ruanui Ryegrass (*Lolium perenne*) dominant.
Condition of soil	Severe moisture stress
Soil Type	"Manawatu fine sandy loam"
Environmental conditions at sowing	Dry under rain canopies
Environmental conditions during trial	Dry under rain canopies (no irrigation)
Herbicide, rate and application	Blanket sprayed, single application 5.6 l/ha paraquat + 1.4 l/ha dicamba, 12/11/73.
Class and cover over seed	triple disc, grade II hoe , grade III chisel , grade IV
Seeding rate	Nominal intra-row spacing 19mm
Seed Metering	Modified vacuum seeder operating at 571.5mm mercury. During drilling, seed number per drilled row was recorded.

Number of seeds sown per row

Treatment		Viability	Rep 1	Rep 2	Rep 3
Triple Disc	LHS	Viable	97	100	99
	MID	Non-viable	97	99	60
	RHS	Non-viable	88	89	89
Hoe	LHS	Viable	73	96	90
	MID	Non-viable	87	94	90
	RHS	Non-viable	101	95	85
Chisel	LHS	Non-viable	66	61	87
	MID	Non-viable	80	54	74
	RHS	Viable	99	91	99

Fertilizer Sown with Seed	Nil
Experimental Design	Randomised block. Each bin represented a treatment plot randomised within one of 3 blocks.

(b) Seed Fate - Direct Drilled Wheat

(Percentage of total seed pool)

(arc-sin transformation in parenthesis)

Time \ Treatment		Triple Disc Rep 1	Triple Disc Rep 2	Triple Disc Rep 3	Triple Disc Mean	Hoe Rep 1	Hoe Rep 2	Hoe Rep 3	Hoe Mean	Chisel Rep 1	Chisel Rep 2	Chisel Rep 3	Chisel Mean	LSD
Day 5	Ungerminated	14.3	5.9	0.0	6.7	0.0	0.0	6.7	2.2	9.5	NO READING	12.5	11.0	
	Germinated but failed to emerge	85.7	94.1	100.0	93.3	100.0	100.0	93.3	97.8	90.5		87.5	89.0	
	Abnormal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	
	Emerged	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	
Day 7	Ungerminated	0.0	0.0	23.1	7.7	0.0	0.0	7.1	2.4	50.0	0.0	0.0	16.7	
	Germinated but failed to emerge	78.6	84.6	69.2	77.5	42.9	64.3	85.7	64.3	50.0	72.7	60.0	60.9	
	Abnormal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	Emerged	21.4	15.4	7.7	14.8	57.1	35.7	7.1	33.3	0.0	27.3	40.0	22.4	
Day 9	Ungerminated	0.0	0.0	7.1	2.4 (1.36)	0.0	0.0	0.0	0.0 (0.0)	7.7	0.0	0.0	2.6 (1.47)	(5.07) (8.42)
	Germinated but failed to emerge	47.1	13.3	85.7	48.7 (31.57)	7.7	18.8	18.8	14.7 (8.70)	23.1	56.2	38.5	39.3 (23.40)	(38.59) (64.00)
	Abnormal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	Emerged	52.9	86.7	7.1	48.9 (32.04)	92.3	81.3	81.3	84.9 (58.72)	69.2	43.8	61.5	58.2 (35.91)	(42.24) (70.06)
Day 12	Ungerminated	0.0	0.0	6.7	2.2	0.0	5.3	6.3	3.9	72.7	6.7	8.3	29.2	
	Germinated but failed to emerge	63.6	35.7	46.7	48.7	0.0	31.6	12.5	14.7	0.0	20.0	16.7	12.2	
	Abnormal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	Emerged	36.4	64.3	46.7	49.1	100.0	63.2	81.3	81.5	27.3	73.3	75.0	58.5	

APPENDIX 11

(c) In-Groove Soil Moisture Content Direct Drilling (Percentage - Wet basis) -arc-sin transformation in parenthesis

All Readings from Single Scoop Sample

Time \ Treatment	Triple Disc				Hoe				Chisel				
	Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean	Rep 1	Rep 2	Rep 3	Mean	LSD
Day 1	17.3	20.0	16.5	17.9	11.7	13.8	20.1	15.2	19.7	10.1	16.8	15.5	
Day 2	18.9	19.9	8.3	15.7	16.1	18.0	20.0	18.0	16.9	14.0	11.7	14.2	
Day 3	19.6	20.4	17.6	19.2	16.0	18.7	20.0	18.2	16.0	10.2	10.0	12.1	
Day 4	17.7	8.5	19.9	12.0	17.6	20.6	16.8	18.3	15.2	10.8	7.8	11.2	
Day 5	16.2	17.8	16.4	16.8	14.8	20.8	15.5	17.1	15.3	13.3	9.9	12.8	
Day 6	16.3	17.1	17.6	17.0	13.2	16.4	16.9	15.5	13.8	14.0	12.4	13.4	
Day 7	12.1	16.6	16.1	14.9	15.1	16.5	20.3	17.3	14.7	11.2	12.6	12.8	
Day 9	15.4	17.1	12.6	15.0	15.7	16.3	16.6	16.2	13.8	12.7	10.6	12.4	
				(8.64)				(9.33)				(7.10)	(1.91) (3.17)
Day 12	13.6	14.6	13.8	14.0	15.4	14.5	13.7	14.5	12.0	11.4	10.3	11.2	
Day 16	8.5	13.8	14.6	12.3	14.7	14.9	11.4	13.7	10.2	9.2	7.7	9.0	
				(6.93)				(7.84)				(5.18)	(3.76) (6.24)
Day 21	8.8	11.3	12.1	10.7	8.4	13.8	10.5	10.9	10.2	10.7	7.2	9.4	
				(6.15)				(6.25)				(5.37)	(1.38) (2.29)
Day 30	10.7	6.9	8.5	8.6	8.8	7.8	6.1	7.6	10.3	7.0	5.6	7.6	
Day 51	2.6	3.1	3.3	3.0	2.6	2.1	2.6	2.4	2.7	2.3	3.7	2.9	
Day 57	2.3	3.2	3.0	2.8	3.1	2.2	2.7	2.7	2.8	2.9	3.1	2.9	

APPENDIX 11

(d) Non Viable Wheat Seed Dry Matter Percentage, Direct Drilling —(arc-sin transformation in parenthesis)

(All Readings from Total Seed Collected for One Scoop Sample)

Treatment / Time	Triple Disc Rep 1 D.M.	No Seeds	Rep 2 D.M.	No Seeds	Rep 3 D.M.	No Seeds	Mean D.M.	Hoe Rep 1 D.M.	No Seeds	Rep 2 D.M.	No Seeds	Rep 3 D.M.	No Seeds	Mean D.M.	Chisel Rep 1 D.M.	No Seeds	Rep 2 D.M.	No Seeds	Rep 3 D.M.	No Seeds	Mean D.M.	LSD
Day 1	71.69	15	70.00	14	70.46	14	70.71	72.04	14	70.56	15	70.28	15	70.96	70.56	14	76.40	13	71.39	12	72.73	
Day 2	67.58	11	67.73	14	72.57	13	69.29	67.85	11	65.10	13	64.29	13	65.74	65.91	13	67.90	12	65.13	12	66.31	
Day 3	62.73	10	60.99	15	62.09	7	61.93	62.65	13	62.59	13	61.03	11	62.09	62.24	13	62.19	11	62.56	6	62.33	
Day 4	61.70	14	61.38	11	60.16	15	61.08	62.37	11	59.66	12	60.64	14	60.89	61.64	6	62.12	12	62.68	13	62.14	
Day 5	60.94	18	64.14	12	52.21	15	59.09	59.54	19	58.62	9	61.86	12	60.00	59.33	15	62.32	12	61.53	10	61.06	
Day 6	61.45	7	60.87	12	59.85	10	60.72	59.29	10	61.61	14	63.06	11	60.69	62.40	10	61.18	9	66.83	10	63.47	
Day 7	62,57	11	59.16	15	58.48	9	60.07	69.03	9	58.62	12	59.15	11	62.27	59.50	14	72.60	12	56.97	10	63.02	
Day 9	56.09	14	56.62	13	53.91	13	55.54	57.00	12	59.00	4	57.89	10	57.96	69.07	12	57.24	9	55.72	14	60.68	
							(33.74)							(35.43)							(37.49)	
																						(7.30 (12.11
Day12	56.58	11	59.11	11	57.66	9	57.78	56.82	10	56.43	7	58.23	12	57.16	63.47	12	54.58	7	57.77	13	58.61	

Initial Dry Matter All Seeds = 88.31 (16 seeds)

APPENDIX 11

(e) Dry Weights of Direct Drilled Wheat Seedlings

Time and Reading / Treatment		Terminal Emergence Percentage at day 12	Computed Equivalent Plant Population Per hectare	Day 33 No Plants	Day 33 Dry Wt per plant (gr)	Day 33 Kg dry Matter/ha	Day 50 No Plants	Day 50 Dry Wt per plant (gr)	Day 50 Kg dry matter/ha
Triple Disc	Rep 1	36.4	1,277,193	12	0.14	178.81	18	0.13	166.04
	Rep 2	64.3	2,256,140	7	0.18	406.11	12	0.07	157.93
	Rep 3	46.7	1,638,596	10	0 07	114.76	6	0.19	311.33
	Mean	49.1				233.25			211.77
Hoe	Rep 1	100.0	3,508,772	20	0.11	385.96	16	0.19	666.67
	Rep 2	63.2	2,217,544	15	0.11	243.93	21	0.06	133.05
	Rep 3	81.3	2,852,631	16	0.13	370.84	16	0.16	370.84
	Mean	81.5				333.58			390.19
Chisel	Rep 1	27.3	957,895	8	0.14	134.11	26	0.10	95.79
	Rep 2	73.3	2,571,930	13	0.12	308.63	23	0.09	231.47
	Rep 3	75.0	2,631,579	7	0.24	631.58	7	0.07	184.21
	Mean	58.5				358.11			170.49

APPENDIX 12

(a) Specifications of Experiment No. 9

Sowing periods	Group 1 Autumn 1973
	Group 2 Spring 1973
Species	Varied: including pasture mixes, fodder radish, barley, lupin.
Germination potential	Unknown
Type of Experiment	Field machine performance trial
Location of Experiment	Agricultural soils in Manawatu and Hawkes Bay
Drill Coulter Assembly	Chisel coulter assembly (Mark II)
Depth Control	Depth restricting bands on either side of pre-disc.
Sowing Depth	Nominally 25mm
Row Spacing	150mm
Operating Speeds	Approximately 4-8 km/h
Type of drill	"Duncan 730 Multiseeder" field direct-drilling machine (modified)
Conditions of parent vegetation	Group 1: Various permanent pastures, Ruanui ryegrass (*Lolium perenne*) dominant.
	Group 2: As for group 1, plus one area of Lucerne (*Medicago sativa*).
Condition of Soils	Various - from hard and dry to approximately field capacity and friable.
Soil Classification	Unknown in all instances
Environmental Conditions at Sowing	Varied
Environmental Conditions During Trial	"
Herbicide, rate and application	Except for Lucerne, all blanket sprayed with various rates paraquat ± dicamba. Rates not thought to be critical to aims of this experiment.
Harrowing delay	Immediate. Field version of bar harrow trailed behind drill.
Class and cover over seed	Grade IV
Seeding rate	Various, but not critical to aims of experiment.
Seed Metering	External forced feed fluted roller type.
Fertilizer sown with seed	Various, but not critical to aims of experiment
Experimental design	Randomised plot
No. of replications	Treatments D, E, F & I - 2
	Treatments A, B, C, Control, G, H, J & K - 3

APPENDIX 12

(b) Weight Loss of Chisel Direct-Drilling Coulters

Reading / Treatment	Position of Coulter on Drill	Coulter Number	Total Initial Weight of Coulter	.33 of Initial Weight of Coulter	Weight loss at end of test	No. of hectares covered		Percentage Wt. loss per hectare (soil engaging portions)	
Group 1	(From RHS)		(g)	(g)	(g)	(ha)			
A	5	27	849.9	280.5	54.2	15.4		1.25	
	13	34	828.3	273.3	39.1	15.4		0.93	
	10	35	845.0	278.9	47.7	15.4		1.11	
Mean							15.4		1.10
B	6	30	852.1	281.2	37.5	15.4		0.87	
	11	31	873.4	288.2	47.4	15.4		1.07	
	16	33	824.9	272.2	17.3	15.4		0.41	
Mean							15.4		0.78
C	3	22	839.6	277.1	18.5	15.4		0.43	
	8	24	860.1	283.8	23.0	15.4		0.53	
	15	29	832.8	274.8	19.4	15.4		0.46	
Mean							15.4		0.47
D	1	18	862.1	284.5	24.8	15.4		0.57	
	14	28	816.8	269.5	23.0	15.4		0.55	
Mean							15.4		0.56
E	4	25	843.1	278.2	35.9	15.4		0.84	
	9	26	893.3	294.8	37.4	15.4		0.82	
Mean							15.4		0.83
Control	2	19	841.7	277.8	50.1	15.4		1.17	
	7	20	845.1	278.9	60.1	15.4		1.40	
	12	21	811.1	267.7	60.9	15.4		1.48	
Mean							15.4		1.35

APPENDIX 12

(c) Weight Loss of Chisel Direct-Drilling Coulters

Reading / Treatment Group 2	Position of coulter on drill (From RHS)	Coulter number	Total initial weight of coulter (g)	.33 of initial wt. (g)	Weight loss at end of test (g)	No. of hectares covered		Percentage wt. loss per hectare (Soil engaging portions)	
F	1	18	719.4	273.5	109.3	36.8		1.09	
	6	21	671.7	260.9	118.8	33.5		1.36	
Mean							35.2		1.22
G	2	19	692.4	278.1	150.3	29.1		1.86	
	5	20	746.4	277.5	94.5	36.8		0.93	
	8	22	725.8	278.0	116.5	36.8		1.14	
Mean							34.2		1.26
H	7	24	787.1	282.5	68.9	36.8		0.66	
	11	25	773.7	272.2	51.2	36.8		0.51	
	14	26	769.7	289.3	106.9	36.8		1.00	
Mean							36.8		0.73
I	13	27	805.5	275.7	30.1	36.8		0.30	
	16	34	762.3	262.2	32.3	36.8		0.33	
Mean							36.8		0.32
J	3	28	769.4	267.2	40.2	36.8		0.41	
	10	29	810.0	277.5	30.9	36.8		0.30	
	12	30	784.0	275.9	52.1	31.5		0.60	
Mean							35.0		0.43
K	4	31	809.2	292.2	76.4	36.8		0.71	
	9	33	795.0	274.9	38.1	36.8		0.38	
	15	35	817.8	280.4	31.8	36.8		0.31	
Mean							36.8		0.47

APPENDIX 13

For the purposes of this text, the following terminology is listed either for definition, (where such has been excluded from British Standard 2468: 1963, "Glossary of Terms Relating to Agricultural Machinery and Implements") or for further explanation.

a. **Drill coulter** — That part of a seed drilling machine which maintains intimate contact with the soil and thereby affects the creation of the seed groove, slit, or furrow and deposits the seed and fertilizer therein.

b. **Hoe coulter** — A drill coulter featuring a rigid upright member as the soil engaging component and which is essentially pointed, V shaped, partly hollow and usually relieved behind the point. (see plate 23)

c. **Chisel coulter** — A drill coulter featuring a rigid upright member as the soil engaging component and which has a narrow, partly hollow vertical shank, to the base of which is attached at right angles a wider, slightly inclined, chisel shaped flat plate (see plate 22 [b])

d. **Suffolk coulter or Shoe coulter** — A drill coulter featuring a rigid upright member as the soil engaging component and which has a narrow partly hollow vertical shank, the front lower portion of which is gently curved.

e. **Ski coulter** — A drill coulter featuring a horizontal skid with upturned front and a narrow vertical wing attached centrally beneath. A hollow tube at the rear of the skid delivers seed to the groove created by the vertical wing.

f. **Flat or vertical pre-disc** — A single flat disc travelling with a vertical attitude and which usually preceeds a drill coulter to prevent the build up of trash.

g. Dished disc coulter

A single concave disc usually travelling vertically or with a negative tilt angle and a slight (approximately 5^{o}) breast (or disc) angle.

h. Flat disc coulter — A single flat disc travelling with zero tilt angle. It may operate with a slight breast (or disc) angle, whereupon it is referred to as an angled flat disc coulter.

i. Triple disc coulter

This is strictly a misnomer in that this drill coulter consists of two flat discs vertically inclined to each other at approximately 10^{o} included angle, forming a V slightly ahead of the base where they touch. Preceeding this is a vertical flat pre-disc. All discs have no breast (or disc) angle. Thus the drill coulter is more aptly termed a double-disc coulter, but common usage has tended to include the flat pre-disc as part of the drill coulter itself with the result that the drill coulter assembly has become known as a triple disc coulter. (see plate 24)

j. Rotary coulter — A drill coulter which has a power driven narrow rotating blade assembly as its soil-engaging device. Placement of seed into the groove so formed is via a separate seed placement tube usually trailing behind the rotating blade.

k. Trailing arm — That part of a seed drilling machine which, (i) locates the horizontal position of the drill coulter and seed boot, (ii) facilitates vertical movement of the coulter and boot to follow ground contour, and (iii) transmits to the drill coulter and seed boot a downward force exerted by penetration springs when activated.

l. Seed boot — That part of a seed drilling machine attached to the trailing arm and to which the coulter is rigidly attached. In some instances the coulter is itself attached directly to the trailing arm, so eliminating the seed boot altogether.