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ASPECTS OF SEED TRANSFER WITHIN

A DIRECT DRILLING COULTER (OPENER).

A thesis presented in partial fulfilment
of the requirements for the degree
of Master of Agricultural Science
in Agricultural Mechanisation at
Massey University.

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ABSTRACT.

A number of laboratory and field experiments were conducted in order to identify and quantify seed and seedling spacing variations produced by an experimental direct drill. Seed contact with both stationary and moving components of the coulter assembly was considered to contribute to the increased variability of seed spacing that resulted from the positioning of a chisel direct drilling coulter beneath a "Nodet Gougis" seed selection mechanism.

Alternatives for transferring the seeds from the seed selection mechanism to the soil were considered. The simplest of these alternatives, a seed-transfer tube, was tested in a number of different shapes and positions. It was found that the seeder required modifications to its release characteristics in order to satisfactorily incorporate the tube transfer system. A number of deflector plates were fitted to the seeder to control seed release trajectory. A 40 degree seed deflector plate was found to produce a seed path that was most compatible with a straight vertical seed-transfer tube.

A video recording technique was used to assess the effects of seeder modifications on seed release trajectory.

The modified seeder and the tube transfer system were combined with the chisel direct drilling coulter, and seed spacing performance was retested. Seed spacing variability was found to be considerably less than with the original experimental drill in the laboratory, although field performance was not improved to the same extent. It was considered that this effect

(ii)

may have been attributable to the effects of soil flow with the direct drilling coulter and the manner with which the seed was released into the soil, which differed with the tube system compared with the unmodified coulter tested initially.

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1 Introduction.

Considerable interest has been expressed in recent years in the technique of direct drilling seeds into undisturbed (zero-tillage) seedbeds. The technique, which was originally used in New Zealand for improving pasture species composition (Blackmore, 1952), was later adopted for use in crop production although yields from direct drilled crops were generally less predictable in comparison with crops established under conventional cultivation.

One major aspect emerging from increased experience with zero-tillage and direct drilling has been the requirement for completely new approaches to many of the disciplines associated with the techniques, including the development of new machinery. This had certainly been the case with study in areas relating to herbicides, pesticides, fertiliser requirements, seed placement, crop agronomy and management. In the case of machinery development, as the more fundamental problems were overcome and a better understanding was gained of the biological requirements of direct drilling coulters, new areas of machine design were investigated such as coulter wear, fertiliser placement, depth control, seed placement and contour following ability.

More recently it has been demonstrated that maize, fresh and processed vegetable and horticultural crops could be established successfully without cultivation (Cox, 1976; 1977; 1979). The specific advantages from direct drilling these crops, in addition to the other generally accepted benefits and limitations of zero-tillage, were considered to be improved weed control, timeliness and soil trafficability. In these respects areas of

interest have centred on "stable" raised seedbeds as well as unshaped uncultivated ground. In both cases the requirement exists for a specialised precision seed drill performing in one operation a range of functions hitherto performed sequentially by conventional cultivating implements and conventional precision seed drills.

If the need for the precision placement of vegetable seeds can be extrapolated from cultivated seedbeds to zero-tillage seedbeds, the major mechanical problem associated with direct drilling of precision sown crops that has not previously been encountered during the development of equipment for direct drilling, appears to be reconciling seed placement accuracy with the specific physical constraints of direct drilling coulters.

This study therefore sought to achieve the following main objectives:

(i) To determine the magnitude of seed spacing variation arising from seed passage through a selected direct drilling coulter.

(ii) To identify the causes of this variation.

(iii) To consider options for reducing the variation by controlled transfer of the seeds from the seeder unit through the coulter to the soil.

(iv) To evaluate selected seed transfer options with a view to incorporating a suitable transfer mechanism within the coulter.

(v) To assess requirements for modifying aspects of seed release from a selected seeder in order to facilitate controlled entry into seed transfer systems.

(vi) To determine the magnitude of seed spacing variation arising from seed passage through a suitably modified direct drilling coulter.

2 Literature Review.

2.1 Definitions.

Many terms have been used in the literature to describe cultural practices under the broad concept of "no-tillage". For example, Phillips and Young (1973) suggested that no-tillage encompassed all operations in the "type of greatly reduced tillage" variously known as zero-tillage, chemical tillage, direct seeding, no-plow tillage, no-till and sod planting. Unger and McCalla (1980) included strip tillage or "slot planting" as a no-tillage practice.

Direct drilling has been defined as being "the placement of the crop seed or crop transplant into the soil by a device which opened a trench or slot through the soil or previous crop residues only sufficiently wide and deep to receive the seed or transplanted roots and to provide satisfactory seed or root coverage. Weeds were controlled by herbicides, crop rotation and crop competition" (Young, 1973).

Staniforth and Baker (1980) stated that "the term (direct drilling) is used widely as a synonym for zero tillage; the technique is reserved almost entirely to the zero tillage production system". These authors suggested that the term zero tillage described the physical state of the seedbed while direct drilling referred to the seeding operation.

The terms "direct drilling" and "zero tillage", as defined by Staniforth and Baker (loc.cit.) will be used for the purposes of this text as collectively they define the varying extents of soil manipulation performed by different direct drilling machines and the processes of seed

introduction. Where applicable, terminology in the literature review has been altered to conform with these definitions.

2.2 Advantages and disadvantages of zero tillage seedbeds.

2.2.1 Soil moisture, temperature, infiltration and erosion.

Several authors have reported conservation of soil moisture as a result of crop residue retention under zero tillage systems. Unger et al. (1971) reported significant evaporation reduction and improved moisture retention as a result of mulching. Other authors have studied soil temperature and soil moisture under crop residue surface layers. The presence of residue on the soil surface was reported to have resulted in reduced temperature fluctuations (Van Wyk et al., 1959; Phillips and Young, 1973; Wilson, 1978). This effect was monitored by Van Wyk et al. (loc.cit.) over several North American states with differing climatic conditions. These latter authors also reported that mulching in areas with low early season temperatures resulted in reduced early crop growth in corn (Zea mays L.) due to depressed soil temperatures. This was confirmed by Phillips et al. (1980) and Unger and Stewart (1976) who considered that mulching could be disadvantageous in the northern and central United States due to depressed soil temperatures.

In warmer climates beneficial effects from mulching have been noted. Burrows and Larson (1962) working in Iowa, U.S.A., reported reductions in soil temperature of up to 4 degrees Celcius at 6mm depth in the presence of corn residue. Lillard and Jones (1964) reported similar effects

from mulching in reducing day and night temperature fluctuations. The reduction in soil surface temperatures was considered by Mathews (1972) to be partially responsible for reduced evaporation under mulching which may also have offered a major advantage in tropical and sub-tropical crop production according to McCown et al. (1981) and Lal (1974).

Micro-environmental in-groove soil moisture retention has also been found to play an important role in direct drilling. For example Choudhary and Baker (1980) reported 58% germination of "Kopara" wheat seeds drilled into soils at near wilting point with an experimental chisel coulter. They attributed the germination and seedling survival properties of this groove to retention of soil moisture vapour in the groove which was covered almost entirely by crop residue. Several other workers had earlier reported increased seed germination and seedling survival in dry soil conditions using an experimental direct drilling coulter specifically designed to retain surface residue (Baker, 1976ab; Mai, 1978). Baker even went as far as classifying the groove cover according to the amount of mulch present and demonstrated a strong correlation ($r=0.86$) between seedling emergence and grade of cover in a dry soil.

Improved water infiltration and storage was recorded by Unger et al. (1971) in areas where surface residues were retained. The effect of mulching on surface runoff and resulting soil erosion has also been recorded by a number

of authors (Harrold and Edwards, 1972; Gard and McKibben, 1973; Young, 1973; Phillips and Young, 1973; Lal, 1974). The potential of zero tillage in areas subject to water and wind erosion was cited by all of the above listed authors and was summarised by Gard and McKibben (loc.cit.) as follows: "A system of crop production which provides for the continuous use of a mulch blanket of crop residues to protect the soil, the no till (zero tillage) system, exhibits the potential for becoming the most significant single conservation measure yet developed to control erosion and sedimentation." The above authors and Lal (loc.cit) also noted the depleting effects of erosion on soil nutrient status.

Jensen (1982) referred to the machinery requirements for utilising mulch in crop production. He noted that "some U.S. croplands have been eroding excessively because we are just beginning to develop practical conservation tillage systems that greatly reduce evaporation and increase soil water storage. We need to develop acceptable farm equipment to enable establishing uniform plant stands under mulched conditions."

2.2.2 Weed control.

"Cultivation is not beneficial to the corn plant except in so far as removing the weeds is concerned." This conclusion was reported to have been reached by Cates and Cox in 1912 after several years of experiments in the U.S.A. (Cox, 1977). Pereira (1975) referred to a series of tillage experiments by Keen and Russell in the 1930's which

apparently indicated the potential for chemical weed control. This author noted that 35 years later, minimum tillage techniques which included zero tillage were still the subject of innovative research, due mainly to the formidable problem of effective weed control. However Pereira (loc.cit.) considered that the advent of herbicides which were able to deal selectively with grasses had finally allowed the plough to be omitted from crop production.

Traditionally cultivated processed vegetable crops such as peas, cabbages, broadbeans, sweetcorn, pumpkins and gherkins have been reported to have been successfully grown without cultivation where chemical weed control was adequate. (Cox, 1976; Cox loc.cit.; Cox, 1979; Phillips and Young, 1973; Wilson, 1978; McLean, 1979). Nevertheless some weed species have been reported as difficult to control with herbicides because of the similar biological characteristics of the weeds and crops (Unger and McCulla, 1980; Cox, 1980). Tomatoes grown under a "stale seedbed" technique (essentially direct drilling into pre-formed zero tilled beds) had apparently exhibited increased yields compared with those grown with conventional cultivation (T.I. Cox, pers.comm. 1980). Seedbeds prepared in the autumn were direct drilled in the spring after herbicide application. Annual weeds closely related to tomatoes, and therefore difficult to control chemically (such as black nightshade; Solanum nigrum) were apparently less evident in the absence of spring

cultivation (Cox, 1980). A similar approach was proposed for weed control in corn production in U.S.A. (Staniforth and Baker 1980) and apparently used in Brazil (Hayward et al., 1980).

The use of herbicides in zero tillage systems has often resulted in reported changes in resident weed species (Richey et al., 1977; Phillips, 1969; Wilson, 1978). As a consequence these workers reported that yields had decreased with continuous zero tillage unless the herbicide resistant species were controlled by tillage. On the other hand Weise and Staniforth (1973) reported that crop rotation made it possible to select crops that were most competitive with perenial weeds.

2.2.3 Soil structure.

Soil conservation from wind and water erosion was seen by Unger and McCalla (1980) and Wilson (1978) as a major goal of zero tillage. Soil physical factors thought to influence water infiltration and soil erodibility have included soil aggregation, porosity and density (Unger and McCalla, loc.at.). In intensive cropping areas preservation of good soil structure was considered by Cox (1975) to be of urgent concern. Phillips and Young (1973) reported that soil aggregate breakdown, leading to surface sealing with resulting increased runoff, was partially caused by the hammering effect of raindrops on bare soil. These authors also reported reduced soil compaction from minimum tillage operations in comparison with conventional cultivation.

Many authors have reported increased earthworm populations and activity in the absence of cultivation (Baeumer and Bakermans, 1973; Edwards and Lofty, 1979; Cannell and Finney, 1973). The presence of earthworms was considered by these authors to benefit the physical condition of soils.

2.2.4 General aspects of the zero tillage system.

Several authors (Bakerman, 1970; Cox, 1980; Cannell and Ellis, 1976) noted that undisturbed soils may have provided improved trafficability both at drilling and harvesting. Soane et al. (1975) suggested that bulk density and shear strength of continuously direct drilled soils increased initially but thereafter remained virtually constant. Thus the effects of wheel traffic on zero tillage seedbeds was reported to be considerably less than on cultivated seedbeds in wide row cropped raspberries.

Two aspects of improved timing of crop rotations have been noted in the literature. With the elimination of time consuming cultivation procedures double cropping within one season was reported by several authors in favourable climatic zones (Phillips and Young, 1973; Weise, 1977; Wilson, 1978; Cox, 1980). In less intensive cropping areas the delay provided by zero tillage in taking pasture out of production for crop establishment was reported to minimize the production loss from grazing land at a time of the year when feed provision for stock was critical (Stonebridge et al., 1973; Frengley, 1981).

The retention of trash under zero tillage was reported

to provide a more favourable habitat for insects and disease (Ivens, 1977; Phillips et al., 1980; Wilson, 1978; Pottinger, 1979). While some of the insects and invertebrae encouraged by the zero tillage system were considered by the above authors to be beneficial (e.g. earthworms) others (e.g. slugs) have been reported as causing significant pest problems in zero tillage (Charlton, 1978; Follas, 1982; Patterson et al., 1980).

Erbach and Lovely (1975) reported no significant effect of surface residue on the effectiveness of herbicides applied at normal rates. Similarly Phillips et al. (1980) reported that pesticides used in direct drilled corn and soya beans did not move appreciably in the environment except by soil erosion. Since zero tillage practices have been shown to significantly reduce soil erosion it was considered by the latter authors that movement of pesticides would have been less than with conventional cultivation.

The presence of crop residue under anaerobic soil conditions was observed to cause reduced plant growth (Cannell et al. 1977). These authors attributed this effect, at least in part, to phytotoxins such as acetic acid produced by micro-organisms. The effect was apparently overcome by coating the seed with calcium peroxide or by ensuring that the seed was not placed in direct contact with residue in cold anaerobic conditions (Baker, 1981).

2.3 Equipment for direct drilling.

Early experiences with direct drilling resulted from modifications to existing field drills (Robinson and Cross, 1960; Blackmore, 1958; Taylor, 1967; Phillips and Young, 1973). These early workers identified problems of penetration into hard soils (Taylor, loc cit.) and trash handling (Phillips and Young, loc.cit.). As a result it became clear that specialist equipment was required for direct drilling (Leonard and Hart, 1977).

Some authors have sought to define design criteria for direct drilling equipment. Most of these criteria have related to physical or mechanical parameters. Krall et al. (1979) used the following criteria for direct drill comparisons:

- "a) Soil movement rating;
- b) Depth of penetration;
- c) Amount of cut stubble;
- d) Bunching of straw;
- e) Seedling emergence;
- f) Plant stand; and
- g) Volunteer plants between rows."

Koronka (1973) defined design specifications for direct drilling equipment in more specific terms. He believed that a successful machine should have the following characteristics:

- "1. Combined seed and fertiliser drill.
2. Row spacing of 150-180mm.
3. Superior trash control and cutting ability.

4. Positive seed insertion with seed/soil contact.
5. Seed/soil contact to be maintained under very hard or wet soil conditions.
6. Wear of the soil working elements must not interfere with efficient trash cutting or seed deposition, or increase load requirement.
7. Long life of soil working elements under hard working conditions.
8. Good seed handling characteristics for small or large seeds at any seedling rate.
9. Good contour following by coulters.
10. Working rate at least equal to conventional drilling rates.
11. Power requirements within current tractors' range.
12. Simple operation.
13. Reasonable price.
14. Low maintenance requirement.
15. Large adjustable hopper."

Phillips and Young (1973) stated that a no-tillage direct drilling planter must "provide a narrow band of tillage for receiving the seed". They suggested a 2-3 inch (50-75mm) wide and 3-6 inch (75-150mm) deep soil manipulation.

Baker et al. (1979b) also outlined several of the above physical criteria as requirements for direct drilling coulters. However Baker (1976a,b) and Choudhary (1979) placed considerably more importance on the biological parameters associated with direct drilling machinery. Choudhary

(loc.cit.) concluded that coulter designs should facilitate the creation of the following soil-seed physical environment:

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

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

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

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

Choudhary (loc.cit.) described experiments using two commercially available direct drilling coulters (a hoe coulter and a triple disc coulter) and an experimental chisel coulter, to determine their respective biological effects on wheat seed germination and seedling establishment in drying soils. While little difference in performance between coulter types was noted at adequate moisture levels, the chisel coulter provided significantly better results as moisture stress was imposed. Choudhary and Baker (1981) concluded that the seed groove profile of the chisel coulter exhibited a higher "moisture vapour potential captivity (M.V.P.C.)". Staniforth and Baker (1980) considered that the interchange of soil humidity with

the atmosphere using the chisel coulter was much slower than other tested coulters which assisted the emerging seedling to overcome the considerable contrast in habitat between the disturbed and undisturbed zones of direct drilled soils.

Baker et al. (1979a) reported work on trash handling characteristics of direct drilling coulters. These authors noted an inherent incapability of any fixed tyne coulter even when preceded by a disc to continually handle soil surface crop residue. Individual coulters were apparently able to operate in some surface residue conditions but this ability was lost when several coulters were tested in normal field drill configuration (e.g. 150mm rows). Baker et al. (1979b) later described design changes to an experimental chisel coulter to incorporate residue handling capabilities whilst retaining the original biological features considered advantageous (Baker, 1979; Choudhary and Baker, 1980, 1981). The redesigned chisel coulter was reported to embody a scalloped disc against which two winged shanks were mounted, one each side. The front edges of the shanks contacted the disc for their entire length and were tilted forward 55 degrees from vertical. The wings of the shanks were inclined 5 degrees to give sub-surface soil shattering. The rear edge of the coulter shanks was held 12mm clear of the disc (later increased to 15mm (C.J. Baker, pers.comm. 1982)) to allow passage of seed and fertiliser. The provision of separate seed and fertiliser placement was later shown to be advantageous in terms of reduced seed damage and improved seedling performance (Afzal, 1981). With the redeveloped

chisel coulter the seed and fertiliser were horizontally separated approximately 20mm. This was shown by Afzal (loc.cit.) to be of greater advantage in undisturbed soils than in cultivated soils.

2.4 Precision Seed Placement.

2.4.1 Crop factors.

Many authors have referred to the requirement for precision spacing of seeds in crop production with conventional tillage. While some of the evidence is conflicting generally there appears to be an advantage in spacing seeds accurately within the row in terms of total yield and yield components (Downey, 1971; Holliday, 1960, 1963; Colville, 1962; Colville and McGill, 1962; Gray, 1978; Daybell, 1980; Muldoon and Daynerd, 1982; Daynerd and Vyn, 1978; Krall et al., 1977). Most of the trials reported refer to grain crops and have shown small yield gains from controlled seed spacing compared with random seed spacing within the row. Few of the above authors however, had quantified spacing variation treatments. Daynerd and Vyn (loc.cit.) showed that gaps between corn seeds of up to a standard deviation of spacing of 210mm (which would have equated with a coefficient of variation = 0.84 based on their stated target spacing) had no effect on total grain yield.

Muldoon and Daynerd (loc.cit.) and Gray (loc.cit.) considered that environmental effects and seeder mal-adjustment in their experiments had had a greater effect on final yield than had absolute seeder spacing

accuracy. McLean (1974) referred to a "field factor" which described the various plant distribution influencing aspects of seed sowing and seedling establishment, many of which were largely uncontrollable. These factors included the following:

- "a) The state of the seedbed at the time of drilling and the conditions likely to occur immediately afterwards;
- b) The activities of insect, bird and animal pests;
- c) Drill performance and blockages; and
- d) The failure of germinated seeds to survive."

Both Gray (loc.cit.) and Wilson (1980) considered that the importance of seed spacing accuracy and population varied between crops. Relatively narrow intrarow - spaced crops such as maize had a greater compensatory growth ability according to Gray (loc.cit.) than did other widely spaced crops such as lettuce and some brassicas. Wilson (loc.cit.) suggested that a standard deviation of seed spacing of 20mm or less would be suitable for crops grown at a target mean spacing greater than 50mm. This would have corresponded to a maximum acceptable coefficient of variation of spacing of 0.40 (40%).

Clearly there has been some disagreement between authors as to the lower limits of acceptability of seed spacing, at least in cultivated soils.

2.4.2 Conventional precision spacing seed drills.

Daynerd and Vyn (1978) compared several commercial maize planters incorporating widely varying seed selection and deposition mechanisms. In cultivated soils the vacuum seeders were reported to provide the most even seed spacing of those tested especially at higher working speeds (12km.hr⁻¹). At 6km.hr⁻¹ the "Nodet pneumasem"* reportedly exhibited a standard deviation of spacing of 57mm (average for smooth and rough seedbeds) and 61mm at 12km.hr⁻¹ (smooth seedbed only), based on a target seed spacing of 240mm. If the target mean spacing was in fact achieved the above variations would have resulted in coefficients of variation of seed spacing of 0.24 and 0.25 respectively.

The factors leading to inaccuracy of seed spacing by precision drills were listed by Kuhnberg (McLean, 1974). These factors were as follows:

1. Selection of single seeds from bulk, when misses and multiples can occur and there is danger of damage to the seed;
2. Delivery, involving errors in seed release, and the danger of further seed damage;
3. Projection, when the characteristics of individual seeds may cause them to follow different trajectories;
4. Impact on the soil surface, when displacement due to bouncing and rolling can occur;

* manufactured by Nodet Gougis, France

5. Covering and firming of the seeds, when seed movement can be caused by soil movement;
6. Germination and emergence, when random losses can occur."

Bufton et al. (1974) and Wilson (1980) reported investigations into the effect of seed trajectory and impact in relation to release from seeder mechanisms. Seeds were allowed to impact onto two different soil types at known velocities and angles, and the amount of displacement due to bouncing and rolling was measured. The results showed that impact velocities and angles, the nature of the soil surface, and the seed type all affected both the magnitude of the mean displacement and the variability of that displacement. The displacement variability was considered by the authors to be as important as the magnitude of the displacement. This was apparently because if the deviation of the seed from its target position was constant, the resulting seed distribution would have been the same as if displacement had not occurred.

Impact angle was considered by Bufton et al. (loc.cit.) to be the result of the trajectory made by seeds after release from the metering mechanism, the trajectory itself being determined by the velocity and direction of movement of the seed and the height of the discharge point above the soil surface. The velocity at which seed was released was calculated to be the sum of the forward speed

of the drill and the peripheral speed of the metering mechanism. Wilson (loc.cit.) considered that in an ideal situation, if the peripheral speed of the metering mechanism was equal and opposite to the forward speed of the drill, no horizontal forces would have been exerted on the seed and it would fall vertically and not be displaced after contact with the soil. This author also considered that with many drill mechanisms the problem was reconciling the requirements of a slowly rotating seed selection mechanism (to ensure satisfactory "cell fill") with the requirement for a high seed discharge velocity to counteract the forward movement of the drill. These two requirements could only be met with current technology at unrealistically slow operating speeds. This principle led to the development of the National Institute of Agricultural Engineering two-stage seeder (Wilson, loc.cit.; McLean, 1979).

The relationship between seed displacement and impact angle was found by Bufton et al. (loc.cit.) to be similar for all seeds tested, which included pelleted and natural sugar beet, cabbage, carrot and lettuce seed. The minimum displacement was reported to occur when the impact angle was between 75 and 85 degrees. Light, irregularly shaped seeds, such as carrot and lettuce, were apparently least affected by changes in impact angle. McLean (1974) concluded that with regard to the irregularly shaped seeds, such as monogerm sugar beet, lettuce or carrot seed, the advantages of pelleting, (which was considered to improve

seed selection and cell fill in belt and cell type seeders) may have been lost by increasing the incidence of variability of displacement in the furrow. McLean concluded that precision drills incorporating pneumatic seed selection mechanisms, which did not require seeds of irregular shape to be pelleted, may have been preferable.

Wilson (loc.cit.) used a mathematical model to predict optimum release points for wheel type or circular arrangement seeders and belt type or linear arrangement seeders. For circular motion seeders he concluded the following:

(i) The peripheral velocity of the release mechanism should have been equal (and at bottom dead centre (BDC), opposite in direction) to the forward speed of the drill.

(ii) The height of the release point had very little effect on the placement error and impact angle for a given release error, but if impact velocity was to be kept as low as possible then the mechanism should have been kept as close to the ground as practicable. This also reduced the length of the seed flight path, which in turn reduced the magnitude of variations occurring during flight.

(iii) When release errors occurred, a reduction in the radius of the release mechanism caused increased impact angles. In this respect the study suggested that a wheel radius of between 70 and 100mm was optimum.

(iv) The optimum release point for a circular mechanism was dependant on the forward speed of the mechanism. At a reasonable drilling speed of 2-3msec-1

(7-11km.hr⁻¹) the optimum release point was considered to be 20 degrees before BDC.

2.4.3 Precision seed spacing direct drilling equipment.

The literature appears to contain few references to the performance of direct drilling machinery designed for the precision placement of seed. Phillips and Young (1973) and Baker (1981) described several machines that were commercially available in the United States. All those reported by Baker (loc.cit.) were apparently designed to give zero or minimum seed drop height. This was reported to be achieved either by tilling a narrow strip into which the seed was placed or removing the residue ahead or to either side of the seeder units, thus eliminating the residue problem. Baker suggested that removing the previous crop residue in the above manner was counter-productive to the moisture conservation and weed control advantages of residue retention and was only made possible mainly by the cultural practice of planting maize and soya beans (and other precision spaced crops) in wide rows (750mm). Dyson and Douglas (1978) considered that the planting of maize in wide rows continued because of tradition and the constraints of drilling, inter-row cultivation and harvesting equipment used. Douglas et al. (1971) had earlier reported a yield advantage from maize planted in 300mm wide rows with low intra-row populations compared with traditional 760mm rows at equivalent total populations. Phillips and Young (1973) suggested that narrower row spacings resulted in improved weed control.

The redeveloped chisel coulter (Baker et al., 1979a) was reported to exhibit effective residue handling even in 150mm row spacing while retaining crop residue directly over the seed groove. However, Baker (1979) noted that the design of the redeveloped chisel coulter would have made it difficult to release seeds at "zero" height. In support of this, Cox (1979) reported trials which used the redeveloped chisel coulter in such a manner that a pneumatic seed metering mechanism released seeds from above the coulter. Poor spacing accuracy was noted but not measured (T.I. Cox pers.comm., 1980).

2.5 Assessment of Seed Spacing Accuracy

Most quantitative assessment of precision seed spacing mechanisms that have appeared in the literature have been expressed in terms of measurements of seedling spacing (McLean, 1974; Daynerd and Vyn, 1978; Muldoon and Daynerd, 1982). However a few authors have attempted to quantify seed spacing variability.

Buften et al. (1974) reported a technique using high speed photography to record seed trajectory and bounce after release from a metering mechanism. From these measurements, a mathematical model was formulated to describe seeder performance in terms of a range of design and release characteristics.

Baker and Collins (unpublished data, 1970a) reported the use of a common procedure for evaluating precision seed spacing mechanisms involving drawing a specially coated adhesive paper under a stationary seeder unit. Seed spacing

was expressed as coefficient of variation of mean spacing distance. The technique was apparently later modified to incorporate the use of a stationary greased tray as the seed receptacle over which the moving seed unit passed (C.J. Baker, pers.comm. 1979).

3 Materials and Methods.

3.1 Selection of a direct drilling coulter.

In addition to operating features considered to be fundamental to any direct drilling coulter, the following special design criteria were considered in the selection of a direct drilling coulter on which to base this project:

- a) The coulter should provide a biologically non-limiting seed groove micro-environment.
- b) The coulter should be capable of operating efficiently in the presence of considerable crop residue without removing or deflecting the residue from the seed groove zone.
- c) Profile dimensions should permit adjustable row spacing within the range 150mm to 1m.
- d) The coulter should be capable of simultaneous but separated placement of fertiliser and seed.

From the literature, it appeared that an experimental chisel coulter developed at Massey University (Baker et al., 1979) was the only known device capable of fulfilling these functions. Its beneficial biological, residue handling and fertiliser placement characteristics have been well documented (Baker, 1976a,b; Choudhary, 1979; Baker et al. loc.cit.; Choudhary and Baker, 1980; Choudhary and Baker, 1981; Mai, 1978; Afzal, 1982). However, in handling residue in situ, the device limited the closeness with which the seeder could discharge seed above the ground. With coulters requiring less

physical size for residue clearance (such as those operating in cultivated seedbeds) seed can be discharged at "zero" drop height above the ground. Such an option is also open to direct drilling coulters which push the residue aside to expose bare soil. In this case, however, the requirement for narrow rows precluded design options which pushed the residue to either side of the path of the seeder in order to allow it to operate at ground level, as if in a cultivated soil. Besides such a design option (together with strip tillage) was considered to conflict with the biologically beneficial effects of residue retention which the chisel coulter was especially designed to achieve. The relatively narrow profile of the chisel coulter also permitted it to be incorporated into a narrow row prototype drill with 150mm row spacing without limiting its residue handling ability (Rennie, 1979).

3.2 Selection of a precision seed metering mechanism.

The following criteria were considered in the selection of a precision seed metering mechanism on which to base the project:

- a) Accuracy of seed spacing should be at least equivalent to that currently achieved by commercial conventional precision seed spacing mechanisms.
- b) Seed spacing should be easily adjusted.
- c) The seeder must maintain seed spacing accuracy at working speeds of up to 12km.hr⁻¹.
- d) The seeder must be capable of accurately singling and sowing a wide range of natural seed (without the need for seed pelleting).

A "Nodet Gougis Pneumasem II" vacuum seeder was chosen as a suitable seed metering mechanism. The "Nodet Gougis" seeder had been reported to provide accurate seed spacing at 12km.hr^{-1} (Daynerd and Vyn, 1978). It was also able to handle a wide range of seeds in an unpelleted state and exhibited a relatively narrow profile. Although 150mm inter-row spacing was not possible with this seeder (except in tandem configuration) there was no other known available vacuum or air seeder of these dimensions either.

An alternative vacuum seeder mechanism similar in working principle to the "Nodet" but with a very narrow profile, was under development at the Forestry Research Institute, Rotorua (T. Hedderwick, pers.comm. 1979) but was unavailable at the time of the project. The "Hassia Exactamat" vacuum seeder was also considered to exhibit acceptable performance (C.J. Baker, pers.comm. 1980) but its profile was even wider than the "Nodet Gougis", and was not as readily available.

A number of other seeders were considered, but rejected for use in this project, for the following reasons. The "Stanhay" belt seeder was considered unsuitable because of its requirement for pelleting of irregularly and non-spherical shaped seeds and its slow operating speed (5km.hr^{-1} maximum). The air pressure seeders, such as the "International Cycloplanter" and the "White Plant/Aire", had been previously tested at Massey University and found to be less accurate than the "Nodet Gougis" (Daynerd and Vyn, 1978; Baker and Collins, 1970b; C.J. Baker, pers.comm. 1980). This was considered to

be due to the effects of variation in operating air pressure with both seeders and the problem of seed bounce at the outlet, in the case of the "International Cycloplanter".

The "John Deere 400" plateless planter had also been tested at Massey University (Baker and Collins, 1970a) and the "John Deere Max-emerge" was tested in U.S.A. by Daynerd and Vyn (loc.cit.). The "John Deere" seeder was reported to maintain accurate spacing up to 12km.hr⁻¹ and effectively handled maize seed of varying grades. However, the "John Deere" seeder mechanism was designed principally to sow maize and soya bean seed, and was considered less adaptable to small seeds than those that operated on a vacuum principle.

3.3 Seed transfer system options.

Because direct drilling coulters appeared to necessitate large and robust construction and, at least in wide-row configuration, would most usefully be required to operate in previous crop residue, design option for seed release appeared to be limited to positioning the seeder unit somewhere above the coulter. This would result in a minimum seed drop height of 300mm for the redeveloped chisel coulter.

Before reaching this conclusion, a number of options for combining the two components, to otherwise ensure satisfactory seed transfer to the ground, were considered. These design options were as listed below:

3.3.1 Seeder/coulter combination on a common axle.

One means of fulfilling the requirement for "zero" seed drop height might have been to build the seed selection mechanism into the hub of the disc component of

the coulter unit. This option was rejected at this stage because of the potential mechanical complexity of such a design and the difficulty which was foreseen when changing or adjusting the seeder (e.g. spacing) and the coulter components. Furthermore it was felt that the increased bulk of such a design might hinder crop residue clearance and narrow row spacing.

3.3.2 Seed transfer through a tube.

As a method of seed transfer employed by most grain drills, the tube transfer system was considered to be a realistic alternative which was worthy of investigation, if for no other reason than because of its relative simplicity and low cost. Seed impact with the tube walls was considered to be potentially one of the major problems with this form of seed transfer.

3.3.3 Air-flow-assisted tube transfer.

Air-flow-assistance of the seed within a tube transfer system was also considered. Several commercial grain drills, and at least one precision spacing drill have incorporated an air distribution system. Spacing tests on an "International Cycloplanter" (C.J. Baker, pers.comm. 1981) and development work on precision spacing seed drills for forestry applications (T. Hedderwick, pers.comm. 1980) had indicated that loss of seed spacing accuracy occurred during the passage of seed within the tube and also at final ejection from the tube. Introduction of seeds of different shape and weight into an air stream without turbulent disturbance of seed flow appeared difficult

unless the seed was positioned within the air stream at the time of release. The differential intensity of air flow thought to be required for different seeds and the difficulty of decelerating the seeds when released from the tube to avoid bounce were also considered.

3.3.4 Electrostatic charging of seeds for tube transfer.

The major limitation to transporting seeds within a mechanical tube was considered to be the unpredictable impacts which seeds might be expected to have with the tube walls. Variation in the number of impacts and also the incident angle of those impacts could be expected to cause variation in the time taken for individual seeds to travel through the tube. Elimination of all collisions between the seed and the tube might therefore be expected to improve seeding accuracy. One possible method for avoiding wall impact may have been to impose similar electrostatic charges on the seed and the tube walls. The seeds might therefore have been induced to travel within the weakest part of the symmetrical electrostatic field (the centre of the tube). On the other hand the intensity of the charge needed on the seed and/or the tube might have been expected to vary with seed size, shape and weight, and might therefore have been difficult to control in a field drilling situation.

Although the potential of this alternative as a transfer mechanism for precision direct drilling equipment was not investigated further in this study it was felt to hold sufficient promise to be worthy of further

investigation in the event of rejection of all of the more simple and potentially inexpensive alternatives.

3.3.5 Fluid drilling.

Salter (1978) described techniques for pre-germinating vegetable crop seed under controlled conditions, and selecting and drilling the viable seed incorporated with a viscous gel. The fluid drilling system was considered to be potentially suited to this precision direct drilling project. Seed suspended in the carrier gel could have been pumped in the normal manner through a delivery tube incorporated in the coulter. However the cost of the whole system and limited application and availability precluded its use at this time. Nevertheless, should the fluid drilling technique become commercially widespread at a reasonable cost, and seed metering aspects prove to be acceptable, its incorporation into at least the redeveloped chisel direct drilling coulter could be relatively simply achieved.

3.3.6 Wheel and belt transfer systems.

None of the tube alternatives considered above could have been expected to make provision for the release of the seed with a velocity equal, and in the opposite direction, to that of the drill. Wilson (1980) had shown that velocity and trajectory of the seed after release from the selection mechanism had a considerable effect on final seed placement accuracy. He devised a counter-rotating transfer wheel which accepted seed from the seed selection wheel (which was rotating at a slow speed to facilitate cell

fill). The transfer wheel was rotated at a speed proportional to the ground speed of the drill. As a result the seed was finally released with a velocity equal to that of the ground speed but in the opposite direction. Incorporation of such a wheel into the redeveloped chisel direct drilling coulter was felt to be impractical due to the physical bulk of such a wheel in relation to the constraints of the coulter design. For example, such a transfer wheel would have had to be approximately 300mm in diameter.

On the other hand as a possible means of overcoming the large drop-height problem and at the same time providing a means of controlling the ejection velocity and direction of the seed, a notched belt transfer mechanism was considered to offer similar principles to the transfer wheel described by Wilson (loc.cit.). In common with the wheel transfer system it was envisaged that the seed selection mechanism could release individual seeds into cells on a flexible rubber belt, phased to correspond with the holes in the selection plate of the seeder. Once in the cells the seeds could be carried down to the base of the coulter where they could be released with a controlled reverse trajectory at "zero" drop height. Such a belt would need to be only slightly wider than the largest seed to be sown. Certainly a belt width of 15mm was feasible within the constraints of the redeveloped chisel coulter design. In addition, because of the flexible nature of such a belt, the space required for its emplacement in the

coulter body could be much reduced when compared with a symmetrical wheel. Furthermore, with a belt transfer system it was considered that the height of the seed selection mechanism above the ground would not be dictated by (or indeed would itself dictate) the wheel diameter.

The belt transfer system was considered to be potentially the most predictable and accurate alternative of the transfer mechanisms considered. However it was also considered to be mechanically more complex than a simple tube transfer system, with or without air or electrostatic assistance. Besides development work at the Forestry Research Institute aimed at designing a vacuum seed selection mechanism combined with a belt transfer system was already in progress (T. Hedderwick, pers.comm. 1981). Comparative testing of equipment resulting from that project was planned as part of the present study. However the equipment did not become available in time to be included in this study.

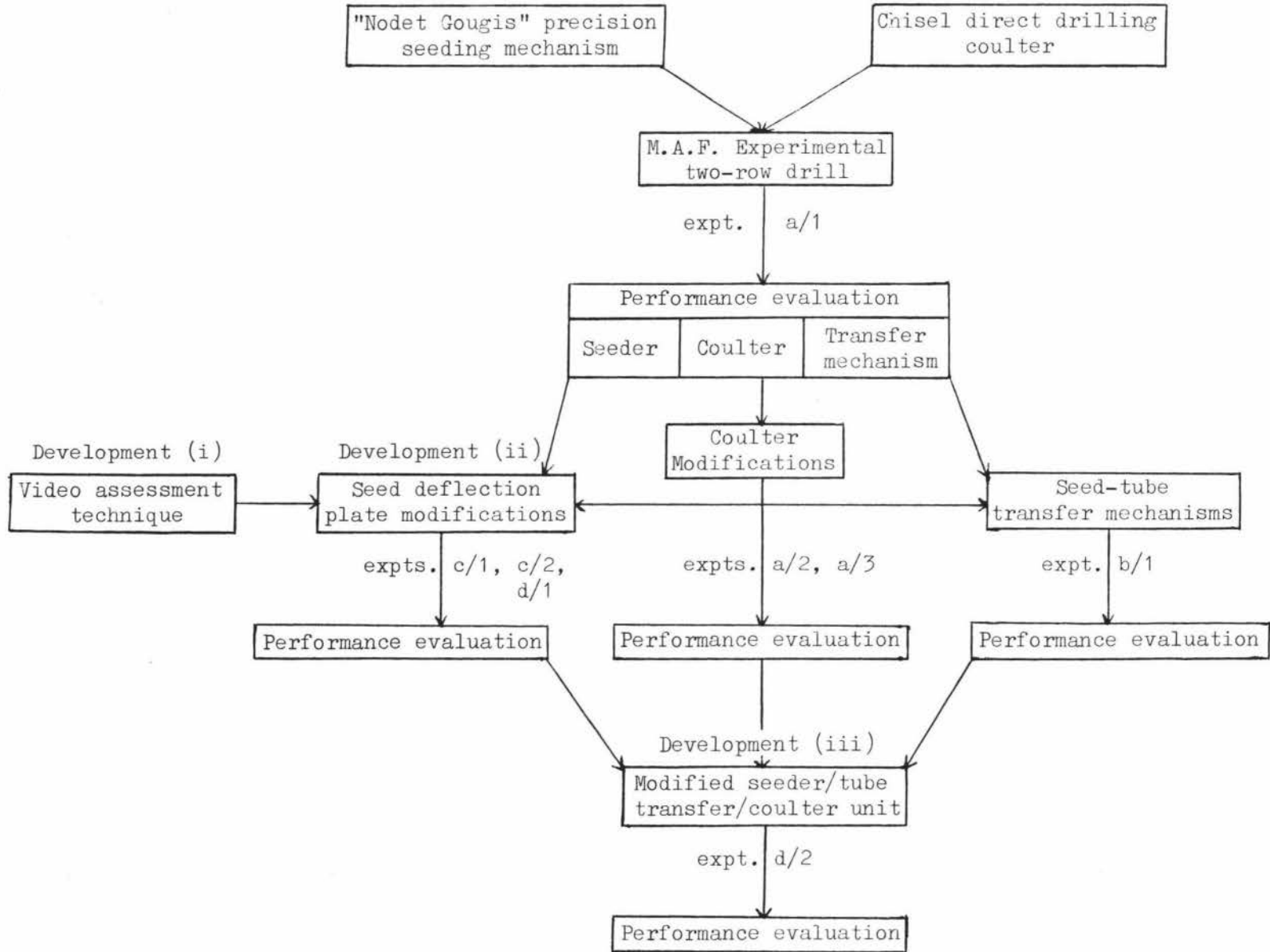
3.4 Experimentation and Development.

Experiments.

The study consisted of four main areas of investigation which resulted from (and resulted in) a number of developments and modifications made to the componentry under examination (fig. 1). The four main objectives of the experiment were as follows:

- a) To examine the influence of the existing redeveloped chisel direct drilling coulter on seed placement performance in the laboratory and in different soil

Figure 1 : Experimentation and Development



conditions (see 3.4.1 below).

b) To evaluate simple mechanisms for transferring seeds from the metering mechanism to the soil through the chisel direct drilling coulter (see 3.4.2 below).

c) To evaluate modifications made to the seeder in order to improve the accuracy of seed transfer accomplished by a tube (see 3.4.4 below).

d) To re-examine the potential seed placement performance of the redeveloped chisel direct drilling coulter, suitably modified in the light of objectives a-c above (see 3.4.6 below).

Developments.

In pursuing these main objectives a number of developmental modifications became necessary. The aims of these modifications were as follows:

(i) To develop a simple and repeatable experimental technique for reflecting the individual and inter-active performances of seeding and seed transfer mechanisms (see 3.4.3 below).

(ii) To modify the "Nodet Gougis" seeder release characteristics in order to improve its suitability for seed release into a simple tube seed transfer system (see 3.4.5 below).

(iii) To modify an existing redeveloped chisel direct drilling coulter in order to incorporate a simple tube seed transfer system (see 3.4.7 below).

Both laboratory and field experimental techniques were used in pursuing the above objectives. The specific experiments conducted to fulfill each one of the listed objectives are detailed below.

3.4.1 Objective (a) - Experimental drill evaluation.

An experimental two-row direct drill, built by the Ministry of Agriculture and Fisheries Horticultural Research Centre in conjunction with the Agricultural/Horticultural Mechanisation section, Massey University, was tested in order to gain an understanding of the magnitude of the seed transfer problem. This machine had been used in agronomic experiments with horticultural and processed vegetable crops (Cox, 1979) and problems with seed spacing had been noted (T.I. Cox, pers.comm. 1980). The chisel coulter used in the experimental drill was essentially the same as that described by Baker et al. (1979) except for modifications made to some above-ground componentry in order to fit a "Nodet Gougis" vacuum seeder unit. The modifications were not considered to have affected the biological performance of the chisel coulter.

3.4.1.1 Experiment a/1 (Laboratory Experiment).

A laboratory experiment sought to determine the relationship between the seed spacing accuracy of a conventional "Nodet Gougis" pneumatic seeder unit in isolation and the performance of an identical unit positioned above the modified chisel coulter. Both units were mounted simultaneously on the two row experimental machine, which was itself mounted on the

three-point-linkage of a wheel tractor. Vacuum for the pneumatic seeder units was supplied by a fan driven by the power-take-off of the tractor.

A 6m by 140mm tray containing a 30mm layer of petroleum jelly was placed on a level concrete floor over which the tractor and test rig was driven. Seeds were released from the conventional seeder with a free drop of 80mm above the greased surface (fig. 2). Identical treatments were applied to the modified chisel coulter test unit with the "Nodet Gougis" seeder mounted above. In this case the seed, after release from the seeder unit, travelled down the entire length of the coulter blade between the blade and the rotating central scalloped disc, a vertical distance of 300mm. For the purposes of this laboratory experiment, the central scalloped disc (400mm diameter) of the modified chisel coulter was replaced by a plain disc (390mm diameter). This was done to overcome an anticipated problem of the seed path being affected by random seed contact with the scallops on the periphery of the disc, an affect that would not be expected to occur in field operation since the scalloped portion of the disc would normally be imbedded in the soil beneath the seed. In the absence of soil, the plain disc was fixed to an extended axle to which a second identical plain disc was fixed. The distance between the two discs was 200mm. A 200mm by 50mm plank was placed adjacent to the greased tray on which the second disc on the extended axle rolled (fig. 3). This caused the central disc of the chisel coulter

Figure 2: Positioning of the conventional "Nodet Gougis" seeder above the greased tray (experiment a/1).



Figure 3: Experimental direct drilling unit modifications for laboratory experiment a/1.



to rotate at an identical speed 40mm above the greased surface, which simulated the movement of such a disc in the soil. The coulter blade was held against the disc by a clamping bolt to simulate the force exerted by the soil (fig. 3). Such a close association between the coulter blade and the disc was reported as being essential for the trash clearance function of the assembly in normal field operation (Baker, et al. 1979). The point at which seeds were released from between the disc and the coulter blade was 80mm above the greased surface.

Experimental design.

Three seed types and sizes (maize grade 3F; lupin variety Kali and sub-terranean clover) and three ground speeds (5, 8, 11km.hr⁻¹) were selected as main treatments. These seed types were chosen in order to give a range of seed size and shape from a small round seed (sub-terranean clover) through to a large irregularly shaped seed (maize). The speed treatments corresponded to:

(i) the accepted field drilling speed for belt type precision seeders (5km.hr⁻¹);

(ii) the accepted field drilling speed for vacuum type precision seeders, (8 km.hr⁻¹) and;

(iii) the speed approaching that reported to be achieved by the NIAE seeder utilizing the principle of seed transfer, without adversely affecting spacing variability (11km.hr⁻¹).

Three 6m replicates in time were used for maize and lupin at all three speeds with nominal seed spacing of 100mm. With sub-terranean clover, three 3m replicates in time were used at all three speeds where nominal seed spacing was 50mm. Plot size was selected to total sixty seeds per plot.

Treatments and replicates were not conducted in a randomised sequence. This was because of the mechanical difficulties in detaching the seeder from the coulter unit and the difficulty in achieving repeatable seeder performance when it was continually adjusted for different seed types and different speeds. Instead it was considered to be more realistic and accurate to standardise on a single adjustment of the seeder for each seed and forward speed and to perform all replicates at this setting before changes were made. In any case each replicate was a repetitive mechanical function which did not depend on biological parameters which were likely to alter between runs. The only biological parameter involved was seed selection and the "Nodet Gougis" seeder had previously been shown to avoid selective rejection of particular seed sizes within limits (C.J. Baker, pers.comm. 1980). Nevertheless the remote possibility exists that undetected mechanical changes between runs may have affected results, but no account has been taken of this.

3.4.1.2 Experiments a/2 and a/3 (Field experiments).

There were two main objectives in the field experiments:

- a) To determine the performance characteristics of the test direct drill in a selection of different ground conditions.
- b) To assess the relationship between laboratory and field performance testing techniques.

Two separate experiments were conducted, one using undisturbed pasture and the other using barley stubble as examples of contrasting soil conditions. The latter area had been cultivated during the previous spring. The test drill with one coulter/seeder unit was used in autumn to drill into plots in each of these experiments. In these experiments the modified chisel coulter was refitted with its original 400mm diameter scalloped disc.

Plots in the pasture experiment were pre-sprayed with glyphosate herbicide at an application rate equivalent to 5 l.ha⁻¹ seven days prior to drilling. Plots in the crop stubble experiment were mown to an even standing stubble height of approximately 50mm and all loose straw was removed. Baker et al. (1979) had reported that windrowed barley straw had caused coulter blockages with the chisel coulter and therefore it was considered necessary to remove the loose straw from the trial site. To facilitate straw removal it was

necessary to mow the stubble to an even height.

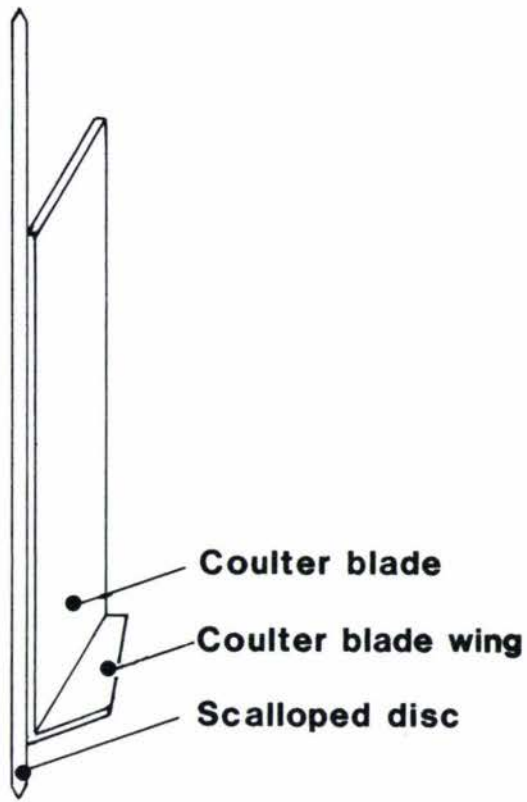
The drilling treatments imposed consisted of the following seed selection and mechanical design options:

a) The redeveloped chisel coulter blade in its original form which included the wing portion protruding from the shank base at 90 degrees but inclined fore and aft approximately 5 degrees from horizontal (fig. 4).

b) A modified version of the redeveloped chisel coulter blade which included the wing portion protruding from the shank upwards at 45 degrees but still inclined fore and aft 5 degrees from horizontal (fig. 4).

c) The addition to the test chisel coulter assembly of a disc scraper positioned against the disc and in the gap between this component and the coulter blade. This thin metal shield extended 100mm horizontally rearwards from the rear edge of the blade. This scraper was designed to prevent soil which adhered to the disc, being carried vertically with the movement of the disc and possibly affecting seed placement (fig. 5). Such an occurrence had been thought to occur in some sticky soils (T.I. Cox, pers.comm. 1981), although Baker (C.J. Baker, pers.comm. 1981) has since isolated the problem to one of seed ejection from the rear of the area between the coulter blade and disc and suggested that this was only partly dependant on

Figure 4: Redeveloped chisel coultter blade
(a) 90° wing



(b) 45° wing

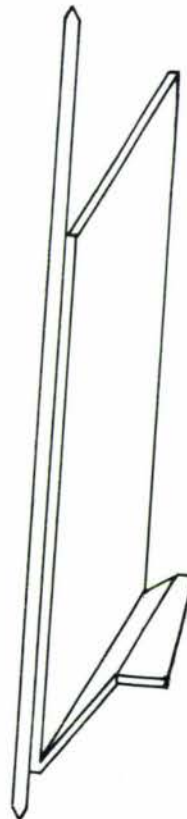
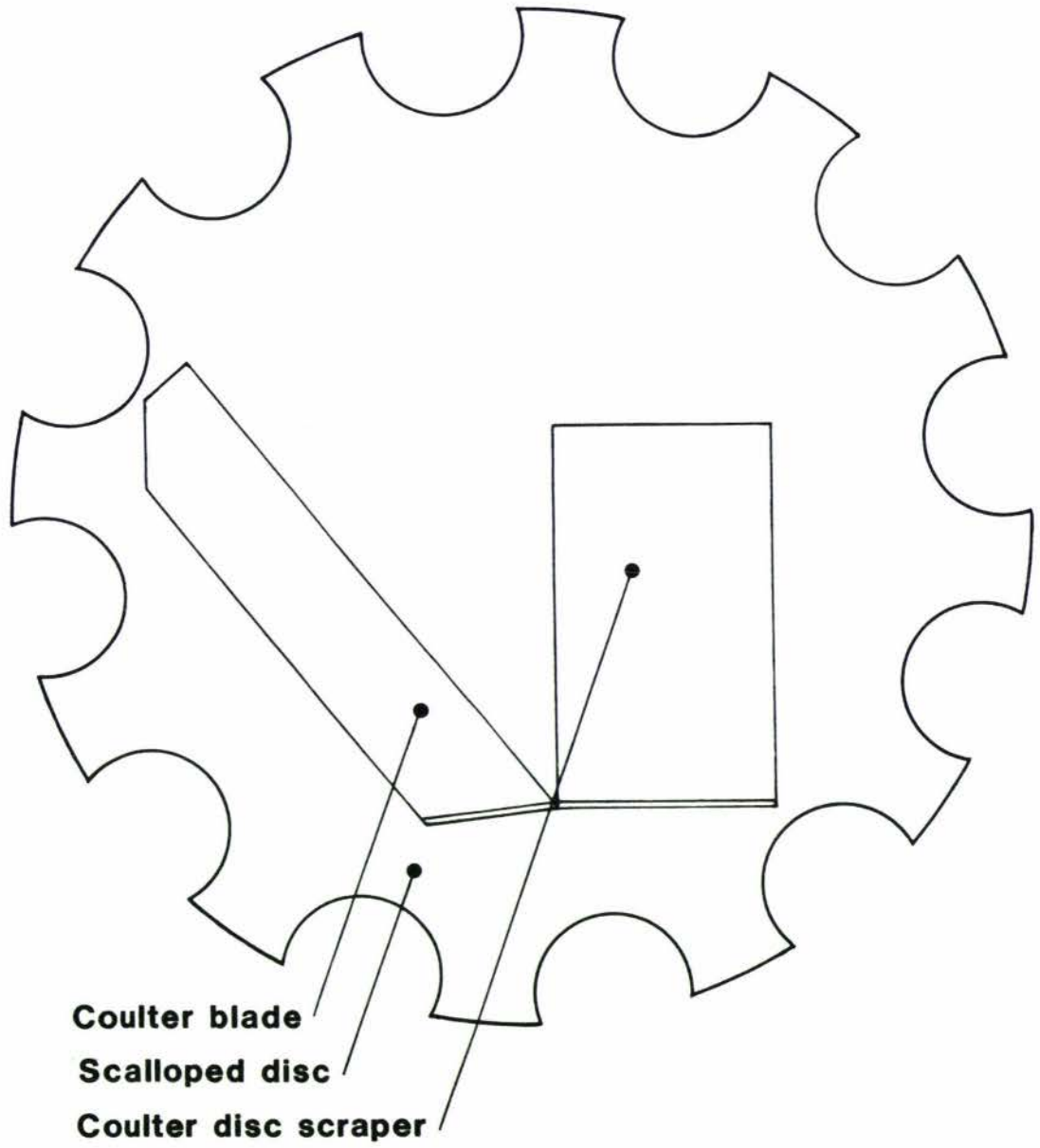


Figure 5: Redeveloped chisel coulter with disc scraper modification.

Note: Axle housing and seed delivery componentry is not shown.



soil sticking to the disc.

d) Three seed varieties -maize

-lupin

-sub-terreanean clover,

being identical to those used in the laboratory experiment.

Experimental design.

The experimental design was a complete randomised block with three replicates for each experiment (figs 6 and 7).

One 10m row per plot was drilled at a constant speed (8km.hr^{-1}) for all plots. The molluscicide methiocarb was applied to all plots by surface broadcasting at approximately 10kg.ha^{-1} in an attempt to avoid slug damage. Adequate moisture levels were maintained in both the pasture and crop stubble plots throughout the experiment.

Measurements.

Seedling number and intra-row seedling spacing was measured 15 days after emergence. The number of seedlings laterally displaced from the seed groove was also recorded.

Recording the position of emerged seedlings in the field was considered to give only an approximation of seed placement in the soil at the time of drilling. The technique was unable to take account of seeds that had not germinated, nor of

Figure 6 : Plot Layout of Field Experiment - Pasture (experiment a/2)

Block A

Plot No.	Treatment
1	Lupin/45 ⁰ /NoScr.
2	Maize/90 ⁰ /Scr.
3	S.Clov./45 ⁰ /Scr.
4	S.Clov./90 ⁰ /Scr.
5	Lupin/45 ⁰ /Scr.
6	Maize/45 ⁰ /NoScr.
7	Lupin/90 ⁰ /Scr.
8	Maize/45 ⁰ /Scr.
9	Lupin/90 ⁰ /N.Scr.
10	S.Clov./90 ⁰ /N.Scr.
11	S.Clov./45 ⁰ /NoScr.
12	Maize/90 ⁰ /NoScr.

Block B

Plot No.	Treatment
1	Maize/45 ⁰ /Scr.
2	Maize/90 ⁰ /Scr.
3	S.Clov./45 ⁰ /NoScr.
4	Maize/45 ⁰ /NoScr.
5	S.Clov./45 ⁰ /Scr.
6	S.Clov./90 ⁰ /NoScr.
7	S.Clov./90 ⁰ /Scr.
8	Lupin/90 ⁰ /NoScr.
9	Lupin/45 ⁰ /NoScr.
10	Lupin/90 ⁰ /Scr.
11	Maize/90 ⁰ /NoScr.
12	Lupin/45 ⁰ /Scr.

Block C

Plot No.	Treatment
1	Lupin/90 ⁰ /NoScr.
2	Lupin/90 ⁰ /Scr.
3	S.Clov./45 ⁰ /NoScr.
4	S.Clov./45 ⁰ /Scr.
5	Maize/90 ⁰ /Scr.
6	Maize/45 ⁰ /NoScr.
7	Maize/45 ⁰ /Scr.
8	Lupin/45 ⁰ /NoScr.
9	S.Clov./90 ⁰ /NoScr.
10	Maize/90 ⁰ /NoScr.
11	Lupin/45 ⁰ /Scr.
12	S.Clov./90 ⁰ /Scr.

Figure 7 : Plot Layout of Field Experiment - Crop Stubble (experiment a/3)

Block A

Plot No.	Treatment
1	Maize/45°/N.Scr.
2	Maize/90°/N.Scr.
3	S.Clov./90°/N.Scr.
4	S.Clov./45°/N.Scr.
5	Lupin/90°/N.Scr.
6	S.Clov./90°/N.Scr.
7	Lupin/45°/Scr.
8	Maize/45°/Scr.
9	Lupin/90°/Scr.
10	Maize/90°/Scr.
11	S.Clov./45°/Scr.
12	Lupin/45°/NoScr.

Block B

Plot No.	Treatment
1	Maize/45°/N.Scr.
2	S.Clov./90°/N.Scr.
3	Lupin/45°/Scr.
4	S.Clov./45°/Scr.
5	Lupin/90°/Scr.
6	Maize/90°/Scr.
7	Maize/90°/N.Scr.
8	Lupin/45°/N.Scr.
9	Maize/45°/Scr.
10	Lupin/90°/N.Scr.
11	S.Clov./45°/N.Scr.
12	S.Clov./90°/Scr.

Block C

Plot No.	Treatment
1	S.Clov./45°/N.Scr.
2	S.Clov./90°/N.Scr.
3	Lupin/90°/N.Scr.
4	S.Clov/90°/Scr.
5	Maize/45°/Scr.
6	Lupin/45°/Scr.
7	Lupin/45°/N.Scr.
8	Maize/90°/Scr.
9	S.Clov./45°/Scr.
10	Lupin/90°/Scr.
11	Maize/90°/N.Scr.
12	Maize/45°/N.Scr.

those which germinated but did not emerge, although the latter category had earlier been shown to be only a minor problem with the chisel coulter, even in sub-optimal soil moisture conditions (Baker, 1976a; Choudhary and Baker, 1981). Even those seedlings which did emerge did not necessarily reflect the original positioning of their seeds because of deflection of the growing tip during emergence. Because it was felt that this latter factor could have been effected differently by the contrasting soil conditions the two different seedbeds (pasture and stubble) were tested separately. Experiment a/2 was therefore conducted in pasture, and experiment a/3 was conducted in barley stubble. Collectively, this range of possible effects discussed above had been referred to by McLean (1974) as "field factors". As this reflected all of the factors involved (even if it was not able to isolate each factor) it was considered to be realistic to measure seedling spacing as a method of assessing drill spacing in the field, especially where direct comparisons with laboratory studies could be made.

It might have been useful to devise a technique for locating the drilled seeds in situ. Attempts to physically locate seeds by removing the soil from above them almost inevitably resulted in movement of the seeds from their original position. On the other hand, Barr (1981) reported a technique which used

x-ray equipment to locate seeds in undisturbed soil blocks. However this technique was not sufficiently developed to be of use in this study. Besides, because the x-ray technique was partially destructive, it would have been difficult to take account of any differences in positioning of seeds and their corresponding seedlings as a function of the influence of overlying soil and competition.

3.4.2 Objective (b) - Evaluation of simple seed transfer alternatives.

The previous laboratory and field experiments (expts a/1, a/2 and a/3) had confirmed the spacing inaccuracy of the test coulter unit first noted by Cox (pers.comm. 1980). A second laboratory experiment was therefore designed to evaluate various simple tube transfer systems for possible combination with the "Nodet Gougis" seeder and the redeveloped chisel coulter. It was considered that if the pathway of seeds between the moving disc and stationary coulter blade could be replaced by a more predictable pathway, a reduction in seed spacing variation might result.

3.4.2.1 Experiment b/1 (Seed-tube transfer).

A laboratory tillage bin rig which was first described by Baker (1976a), was modified to test the seeder and transfer mechanism in isolation. The rig consisted of two supported parallel rails 10m in length which in their original form provided a bed for a number of 2m long soil bins. A moving gantry was designed to

straddle these bins, to which various direct drilling coulters were normally attached. For the purposes of this experiment a "Nodet Gougis" seeder unit was mounted on the special gantry. The seeder mechanism was driven by a single-phase electric motor and gearbox at 25rpm. Vacuum for the seeder was provided by a PTO driven, tractor-mounted vacuum pump.

A 3m by 140mm tray containing a 30mm layer of petroleum jelly was positioned on guide rails on the support bed in such a way that it could be moved in a sliding motion parallel with the tillage bin rails and in so doing passed below the seeder unit. The greased tray was connected to the variable speed chain drive of the tillage bin rig by a special bracket which replaced the usual drive to the movable gantry. The stationary seeder unit was operated with a peripheral plate speed of 0.12m.sec⁻¹.

Five replicates in time of each of the following treatments were conducted:

- Main treatments:- maize seed (grade 3F)
- pea seed (variety "Huka")
 - ball bearings (3mm diameter)

Ball bearings were used in this experiment in preference to sub-terranean clover (as used in experiments a/1, a/2 and a/3) in an attempt to isolate the effects of variable seed shape and weight.

Sub-treatments: a) Free "seed" drop from 80mm

above the greased tray. This corresponded to the height at which seeds are released from a conventional precision seeder operating in cultivated soil.

b) Free "seed" drop from 300mm above the greased tray. This corresponded to the minimum height at which seed would have to be released if a seeder was to be placed above the chisel direct drilling coulter.

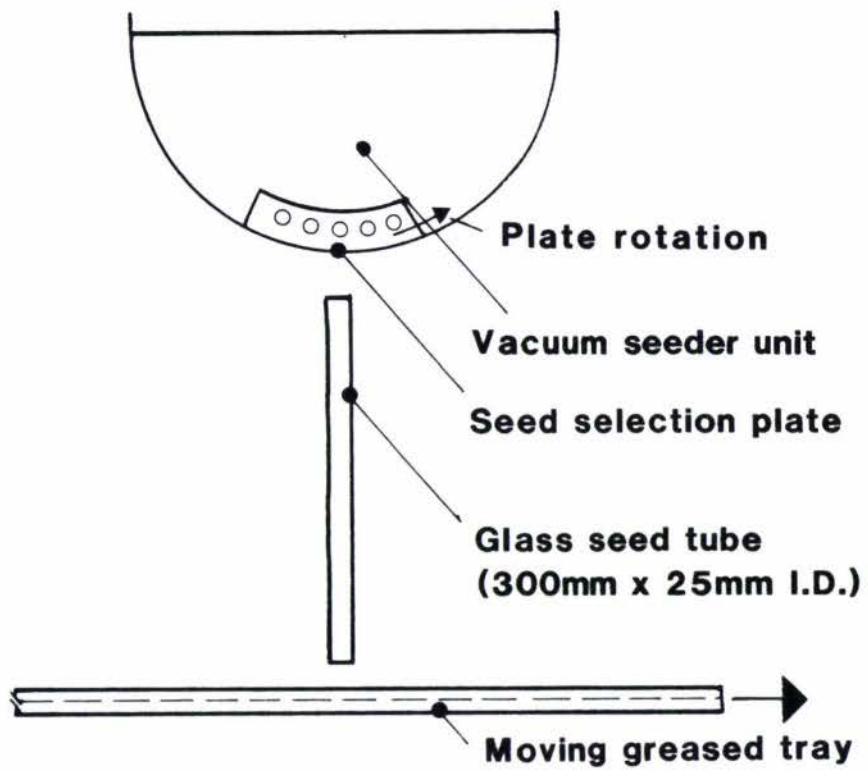
c) "Seed" drop through a straight, vertical seed tube made of glass (25mm inside diameter) from 300mm above the greased tray (fig. 8). This treatment and the following three treatments were considered as possible options for combining a simple seed-tube transfer system with the chisel direct drilling coulter.

d) "Seed" drop through a glass seed tube (25mm inside diameter), curved with a radius of curvature of 250mm, through a total angular change of 50 degrees from the vertical. The tube was positioned to curve in the opposite direction to the tray movement with the "seeds" introduced in such a way that they were induced to slide around the outside of the curve (fig. 8).

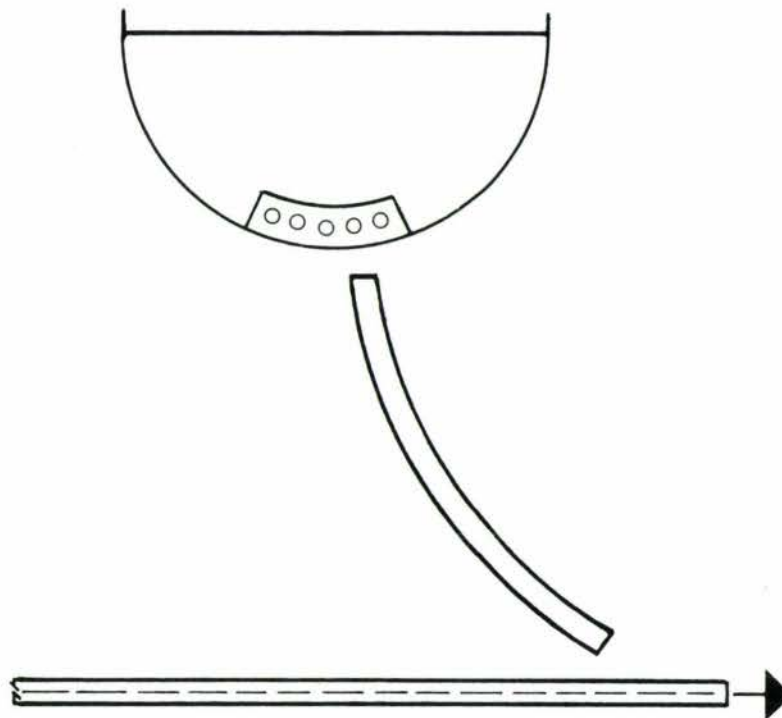
e) "Seed" drop through a curved glass seed tube (25mm inside diameter), with a radius of curvature of 250mm, through a total angular change of 50 degrees from the vertical.

Figure 8: Seed-transfer tube configuration.

(a) Straight vertical seed tube



(b) Curved seed tube.



The tube was positioned to curve in the same direction as tray movement with the "seeds" introduced in such a way that they were induced to slide around the curve.

f) "Seed" drop through a curved glass seed tube (25mm inside diameter), with a radius of curvature of 25mm, through a total angular change of 50 degrees from vertical. The tube was positioned to curve in the opposite direction to tray movement with the "seeds" introduced in such a way as to cause them to bounce off the tube inner walls.

Random seed impact with the tube walls had been considered to be potentially a major problem with the tube seed transfer system. Therefore treatments d and e described above were imposed in an attempt to overcome this problem. Nevertheless, differences in seed shape and size had been predicted to result in differential friction coefficient values between seeds of any one variety which might partially negate the predicted beneficial effects of reduced random seed bounce.

Glass seed tubes were used to facilitate visual monitoring of seed movement and to provide a polished surface within the tube. Clearly a polished inner surface would be difficult to maintain in the field, but it was felt to be realistic to firstly establish the performance of an "ideal" surface before attempting

field evaluation. The glass tubes were suspended under the seeder unit using a special bracket (fig. 9).

3.4.3 Development (i) - An experimental technique for assessing seeder/transfer mechanism interaction.

A problem with the "Nodet Gougis" seeder which was highlighted by the initial tube transfer mechanism laboratory experiment (expt b/1) was the variability that occurred at the time of release of the seeds. This variability in release time was thought to occur as a result of the differential vacuum holding each seed to the plate and the difference in time taken for that vacuum to reduce sufficiently to release the seed. "Leakage" of air past the seeds (resulting in differential vacuum) was thought to arise from variations in seed shape and size. The results obtained in the previous laboratory experiment, using ball bearings, indicated that constant seed shape and weight may assist seeder performance. Consequently seeds with different release trajectories were observed to enter the seed tubes tested at different points and with varying horizontal and vertical components of velocity. This made it difficult to position a seed tube in such a way as to obtain a constant seed path down the tube, such as with all seeds sliding around the outside of a curved tube.

In order to evaluate the effectiveness of seeder modifications in overcoming the above problem it was necessary to develop a technique for recording seed trajectory. A technique described by Bufton et al. (1974) using high speed photography to trace seed path after

Figure 9: Attachment of the seed-transfer tube to the "Nodet Gougis" seeder.



release from a precision seeding unit was considered but not used in this project due to cost, time and difficulty in identifying individual seeds. Consequently a simplified technique which would provide instantaneous results at relatively low cost was considered necessary.

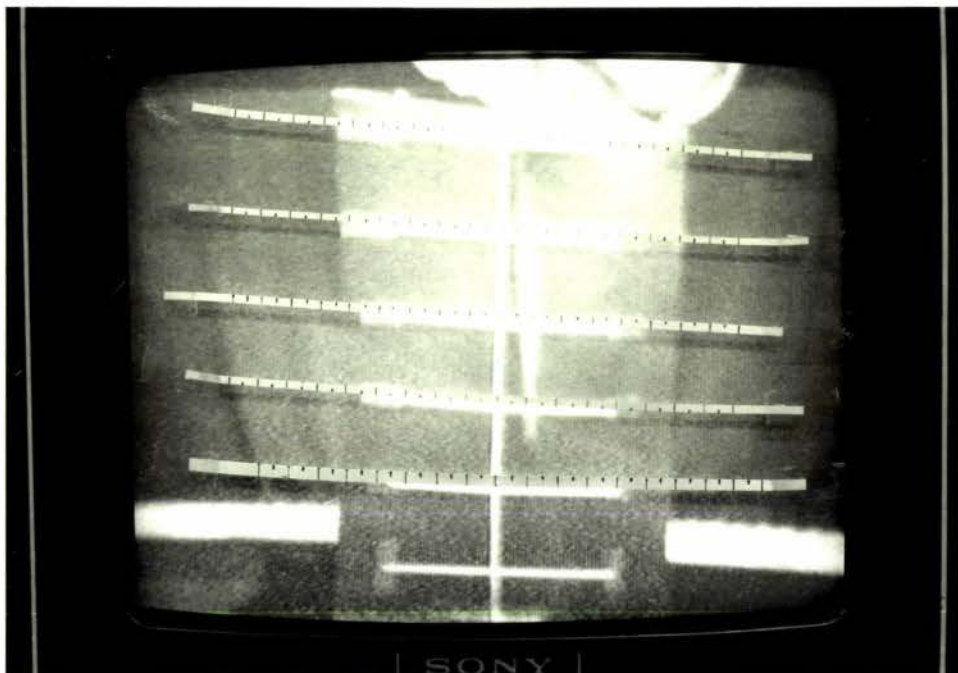
A V.H.S. colour video recording system incorporating a camera (JVC - GX77E) and recorder (JVC - HR2200) were used to record seed release and resulting trajectory from a seeder mechanism positioned on the special gantry described in 3.4.2 above (fig. 10). A grid was placed behind the path of the seeds as a positional reference. Each treatment was video recorded at normal camera speed and replayed using the slow motion "frame by frame" mode video playback. Reference lines corresponding to the grid were superimposed on the screen of a 325mm colour video monitor (fig. 11). This enabled a quantitative assessment of seed trajectory to be made for each seed by recording its position as it crossed each of the five horizontal reference lines which were equally spaced in the vertical plane over the 300mm drop zone.

In order to gain acceptable definition of the seed path on the video monitor, a large, distinctive seed variety had to be used together with high intensity, lighting and a black mat-finish background. Lupin seed (variety Kali) was chosen because of its large size and light colour and also its irregular shape. Using white seeds against a black background was found to provide a sharper definition on the video monitor than did black

Figure 10: Video recording apparatus.



Figure 11: Video monitor reference lines.



seeds against a white background.

Both the longitudinal and the lateral components of the free drop seed trajectory from a seeder were able to be recorded by changing the camera position relative to the seeder.

3.4.4 Objective (c) - Evaluation of seeder release characteristics.

The following separate experiments were conducted in order to evaluate various aspects of seed release from vacuum seed selection mechanisms:

- a) Comparison of an alternative vacuum seeder, which featured a different seed-release mechanism, with the unmodified "Nodet Gougis" seeder (see 3.4.4.1).
- b) Comparative evaluation of a number of modifications made to the seed-release mechanism of the "Nodet Gougis" seeder and the effect of varying plate speed on the seed-release characteristics (see 3.4.4.2).

3.4.4.1 Experiment c/1 (Seed cell release).

The seed release trajectory characteristics of a "Nodet Gougis" seeder and a "Hassia Exactamat" seeder were tested using the video technique. The "Hassia Exactamat" seeder operated with a similar vacuum selection principle to the "Nodet Gougis". However in the case of the "Hassia" each seed, once selected, was transferred to an individual cell before release rather than being released directly from the vacuum selection mechanism, (as was the case with the "Nodet"). It was

considered that the "Hassia" system may have provided a more consistent seed path after release due to the elimination of the differential vacuum release effect that was thought to have been causing release variations with the "Nodet Gougis" seeder. Even so, Daynerd and Vyn (1978) had noted problems with random variations in the rate with which seeds "tumbled" from a seed delivery pocket or cell.

Experimental design.

Both seeders were tested in an unmodified state. A sample of approximately sixty seeds was video recorded as described in 3.4.3. Seed position was determined at each of five horizontal reference lines spaced at 50mm intervals vertically below the seed release point. The top reference line was placed approximately 50mm below the seed release point. Seed path from the release point to the top reference line was unable to be detected clearly enough on the video monitor to provide accurate information on the actual point of seed release and the initial path taken by the seed. However, it was considered that variation in seed release time and initial seed path would be reflected in the subsequent seed trajectory through the reference area. Furthermore it was to this resultant seed path that a tube transfer system was sought to be matched.

3.4.4.2 Experiment c/2 (Seed deflection mechanisms).

Results from the previous experiment indicated that there may have been potential for reducing the variation in trajectory with which seeds were released from the "Nodet Gougis" seeder. Various seed deflection mechanisms (as will be described in 3.4.5 below) were developed and tested using the video technique previously described.

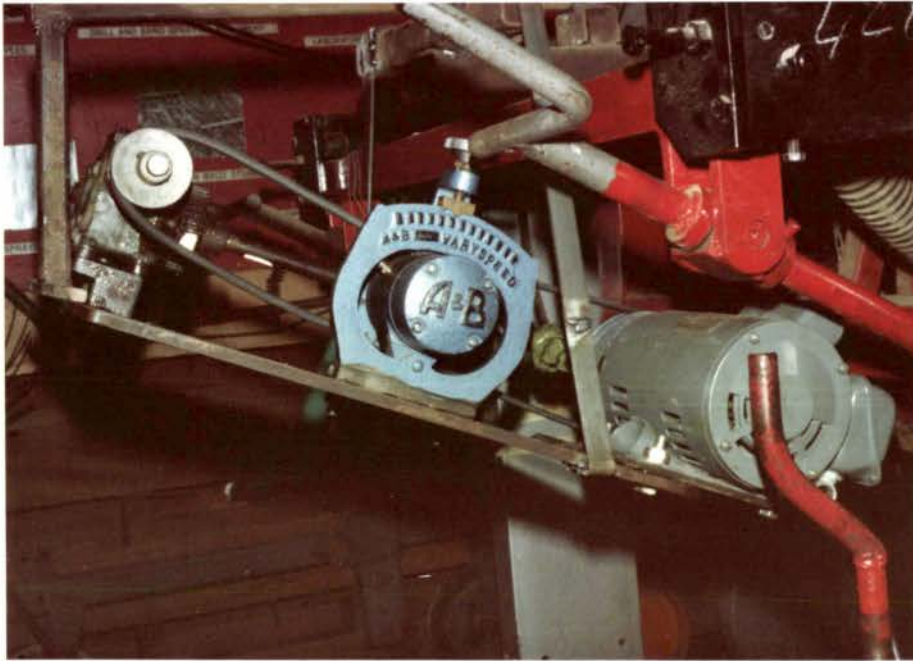
The 40 degree and straight seed deflector plates fitted to the "Nodet Gougis" seeder had appeared to have improved the release trajectory of the lupin seed at a peripheral plate speed of $0.12\text{m}\cdot\text{sec}^{-1}$. In order to determine the interrelationship between plate speed and the seeder modifications, peripheral plate speed was also increased to $0.36\text{m}\cdot\text{sec}^{-1}$.

The slow speed electric motor used to drive the seeder unit in Experiment b/1 was replaced with a 0.18kW single phase electric motor (shaft speed 1420rpm). A variable speed vee-belt drive system, combined with a 30:1 reduction gearbox, provided an infinitely variable seeder input shaft speed of between 40rpm and 140rpm (fig. 12).

Experimental design.

The video recording technique, as previously described, was used to evaluate seed release trajectory characteristics of the "Nodet Gougis" seeder at the two plate speeds; in its unmodified form and also with a 40 degree seed deflector plate

Figure 12: Variable speed seeder drive mechanism.



and a straight seed deflector plate fitted (as described in 3.4.5 below). A sample of approximately forty seeds for each treatment was recorded and analysed in the same manner as described in 3.4.4.1 above.

3.4.5 Development (ii) - "Nodet Gougis" seeder modifications.

In an attempt to improve the seed release trajectory characteristics of a "Nodet Gougis" seeder the following seed deflection plates were fitted to the seeder at the point of seed release from the vacuum selection plate (fig. 13). The seeder housing was cut away at the point of attachment of the deflector plates in order to allow video monitoring of seed interactions with deflector plates.

(i) A straight deflector (made of 1mm thick aluminium plate, 80mm long by 50mm wide) positioned slightly off the tangent to the movement of the seed selection plate holes. This deflector was designed to wipe off any seeds that were held by the vacuum for longer than the mean period during seed release (fig. 14).

(ii) A deflector of the same dimensions as that described above, but curved through 20 degrees and positioned to gently wipe the seeds from their position on the plate and deflect them downwards at a terminal angle of approximately 15 degrees from vertical (fig. 14).

(iii) A deflector of the same dimensions as that

Figure 13: Seed deflector plate modifications to the "Nodet Gougis" seeder.

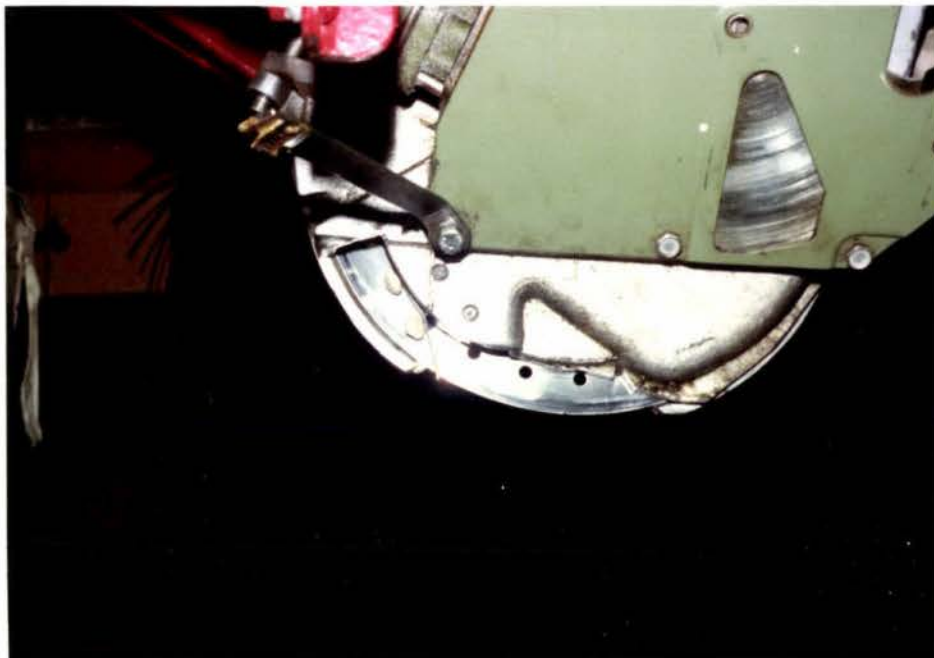
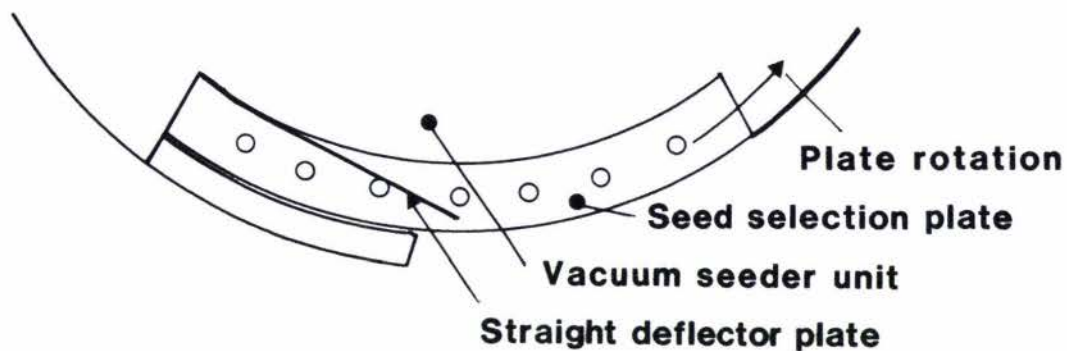
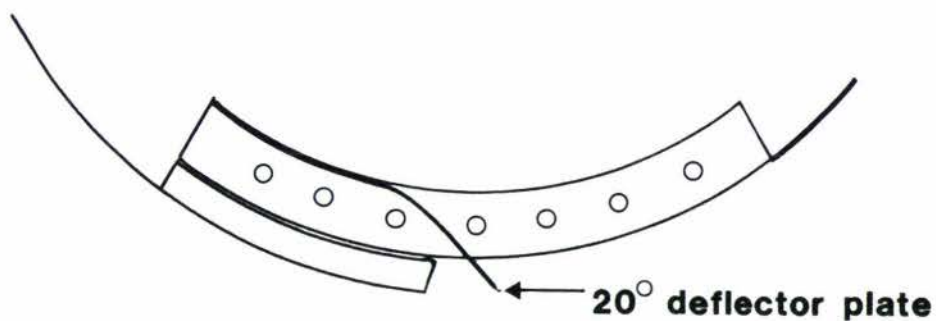


Figure 14: Seed deflector plate configuration.

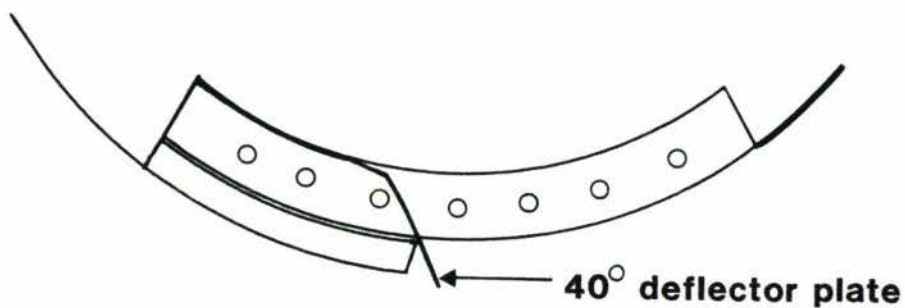
(a) Straight deflector plate



(b) 20° deflector plate.



(c) 40° deflector plate.



described above, but curved through 40 degrees positioned to turn all seeds abruptly in a vertical direction (fig. 14).

3.4.6 Objective (d) - Assessment of modified equipment.

The assessment of equipment, after modifications had been made to improve the overall performance of the "Nodet Gougis" seeder/chisel coulter combination, took place in the following two stages:

1. Laboratory performance testing of the modified seeder/tube transfer mechanism in isolation (see 3.4.6.1).
2. Laboratory and field performance testing of the modified seeder/tube transfer mechanism/chisel coulter combination (see 3.4.6.2).

3.4.6.1 Experiment d/1 (Modified seeder/tube transfer performance testing).

Having improved the release trajectory characteristics of a "Nodet Gougis" seeder the greased tray technique, as described in 3.4.2, was re-employed to determine the effects of the 40 degree deflector mechanism on the resulting seed spacing. The 40 degree deflector plate had been found to be the most effective mechanism, of those tested, in reducing the variation in seed release trajectory and was therefore expected to provide an improvement in seed spacing on the greased tray and in the field.

Experimental design.

A number of tube transfer mechanisms were retested at two plate speeds with the 40 degree deflector plate fitted to the "Nodet Gougis" seeder. A sample of approximately 40 seeds (Lupin, variety Kali) was recorded for each of the following treatments:

Main treatments:- A peripheral plate speed of 0.12m.sec⁻¹.

- A peripheral plate speed of 0.36m.sec⁻¹.

Sub-treatments:- a) Free seed drop from 300mm above the greased tray.

b) Seed drop through a straight, vertical seed tube made of glass (25mm inside diameter) from 300mm above the greased tray.

c) Seed drop through a glass seed tube (25mm inside diameter), with a radius of curvature of 250mm, though a total angular change of 50 degrees from the vertical. The tube was positioned to curve in the opposite direction to tray movement with the seeds introduced in such a way that they were induced to slide around the curve.

d) Seed drop through a glass seed tube (25mm inside diameter), with a radius of curvature of 250mm, through a total angular

change of 50 degrees from the vertical. The tube was positioned to curve in the same direction as tray movement with the seeds introduced in such a way that they were induced to slide around the curve.

3.4.6.2 Experiment d/2 (Modified seeder/tube transfer/coulter performance testing).

Having previously established the effect of seeder modifications and a tube transfer mechanism in isolation on seeder performance it was considered necessary to determine the effects of the best of the above modifications in conjunction with the chisel coulter under laboratory conditions and in the field. The results could then be compared with those of experiments a/1, a/2 and a/3 (performance evaluation of the original experimental "Nodet" seeder/chisel coulter configuration).

Experimental design.

A modified seeder/tube transfer/direct drilling coulter unit, (as described in section 3.4.7 below), was evaluated using an experimental technique similar to that described in 3.4.1.1. The test direct drilling rig was driven over the 6m greased tray as before, but in this case the scalloped disc was not rotated to simulate field sowing conditions because the seed tube isolated the seeds from contact with the disc. It was considered that movement of the

disc would have had no influence on the seed path in the laboratory situation.

Five replicates of each of three operating speed treatments (5, 6.4 and 8km.hr⁻¹) were recorded using lupin seed (variety Kali). The modified unit was also used to drill into pasture plots sprayed four weeks previously with glyphosate herbicide at 5 l.ha⁻¹ equivalent application rate. The glass seed tube used in the previous experiment was replaced with an aluminium tube of the same dimensions. The glass tube had proved insufficiently robust for field operation. It was considered that the smooth inner surface of the aluminium seed tube was unlikely to result in different seed travel characteristics down the tube in comparison with the glass tube but no comparative measurements were made between the two surfaces to verify this.

Five plots were drilled with lupin seed at a mean target seed spacing of 100mm. Methiocarb molluscicide was surface broadcasted on the plots at 10kg ha⁻¹ equivalent application rate at the time of drilling and also seven days after drilling in an attempt to avoid slug damage. The lupin seed was also treated with Benomyl fungicide prior to drilling. All plots were drilled at a constant speed of 6.4km.hr⁻¹.

Intra-row seedling spacing was measured 15 days after drilling. A 10m single row sample for each of

the five replicate plots was recorded.

3.4.7 Development (iii) - Incorporation of a tube transfer system with a modified "Nodet Gougis" seeder and a chisel coulter.

In order to evaluate the effects of a straight vertical seed transfer tube on reducing the seed spacing variation of a "Nodet Gougis" seeder/chisel coulter combination it was considered necessary to build a test unit combining these three separate components and test such a unit in the laboratory and in the field.

A modified "Nodet Gougis" seeder unit, incorporating a 40 degree seed deflector plate mounted at the point of seed release, was mounted above a specially modified chisel coulter. The central scalloped disc of the coulter was mounted on a cantilever axle leaving one side of the disc unobstructed to enable a straight vertical seed tube to be positioned directly below the seeder unit. Coulter blades were attached to the coulter frame in such a way that they could be expected to perform the same physical and biological functions as with the previously described form of the coulter (Baker et al., 1979) (figs. 15 and 16). A depth control wheel was mounted on the extended coulter disc axle on the opposite side to the transfer tube (fig. 17).

A glass seed tube was mounted vertically below the seed release point of the seeder and directly behind the rear edge of the coulter blade. The tube could not be positioned between the coulter blade and the disc (a 15mm

Figure 15: Modified seeder/tube transfer/direct drilling coulter unit.



Figure 16: Modified seeder/tube transfer/direct drilling coulter unit operating in a sprayed pasture plot.



Figure 17: Modified seeder/tube transfer/direct drilling coulter unit depth control wheel.



gap) as modification of the tube to fit the 15mm coulter profile resulted in lupin seeds bridging in the base of the tube.

The test seeder/tube/coulter assembly was mounted on a test drilling rig using parallelogram coulter drag arms and hydraulically actuated coulter penetration forces. The seeder unit was driven by the variable speed drive mechanism described in experiment c/2 (section 3.4.4.2) which was mounted on the test rig. Electric power was supplied by a portable generator.

3.4.8 Measurements.

Longitudinal inter-seed and inter-seedling spacing was measured between adjacent seeds/seedlings where appropriate in the above experiments and expressed in terms of standard deviation and coefficient of variation of seed spacing. While the standard deviation provided an absolute measure of seed spacing variation as a result of mechanical treatments applied in the laboratory, the coefficient of variation of seed/seedling spacing was also considered relevant (especially for field experiments) from a biological viewpoint in that the relationship of seed spacing variation to the mean spacing distance had been considered to vary in importance between crops (Gray, 1978; Wilson, 1980).

Seed trajectory as video-recorded in experiments c/1 and c/2, was expressed in terms of the standard deviation of seed path at each of the five horizontal reference lines positioned vertically below the seeder.

Results were statistically analysed using a Sharp Compet 365P card insertion programmable desk top calculator. Standard 'F' and "Studentised T" statistic tests were applied using a simple analysis of variance (ANOVA) programme (I.L. Gordon, pers.comm. 1981).

4 Results and Discussion.

The results of the experiments conducted in order to achieve each of the four main objectives are discussed separately in the following sections:

4.1 Objective (a) - Experimental drill evaluation.

4.1.1 Experiment a/1 (Laboratory experiment).

Results

Raw data for experiment a/1 are contained in appendix 1.

Table 1 lists the coefficients of variation of seed spacing for experiment a/1 which involved the "Nodet Gougis" seeder fitted to the M.A.F. two-row direct drilling unit. The data are listed in order of increasing variation from mean seed spacing, together with indications of statistically significant differences. From the table a clear trend was apparent which indicated that the least variability occurred with the seeder in its conventional form.

Tables 2, 3 and 4 summarise the main treatment effects of experiment a/1. Table 2 compares the main effects of coulter type for pooled seed types and speeds. From the table the variability of seed spacing with the "Nodet Gougis" seeder in isolation was significantly less than a similar seeder used in combination with the chisel direct drilling coulter ($P < 0.05$). The effect of introducing the coulter was considered to be to introduce seed impact with the coulter blade and revolving disc. On the other hand the possibility cannot be discounted that some variability

Table 1. Effects of coulter type, ground speed, and seed type on evenness of seed spacing by a "Nodet Gougis" seeder.

<u>Treatment</u>	<u>Seed Spacing</u> (C of V)
Conventional seeder/sub-clover/5 km.hr-1	0.270 A a
Conventional seeder/maize/5 km.hr-1	0.317 AB a
Conventional seeder/lupin/5 km.hr-1	0.317 AB a
Conventional seeder/sub-clover/8 km.hr-1	0.320 AB a
Conventional seeder/maize/8 km.hr-1	0.383 ABC ab
Conventional seeder/lupin/8 km.hr-1	0.457 BCD bc
Conventional seeder/sub-clover/11 km.hr-1	0.507 CD bd
Direct drilling seeder/lupin/5 km.hr-1	0.537 CDE cd
Conventional seeder/maize/11 km.hr-1	0.580 DF cde
Direct drilling seeder/maize/5 km.hr-1	0.617 DEF df
Direct drilling seeder/maize/8 km.hr-1	0.703 EFG efg
Direct drilling seeder/maize/11 km.hr-1	0.713 FG fg
Direct drilling seeder/lupin/8 km.hr-1	0.717 FG fg
Conventional seeder/lupin/11 km.hr-1	0.807 GH gh
Direct drilling seeder/sub-clover/5 km.hr-1	0.807 GH gh
Direct drilling seeder/sub-clover/11 km.hr-1	0.853 GH hi
Direct drilling seeder/sub-clover/8 km.hr-1	0.943 H i
Direct drilling seeder/lupin/11 km.hr-1	1.133 I j

Unlike letters indicate significant differences between treatments (capitals $P < 0.01$; lower case $P < 0.05$).

Table 2. Effect of seed passage through a chisel coulter on seed spacing.

<u>Seeder Configuration</u>	<u>Seed Spacing</u> (C of V)
Conventional "Nodet Gougis" seeder	0.437
"Nodet Gougis" seeder above a chisel direct drilling coulter	0.743*

* Denotes significant difference at $P < 0.05$.

Table 3. Effect of ground speed on seed spacing performance by a precision seeder and direct drilling coulter.

<u>Speed</u> (km.hr ⁻¹)	<u>Seeder Configuration</u>	
	Conventional "Nodet Gougis" seeder (C of V)	"Nodet Gougis" seeder above a chisel coulter (C of V)
5	0.293 Aa	0.654 Bb
8	0.383 Aa	0.788 BCc
11	0.631 Bb	0.900 Cc

Unlike letters indicate significant differences (capitals $P < 0.01$; lower case $P < 0.05$).

Table 4. Effect of seed type on seed spacing performance by a precision seeder and direct drilling coulter.

<u>Seed Variety</u>	<u>Seeder Configuration</u>	
	Conventional "Nodet Gougis" seeder (C of V)	"Nodet Gougis" seeder above a chisel coulter (C of V)
Subterrenean clover	0.365 Aa	0.868 De
Maize	0.419 ABa	0.678 Cc
Lupin	0.527 Bb	0.795 Dd

Unlike letters indicate significant differences (capitals $P < 0.01$; lower case $P < 0.05$).

was attributable to differences in seeder unit performance with each run.

In an attempt to achieve comparative performance with the two "Nodet" seeder units (which were originally from the same machine), both units were adjusted to the same scale settings. Any variation in the relationship between the two seeder units would therefore cause variations in seed selection (multiplies and misses) which would have been accounted for. In this respect the average number of seeds delivered in the length of the sampling tray was 50.4 when the chisel coulter was absent and 44.6 when the coulter was present. The difference between the counts was significant at $p < 0.01$. Variation in seeder performance must therefore be considered as a possible cause of the increased seed spacing variation that occurred with the Nodet/chisel direct drilling unit. Nevertheless, the 12% difference in seed counts is unlikely to fully explain the 1.7 fold difference in coefficients of variation attributable to the two treatments listed in table 2.

Table 3 summarises the effect of seeder ground speed on seed spacing variability for pooled seed type treatments. From the table it appears that there was no significant difference in spacing variation when ground speed was increased from 5km.hr⁻¹ to 8km.hr⁻¹ when the seeder was used in isolation. At 11km.hr⁻¹ however, seed spacing was significantly more variable ($P < 0.01$) than at either 5km.hr⁻¹ or 8km.hr⁻¹. The direct drilling unit was more variable than the seeder unit in isolation at all

three speeds tested ($P < 0.01$), although the seed spacing variability with the direct drilling unit appeared to be less affected by increasing ground speed above 8 km.hr^{-1} than was the seeder unit in isolation. This could have been as a result of two functions: Either the magnitude of the seed spacing variation, arising from the effects of the coulter, overshadowed any change in variation arising from seeder performance; or the greater coulter-disc speed at 11 km.hr^{-1} in fact produced an improved pathway for the seed (because of agitation) which perhaps partly offset any deterioration in seeder performance as a result of increased seeder speed.

The effect of seed type on seed spacing variation is summarised in table 4. From the table sub-terranean clover, when distributed by the "Nodet" seeder unit in isolation, appeared to be the least variable treatment, although there were no clear interactions between seed types and seeder/coulter configurations. For example the least variable output with the direct drilling unit occurred with maize seed, while sub-terranean clover seed was the most poorly distributed of the three seed types with that coulter.

Discussion

The more precise spacing obtained using sub-terranean clover seed with the "Nodet Gougis" seeder in isolation, may have been attributable to the regular shape of that seed type in comparison with lupin and maize seed. Regular seed shape, weight and size was shown in a subsequent

experiment to beneficially effect performance of the "Nodet Gougis" seeder (see experiment b/1)

When seed was directed down the coulter it is possible that the spacing variation due to interference by the chisel coulter blade and revolving disc may have partly masked any effects on the seeder or seed type. Alternatively, sub-terrestrial clover seed, being smaller, may have been affected to a greater extent by contact with the moving coulter disc than were the larger seed types, although field experience would suggest that the reverse was true (Baker, pers.comm. 1981).

4.1.2 Experiments a/2 and a/3 (Field experiments).

Two separate field experiments were conducted, one in pasture and the other in barley stubble. No data were available for treatments involving sub-terrestrial clover in the pasture experiment. Despite the use of glyphosate herbicide prior to drilling of the pasture plots (see 3.4.1.2), suppression of resident clover plants in the sward was not sufficient to enable accurate identification of the position of emerging sown sub-terrestrial clover seedlings. Thus it was considered that any data obtained from this treatment may not have accurately reflected the effects of the imposed treatments.

Results

Raw data for experiments a/2 and a/3 are contained in appendices 2-7.

Tables 5 and 6 summarise the seedling spacing

Table 5. Effect of seed type, coulter blade wing angle and a coulter disc scraper on seedling spacing using an experimental direct drilling unit in pasture.

<u>Treatment</u>	<u>Seedling Spacing</u> (C of V)	
Maize/90 /No Scr.*	0.687	Aa
Maize/90 /Scr.	0.737	Aa
Lupin/90 /No Scr.	0.737	Aa
Maize/45 /No Scr.	0.763	Aab
Lupin/90 /Scr.	0.770	Aab
Maize/45 /Scr.	0.790	Aab
Lupin/45 /No Scr.	0.870	Aab
Lupin/45 /Scr.	0.963	Ab

Unlike letters in the column indicate significant differences between treatments (capitals $P < 0.01$; lower case $P < 0.05$).

* 90 refers to coulter blade angle (see 3.4.1.2).

Scr. refers to the presence of a coulter disc scraper (see 3.4.1.2).

Table 6. Effect of seed type, coulter blade wing angle and a coulter disc scraper on seedling spacing using an experimental direct drilling unit in barley stubble.

<u>Treatment</u>	<u>Seedling Spacing</u> (C of V)		
Maize/45 /No Scr.*	0.733	A	a
Lupin/90 /No Scr.	0.817	AB	ab
Maize/45 /Scr.	0.823	AB	ab
S.Clover/45 /No Scr.	0.823	AB	ab
Lupin/90 /Scr.	0.853	AB	ab
Lupin/45 /No Scr.	0.907	AB	abc
Maize/90 /No Scr.	0.913	AB	abc
S.Clover/45 /Scr.	0.920	AB	abc
S.Clover/90 /No Scr.	0.940	AB	abc
Maize/90 /Scr.	0.947	AB	abc
Lupin/45 /Scr.	0.993	AB	abc
S.Clover/90 /Scr.	1.110	B	c

Unlike letters in the column indicate significant differences between treatments (capitals $P < 0.01$; lower case $P < 0.05$).

* 90 refers to coulter blade wing angle (see 3.4.1.2).
Scr. refers to the presence of a coulter disc scraper (see 3.4.1.2).

measurements for the pasture and barley stubble experiments respectively which both used the experimental direct drilling unit.

From both tables it appears that there were few significant differences between treatments and no clear trends which might have indicated a more accurate performance from any one group of treatments.

Tables 7-12 summarise the main treatment effects in each of the two experiments. In each of the tables 7-12 there were no significant differences between the main treatments of seed type, coulter blade wing angle and a disc scraper. This confirmed the data in tables 5 and 6.

Tables 13 and 14 list the combined treatment effects attributable to coulter blade wing shape, in terms of lateral displacement of seeds from the seed groove centre. From both of the tables, the most notable trend appeared to be that lupin seed was generally less displaced than maize seed which itself was displaced less than sub-clover seed in the one experiment in which the latter seed was monitored.

Tables 15 and 16 confirmed the effect of seed type on seedling displacement from the seed groove centre. From table 15, lupin seed was displaced 7 times ($P < 0.05$) less than maize from the groove centre. From table 16, there was no significant difference ($P < 0.05$) between the numbers of lupin and maize seeds laterally displaced from the seed groove centre in barley stubble although

Table 7. Effect of coulter blade wing angle on seedling spacing variation using an experimental direct drilling unit in pasture.

<u>Coulter Blade Wing Angle</u> (degrees)	<u>Seedling Spacing</u> (C of V)
45	0.847 N.S.
90	0.733

(N.S. - not significant at $P < 0.05$.)

Table 8. Effect of coulter blade wing angle on seedling spacing variation using an experimental drilling unit in barley stubble.

<u>Coulter Blade Wing Angle</u> (degrees)	<u>Seedling Spacing</u> (C of V)
45	0.867 N.S.
90	0.930

(N.S. - not significant at $P < 0.05$.)

Table 9. Effect of seed type on seedling spacing variation using an experimental direct drilling unit in pasture.

<u>Seed Type</u>	<u>Seedling Spacing</u> (C of V)
Maize	0.744
Lupin	0.835

N.S.

(N.S. - not significant at $P < 0.05$.)

Table 10. Effect of seed type on seedling spacing variation using an experimental direct drilling unit in barley stubble.

<u>Seed Type</u>	<u>Seedling Spacing</u> (C of V)
Maize	0.854 Aa
Lupin	0.894 Aab
Subterranean clover	0.949 Ab

Unlike letters indicate significant differences between treatments (capitals $P < 0.01$; lower case $P < 0.05$).

Table 11. Effect of a coulter disc scraper on seedling spacing variation using an experimental direct drilling unit in pasture.

	<u>Seedling Spacing</u> (C of V)
Coulter disc scraper	0.815
No coulter disc scraper	0.764

N.S.

(N.S. - not significant at $P < 0.05$.)

Table 12. Effect of a coulter disc scraper on seedling spacing variation using an experimental direct drilling unit in barley stubble.

	<u>Seedling Spacing</u> (C of V)
Coulter disc scraper	0.941
No coulter disc scraper	0.856

N.S.

(N.S. - not significant at $P < 0.05$.)

Table 13. Effect of seed type, coulter blade wing angle and a coulter disc scraper on lateral displacement of seedlings from the seed groove centre using an experimental direct drilling unit in pasture.

<u>Treatment</u>	<u>Seedlings Displaced</u> (%)	
Lupin/45 /Scr.*	0.7	A a
Lupin/90 /Scr.	0.7	A a
Lupin/45 /No Scr.	2.7	A a
Lupin/90 /No Scr.	3.3	A a
Maize/90 /Scr.	3.7	A a
Maize/45 /Scr.	11.3	B b
Maize/90 /Scr.	16.0	BC b
Maize/45 /N.Scr.	22.3	C c

Unlike letters in a column indicate significant differences between treatments (capitals $P < 0.01$; lower case $P < 0.05$).

* 45 refers to coulter blade wing angle (see 3.4.1.2).
Scr. refers to the presence of a coulter disc scraper (see 3.4.1.2.).

Table 14. Effect of seed type, coulter blade wing angle and a coulter disc scraper on lateral displacement of seedlings from the seed groove centre using an experimental direct drilling unit in barley stubble.

<u>Treatment</u>	<u>Seedlings Displaced</u> (%)		
Maize/45 /Scr.*	6.0	A	a
Lupin/45 /No Scr.	6.0	A	a
Lupin/90 /Scr.	7.3	AB	a
Lupin/90 /No Scr.	9.0	AB	ab
Maize/90 /Src.	9.7	AB	ab
Maize/90 /No Scr.	9.7	AB	ab
Lupin/45 /Scr.	12.3	AB	abc
S.Clover/45 /No Scr.	14.0	ABC	bc
S.Clover/45 /Scr.	19.3	BC	c
Maize/45 /No Scr.	15.3	ABC	bc
S.Clover/90 /Scr.	18.3	BC	c
S.Clover/90 /No Scr.	26.0	C	d

Unlike letters indicate significant differences between treatments (capitals $P < 0.01$; lower case $P < 0.05$).

* 45 refers to coulter blade wing angle (see 3.4.1.2).
Scr refers to the presence of a coulter disc scraper (see 3.4.1.2).

Table 15. Effect of seed type on the lateral displacement of seedlings from the seed groove centre using an experimental direct drilling unit in pasture.

<u>Seed Type</u>	<u>Seedlings Displaced</u> (%)
Maize	13.37 *
Lupin	1.87

(* - denotes significant difference at $P < 0.05$.)

Table 16. Effect of seed type on the lateral displacement of seedlings from the seed groove centre using an experimental direct drilling unit in barley stubble.

<u>Seed Type</u>	<u>Seedlings Displaced</u> (%)
Maize	10.17 ab
Lupin	8.70 a
Subterranean clover	19.47 b

(Unlike letters indicates significant differences at $P < 0.05$.)

the percentage of sub-clover seeds that were laterally displaced was 2.2 times greater than the percentage of lupin seeds displaced and 1.9 times greater than the percentage of maize seeds laterally displaced.

Tables 17 and 18 show the main effect of coultter blade wing angle on the lateral displacement of seeds from the seed groove centre. From table 17 it appears that the effect of changing the lateral wing angle from its normal 90 degree angle, to sloping upwards at 45 degrees from the vertical was to significantly increase ($P < 0.05$) the displacement of the seed from the seed groove centre, in pasture. This was surprising as it was expected that the 45 degree wing angle may have assisted seeds in rolling back towards the centre of the seed groove directly below the vertical groove slit, and avoiding being lodged under the turf flap. What was even more surprising was that where the soil flap might have been expected to be less well defined (barley stubble, table 18) the number of seeds displaced was not significantly different ($P < 0.05$) between treatments.

In the pasture plots 94% of viable maize seeds sown emerged compared with 72% of viable lupin seeds. In the barley stubble plots the figures were 85% and 76% respectively (see appendix 6). It is possible that the displacement of lupin seeds beneath a pasture flap might have explained the 4% reduction in emergence of that crop, in terms of physical impidence to a dicotyledonous species with epigeal germination. However it is

Table 17. Effect of coulter blade wing angle on the lateral displacement of seedlings from the seed groove centre using an experimental direct drilling unit in pasture.

<u>Coulter Blade Wing Angle</u>	<u>Seedlings Displaced</u> (%)
90	5.93
45	9.27

*

(* denotes a significant difference at $P < 0.05$.)

Table 18. Effect of coulter blade wing shape on the lateral displacement of seedlings from the seed groove centre using an experimental direct drilling unit in barley stubble.

<u>Coulter Blade Wing Angle</u>	<u>Seedlings Displaced</u> (%)
90	13.33
45	12.17

N.S.

(N.S. - no significant difference at $P < 0.05$.)

difficult to see how any corresponding explanation could account for the 9% reduction in monocotyledonous maize emergence which was attributable to the more broken flap in the barley stubble plots (see appendix 6).

Discussion.

The results obtained from the two field experiments - a/2 and a/3 (expressed in terms of variation of seedling spacing) indicated that the range of treatments applied had had little effect on seed spacing. While this may have reflected the true position, it was more likely that the experimental technique of assessing seed spacing variation in the field by measuring seedling spacing did not provide sufficiently accurate data to determine the effects of those treatments. As previously discussed, a method of non-destructive or semi-destructive sampling would have been useful in order to locate the position of seeds in situ. In this way other biological factors associated with seed and seedling survival which may have affected final seedling spacing might have been isolated. On the other hand, the final stand of any drilled crop will always be influenced by the full range of field factors and it may therefore be realistic to continue to measure them. For example, spacing variation was on average 11.3% greater in the crop stubble plots than in the pasture plots. This may have been due to greater soil disturbance and movement by the coulter in those ground conditions which affected seed placement.

While it was not considered statistically appropriate

to make comparisons between the field experiments and the laboratory experiments it should be noted that the average coefficient of variation of seedling spacing for all maize treatments in pasture was 5.7% greater than the average coefficient of variation of maize seed spacing in the laboratory at 8km.hr⁻¹ with the same experimental direct drilling unit. The corresponding comparison using lupin seed resulted in a 15.3% increase in spacing variation from laboratory to pasture (see appendix 7). In the crop stubble plots the average coefficient of variation of seedling spacing over all maize treatments was 21.4% greater than in the laboratory, 23.6% with lupin and 1.1% with sub-clover. Even considering the germination and emergence losses that may have occurred in the field, these comparisons suggest that assessment of drill performance in the laboratory had not provided a consistently proportional indication of resultant field performance.

4.2 Objective (b) - Evaluation of simple seed transfer alternatives.

4.2.1 Experiment b/1 (Seed-tube transfer).

The assessments of seeder performance reported in this experiment are expressed as standard deviations of seed spacing. Standard deviation was considered to more accurately reflect changes in spacing variation between treatments where all treatments had similar (though not identical) mean seed spacings.

Results.

The raw data for experiment b/1 are contained in

appendix 8.

Table 19 summarises the effects of "seed" type for all seed-tube transfer treatments. From the table it appears that ball bearings, having a constant size, shape and weight, gave significantly ($P < 0.01$) better spacing performance than the other two seed types. Pea seed also gave significantly less variable results than maize seed. This may have been due to the relatively regular round shape and size of the pea seed in comparison with maize seed and this apparently produced seeder release characteristics intermediate between ball bearings and maize.

The effects of the different seed transfer tubes tested are summarised in table 20. Free seed drop from 80mm above the greased tray, and seed drop through a straight vertical glass tube from 300mm above the greased tray both gave significantly ($P < 0.01$) less spacing variation than all other treatments. Sliding the seeds around a curved seed tube resulted in the greatest seed spacing variation which remained consistent, regardless of whether the curve was facing forwards or rearwards. Perhaps the most interesting comparison was that between free seed drop from 300mm and seed drop through a straight vertical tube from the same height. The reduction in seed spacing variation on the moving tray resulting from confining the seed within the tube was highly significant

Table 19. Effect of "seed" type on seeder and transfer tube seed spacing performance with a "Nodet Gougis" seeder unit.

	<u>Ball Bearings</u>	<u>Huka Pea seed</u>	<u>Maize seed</u>
Standard deviation of seed spacing for all tube transfer options	4.86 A	8.32 B	9.26 C

Unlike letters indicate significant differences at $P < 0.01$.

Table 20. Effect of tube transfer configuration on seed spacing performance with a "Nodet Gougis" seeder.

	<u>Standard Deviation Seed Spacing (average of three seed types)</u>
Free seed drop (80mm)	4.85 A a
Straight vertical seed tube (300mm)	5.85 A a
Free seed drop (300mm)	8.07 B b
Curved seed tube (seeds bouncing)	8.12 B b
Curved seed tube (seeds sliding) (curved in the direction of tray movement)	9.27 B c
Curved seed tube (seeds sliding) (curved in the opposite direction to tray movement)	9.32 B c

($P < 0.01$) and in the order of 35%. Lateral seed placement variation was also observed to be considerably reduced when seed drop was confined to a tube in comparison with free seed drop (fig. 18).

Table 21 summarises the effects of the different tube transfer systems on seed spacing variation for each of the three "seed" types tested. The table appears to indicate that the straight vertical seed-tube treatment was bettered ($P < 0.05$) only by the free seed drop from 80mm treatment and then only in the case of maize seed. This could have reflected the fact that the maize seed was the most irregularly shaped and sized seed of those tested. With ball bearings there appeared to be two distinct statistically significant ($P < 0.01$) groups of treatments. Free seed drop from 80mm and 300mm and seed drop through a straight vertical seed tube from 300mm were in the group of least variable seed spacing, while those treatments involving curved seed tubes were in the group of most variable seed spacing. Treatments using maize seed appeared to follow a similar trend although not in such well defined groups as was the case with ball bearings. Treatments using maize also resulted in greater differences in spacing variation between treatments.

In view of the above trends with ball bearings and maize seed, and the relative performance of all three "seed" types as expressed in table 19, the seed spacing variation due to the different seed transfer treatments with pea seed might also have been expected to have been

Figure 18: Lateral seed placement variation with a "Nodet Gougis" seeder with (right) and without (left) a straight vertical seed-transfer tube.



Table 21. Effect of seed transfer tube shape on spacing performance of a "Nodet Gougis" seeder.

<u>Treatment</u>	<u>Standard Deviation of Seed Spacing</u>		
	<u>Ball Bearings</u>	<u>Huka Pea seed</u>	<u>Maize seed</u>
Free seed drop (80mm)	3.48 A a	6.25 AB ab	4.83 A a
Free seed drop (300mm)	3.66 A a	12.28 C c	8.28 BC b
Straight, vertical seed tube (300mm)	3.89 A a	4.69 A a	7.13 AB b
Curved seed tube - seeds bouncing (300mm)	5.59 B b	8.05 B b	14.18 E d
Curved seed tube - curved in the direction movement; seeds sliding (300mm)	5.92 B b	7.21 AB b	11.22 D c
Curved seed tube - curved in the opposite direction to tray movement; seeds sliding (300mm)	6.62 B b	11.41 C c	9.92 CD c

Unlike letters in columns indicate significant differences between treatments (capitals $P < 0.01$; lower case $P < 0.05$).

intermediate between ball bearings and maize seed. In fact the seed spacing variations resulting from each of the seed transfer treatments with pea seed bore considerably different relationships to one another than was the case with ball bearings and maize. For example, free seed drop from 300mm gave the most variable seed spacing with pea seed but there appears to be no logical explanation why this should be so.

Discussion.

Visual observation in this experiment suggested that variations in seed trajectory occurred after release from the seeder. This made it difficult to accurately position the seed transfer tube so as to achieve a consistent seed path into and through the tube. The variation in seed release trajectory and resulting seed drop appeared to be greater with both pea and maize seed than with ball bearings. This may have contributed to the greater variation in seed spacing with these seeds than with ball bearings on the greased tray.

Variation in seed trajectory was considered to largely result from variation in the time taken for individual seeds to be released from the seed selection plate. Seeds with differing shapes and sizes were thought to be held to the plate with differing forces arising from variations in vacuum leakage around the seeds. When the source of vacuum was removed during the cyclic operation of the seeder, a finite time would be required for the residual vacuum to reach zero. Seeds located on holes where leakage of air

was greater than other holes, were expected to be released more rapidly than those seeds that completely sealed the selection holes, as the critical minimum vacuum for seed drop would be reached fractionally sooner than where less leakage occurred. If such variable release times did occur with individual seeds, then it would be reasonable to expect that the circular movement of the plate would have imparted velocity to the seeds with differing horizontal and vertical components because of differing points of release on the circle. A seed released earlier in the seed selection plate rotation than the mean release point (20 degrees before bottom dead centre (B.D.C.)) would have been expected to have had a greater vertical component of velocity than would a seed released later than the mean release point. It seemed clear that if a seed-tube transfer system was to be utilised in this project then the seed release characteristics of the seeder mechanism needed to be modified in such a way that seed trajectory could be predetermined with considerably less variability than was observed with the unmodified "Nodet Gougis" seeder. The following experiment therefore sought to quantitatively assess the variation in seed release observed with the "Nodet Gougis" seeder, and to evaluate possible alternative modifications designed to reduce that variation.

4.3 Objective (c) - Evaluation of seeder release characteristics.

Two separate experiments were conducted in order to evaluate alternative means of improving seed release from vacuum seed selection mechanisms.

4.3.1 Experiment c/1 (Seed cell release).

Results.

Table 22 shows the standard deviation of lupin seed-path at five vertically spaced reference points through the seed drop zone for "Nodet Gougis" and "Hassia" vacuum seeder units. The results indicate that despite the transfer of seeds to cells before release from the seeder, the "Hassia" seeder apparently exhibited twice as much mean variation ($P < 0.01$) in seed trajectory as did the direct releasing "Nodet Gougis" seeder. This appears to confirm the findings of Daynard and Vyn (1978) who suggested that variations arose because of seeds "tumbling" from the seed delivery cells at varying rates.

The results from this experiment suggested that there was no inherent advantage in the intermediate cell system used by Hassia. Furthermore there was limited opportunity to modify this system because the seed, at release, was resting under the influence of gravity. By contrast, the "Nodet Gougis" seeder offered the prospect of modifying the seed release zone to suit entry into a tube because just prior to release the seed was still under the influence of the vacuum force.

Table 22. Comparisons of free drop seed trajectory of lupin seeds released from "Nodet Gougis" and "Hassia" seeders.

Vertical Distance from Seeder Base	Standard Deviation of Seed Path	
	<u>Nodet</u>	<u>Hassia</u>
50mm	0.25	0.51
100mm	0.31	0.61
150mm	0.37	0.71
200mm	0.39	0.79
250mm	0.43	0.88
Mean	0.35	** 0.70

(** denotes significant difference at $P < 0.01$.)

4.3.2 Experiment c/2 (Seed deflection mechanisms).

Results.

The effects of fitting a number of differently shaped seed deflector plates to the "Nodet Gougis" seeder at two different seed selection plate peripheral speeds are shown in table 23. From the table it appears that modification of the seeder by fitting a deflector plate angled through 40 degrees at the point of seed release which turned the seeds abruptly in a vertical direction resulted in a 31% ($P < 0.01$) reduction in the variation of lupin seed trajectory compared with unmodified seed release at a selection plate peripheral speed of 0.12m.sec⁻¹. The other two deflector plates fitted appeared to have no significant effects ($P < 0.05$) on the seed release trajectories of lupin seed at that speed. At the higher peripheral speed of rotation of the seed selection plate the variations in seed trajectory appeared to be greater where seed deflectors were fitted than when the seeder was operated in its unmodified form. Table 23 also shows that at a selection plate peripheral speed of 0.36m.sec⁻¹ there was no significant effect on seeder performance from fitting a 40 degree seed deflection plate in comparison with the unmodified release. However the fitting of a straight seed deflector plate resulted in a 41% ($P < 0.01$) increase in spacing variation compared with unmodified seed release.

Standard deviation of seed path at the first reference point was the same for both peripheral plate speeds when the seeder was unmodified but seed trajectory variation

Table 23 Effect of seed selection plates fitted to a "Nodet Gougis" seeder mechanism on lupin seed release trajectory at two seed selection plate speeds.

<u>Vertical distance from the seeder base (mm)</u>	<u>Standard deviation of seed path</u>						
	Peripheral plate speed = 0.12m.sec ⁻¹				Peripheral plate speed = 0.36m.sec ⁻¹		
	Unmodified release (no deflector)	40° deflector	Straight deflector	20° deflector	Unmodified release (no deflector)	75° deflector	Straight deflector
50	0.25	0.16	0.21	0.20	0.25	0.20	0.28
100	0.31	0.19	0.30	0.30	0.34	0.29	0.44
150	0.37	0.22	0.38	0.37	0.38	0.40	0.57
200	0.39	0.28	0.44	0.45	0.46	0.48	0.66
250	0.43	0.34	0.50	0.53	0.52	0.55	0.78
Mean	0.35 Bb	0.24 Aa	0.37 Bb	0.37 Bb	0.39 Bb	0.38 Bb	0.55 Cc

Unlike letters indicate a significant difference between treatments (capitals P<0.01; lower case P<0.05).

increased to a greater extent at the faster plate speed as the vertical distance from the release point increased. This would not be surprising if the differential vacuum release effect, discussed previously, had occurred.

Discussion.

The adverse effect which arose from increasing the seed selection plate peripheral speed where seed deflector plates were fitted, may have been caused by some seeds "bouncing" off the deflector plates. This could have resulted in those seeds attaining a horizontal component of velocity in the opposite direction to that normally imparted by the plate movement. It is possible that where seeds were held on the selection plate for longer than the mean release time they were "flicked" rather than deflected from the plate because of the speed of the plate. If this was the case then the positioning of the deflector plate at the seed release point of the "Nodet Gougis" seeder would need to be adjustable to account for variation in the speed of rotation of the selection plate. Nevertheless, the variation of the seeder (in terms of seed trajectory) was not increased by the presence of a 40 degree seed deflector plate. In fact, seed trajectory variation at a point 50mm below the base of the seeder appeared to be less where the 40 degree deflector plate was fitted, even at the faster selection plate speed. This was considered to be a potentially useful characteristic where a seed transfer tube was to be fitted to the seeder.

The 40 degree deflector plate fitted to the "Nodet

Gougis" seeder was therefore considered to fulfill two functions:

(i) It overcame the proposed problem of differential vacuum release time by wiping the seeds off the selection plate holes just prior to release of the vacuum.

(ii) It diverted the seeds downwards which largely eliminated the differing horizontal components of velocity in the absence of the deflector plate. The result was a much narrower spectrum of seed path distribution (figs. 19-21) and a more vertically linear seed trajectory (figs. 22-24).

4.4 Objective (d) - Assessment of modified equipment.

4.4.1 Experiment d/1 (Modified seeder/tube transfer performance testing).

Results.

The raw data for experiment d/1 are contained in appendix 9.

Table 24 summarises the effects on lupin seed spacing variation on a greased tray, arising from the fitting of a 40 degree seed deflection plate to a "Nodet Gougis" seeder with different seed transfer tubes. From the table it appears that transferring the seed in a tube reduced seed spacing variation more than did allowing the seeds to free drop from the same height (300mm). As with maize seed (experiment b/1) a straight vertical seed tube provided the least variable lupin seed spacing on the greased tray.

Figure 19: Seed trajectory distribution from "Nodet Gougis" and "Hassia" seeders.

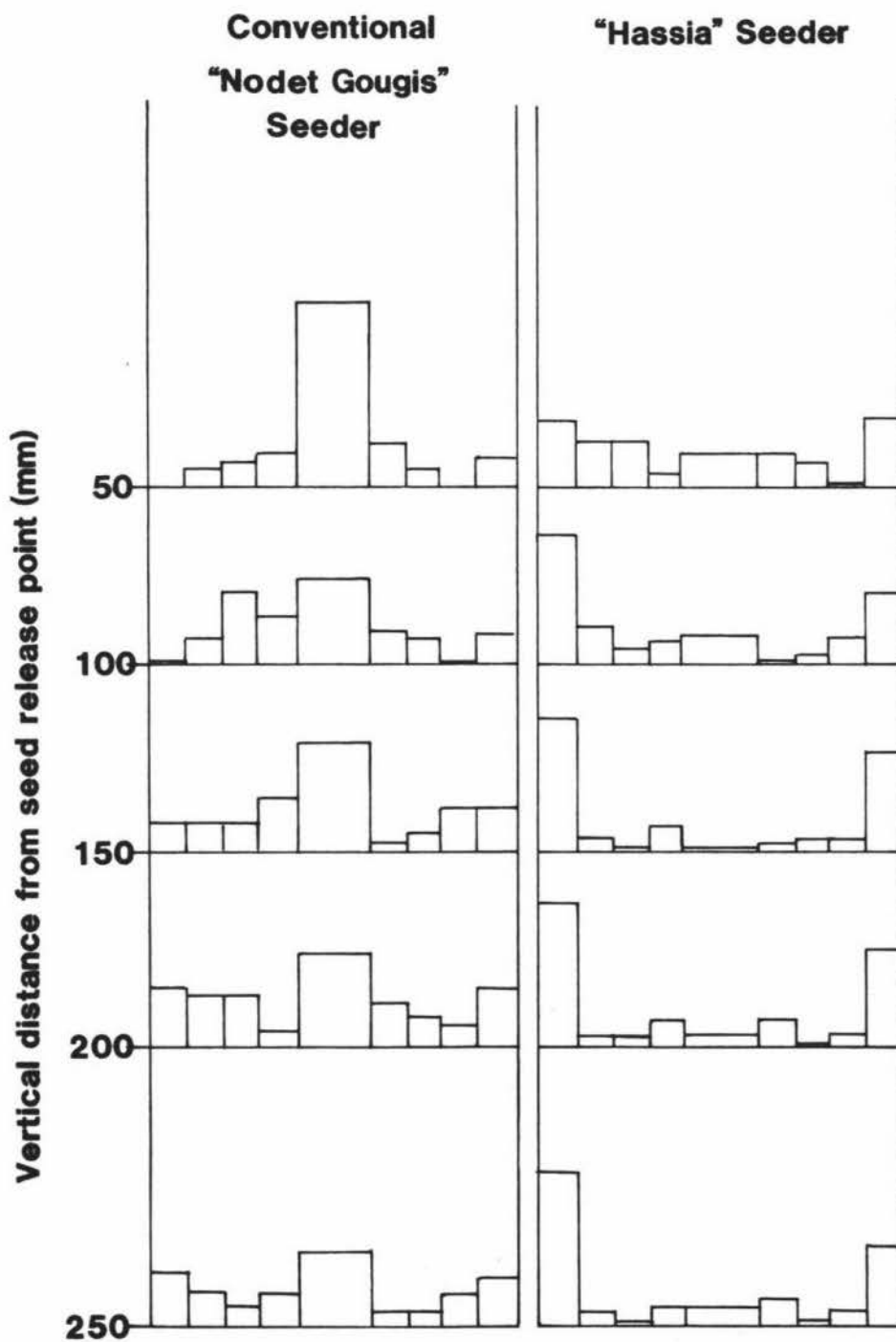


Figure 20: Seed trajectory distribution from a "Nodet Gougis" seeder - peripheral plate speed = $0.12\text{m}\cdot\text{sec}^{-1}$.

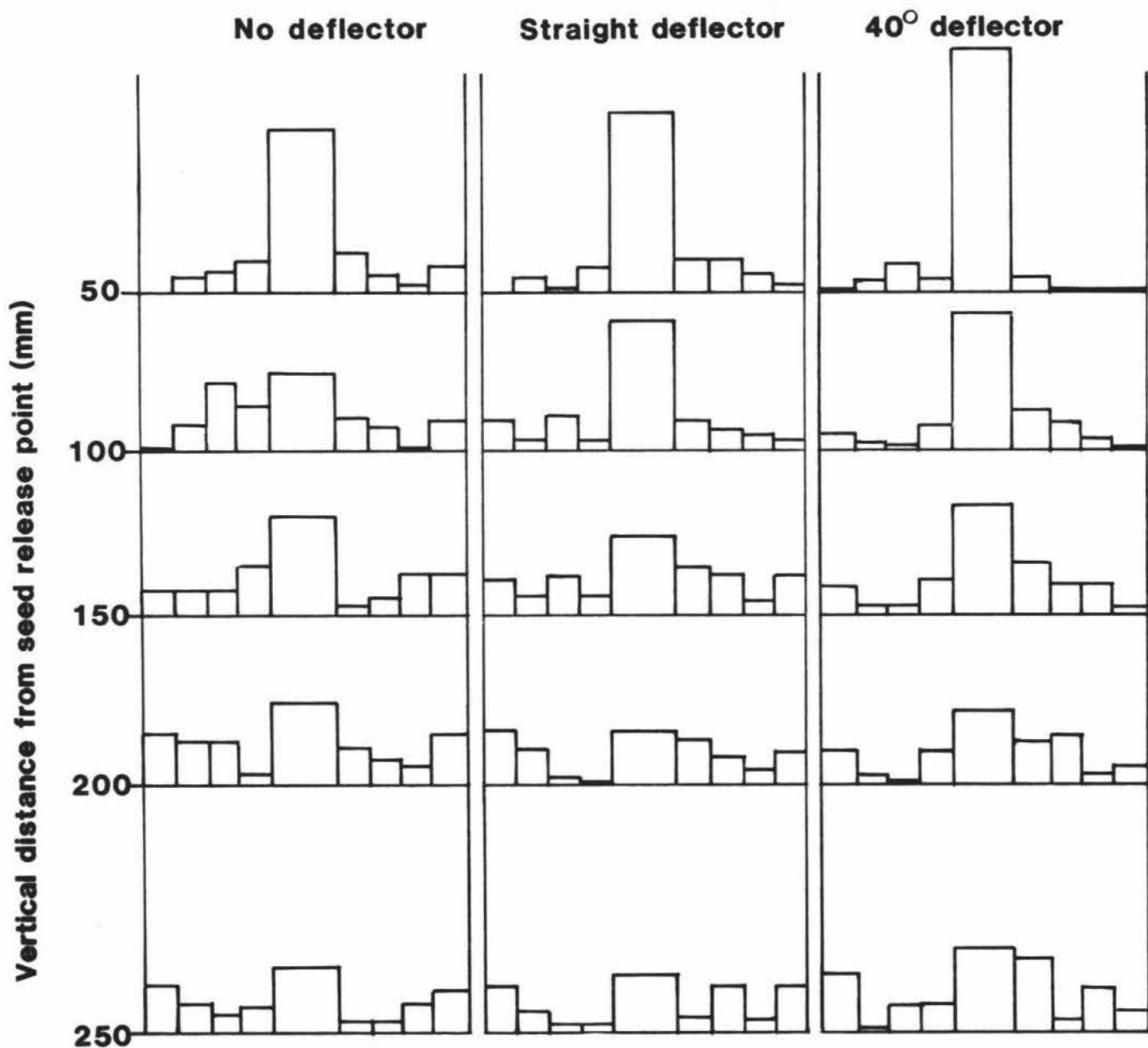


Figure 21: Seed trajectory distribution from a "Nodet Gougis" seeder - peripheral plate speed = $0.36\text{m}\cdot\text{sec}^{-1}$.

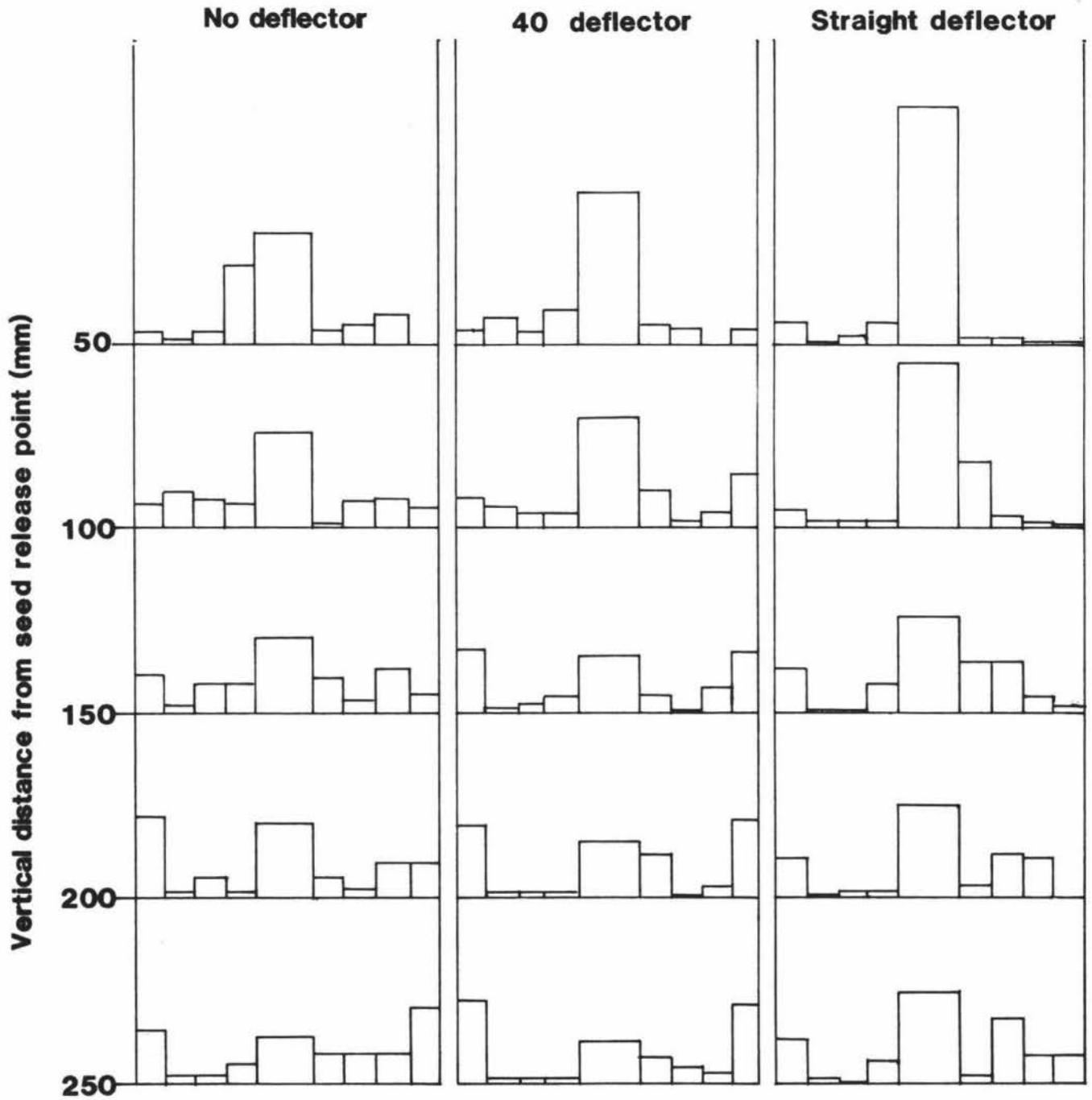


Figure 22: Seed path from a "Nodet Gougis" seeder fitted with a straight deflector plate.

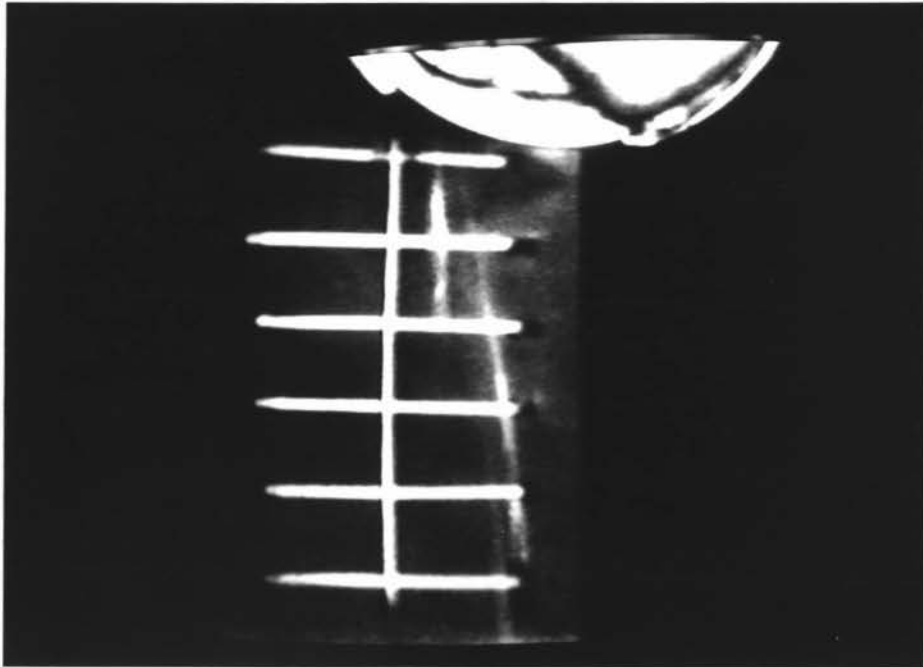


Figure 23: Seed path from a "Nodet Gougis" seeder fitted with a 20° deflector plate.

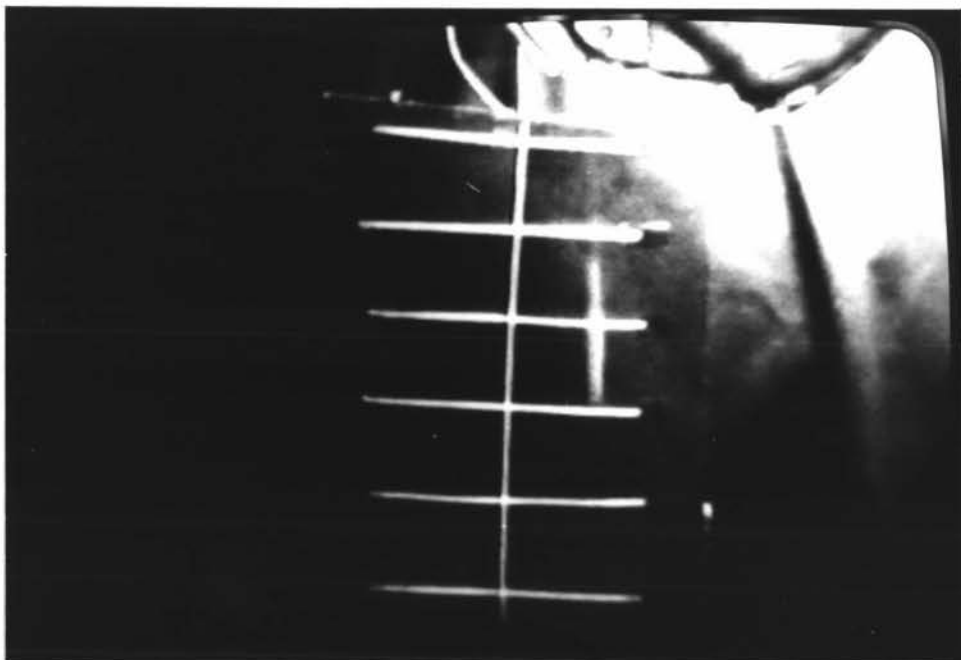


Figure 24: Seed path from a "Nodet Gougis" seeder fitted with a 40° deflector plate.

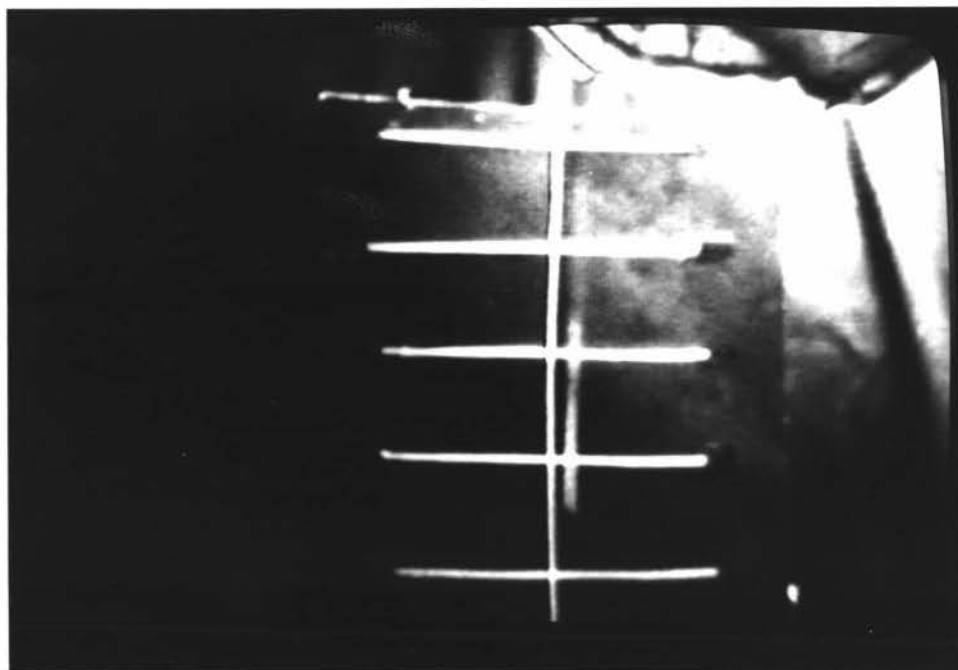


Table 24. Effect of seed deflection modifications and different seed transfer tubes on lupin seed spacing variation with a "Nodet Gougis" seeder.

<u>Treatment</u>	<u>Standard Deviation of Seed Spacing</u>	
Seed drop through a straight vertical seed tube (300mm) - 40 degree seed deflector	7.06	A a
Curved seed tube - curving in the direction of tray movement (300mm) - 40 degree seed deflector	8.22	AB ab
Curved seed tube - curving in the opposite direction to tray movement (300mm) - 40 degree seed deflector	9.42	B b
Free seed drop (300mm) - no seed deflector fitted	9.54	B b
Free seed drop (300mm) - 40 degree seed deflector	12.27	C c

Unlike letters indicate significant differences between treatments (capitals $P < 0.01$; lower case $P < 0.05$).

Free seed drop with the 40 degree deflector plate fitted to the "Nodet" seeder resulted in the greatest lupin seed spacing variation.

As an illustration of the magnitude of seed spacing variation, fig. 25 shows a typical comparison of lupin seeds spaced at zero and 10% (0.01) coefficients of variation.

Discussion.

While modification of the "Nodet Gougis" seeder decreased the variation in seed release trajectory (experiment c/2), experiment d/1 indicated that final placement of the seeds was more variable than with the unmodified form of the seeder. Examination of the video recordings of seed release used in experiment c/2 indicated that some seeds were being reorientated on the seed selection plate when they came in contact with the deflection plate before being released. This appeared to be largely a function of variations in seed shape. The fractional time delay that occurred while reorientation of the seeds took place may have caused the increase in seed spacing variation, despite the improvement in seed trajectory variation. Nevertheless, seed spacing variation was least, in this experiment, where the seed path was confined within a tube, especially when this was a straight vertical tube. If the variation that occurred in the free drop treatment resulted from seed release delays due to the seed/deflector interaction discussed above, it would be reasonable to expect this factor to be common to all

Figure 25: Comparison of lupin seed spacing variation.

C of V = 0.00 (left hand side of tray)

C of V = 0.10 (right hand side of tray)



treatments. Thus it appeared that confining lupin seeds to an essentially vertical trajectory using a 40 degree deflector plate and reducing trajectory variation with a tube through the drop zone, had the effect of more than compensating for any variation in release time caused by the deflector.

4.4.2 Experiment d/2 (Modified seeder/tube transfer/coulter unit performance testing).

Results.

The raw data for experiment d/2 are contained in appendices 10-12.

Table 25 shows the effect of speed on seed spacing variation with the modified seeder/tube-transfer/coulter test unit. The table indicates that increasing the ground speed progressively from 5km.hr⁻¹ to 8km.hr⁻¹ had a significantly adverse effect on seed spacing variation ($P < 0.01$).

Table 26 compares spacing variation with the test unit in the laboratory and in the field at 6.4km.hr⁻¹. The table indicates that there was a 74% increase in spacing variation attributable to the field conditions (compared with the laboratory conditions) and that this difference was statistically significant ($P < 0.01$).

Discussion.

The effect of increased speed on the seed spacing performance of the modified seeder/tube-transfer/chisel coulter test unit appeared to be greater than with the original experimental unit where the seed had been allowed

Table 25. Lupin seed spacing variation with a modified "Nodet Gougis" seeder/tube transfer/chisel coulter test unit as measured in the laboratory.

<u>Ground Speed</u> (km.hr-1)	<u>Seed Spacing</u>		
	Standard deviation		Coefficient of variation
5	30.10	A a	0.29
6.4	47.75	B b	0.42
8	53.84	B c	0.47

Unlike letters indicate significant differences between treatments (capitals $P < 0.01$; lower case $P < 0.05$).

Table 26. Lupin seed spacing variation with a modified "Nodet Gougis" seeder/tube transfer/chisel coulter test unit, laboratory/field comparison.

<u>Seed/Seedling Spacing</u>	
<u>Laboratory</u>	<u>Field</u>
0.42	** 0.73

** denotes a significant difference ($P < 0.01$).

to trickle down between the coulter disc and blade. Nevertheless absolute seed spacing performance of the modified test unit (with coefficients of variation of 0.29 at 5km.hr⁻¹ and 0.47 at 8km.hr⁻¹ for lupin seed) appeared to be superior to the original experimental unit (with comparative coefficients of variation of 0.54 and 0.72 respectively) although no direct comparisons could be made due to the different conditions which may have existed in each experiment.

The performance of the modified test unit in the laboratory in comparison with its field performance in pasture indicated that seed spacing variation of lupin seed at 6.4km.hr⁻¹ was increased by 74% from the laboratory to the field whereas lupin seed spacing variation with the original test unit had increased by only 15% from laboratory to pasture plots even at the higher speed of 8km.hr⁻¹.

The numbers of seeds and seedlings did not vary significantly between the laboratory and the field plots (see appendix 12) which indicated that seeder performance had not changed markedly during the experiment even although there appeared to be a slight reduction in established seedling numbers in the field plots.

The positioning of the seed transfer tube behind the coulter blade may have also contributed to the considerable increase in seed spacing variation observed in this experiment. Because of the restricted space between the rear edge of the coulter blade and the disc (15mm) it was

necessary to position the tube in a particular position (see 3.4.7). This was where the seed was directed into the seed groove at a point where soil, which was horizontally displaced by the angled coulter blade, was flowing around the rear edge of the blade. Movement of the seed after release from the base of the transfer tube could have been substantially affected by this soil flow. The lesser effect on seed spacing comparisons between the laboratory and field in experiments a/1 and a/2 when using the original experimental seeder/coulter unit may have been due to the fact that the seed travelled down between the coulter blade and disc and was directed into the soil beneath the blade wing in such a manner that it may have been protected from soil movement by the wing.

5 Summary and Conclusions.

It seemed reasonable that the starting point for a study of this nature should be to identify the most potentially suitable seed metering mechanism and direct drilling coulter which might be combined to provide specialist equipment for precision seeding under zero-tillage conditions. The "Nodet Gougis" vacuum seeder was considered potentially the most accurate and versatile of the available precision seeders and the redeveloped chisel direct drilling coulter clearly provided the most reliable environment for seed and seedling survival, of available coulters. However this coulter, in common with some others, posed potential problems in terms of its combination with a precision seeding mechanism, brought about by the extended seed path required by the larger direct drilling coulters.

Results from initial experiments with an experimental two-row direct drill which incorporated these two components indicated that the positioning of a chisel coulter beneath the "Nodet Gougis" seeder, in such a way that seeds "tumbled" down between the coulter disc and blade, markedly increased seed spacing variation. It seemed possible that much of this variation was attributable to seed contact with the revolving disc. Certainly the effect was shown to be related to seed type and forward speed. Both of these variables would normally be expected to alter under field conditions.

A number of options were considered as possible means of isolating the seed passage through the chisel direct drilling coulter from undesirable interference with stationary or moving

coulter components. During the testing of a number of simple seed transfer tubes it became apparent that modifications to the seeder might also have been required in order to improve its ability to release seeds into the tubes. The seeds appeared to be entering the seed transfer tubes with varying horizontal and vertical components of velocity. This was considered to result in differences in the seed path within the tube and consequently variations in the time taken for individual seeds to complete the transfer process of passage through the tube. Seeder release characteristics had not hitherto been considered critical for operation of this seeder in cultivated seedbeds as seeds were not transferred into a seed tube, but were instead free-dropped a small distance into the soil.

In order to assess the effectiveness of seeder modifications designed to reduce the variations of seed release trajectory, a video recording experimental technique for measuring seed trajectory was developed. This technique provided both quantitative data which reflected the effects of the seeder modifications and also visual observation of the seeder and the deflector plate interactions by way of slow motion replays.

Results of experiments using this technique showed that a 40 degree seed deflector plate fitted to the "Nodet Gougis" seeder provided the least variable and most vertical seed trajectory of the several alternatives tested. It was considered that this seed trajectory was potentially the most suitable path to which an appropriate seed transfer tube could be matched.

When a range of seed transfer tubes was retested with the modified "Nodet Gougis" seeder, a straight vertical seed tube in

combination with a 40 degree deflector plate fitted to the seeder was found to provide the least variable final seed spacing. On the other hand, in the absence of any seed tube, seed spacing variation was increased by the fitting of the 40 degree seed deflector plate to the seeder unit. This affect was attributed to interaction between the seed deflection plate and seeds of differing shapes. Some seeds had been observed to reorientate themselves on the seed selection plate when they came in contact with the deflector plate. By combining a straight vertical seed transfer tube with the 40 degree seed deflection plate modification to the seeder, a compromise was reached between the variations arising from seed release and the variations arising from seed trajectory.

The "Nodet Gougis" seeder and chisel coulter components were retested in combination with the seed transfer modifications described above. The relative improvement in seed spacing performance of this modified coulter assembly in comparison with the original experimental coulter appeared to be greater in laboratory tests than in field tests. It is possible that the beneficial effects of the seed transfer tube, in isolating the seed path from interference with coulter components, was partially negated in the field by the requirement to release the seeds from the base of the transfer tube at a position behind the rear edge of the coulter blade. This contrasted with the original experimental coulter where the seeds were released into the soil from the area between the coulter blade and the disc, and in this way they may have been isolated from the effects of soil disturbance created by the coulter blade and wing. It is

possible therefore that there may be an advantage in using a seed transfer mechanism that performs a similar function to the tube in isolating the seed path, but which is also able to release the seed into the soil without influence from the coulter or the soil reaction. Such a device was not tested in this study.

Future Work.

It was difficult to form firm conclusions as to the absolute suitability of any one seed transfer system in this study. The simple tube transfer system may not provide sufficiently accurate final field seed spacing to be suitable for combination with the redeveloped chisel direct drilling coulter. It is possible that a notched belt transfer system may more effectively fulfill the criteria discussed above than did the tube transfer system. Although a belt transfer system would undoubtedly be mechanically more complex, such a system would have the potential advantages of being largely independent of seeder release trajectory, and be more effectively combined with the coulter so that seed release could be protected from soil disturbance. Such a system would also allow controlled seed release, in the opposite direction to coulter travel. None of the tube transfer systems considered in this project could meet all these requirements.

Further study is required in this area in order to determine the most effective means of transferring the seed from the selection mechanism to the soil through a direct drilling coulter. There is also a requirement for further agronomic investigation into seed spacing requirements of fresh and processed vegetable and horticultural crop production with zero-tillage. Currently there appear to be no data to support

the validity of extrapolating population and seed spacing data from cultivated seedbed situations to zero-tillage.

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Appendix 1. Seed spacing variation with a "Nodet Gougis" seeder on the greased tray - Raw data.

		C of V								
		<u>Conventional "Nodet Gougis" seeder</u>								
		Maize			Lupin			Sub-terranean clover		
Replicate		5	8	11	5	8	11	5	8	11
1		0.29	0.35	0.69	0.33	0.44	0.78	0.27	0.35	0.56
2		0.30	0.39	0.50	0.33	0.38	0.86	0.24	0.28	0.45
3		0.29	0.41	0.55	0.29	0.55	0.78	0.30	0.33	0.51
Mean		0.293	0.383	0.580	0.317	0.457	0.807	0.270	0.320	0.507

		<u>"Nodet Gougis" seeder with chisel direct drilling coulter</u>								
		Maize			Lupin			Sub-terranean clover		
Replicate		5	8	11	5	8	11	5	8	11
1		0.61	0.74	0.69	0.50	0.68	0.98	0.80	0.95	0.84
2		0.60	0.75	0.66	0.58	0.82	1.01	0.82	0.96	0.80
3		0.64	0.62	0.79	0.53	0.65	1.41	0.80	0.92	0.92
Mean		0.617	0.703	0.713	0.537	0.717	1.133	0.807	0.943	0.853

Appendix 2. Seedling spacing variation with an experimental direct drilling unit in pasture - Raw data.

<u>Treatment</u>	(C of V)			Mean
	<u>Replicate</u>			
	1	2	3	
Maize/45/Scr.	0.75	0.80	0.82	0.790
Maize/45/No Scr.	0.77	0.73	0.79	0.763
Maize/90/Scr.	0.81	0.77	0.63	0.737
Maize/90/No Scr.	0.67	0.71	0.68	0.687
Lupin/45/Scr.	0.83	0.79	1.27	0.963
Lupin/45/No Scr.	1.03	0.78	0.80	0.870
Lupin/45/90/Scr.	0.87	0.73	0.71	0.770
Lupin/90/No Scr.	0.75	0.82	0.64	0.737

Appendix 3. Seedling spacing variation with an experimental direct drilling unit in barley stubble - Raw data.

<u>Treatment</u>	(C of V)			Mean
	<u>Replicate</u>			
	1	2	3	
Maize/45/Scr.	0.73	0.83	0.91	0.823
Maize/45/No Scr.	0.79	0.65	0.76	0.733
Maize/90/Scr.	0.91	0.92	1.01	0.947
Maize/90/No Scr.	1.05	0.62	1.07	0.913
Lupin/45/Scr.	1.08	0.66	1.24	0.993
Lupin/45/No Scr.	0.85	1.05	0.82	0.907
Lupin/90/Scr.	0.78	0.83	0.95	0.853
Lupin/90/No Scr.	0.97	0.75	0.73	0.817
Sub-clover/45/Scr.	0.95	0.98	0.83	0.920
Sub-clover/45/No Scr.	0.83	0.69	0.95	0.823
Sub-clover/90/Scr.	1.03	0.94	1.36	1.110
Sub-clover/90/No Scr.	0.85	0.90	1.07	0.940

Appendix 4. Seedling displacement from the seed groove centre with an experimental direct drilling unit in pasture - Raw data.

<u>Treatment</u>	(percentage)			
	<u>Replicate</u>			Mean
	1	2	3	
Maize/45/Scr.	4	14	16	11.3
Maize/45/No Scr.	23	26	18	22.3
Maize/90/Scr.	4	5	2	3.7
Maize/90/No Scr.	14	17	17	16.0
Lupin/45/Scr.	0	2	0	0.7
Lupin/45/No Scr.	3	0	5	2.7
Lupin/90/Scr.	0	2	0	0.7
Lupin/90/No Scr.	2	4	4	3.3

Appendix 5. Seedling displacement from the seed groove centre with an experimental direct drilling unit in barley stubble - Raw data.

<u>Treatment</u>	(percentage)			Mean
	<u>Replicate</u>			
	1	2	3	
Maize/45/Scr.	9	6	3	6.0
Maize/45/No Scr.	14	19	13	15.3
Maize/90/Scr.	11	16	2	9.7
Maize/90/No Scr.	12	7	10	9.7
Lupin/45/Scr.	23	14	0	12.3
Lupin/45/No Scr.	9	9	0	6.0
Lupin/90/Scr.	14	6	2	7.3
Lupin/90/No Scr.	17	6	4	9.0
Sub-clover/45/Scr.	25	20	13	14.0
Sub-clover/45/No Scr.	27	13	2	14.0
Sub-clover/90/Scr.	33	17	5	18.3
Sub-clover/90/No Scr.	32	33	13	26.0

Appendix 6. Percentage seedling establishment in experiments u/2 and u/3.

	Seeds/10m	Germination %	Total viable seeds/seedlings	Percentage establishment
<u>Laboratory Experiment</u>				
Maize	86	94	18	
Lupin	71	96	68	
Sub-clover	166	90	149	
<u>Pasture Experiment</u>				
Maize			76	94
Lupin			49	72
<u>Barley Stubble Experiment</u>				
Maize			69	85
Lupin			52	76
Sub-clover			123	83

Appendix 7. Seed/seedling spacing with an experimental direct drilling unit - comparison of laboratory and field experiments.

	(C of V)			
	<u>Maize</u>	<u>Lupin</u>	<u>S.clover</u>	<u>Av.</u>
<u>Laboratory</u>	0.70	0.72	0.95	0.79
<u>Pasture</u>	0.74	0.83		0.79
<u>Crop Stubble</u>	0.85	0.89	0.95	0.90
<u>% increase in variation lab - pasture</u>	5.7	15.3		0
<u>% increase in variation lab - crop st.</u>	21.4	23.6	1.1	13.9

Appendix 8. "Seed" spacing variation with a "Nodet Gougis" seeder with different seed transfer tubes
- Raw data.

<u>Replicate</u>	Standard Deviation					
	<u>Ball Bearings</u>					
	<u>Treatment</u>					
	Free seed drop (80mm)	Free seed drop (300mm)	Vertical seed tube	Curved tube (seeds bouncing)	Curved tube with tray movement (seeds sliding)	Curved tube opposite tray movement (seeds sliding)
1	2.98	3.79	4.77	7.31	5.09	5.87
2	2.75	3.88	3.99	4.73	6.16	5.88
3	3.56	3.46	3.16	4.46	5.65	6.61
4	4.51	3.78	4.13	5.39	6.77	6.32
5	3.59	3.37	3.42	6.04	5.92	6.62
Mean	3.48	3.66	3.89	5.59	5.92	6.62
<u>Replicate</u>	<u>Maize Seed</u>					
1	3.99	8.33	8.20	14.48	13.87	8.08
2	4.64	8.81	6.34	16.10	11.55	9.07
3	4.53	9.24	7.52	13.46	8.77	10.39
4	5.64	8.21	7.92	12.74	10.55	12.78
5	5.35	6.83	5.68	14.13	11.38	9.30
Mean	4.83	8.28	7.13	14.18	11.22	9.92
<u>Replicate</u>	<u>Huka Pea Seed</u>					
1	6.19	9.35	4.77	5.33	8.71	11.17
2	5.71	13.41	6.79	8.70	6.02	12.15
3	5.90	13.26	4.04	7.53	7.10	7.92
4	6.84	13.72	3.75	10.51	6.97	14.32
5	6.59	11.67	4.08	8.20	7.25	11.50
Mean	6.25	12.28	4.69	8.05	7.21	11.41

Appendix 9. Lupin seed spacing variation with a "Nodet Gougis" seeder with different seed deflection plates and seed transfer tubes - Raw data.

<u>Treatment</u>	Standard Deviation					Mean
	<u>Replicate</u>					
	1	2	3	4	5	
Free seed drop (300mm) - no deflector	9.10	8.27	12.54	9.04	8.74	9.54
Free seed drop (300mm) - 40° deflector plate	12.20	11.95	11.90	11.59	13.71	12.27
Straight vertical seed tube - 40° deflector plate	7.15	5.42	7.59	7.60	7.53	7.06
Curved seed tube opposite tray movement - 40° deflector	8.63	9.02	11.75	8.89	8.82	9.42
Curved seed tube with tray movement - 40° deflector	8.57	10.04	8.36	7.09	7.03	8.22

Appendix 10. Lupin seed spacing variation with a modified "Nodet Gougis" seeder/tube transfer/chisel coulter test unit - Raw data.

(standard deviation)

<u>Treatment</u>	<u>Replicate</u>					Mean
	1	2	3	4	5	
5 km.hr-1	33.83	34.44	31.97	25.44	24.81	30.098
6.4 km.hr-1	47.00	44.15	49.27	50.75	47.57	47.748
8 km.hr-1	59.36	51.58	52.58	49.67	56.00	53.838

Appendix 11. Lupin seed/seedling spacing variation with a modified seeder/tube transfer/chisel coulter test unit at 6.4km.hr-1 - Raw data.

<u>Treatment</u>	(C of V)					Mean
	<u>Replicate</u>					
	1	2	3	4	5	
Laboratory	0.42	0.40	0.44	0.43	0.42	0.422
Field	0.63	0.84	0.71	0.69	0.77	0.728

Appendix 12. Seed/seedling numbers in experiment d/2.

Laboratory seed number/10m (germination percentage adjusted)		Field seedling number/10m
79.8	N.S.	70.8

N.S. - not significant at $P < 0.05$.