AN X-RAY TECHNIQUE FOR DETERMINING SEED PLACEMENT IN DIRECT DRILLED SOILS

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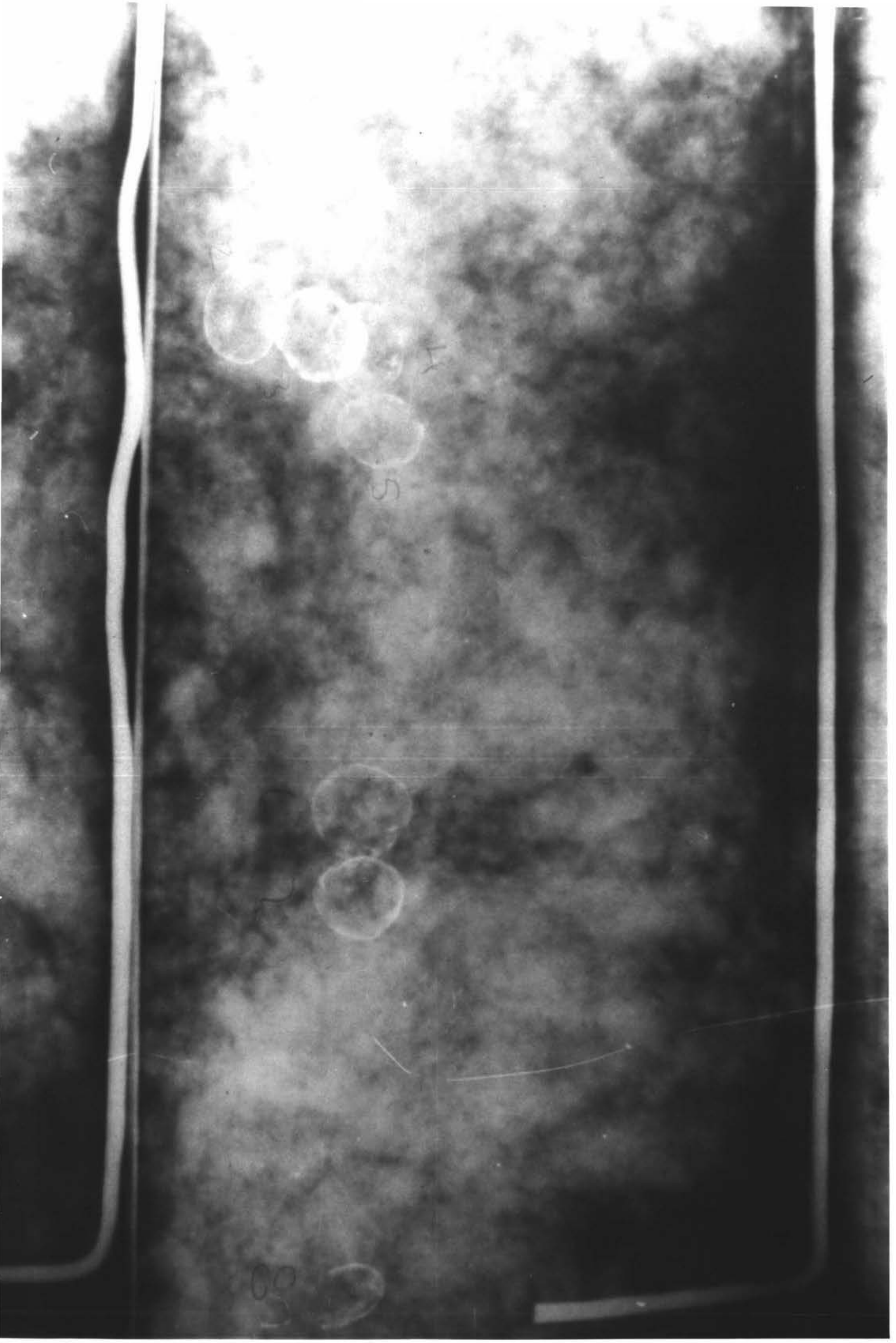
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ABSTRACT

The objectives of this study were to develop and document a reliable workable X-ray technique for identifying seed placement in the soil; to examine those factors which might influence this procedure and to demonstrate the use of the technique in a field experiment.

The X-ray technique was based on the principle that seeds coated with a heavy metal powder, when X-rayed within a soil mass, appeared on the X-ray film as white or grey images on a dark background.

A coating procedure (based on commercial pelleting) was developed to apply the heavy metal powder to the seed. As the seed images on the X-ray film were to be a shadow representation of the actual seed position in the soil mass, a correction procedure to locate the true positions of the seed was developed.

A series of laboratory experiments confirmed that red lead oxide was the most suitable coating material and that higher intensities of coating were required as seed size decreased. Neither soil type nor soil moisture content appeared to have a marked affect on the clarity of the X-ray images. Seed germination was not affected by the amount of red lead oxide coating, the coating procedure, or exposure to moderate levels of radiation.

Soil blocks measuring 75 mm by 75 mm by 240 mm long containing the coated seeds should be taken as soon as possible after sowing, as image clarity diminished over time and seed movement occurred in the case of seeds with epigeal germination.

Equipment developed to assist in field sampling included a soil-block-cutter, re-useable sample bins and a holding jig for X-raying the soil blocks in their bins.

Thus the X-ray technique had the ability to determine three dimensional seed placement within a soil mass (sowing depth, in-row width and in-row spacing). The ability of the X-ray technique offers new possibilities for explaining those factors which affect seed placement by direct drilling equipment in field situations.

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1. INTRODUCTION

The general practice in crop production has been to till the soil to prepare a uniform level seedbed into which seeds were placed (Loveday, 1980). Increases in tractor fuel and labor costs, together with decreases in available labor, recognition of the need for erosion control and the development of modern herbicides have all lead to a reduction in cultivation and the concept of no-tillage or direct drilling (Allen, 1981; Dickey and Rider, 1980). Erbach (1980) described the difference between no-till and cultivated seedbed conditions. According to Erbach, in using conventional tillage the soil was worked to produce a smooth, level and uniform seedbed. In direct drilling, residues were either absent or left on the undisturbed soil prior to planting. As a result, direct drilling openers were forced to operate in a different soil environment compared with conventional seed drills.

Early work in developing direct drilling openers entailed using or modifying conventional openers (Allen, 1981; Erbach, 1980). This practice met with only limited success due to the harder nature of the direct drilling seedbed. Early modifications to direct drilling openers concentrated on improving the mechanical performance (Allen 1981, Erbach 1980). As mechanical performance improved, hitherto unidentified problems associated with biological performance became apparent (Baker, 1976; Erbach, 1980). One area which affected both mechanical performance and biological performance was the depth at which the seed was placed in the soil.

In an attempt to accurately determine seeding depth, Barr (1981) put forward an idea for coating seeds with a heavy metal coating and determining seed placement by removing soil samples and X-raying them to locate the position of the seeds in the soil.

The objectives of this project were: 1. To develop and refine the X-ray technique so that it could form a reliable and workable technique for determining seed placement by direct drilling openers in the field; and 2. to demonstrate the ability of the X-ray technique in evaluating seed placement by selected direct drilling openers in a field experiment.

LITERATURE REVIEW

2.1 INTRODUCTION

This literature review examines the biological and mechanical performance of direct drilling openers, with particular reference to seed placement.

2.2 BIOLOGICAL PERFORMANCE OF DIRECT DRILLING OPENERS

In order to discuss the biological performance of a direct drilling opener it is necessary to establish seed requirements for germination and emergence. Many authors agreed that there were four basic requirements for germination and emergence. These were; adequate soil moisture, soil aeration, a suitable temperature, and a location that did not physically impede their growth (Collis-George and Lloyd, 1979). Table 2.2 (Gorden 1973) provides a more detailed list of the factors affecting seed germination and germination rates. In general terms, sub-optimal levels, or the absence of any of these major requirements will prevent or reduce germination. The discussion which follows deals with the soil environment as it pertains to seed germination and seedling emergence. This had been referred to as the micro-environment (Collis-George and Lloyd, 1979).

Table 2.2 Factors which affect the rate of germination (Gordon, 1973).

1. The temperature of the germinating seed.
2. The initial temperature of the germinating water.
3. The amount of water present.
4. The position of the embryo relative to the level of the germination water.
5. The amount of oxygen present in the germination medium.
6. The level of infestation by micro-organisms.
7. The presence of dissolved ions in the germination medium.
8. The number of pre-germinated seeds present.
9. The length of storage time at a high temperature.
10. The seed moisture content during storage.
11. The moisture content of the seeds as they go into the test.

2.2.1 Soil moisture

Collis-George and Lloyd (1979) stated that in considering soil moisture, both the soil moisture content and the matrix potential were important. These factors were related, using the soil's wetting and drying curves. The soil moisture content referred to the amount of liquid moisture in the soil while the soil matrix potential referred to the force required to remove water from the soil at that moisture content. A number of authors had also shown that soil water vapour was important when considering seed germination and emergence (Choudhary and Baker, 1981a; Collis-George and Lloyd, 1979; Rogers and Dubetz, 1980).

Choudhary and Baker (1980) tested direct drilled seed grooves of three general shapes; a "V" shaped groove with well defined sides, a "U" shaped groove with rough sides and bottom, and an inverted T-shaped groove with a narrow opening at the top and a wider shattered zone under the surface. Baker (1976) subjected the three seed grooves outlined above to moisture stress conditions. He found that the inverted T-shaped groove, which was created by what he then termed an experimental chisel opener (but which has since been referred to as a winged opener (C.J. Baker, pers.comm., 1984) permitted better seed germination and emergence than "U" or "V" shaped grooves, even when covered. He suggested that the inverted T-shaped groove resisted drying out and thus created a better seed micro-environment than the "V" shaped or "U" shaped grooves. He also noted a strong correlation (R.97) between arbitrary grades of groove cover and seedling survival, with the inverted T-shaped groove being characterized by a predominance of residue-mulch as the covering medium. Further experiments (Choudhary and Baker, 1977; 1980; 1981a) confirmed that variations in the slot micro-environment had accounted for those differences. They defined the ability of a groove to resist the loss of vapour-phase water as the "Moisture Vapour Potential Captivity" (MVPC). Choudhary and Baker (1981b) measured the in-groove relative humidity and found that the groove formed by the winged opener had a lower daily loss of in-groove moisture vapour than the "V" shaped or "U" shaped grooves. They defined MVPC as the inverse of the mean daily relative humidity loss from the seed groove. The authors used this value as a prediction of whether or not seedlings would emerge from drying soils. Field experiments conducted by Choudhary and Baker (1982) confirmed that under drying soil conditions the winged opener, with its inverted T-shaped groove, permitted better seedling establishment than the hoe opener with its "U" shaped groove or the triple disc opener with its "V" shaped groove. Wilkins et al. (1983) also measured the effects of opener design on the moisture content in the seed zone of conventional seedbeds. These authors found that hoe type openers tended to move the dry surface soil to one side and placed the seed in the moist soil below. Disc openers allowed the dry surface soil to filter down, thus reducing the resulting moisture content in the seed zone. This subsequently caused more seeds to be placed in contact with dry soil. Earlier, neither Baker (1976), nor Choudhary and Baker (1977), could detect any differences between soil liquid moisture contents from small quantities of soil removed from in or around contrasting direct drilling grooves.

2.2.2 Soil temperature

Many authors have agreed that in general terms, soil temperature was best measured at the seed depth in the soil (Collis-George and Lloyd, 1979). Dubetz et al. (1962) presented data showing that as temperature rose from 6° C to 24°C in a tilled soil, the speed of seedling emergence increased. In general, crops required a specific number of degree-days above a base line before seedling emergence would occur. Winter wheat required 149 to 210 degree-days above 0.7 and 0.4 °C respectively to reach 70% emergence. Barley required 92 and 159 degree-days above 6.1 and 5.5°C respectively (Russelle and Bolton, 1980).

In examining the micro-environment of the seed zone of tilled soils, Collis-George and Lloyd (1979) suggested measuring temperatures at seed, root and shoot zones in order to adequately estimate the effects on an emerging plant. Baker (1976) examined temperature differences between direct drilled seed grooves. He concluded that in his experiments, there was only 1.0°C difference between grooves. Both the "U" and "V" shaped grooves of the hoe and triple disc openers were 0.5°C above the general soil temperature, and the inverted T-shaped groove of the winged opener was 0.5°C below the general soil temperature. Lindwall and Erbach (1983a) measured temperature differences at 10 mm and 50 mm soil depths in untilled corn plots with no cover, burlap cover, and corn stover cover. The authors found temperatures in the uncovered plots to be as much as 10°C higher than those of the corn stover plots at the 10 mm depth. At the 50 mm depth, the difference was 4.0°C. A further study by Lindwall and Erbach (1983b) examined the effect on soil temperatures and corn seedling emergence of a mulch-free space around the seed. The authors concluded that, in general, increasing the amount of residue-free area above the seed decreased the time required for emergence, and increased soil temperatures.

2.2.3 Mechanical impedance

Collis-George and Lloyd (1979) defined mechanical impedance as the impedance experience by either the seedling root or shoot. Root or shoot elongation took place in two ways: 1. Growth could be through existing pores in the soil; or 2. the roots or shoots created their own pore space by deforming or displacing soil aggregates. In the first case, impedance was a function of the shape and nature of the existing soil pore space. In the second case, growth was a function of soil strength. Dicotyledonous seedlings with hypogeal germination had more problems in emerging than seeds with epigeal germination (Martin et al., 1976).

A number of authors have studied the effect of soil crusting on seedling emergence in conventional seedbeds (Morton and Buchele, 1960; Hanks and Thorp, 1956; 1957). These authors concluded that in general, crusts were formed over the seed after planting and may have been caused by the breakdown of surface aggregates by raindrops, press wheels or rollers. As the soil was wetted and then dried, crusts were formed which inhibited seedling emergence. Mai and Baker (1977) and Baker and Mai (1982a,b) examined soil physical properties in the "V" shaped grooves of a triple disc opener and the inverted T-shaped grooves of an experimental winged opener in direct drilled soils. In soils at an initially high bulk density (1.2 gm/cm^3), the triple disc opener compacted the sides and bottom of the groove to an extent that impeded root growth of lupin seedlings but not wheat seedlings. Choudhary and Baker (1977) studied the effect of press wheel pressures on surface impedance in direct drilled seed grooves. In soil bins removed from the field, they created seed grooves with triple disc, hoe and winged openers, followed by press wheel pressures of 0, 35, and 70 kPa. Emergence forces were measured by pushing a 2.0 mm diameter "mechanical seedling" upwards from beneath the soil bins, and grooves. The authors concluded that there were no significant differences in emergence forces but noted that such a "mechanical seedling" might not be representative of true seedling impedance, especially in direct drilling with its more well defined paths of least resistance.

Lindwall and Erbach (1983a) studied the effect of press wheel types on soil bulk densities in the seed zone in direct drilled situations. They concluded that iron press wheels with a 312 N downward force, and a rubber press wheel with 156 N downward force did not change the bulk density within the seed row. In a second experiment, an air-fed cultivator seeder, a triple disc drill and a four row planter were tested. Although the cultivator tended to loosen surface soil more than the other two seeders there were no significant differences in bulk density in the seed zone (30-60 mm).

2.2.4 Aeration

Collis-George and Lloyd (1979) defined aeration as the supply of oxygen, and the subsequent removal of carbon dioxide from the germinating seed by molecular diffusion through the air filled pores. In tilled soils, Room Singh and Ghildyal (1977) reported the critical value for oxygen diffusion was 40 x 10-8 gm/cm^2/min for emerging corn seedlings. Hanks and Thorp (1956) measured a value of 75 x 10-8 gm/cm^2/min for wheat seedlings.

In direct drilled soils, Choudhary and Baker (1981a) covered the "V" shaped grooves created by a triple disc opener with a layer of polythene. Germination was 100% but seedling emergence was reduced, compared with uncovered grooves, and 37% of the seedlings died. The authors suggested that the seedling mortality was caused by poor oxygen availability within the seed groove due to the polythene cover.

A.D. Chaudhry (pers. comm., 1984) tested direct drilling openers extensively in a soil with a high moisture regime. He concluded that under these conditions, the groove created by a winged opener had an oxygen diffusion rate 24% higher, 44% more earthworms, and a 9% lower soil bulk density, than the grooves created by a triple disc opener. He attributed these results to the fact that the winged opener shattered the soil around the seed groove as it created the groove and returned the surface residues to a position over the groove.

The hoe opener was found to have an in-groove oxygen diffusion rate similar to the winged opener, but seedling performance was slightly inferior to the winged opener. (A.D. Chaudhry, pers. comm., 1984).

Chaudhry also concluded that if surface residues were maintained, the oxygen diffusion rate through a groove created by an opener tested was increased by 30% compared with where the residues were removed. It was also noted that the above effects on oxygen diffusion rate were negligible if earthworms were absent from the experiments.

2.3 DIRECT DRILLING OPENER ASSEMBLIES

The term "opener assembly" was defined as a group of machine parts forming a self-contained unit which created a groove in the soil into which the seed was placed (Williams, 1979; Schaaf et al., 1980). Schaaf et al. (1980) and Cochran et al. (1974) considered that the opener assembly had to include an opener, and might also contain a cutting disc, a press wheel and or a depth control mechanism.

2.3.1 Description of opener components

Schaaf *et al*. (1980) defined an opener as a device which opened a groove in the soil where the seed was placed. The authors conducted a detailed study on a number of opener types. Their work, though extensive, was not complete. An experimental winged opener was developed and tested by Baker (1976) and a revised version of this opener was described by Baker *et al*. (1979b). Table 2.3.1 lists a range of openers which have been tested, together with the type of seed grooves they created.

Table 2.3.1 Description of direct drilling opener types.

Opener type	Apparent shape of seed slot	Reference
Semi deep furrow	Inverted T	Schaaf *et al*. (1980)
Spear point	U Shaped	Schaaf *et al*. (1980)
Hoe	U Shaped	Schaaf *et al*. (1980)
Conventional angle double disc	V Shaped	Schaaf *et al*. (1980)
Narrow angled double disc	V Shaped	Schaaf *et al*. (1980)
Spike	U Shaped	Schaaf *et al*. (1980)
Lister	V Shaped	Schaaf *et al*. (1980)
Planting	V Shaped	Schaaf *et al*. (1980)
Anhydrous	U Shaped	Schaaf *et al*. (1980)
Simple winged	Inverted T	Baker (1976)
Experimental winged	Inverted T	Baker *et al*. (1979b)

Schaaf et al. (1980) defined the cutting disc as the device which cut trash, thus preventing its build-up on the opener. They found that as disc diameter increased from 250 mm to 610 mm, the penetration forces increased significantly. These authors had also shown that there where no significant differences in vertical or draft forces between plain, fluted, rippled or notched cutting discs of the same diameter.

Located behind an opener, press wheels firmed the soil around the seed to create better seed-soil contact, according to Choudhary and Baker (1980). Narrow press wheels, which pressed the seed into the base of the groove, significantly improved wheat seedling emergence, compared with those which pressed the soil over the seed (Lillard and Jones, 1964; Decker et al. 1964; Choudhary and Baker, 1977; 1980; 1981a).

Because un-tilled seedbeds were often rougher than cultivated seedbeds, it was considered desirable to have a depth-control mechanism attached to each opener assembly (Erbach, 1980). Morrison (1978) tested gauge wheels, slides and depth bands. He concluded that forward speed did not affect the vertical forces on these depth control devices in tilled soils. It was also noted that depth bands were more sensitive than depth wheels, but provided less floatation in soft soil. Baker et al. (1979b) developed a winged opener assembly for direct drilled soils with two gauge wheels angled vertically and located slightly behind and to one side of the openers. It was claimed that these also closed the inverted T seed groove, as well as provided depth control.

2.3.2 Opener assemblies

Allen (1981) stated that the triple disc was the most common direct drilling opener assembly. The triple disc mechanism he described consisted of a cutting disc in front followed by an opener consisting of two discs arranged side by side to form a "V" shaped groove in the soil where the seed was placed. The triple disc opener coped well with residues except where the residue was not completely cut by the opener and pushed to the bottom of the seed groove. Under wet soil conditions, the author suggested that residues might produce toxins which inhibited germination. Also, in wet soil the triple disc caused smearing on the sides of the "V" shaped seed groove (Allen, 1981; A.D. Chaudhry, pers. comm., 1984). A variation on the triple disc was to replace the double disc opener with a hoe opener. This configuration had problems coping with large residue levels (Allen, 1981; Baker et al., 1979a).

Increasing in popularity was the "culivator", or "tined" drill, according to Allen (1981). This drill consisted of a cultivator with a seed metering system and seed tubes to deliver the seed to the cultivator points. In Britain, these drills were narrow (less than four meters) and fed by a conventional seed box (Allen, 1981). In North America, large cultivators (greater than six meters in width) were used, and the seed was conveyed to the openers by pneumatic systems. Two major problems were that they had poor depth control across the drilling width and they would not cope with large residue levels (Allam and Wiens, 1982; Allen, 1981; Giblett, 1983.)

Tractor-powered cutting openers have also been marketed. In Britain, a rotary cultivator had its cutting blades changed to cut only a narrow groove into which the seed was placed (Allen, 1981). In North America, a powered drill was developed using "saw like discs" which cut narrow grooves into which the seeds were placed (Smith and Bencok, 1979). These drills worked well as narrow machines but power requirements and expense prevented them from competing with the wider drills on the market.

Single disc drills were marketed as well. In Britain, a single disc, angled to the direction of travel, was marketed. On the inside of the disc, in the disturbed soil, a seed tube placed the seed in the narrow groove created by the disc (Allen, 1981). A prototype drill developed in New Zealand used a single notched disc. In this case winged openers were placed on either side of the disc (seed on one side and fertilizer on the other) (Baker et al., 1979b). Both drills employed individual depth control wheels for each opener. Because the openers were not below the cutting plane of the disc, trash not cut by the disc passed under the opener.

2.4 SEED PLACEMENT BY DRILLING OPENERS

Hilton et al. (1979) reported that the two most important drill design problems for tilled soils were: 1. To achieve the desired spatial arrangement; and 2. to achieve maximum and uniform early seedling emergence. In considering the performance of drill openers, an important aspect has been the in-row function of the opener. Ritchie (1982) divided this function into two distinct parts. The above-ground aspects dealt with seed selection, delivery and projection. The below-ground aspects included impact, bounce, roll, covering and firming. Only the below-ground aspects of openers are considered below.

The following discussions of in-row spacing and depth of seed placement deal almost exclusively with tilled seedbeds. Lindwall and Erbach (1983b) were the only authors to deal with untilled soils. Baker (1976), Choudary and Baker (1977, 1980, 1981a,b, and 1982) and A.D. Chaudhry (pers. comm., 1984), particularly, have shown that extrapolation of aspects of drilling from tilled soils to untilled soils may be at best unjustified and at worst quite misleading. Nevertheless, in the absence of specific information from untilled soils, a review of the data for tilled soils may contain pertinent principles common to both soil conditions.

2.4.1 Agronomy of in-row spacing

Most work on precision seeding has been conducted with vegetables, maize, soybeans and cotton in tilled soils (Kepner et al., 1975). Erbach et al. (1972) suggested that the yield of corn planted in 0.76 m rows was not likely to be improved by improving in-row spacings over what was normally obtained with conventional planting equipment. Muldoon and Daynard (1981) concluded that the yield of corn seeded in 0.76 m rows was unaffected by gaps of up to one meter in length. They concluded that improving in-row spacing compared with what was generally found on commercial corn planters, would not result in yield increases. On the other hand Johnson and Mulvaney (1980) found that small gaps (0.42 to 0.85m) reduced corn yields by 1.9% and large gaps (less than 1.5 m) reduced yield by 5.4% compared with a uniform in-row spacing.

With soybeans seeded in narrow rows, Ewen et al. (1981) found that in-row skips of up to 0.46 m failed to reduce yields. Alessi and Power (1982) tested the affect of in-row spacing of soybeans under moisture stress conditions. They concluded that in-row spacing affected soybean yields in only one of the four years of the trial. Stivers and Swearing in 1980 concluded that with soybeans planted in 0.76 m rows, several short skips reduced yields less than one long skip of the same total length. Skips of 0.3 m reduced yield by 1.1% while skips of 1.22 m reduced yield by 15.3%.

Evans (1978a) examined the effect of in-row spacing of barley seeds on row widths of 100 and 200 mm. The author concluded that as in-row spacing was adjusted towards a square planting pattern, yields improved. Roebuck and Trenerry (1978a) seeded cereals with a precision seed drill and a conventional grain drill. The authors found that precision seeding of cereals in 100 mm rows improved yields of barley by 14% and yields of wheat by 18%, compared with conventional drilling in 200 mm row spacings. Precision drilling in 200 mm rows did not improve yields. Kemp et al. (1983) examined the effect of in-row spacing and plant densities on wheat yields. The authors concluded that there was a general trend to higher yields as the planting pattern was made less rectangular. The trend was more dramatic at lower planting densities than at high planting densities.

Most authors agree that as gaps in in-row spacing became large, yield losses resulted. They also tended to agree that square planting generally improved yields. Authors who have tested present planting equipment, have concluded that improving in-row spacing over what was commercially available, did not result in any significant improvement in cereal yields.

2.4.2 Agronomy of depth of seed placement

"In order to achieve a maximum and uniform early seedling emergence, seeds should be placed accurately at a predetermined optimum depth" (Hilton et al., 1979). He defined the optimum depth as that depth where temperature, moisture content and oxygen diffusion were at their optimum values.

Alessi and Power (1971) studied the effects of soil temperature and seeding depth on corn. They concluded that as corn was sown deeper, emergence was delayed due to two factors: 1. The lower soil temperature at deeper placements; and 2. the longer time required for the plant to reach the soil surface. They suggested that for each 25 mm increase in depth, emergence was delayed by one day. At a seeding depth of 76 mm, they found that 68 degree-days above 10°C were required for corn seedling emergence. Muldoon and Daynard (1981) found that populations of corn established with variable seedling sizes tended to yield less than those established with even seedling sizes. Stibbe et al. (1980) concluded that different tillage treatments affected seeding depth of corn, and resulted in delayed emergence. This did not, however, affect final yields. Work by Lindwall and Erbach (1983b) examined relationships between seed depth and placement of surface residue cover, on soil temperature and seedling emergence. As more surface soil was left bare around the seed, soil temperatures were higher, thus improving emergence rate. When seeds were placed deeper, seedling emergence rate was reduced. The authors concluded: "Overall, planting depth was much more critical than degree of residue cover, with respect to the time required for emergence."

Banks and Gilmour (1979) and Johnson and Wax (1979) studied the effect of planting depth and soybean cultivars on seedling emergence. The authors concluded that a depth of 40 to 60 mm provided for the most reliable seedling emergence. Deeper sowing was found to reduce and delay emergence. Shallower seeding in dry years had similar effects. These results were confirmed by Nave et al. (1977) and Fehr et al. (1973). Stucky (1976) compared depth of planting under dry soil conditions. The results showed that soybeans would emerge from as deep as 75 mm, provided there was adequate soil moisture at that depth.

Evans (1978b) extensively studied the effects of seeding depth on spring seeded barley. Barley was shallow seeded (10-20mm) and deep seeded (70-80mm). Evans concluded that the shallow planting provided better tiller production and survival, thus improving yield compared with the deeper planting. His results are summarized in Table 2.4.2.

Table 2.4.2 Effect of planting depth on barley performance (Evans, 1978b)

	Year	Deep	Shallow
Vegetative Tillers per Plant	1971	1.8	2.7
	1972	2.0	2.5
	1973	1.9	2.9
Heads per Plant at Harvest	1971	3.2	4.2
	1972	2.7	2.8
	1973	N/A	N/A
Grains per Head	1971	23.9	25.2
	1972	22.5	22.5
	1973	34.7	34.3
Comparative Yield Mean Equals 100	1971	83	117
	1972	98	102
Length of Second Leaf in mm	1972	42.5	61.0
% Plant with Awns Visible	1972	21.5	39.0

Roebuck and Trenerry (1978b) also compared shallow (25-35 mm) and deep (60-75 mm) seeding of cereals. The authors concluded that deep seeding delayed emergence, reduced establishment and lowered plant heights. Generally, treatments did not affect yield but in one experiment, which had a "badly planned seedbed", yield of the deep planted barley was reduced by 27%. Roebuck and Trenerry also stated that deeper sowing reduced fertile tiller population, but in this experiment, yield was not affected due to increases in grain size and weight. Duczek and Piening (1982) examined the effect of seed size, seeding date and seeding depth, on the symptoms of root rot and grain yield of spring sown barley. The authors found that as seeding depth was increased, disease increased, while emergence and yield decreased. The authors concluded that an increase in seeding depth was linked to the increase in disease incidence.

In general, authors have agreed that as seeds were sown deeper, emergence was delayed and sometimes reduced. Deeper sowing was also linked to reduced tiller numbers, reduced tiller survival, increased disease incidence and, in some cases, reduced yields. Soetono and Donald (1980) found that late emerging cereal plants remained at an agronomic disadvantage over the entire growing season. In cases where soil moisture in the surface layer was a limiting factor, deeper seeding into an adequate moisture condition, was found to improve cereal emergence (Wilkins et al., 1983). It is thus apparent from the literature that planting crops at an optimum, even depth has been desirable for obtaining an adequate stand and maintaining maximum crop production.

2.4.3 Mechanics of seed depth placement

A number of authors have pointed out the importance of uniform seed placement at a preselected target depth (Bufton et al., 1974; Erbach, 1980; Hilton et al., 1979). Gray and MacIntyre (1983) stated that direct drilling opener penetration was a function of both the opener and drill design.

Lindwall and Erbach (1983a) tested three commonly available direct drilling seed drill configurations: These were: 1. A cultivator seeder; 2. an independently mounted opener grain drill; and 3. individual planter units. The authors concluded that the planter units provided for the best depth control because of their individual mounting. The grain drill was second and the cultivator seeder was third. The cultivator seeder was found to seed deeper and less evenly. Despite this fact, there were no differences in seedling emergence or establishment and it produced the highest yields. These authors did not, however, attempt to explain the possible contribution to these results, of the different row spacing (which ranged from 180 mm for the cultivator to 330 mm for the planter units with the grain drill at 250 mm). Allam and Wiens (1982) compared a number of types of independent openers. The authors found that the hoe drill provided a more even seeding depth than the cultivator seeders due to: "1. The hitch length; 2. the width of each frame section; 3. the distance between the rows of shanks; 4. the position of the cultivator wheels; 5. the type of wheel axle; and 6. the condition of the field surface."

Nave et al. (1977) examined the effect of conventional drill types on the establishment and yield of soybeans in a tilled seedbed. They concluded that a suitable stand of soybeans could be obtained with a grain drill, provided the tractor wheel tracks were removed prior to drilling. It was also noted that depth bands and firming wheels on the grain drill helped to improve establishment. Morrison (1978) evaluated two commercial direct drilling planters and one experimental planter with field corn, sweet corn and soybeans. The experimental planter could be equipped with depth wheels located on either side of the opener, or depth bands. The author suggested that the depth bands provided better depth sensing but lacked floatation.

Gray and MacIntyre (1983) looked at the performance characteristics of no-till drills marketed in England. They found that the method of weight transfer from the drill to the openers varied.

The "Moore Unidrill" achieved weight transfer by altering the pitch of the drilling openers. Therefore, most of the weight of the drill could be applied to the openers.

Cochran et al. (1974) examined the mechanical performance of depth control devices, on single openers in tilled seedbeds. There were no differences in vertical pressures at speeds up to 5.5 kph on either a depth wheel, a depth slide or depth bands. Schaaf et al. (1980) studied ten furrow openers, six cutting discs and nine types of press wheels in artifically prepared soil bins. As opener depth was increased from 30 mm to 70 mm, the penetration forces increased from 176 N to 237 N in sand and 291 N to 384 N in clay. A double disc opener required as much as seven times the penetration force of a hoe opener. A narrow spike opener required the lowest penetration force of 65 N in sand and 148 N in clay. As depth was increased, the amount of soil cover over the seed, the width of the furrow, and the soil shatter zone were all increased. The results for the six direct drilling cutting discs were similar to those described for the disc openers examined earlier. Gray and MacIntyre (1983) found that smaller and sharper discs, and lower forward speeds, all reduced penetration forces and draft forces on the disc openers they tested in soil bins.

Choudhary et al. (1983) examined the effect of direct drilling opener types on seedling emergence. The authors found a high negative correlation between coefficient of depth variation, and seedling emergence of peas and fodder radish. In their trials, they found that a simple winged opener performed better than an experimental winged opener with a cutting disc located between the two winged blades. They concluded that the relatively poor performance of that version of the experimental opener was due to its inability to sow seeds at a target depth. Wilkins et al. (1983) tested six drilling openers in a conservational tillage situation and measured changes in soil moisture, seeding depth and seedling emergence. In these experiments two openers, which were modified to place fertilizer below the seed, had larger variations in depth than did the standard opener. This was due to seeds falling into the lower (fertilizer) part of the seed groove.

Openers which created a uniform groove, had the lowest standard deviation of planting depth. Hoe and boot openers tended to move the dry surface soil to one side and did not allow it to filter down into the seed zone. As a result seedling emergence was faster with these openers, compared with disc openers which allowed dry surface soil into the seed zone.

2.4.4 Methods of determining seeding depth

Researchers have used various methods of determining seed depth, but Morrison (1978) stated that, "Because techniques for large-scale measurements of seeding depth have not been developed, depth uniformity and achievement was assumed to be indicated by statistical analysis of differences in emergence across depth regulation methods, planting dates and plant stands on observation dates." Morrison used statistical methods to determine which factors caused the largest effect on planter performance.

The most common method for determining seeding depth has been to use seedling tracing. Techniques have differed from researcher to researcher, but all were based on identifying some point on the seedling and measuring down into the soil to the seed location (Allam and Wiens, 1982; Stibbe et al, 1980; Pidgeon, 1981; Moch and Erbach, 1977; Ball and O'Sullivan, 1982; Choudhary et al., 1983). The seedling tracing technique, however, failed to identify seeds which had not emerged, and caused problems in seed grooves created by direct drilling, in that the seedlings might not grow straight to the surface. Only Moch and Erbach and Choudhary et al. had taken time to examine samples and determine the position of ungerminated seeds. This process of finding unemerged seeds was found to be tedious, and since the position of the seeds was not known, the soil had to be carefully removed so as not to disturb the seed position. In the case of direct drilling, the surface soil could be quite hard and difficult to remove without damaging or displacing the seedlings.

Wilkins et al. (1983) used an incremental soil sampler which removed a soil core, 50 mm by 50 mm by 100 mm deep. This core was then divided into 10 mm sections which were examined for seed location. This method had the added advantage in that it provided soil samples for other measurements of the seedbed profile. The disadvantages were that it was accurate to only 10 mm, and the sampling procedure was also very tedious.

Barr (1981) put forward the idea of coating seeds with a heavy metal prior to seeding. After seeding, lengths of row containing seeds were sampled and X-rayed using standard veterinary X-ray equipment. Choudhary et al. (1983) tested this method in the field but found seed coating rather difficult and field sampling laborious. Giblett (1983) also attempted to use the technique in Australia. He found the coating expensive, field sampling laborious, and the technique did not account for all seeds in the sample. It was suggested, however, that the technique did offer the possibility of being able to determine not only seeding depth but also width of spread and in-row spacing. Further to this it was suggested by Ritchie and Cox (1981) that determining seed placement in three dimensions would be desirable in determining opener performance.

3. DEVELOPMENT OF AN X-RAY TECHNIQUE

3.1 INTRODUCTION

Barr (1981) appeared to be the first worker to put forward the concept of using an X-ray technique to locate seeds in the soil. He suggested coating seed with a heavy metal prior to drilling with the openers to be tested. After drilling, small blocks of soil from the seeded row would be carefully removed and taken to the laboratory where they were to be X-rayed using standard veterinary X-ray equipment. The X-ray films were then examined and the seeds appeared as white or gray images on a darkened background. Using this concept the X-ray technique had the ability to determine seed position in the X, Y, and Z planes. It appeared possible that by positioning reference markers in specific positions, distances to the soil surface and amount of seed cover could also be measured.

It was suggested by Choudhary et al, (1983) that seeds coated with red lead oxide, had germinated successfully. Giblett (1983) found that wheat seed germination was not affected by coatings of lead oxide. If this was true, then rows sown with coated seed could be monitored in the field for determining emergence and other agronomic parameters. Samples removed from the rows could be returned to the field or placed in growth chambers where climatic conditions could be controlled to further examine the effects of seed placement on seedling emergence.

From the literature review it appears that work on the effect of other types of seed coating, soil sample size, seed size, soil type and soil moisture content had not been determined for the X-ray technique. It was therefore proposed to develop the X-ray technique by defining the parameters which affected the technique, and to develop a fast and reliable method for field sampling.

3.2 EXPERIMENTAL APPROACH

In examining the possibility of developing an X-ray technique, the factors given in Table 3.2 were considered as important.

Table 3.2 Possible factors affecting X-ray technique for locating seeds in soil .

Coatings	-Type -Amount -Application method
Soil	-Depth -Type (particularly texture, organic matter content) -Moisture content
Seed	-Type (size, shape) -Germination
Germination	-Image clarity -Image movement

In order to simplify the development of the procedure, the parameters to be tested were grouped together in the following sections.

1. Development of a distortion-correction procedure.
2. Development of a seed coating procedure.
3. Evaluation of coating types and amounts.
4. Evaluation of effects of soil on X-ray clarity.
5. Evaluation of effects of seed coating on germination.
6. Evaluation of elapsed time on clarity and seed movement in the soil.
7. Development of field sampling procedures.

The aim of this major section of the study was to produce a reliable technique for field use. Therefore each set of new experiments was designed to build on the data obtained from the preceding experiments.

3.3 X-RAY IMAGE DISTORTION: PROBLEM AND SOLUTIONS

Previous authors (Barr, 1981; Choudary et al., 1983; Giblett, 1983) had apparently not recognized that the image on the X-ray film was a shadow and was therefore subject to distortion, dependent on the geometry of the X-raying equipment and placement of the samples. It therefore became necessary to develop a correction technique to compensate for this distortion. The distortion caused by X-ray machines results from the nature of the machine. This is shown in Figure 3.3. As the X-ray beam is emitted, it diverges from a pointsource. As the beam passes through an object or soil sample, the dense portions of the sample absorb the beam (in this case, the seeds coated with a heavy metal). Once the beam has passed through the sample, it contacts an X-ray cassette containing an unexposed film. The intensity of the beam contacting the film causes differences in exposure. The dense seed caused images to appear as light gray spots while the surrounding soil appeared darker indicating the transmission of greater ray intensities. As can be seen from Figure 3.3, the image at A is not a true representation of a seed located at D. The amount of distortion is proportional to the distance from the film to the seed (BC) and the distance from the film to the source (BS).

3.3.1 Possible solutions

The following is a list of possible ways of solving the problem of image distortion, caused by using the X-ray technique.

1. Positioning of the soil sample, which contained the seeds, so it was located in the centre of the film. This solution would have reduced the distortion rather than eliminating it. The method would also have allowed for only one sample to be X-rayed at a time.

2. Arranging the soil samples so that they were always in the same location and applying a single correction factor to each sample. This procedure would have corrected for only

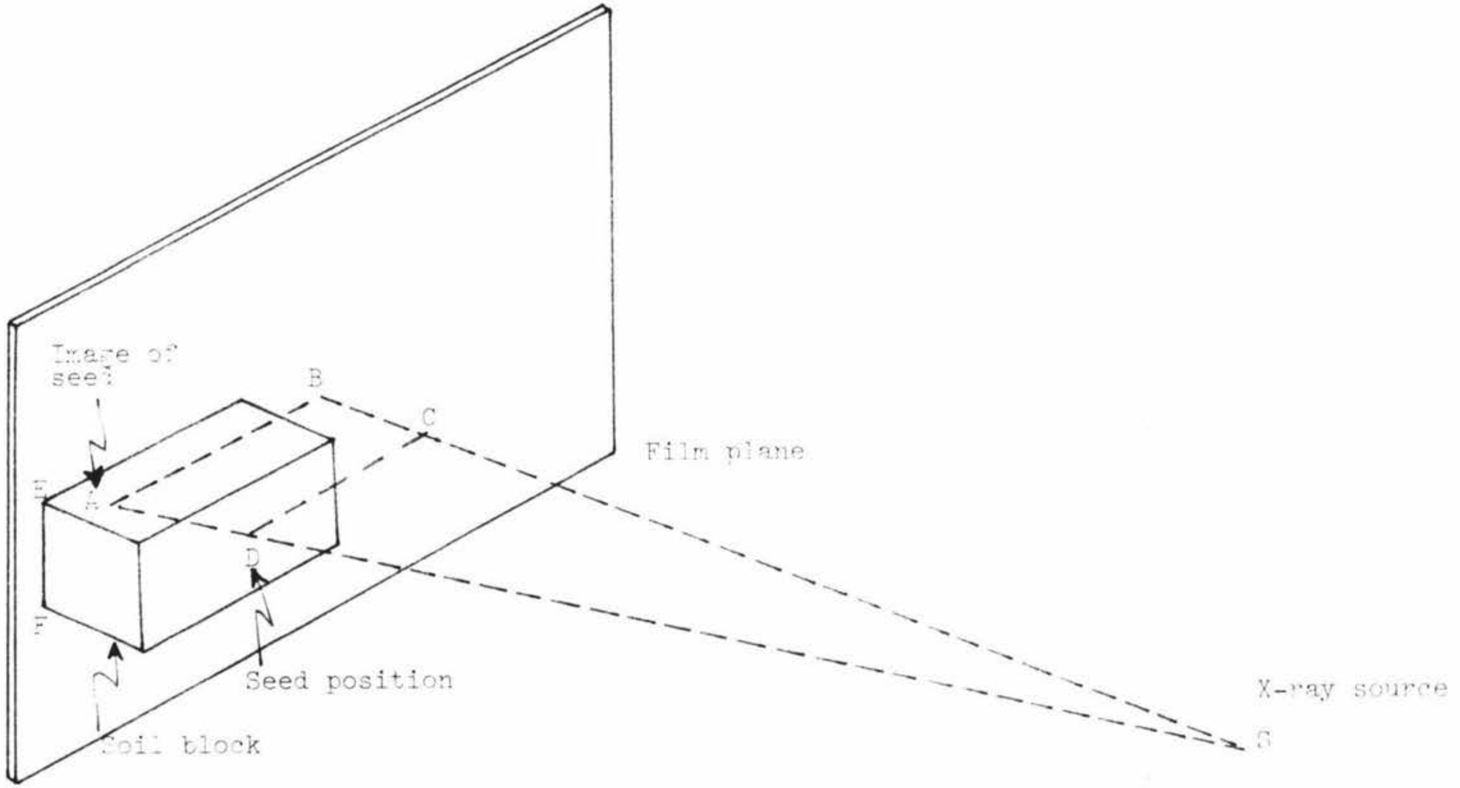

Figure 3.3 Three dimensional representation of the X-ray distortion problem.

one spot in the sample, and as the distances away from this spot increased, then increased distortion would also occur.

3. Positioning of the soil samples on wedges so that the distances on the film represented what was in the soil. This could have been accomplished (as shown in Figure 3.3) by raising end EF off the film cassette so that angle CDS became 90 degrees. This solution would have allowed numerous samples to be X-rayed, but a complicated series of wedges would have had to be constructed, and distortion would not have been completely eliminated.

4. Using an extra long source distance (BS) would have reduced the amount of distortion. This however would have meant that the strength of the X-ray beam would have had to be increased, and the distance (BS) (Figure 3.3) would have been limited by the size of the X-ray facility.

5. Correction of all points D to the centre position B by measuring distance (AB) and finding distance (BC). By using similar triangles the true distance DC could be calculated. This allowed for each seed to be corrected individually, and thus a true position could be determined for each seed. The problem however, was how to obtain distance (BC).

From the previous discussion, it appeared that the most satisfactory approach was to pursue Solution 5 and develop a procedure which allowed for the correction of the position of each seed in the soil.

3.3.2 Distortion correction technique

Two methods were considered for finding (MN), the Z component in Figure 3.3.2a. These were: 1. To use an X-ray stereo technique; or 2. to X-ray the seeds in a second plane.

Figure 3.3.2a is a diagramatical representation of the stereo correction procedure for the Z component. This figure shows the principles involved in using the stereo technique. The X-ray sources were positioned at G and H to produce images J and K on the X-ray film. The power setting of the X-ray equipment was reduced by one half for each shot taken to avoid overexposure of the X-ray plate. The calculation for the Z component (MN) is given below (Figure 3.3.2a).

Using similar triangles GJL and JMN

$MN : JN \text{ as } GL : JL$

or $JN = MN * JL / GL$

Using similar triangles HIK and KMN

$MN : NK \text{ as } HI : IK$

$HI = GL$

or $NK = MN * KI / GL$

since $JK = JN + KN$

therefore $JK = (MN * JL / GL) + (MN * IK / GL)$

or $JK = [MN * (JL + KI)] / GL$

but $JL + KI = IL + JK$

therefore $JK = [MN * (IL + JK)] / GL$

finally $MN = (JK * GL) / (IL + JK)$

Where MN = Distance from the seed to the film.
JK = Distance between the images on the stereo film.
IL = Distance between the source locations.
GL = Distance between the sources and the film, = HI.

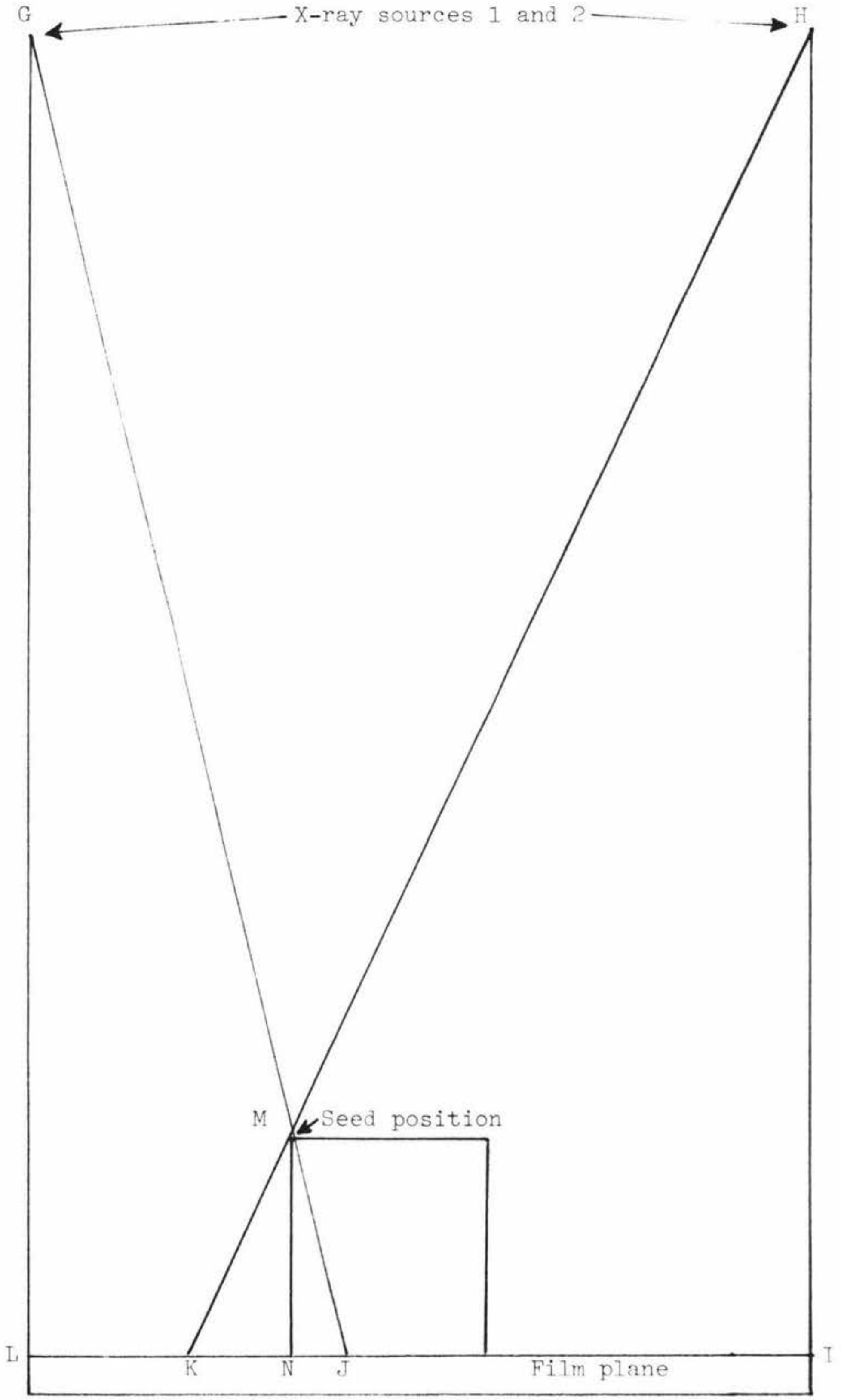

Figure 3.3.2a Principles involved in using the X-ray stereo technique for determining the Z component.

Example JK = 25 mm
IK = 360 mm
GL = 1000 mm

MN = (25 * 1000) / (360 + 25)

MN = 64.9

The second method was to turn the sample bins 90 degrees and X-ray them a second time in that plane. By measuring the distance from each seed to the side of the bin, the Z value could be obtained.

After obtaining the Z component by one of the methods outlined above, a single X-ray exposure was taken on a new film. Figure 3.3.2b is a three-dimensional representation of the correction procedure for the X and Y coordinates. From the X-ray projection, each seed was located from the centre by an X coordinate (EA) and a Y coordinate (EB). The calculations are given below for correcting the X and Y coordinates of the seed positions.

Using similar triangles SBE and SCF

CF: EB as SC : SB

Therefore CF = SC * EB / SB

and SC = SB - BC

Where CF = Corrected value of Y
EB = Uncorrected Y coordinate
SB = Source Distance to the film
CB = Z coordinate measured by the technique described earlier

The X coordinate was obtained in a similar manner.

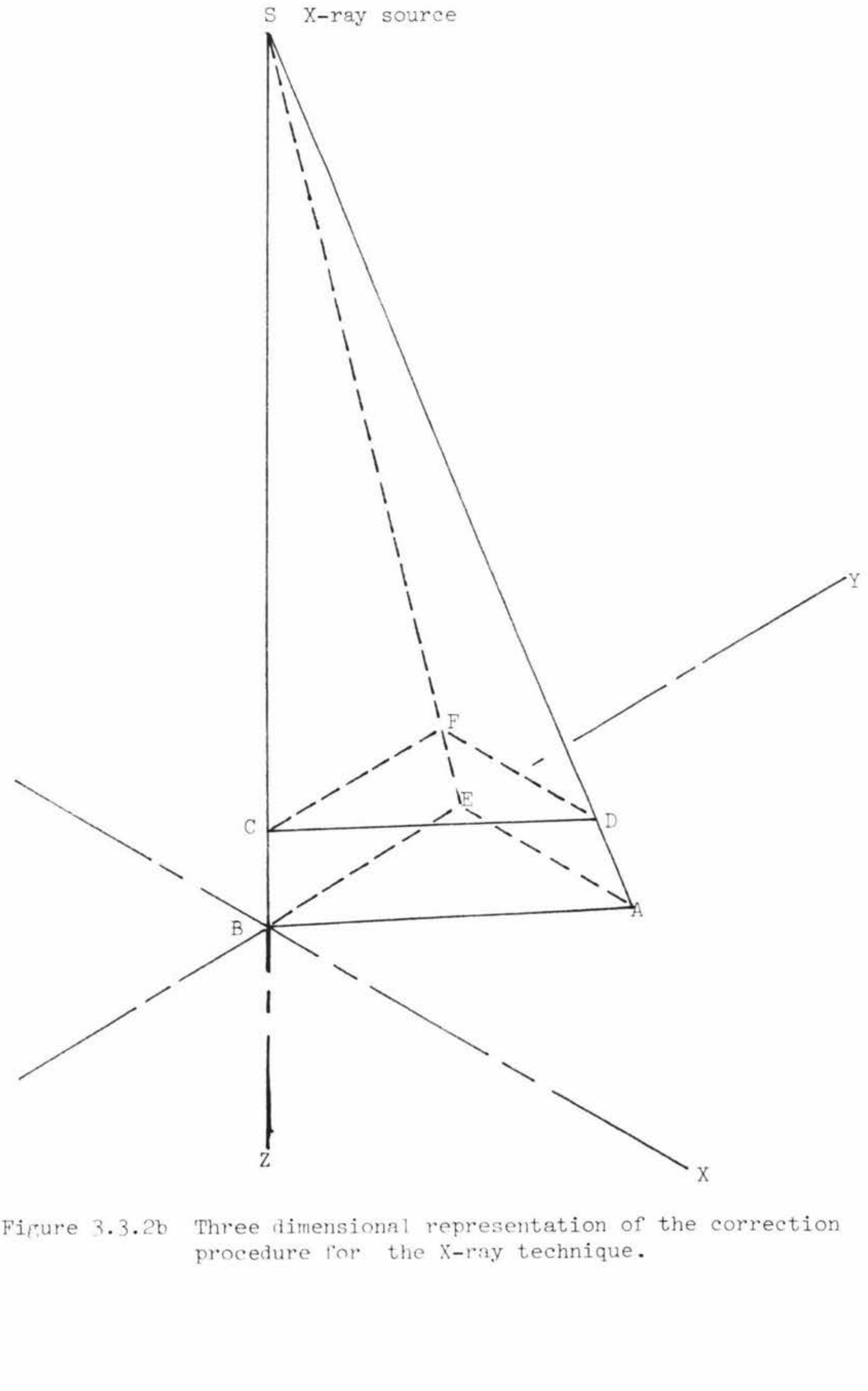

Figure 3.3.2b Three dimensional representation of the correction procedure for the X-ray technique.

By using this system to identify each seed and reference point on the soil surface, or on the top of the seed groove, values for seed depth, seed in-row spread, and in-row spacing could be obtained by subtracting the appropriate X, Y and Z coordinates. A computer program writen by the author is given in Appendix 1. This program was developed not only to calculate the seed placement values for each seed, but also to average these for each soil block sampled and calculate the standard errors of each.

3.4 DEVELOPMENT OF SEED COATING PROCEDURES

Two options were considered in developing seed coating procedures. The first dealt with using liquid solutions applied to the outside of the seed. The second was to coat the outside of the seed with a heavy metal powder and sticker.

3.4.1 Liquid coatings

Since liquids are presently used as seed coatings in the form of fungicides (M. Suckling, pers. comm., 1983), it was considered to be one possible form of coating. The process involved the coating of seeds with liquid solutions, using successive soaking and drying periods. Seeds were counted and placed in petri dishes with the appropriate liquid coatings. The seeds were left to soak for 24 hours, removed from the liquid and were allowed to dry for 24 hours. The procedure was repeated (up to three times) to increase the level of each coating.

3.4.2 Powdered coatings

The logical approach in powdered coating of seeds was to examine commercial seed coating processes and adapt present technology. It was felt that with this approach, if successful, future seed lots could be coated by commercial companies. After consultation with Hodder and Tolley Ltd., the following seed coating procedure was adopted (M. Suckling pers. comm., 1983).

1. Seeds to be coated were weighed and placed in a revolving container inclined at 30 degrees (Figure 3.4.2).

2. The speed of rotation of the inclined container was adjusted to 30 to 40 rpm (using an infinatly variable speed transmission) so that the seed covered the bottom of the container as it rotated.

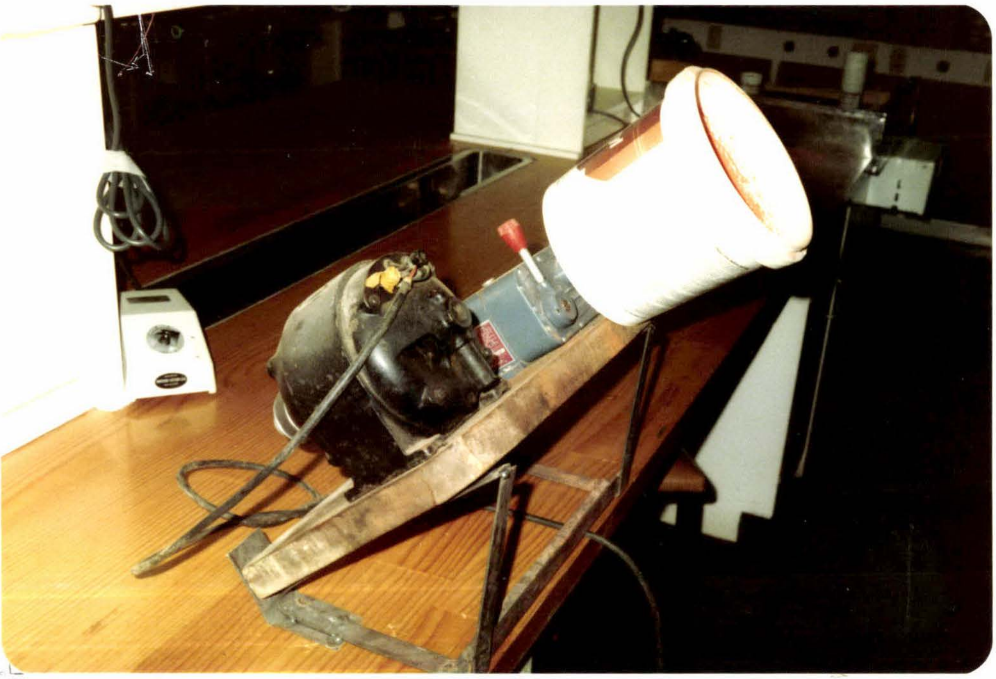

Figure 3.4.2 Seed coating apparatus.

3. A glue solution was prepared by mixing 42 g of a water-soluable commercial powdered glue in 300 ml of water as instructed on the product label.

4. For each 500 g of seed to be coated, 25 ml of the glue solution was added to the seed container and mixed so that it thoroughly coated the outside of the seed.

5. The weight of coating powder was calculated for the initial seed weight, and added to the revolving container. The weight of coating on the seed was checked by removing the coated seed from the container, screening it to remove loose material and weighing the treated seed. The maximum amount of coating achievable in one coat was found to be approximately 50% of the seed weight.

6. To increase coating levels beyond 50%, additional glue was sprayed on to the seed, followed by the addition of more coating material. The amount of coating was checked by the method outlined in step 5 above.

7. When the desired coating level was reached, the seed was sprayed with a fine water mist and a commercial seed coat hardener was added at a rate of two percent by weight of the untreated seed.

8. The seed was then removed from the coating container and dried in a warm air flow at approximately 30 °C.

Example of a 30% coating process on barley seed lot

500 g barley seed
25 ml glue solution
150 g coating material
water added in a fine mist
10 g hardener
remove and dry in warm air flow

Note: To obtain a coating of 30% in one application, it was sometimes necessary to add an extra 30 g of coating material to allow for coating not being affixed to the seed.

3.5 EVALUATION OF TYPE AND AMOUNT OF COATING

The examination of coating types and amounts, were carried out in three laboratory experiments. The general objectives of these experiments were: 1. To select an appropriate coating material; 2. to decide on an appropriate amount of coating for each seed size and the effects of increased coatings on X-ray image clarity.

3.5.1 Experiment 1. Effects of coating types and amounts on the clarity of X-ray images

Objectives

Experiment 1 was designed as a preliminary screening experiment. The objectives of the experiment were:

1. To select the best of four commonly available coating materials.
2. To determine a baseline level for each coating material.
3. To determine the effect of seed size and shape on the clarity of X-ray images.

Materials and methods

Four seed coating types were chosen; two liquids and two powders. The primary concerns in selecting the chemicals were: 1. That there was some knowlage about their effects on X-ray radiation; 2. that they be readily available and accessible for future use.

A concentrated iodine solution and a barium sulphate powder were obtained from the Radiology Department of the Veterinary Science Faculty of Massey University. The iodine solution was generally used for injection into animals as a tracer prior to X-raying. Similarly, barium sulphate powder was mixed with water and swallowed prior to X-raying, thus providing a tracer for the digestive tract.

A weak barium chloride solution was obtained from the Seed Technology Centre, Massey University. This solution had been used to soak seeds, in order to imbibe them. The imbibed seeds were later X-rayed with low levels of radiation to examine their internal structures.

Red lead oxide is sold as a bird repellent for grass seed. Barr (1981), Choudhary et. al. (1983), and Giblett (1983) all successfully used lead oxide as a seed coating material in their X-ray techniques. Although these authors used lead oxide as a seed coating material, none made accurate measurements as to how much lead oxide was used.

Since this was an initial screening experiment, at least four levels of coating were choosen. For the liquids these were; no soaking, one soaking, two soakings and three soakings (Section 3.4.1). For the powdered coatings the levels were; no coating, 50% by weight, 100% by weight and 150% by weight (Section 3.4.2). These arbitrary levels of coating were selected because they provided a practical workable range. To exceed these levels would have involved putting very thick coatings on the seed. Such coating levels were difficult to achieve and would also have greatly altered the shape and weight of the seeds.

The two seed types selected were barley (Hordeum vulgare, var Hassan), an irregular shaped medium sized seed; and soybean (Glycine max, var AMT 19), a large round shaped seed. These two seed species were selected because: 1. It was felt that they would provide a good contrast in seed shapes; and 2. they were likly to be of interest in future field experiments.

The experiments thus involved the following treatment factors; two seed types, four types of coating and four coating levels. The experimental design was a completely randomised block with two replications. The results were analysed using a standard analysis of variance program ("Genstat").

Seed lots were drawn randomly from stocks of barley and soybean. The seeds were divided into smaller lots and soaked or coated using the procedures outlined in Section 3.4 to obtain the necessary coating levels. Each treatment for X-raying consisted of five randomly selected seeds. The coated seeds were attached to cards 125 mm wide by 175 mm long on a 20 mm by 20 mm grid as shown in Figure 3.5.1a.

The cards were taken to the Veterinary Clinical Science Radiology Laboratory, Massey University, where they were X-rayed using a Triplex Optimatic 1023 X-ray machine made by Elema-Schonander in Stockholm, Sweden. The cards were X-rayed in groups of four using a Mamoray RPI non screen film with a focal film distance of 1.5 m and machine settings of 60 kVa (kilovolts) and 0.64 mAs (milliampers per second).

After X-raying, the films were taken to the Chemistry Department of the Science Faculty, Massey University where each card was analysed by a microdensitometer Model P-1000 made by Optronics International Inc., Chelmsford, Massachusetts, U.S.A. The microdensitometer was designed to measure the light transferred through a film and was set to read a 200 micron by 200 micron grid. The output values ranged from 1 to 256 and were read onto magnetic tape. The magnetic tape was transferred to the Computer Centre where the binary values on the tape were read onto a main frame Prime Computer using the system program "Magnet.182". The data values were then converted using a program developed by B. Anderson (pers. comm., 1983) to a letter with each letter of the alphabet representing a span of ten numbers. This program is given in Appendix 2, and a sample output is given in Figure 3.5.1b. A second computer program, written by the author, was used to calculate the average intensity for each of the seeds, by assigning each letter a value (Z=1, A=26). The program is given in Appendix 3. The closer the values were to A, the greater the light transmitted. The Z value represented the backround level. The intensity value for the five seeds of each treatment were averaged, to give a single value for each treatment, thus providing a quantitative value for seed image intensity.

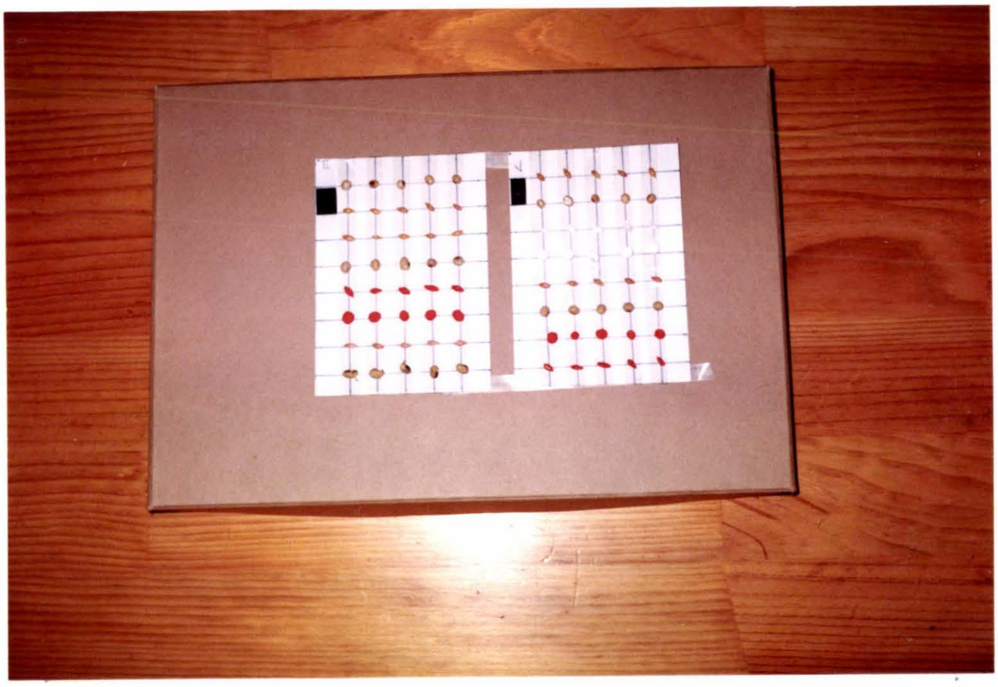

Figure 3.5.1a Coated seeds for X-raying on a 20 mm X 20 mm square grid.

Left side. Row 1. Soybean, Iodine, 2 soakings.
2. Barley, Iodine, 2 soakings.
3. Barley, Iodine, 1 soaking.
4. Soybean, Iodine, 1 soaking.
5. Barley, Barium Chloride, 1 soaking.
6. Soybean, Barium Chloride, 1 soaking.
7. Barley, Barium Chloride, 1 soaking.
8. Soybean, Barium Chloride, 1 soaking.

Right side. Row 1. Barley, Iodine, 4 soakings.
2. Soybean, Iodine, 4 soakings.
3. Barley, Barium Sulphate, 50% coating.
4. Soybean, Barium Sulphate, 50% coating.
5. Barley, Iodine, 1 soaking.
6. Soybean, Iodine, 1 soaking.
7. Soybean, Red Lead Oxide, 50% coating.
8. Barley, Red Lead Oxide, 50% coating.

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Figure 3.5.1b Computer output of microdensitometer reading.

Top. Soybean seed.

Bottom. Barley seed.

Results and discussion

Table 3.5.1a lists the effects of coating types on the intensity of X-ray images.

Table 3.5.1a Effect of chemical seed coating type on X-ray image intensity.

Coating type	Intensity values
Red lead oxide powder	11.5
Barium sulphate	8.2
Iodine solution	3.4
Barium chloride solution	1.5
LSD (P 0.01)	1.1

See Appendix 4 for complete data.

From the table, there were highly significant differences (P 0.01) between all of the coatings tested with red lead oxide producing clearly the best image. It was also evident that the powdered coatings provided much clearer images than the liquid coatings.

Table 3.5.1b shows the effects of the amount of chemical seed coating on the intensity of the X-ray images.

Table 3.5.1b Effect of amounts of chemical seed coating type on the intensity of the X-ray image.

	Intensity values			
Amount of coating	Red lead oxide powder	Barium sulphate powder	Iodine solution	Barium chloride solution
0% uncoated	2.0	1.8	1.5	1.0
50% or 1 soaking	12.4	7.8	2.8	1.6
100% or 2 soaking	15.3	10.6	4.1	2.0
150% or 3 soaking	16.3	12.6	5.2	1.3

LSD (P 0.05) 1.5
(P 0.01) 2.2

See Appendix 4 for complete data.

Table 3.5.1b showes that in the case of powdered coatings there were significant differences (P 0.01) in image intensity as coating levels were increased from 0% to 50% and 50% to 100% but not between 100% and 150% levels. In the case of the barium sulphate coatings there were significant differences (P 0.05) between the 100% coating level and the 150% coating level. In the case of the iodine liquid solutions there were significant differences (P 0.05) between the 0% coating level and the 100% coating level. There were also significant differences between the 50% level and the 150% level. In the case of the barium chloride solution there were no significant differences between any of the coating levels.

In the case of the powdered coatings the intensity readings for 0%, 50%, 100%. and 150% provided a range of readings with a gap between 2.0 and 12.4 for the red lead oxide and 1.8 and 7.8 for the barium sulphate. Thus it was felt possible that coating levels below 50% might also provide acceptable intensity values.

Table 3.5.1.c shows the effect of seed type and chemical coating on the intensity of the seed images.

Table 3.5.1c Effects of seed type and chemical seed coating type on X-ray image intensity.

Seed type	Intensity values Red lead oxide powder	Barium sulphate powder	Iodine liquid	Barium chloride liquid
Barley	9.9	6.9	1.8	1.2
Soybean	13.1	9.5	5.0	1.7

LSD (P 0.05) 0.9
(P 0.01) 1.3

See Appendix 4 for complete data.

From the table it appeares that with both powdered type coatings and the iodine solution, the larger seed (soybean) provided significantly (P 0.01) more intense images than the smaller seed (barley). The barium chloride solution had no effect on the intensity of the seed images accross the seed types tested.

From the above experiment it was clear that the powder type coatings were superior to the liquid soakings. Liquid coatings were thus eliminated from further studies. There appeared to be a gap in intensity readings for the powdered coating levels between no coating and the 50% level. It was decided therefore, to further examine powdered coating levels within this range. Similarly, seed size had also shown an effect on the image intensity and therefore warranted further examination.

3.5.2 Experiment 2. Evaluation of powder seed coatings at low rates (less than 50%).

Objectives

To evaluate the effect of lower levels of red lead oxide and barium sulphate coatings on the image intensity of X-rayed seeds.

Materials and methods

Based on the results of Experiment 1, the following four coating levels were used; no coating, 10%, 30% and 50% by weight. This was done to establish image intensities at the lower end of the coating scale, and to the confirm and obtain additional imformation on the effects of seed size. Thus soybeans and barley were again used as the seeds. The procedures, analyses and experimental design were similar to those of Experiment 1, except that three replications were used instead of two.

Results and discussion

Table 3.5.2a shows the effect of powdered chemical coatings on the intensity of the X-ray images for low levels of coating.

Table 3.5.2a Effects of chemical seed coating type and amount on the intensity of the X-ray image.

	Intensity values	
Coating amount	Red lead oxide powder	Barium sulphate powder
0%	1.7	1.2
10%	7.2	6.0
30%	10.8	6.5
50%	12.4	7.9
LSD (P 0.05)	1.0	

See Appendix 5 for complete data.

Table 3.5.2b shows the effects of seed type and chemical coating material on the intensity of the X-ray images.

Table 3.5.2b Effect of seed type and chemical seed coating type on X-ray image intensity.

	Intensity values	
Coating amount	Red lead oxide powder	Barium sulphate powder
Barley	6.6	4.6
Soybean	9.5	6.1
LSD (P 0.01)	0.9	

See Appendix 5 for complete data.

It appears from the data in Tables 3.5.2a and 3.5.2b that red lead oxide continued to exhibit a higher image intensity than did barium sulphate, and that the image intensity for soybean seeds was clearer than that of the barley seeds (P 0.01). Based on this result it was decided to use only red lead oxide in furture experiments because it was clearly superior to barium sulphate in image intensity values. Barium sulphate was clearly the second choice and if red lead oxide was discarded in later trials then barium sulphate would be the next logical choice.

3.5.3 Experiment 3. Evaluation of red lead oxide coating levels on a small round seed (rape) (Brassica campestris)

Objective

To determine the effects of red lead oxide coating levels on the intensity of X-ray images with small round seed.

Materials and methods

The data from Experiment 1 and 2 had shown consistent differences in image intensities betweem large round seed (soybean) and smaller irregular shaped seed (barley). To further examine the effect of seed size, a small round seed (rape) was evaluated with four coating levels of red lead oxide. These levels were no coating, 50%, 100% and 150% by weight, since with smaller seed it was felt possible that coating intensities in the higher range would be required. There were two replicates in a complete randomised block design.

Results and discussion

Table 3.5.3a shows the effect of red lead oxide seed coating on the intensity of the X-ray images when used with a small round seed.

Table 3.5.3a Effect of red lead oxide coating on the intensity of the rape seed X-ray images.

Coating amount	Image intensity
0%	1.5
50%	10.2
100%	13.0
150%	15.0
LSD (P 0.05)	2.8

See Appendix 6 for complete data.

From the table it can be seen that as coating levels were increased from 0% to 50% and 50% to 100%, there were significant increases (P 0.05) in image intensity.

3.5.4 Discussion of Experiments 1,2 and 3

Figure 3.5.4 illustrates the effects on image intensity of the three seed sizes (soybean, barley, rape) with varying amounts of red lead oxide coating. The figure demonstrates that generally as the seed size was reduced image intensity was reduced. All curves were of a similar shape with a sharp increase in intensity between no coating and 50%. Thereafter image intensity tended to level off as coating was increased. It seemed unlikely that coating levels above 150% for all seeds would have improved image intensity.

As a result of these experiments seed coating levels selected were as follows; soybeans 30%; barley 30%, and rape 150%. Figure 3.5.4 indicated that perhaps barley should be coated at the 50% level. This was not done in an effort to keep the same seed coating level (30%) for all seeds in this size range (barley to soybeans). With rape being smaller, it was clear that a heavier coating was required to make it more distinguishable in the soil. All decisions relating to coating level were arbitary, and further experiments were felt justified to test their validity.

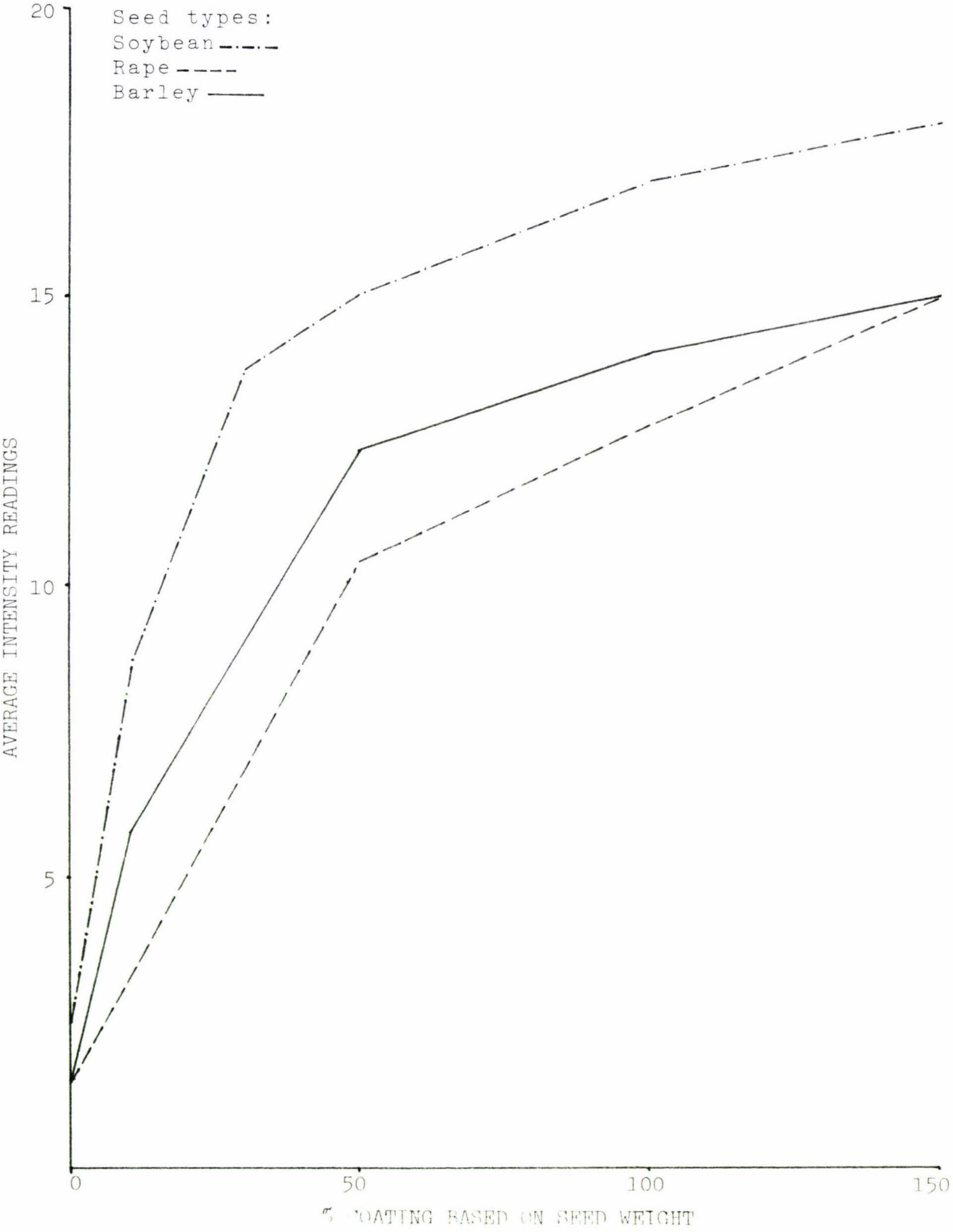


Figure 3.5.4 Plot of image intensity versus red lead oxide coatings.

3.6 EVALUATION OF THE EFFECT OF SOIL ON X-RAY IMAGE CLARITY

Having decided on a coating material and application rate, in Section 3.5 the next logical step was to determine the effect of soil characteristics on the clarity of X-ray images. This section is divided into two laboratory experiments: The first was to determine the effect of soil thickness on X-ray intensity; the second was to determine the effect of soil type and soil moisture content on X-ray intensity and clarity.

3.6.1 Experiment 4. Evaluation of the effects of soil thickness on the clarity of X-ray image

Objectives

1. To determine the effects of various soil thicknesses on the clarity of X-ray images.

2. To select a standard soil thickness suitible for the X-ray seed-location technique.

Materials and methods

Barr (1981) suggested that a soil block size range of 100 to 150 mm had been satisfactory in his experiments. Choudhary et. al. (1983) used a soil block size of 75 by 75 by 75 mm deep while Giblett (1983) used a soil block size of 100 by 100 by 250 mm long. It was therefore decided to screen four soil thicknesses; 25 mm, 50 mm, 75 mm and 100 mm. This represented a range determined by a minimal size for mechanical stability, (25 mm) and a maximum size obtainable between 150 mm spaced rows.

To provide a uniform soil medium and facilitate ease of preparation of the samples it was decided to use dry sand for this experiment. The procedure was to fill deep plastic greenhouse pots (140 mm by 140 by 140 mm) with sand to a level half that of the desired treatment thickness. Seed cards were prepared as in Experiment 1, with 3 rows of five seeds of each type (soybeans, barley and rape) in a 20 mm by 20 mm square grid and placed in the pots. The pots were then carefully filled to the desired treatment level. The red lead oxide seed coating levels were 30% for both soybeans and barley and 150% for rape, as suggested earlier in Section 3.5.

The experiment therefore consisted of four soil thicknesses, three seed types with two replications in a complete randomised block design. The evaluation of image clarity was provided by the microdensitometer described in Section 3.5.1, together with a visual scoring system.

The X-ray equipment used, was the same as that outlined in Section 3.5.1. The X-ray settings for each thickness are given in Table 3.6.1a. In this experiment a fast intensifying screen was used in a cassette with a standard speed film.

Table 3.6.1a X-ray settings for soil thickness.

Soil thickness	kVa	mAs
25 mm	60	2.5
50 mm	75	3.2
75 mm	85	4.0
100 mm	95	5.0

Results and discussion

An attempt was made to quantify the X-ray images using the microdensitometer. This was unsuccessful because the soil medium caused the backround level to be inconsistant (not all Z as shown in Figure 3.5.1b). The highly variable backround level around each seed made it difficult for the computer to identify the boundries of each seed without substanially expanding the microdensitometer procedure, developed in Section 3.5. Since it was not certain that further expansion of the microdensitometer procedure would be successful, nor useful for any other purpose, it was decided to develop a visual scoring system for this and future experiments. The scoring system consisted of atributing a score to each treatment within the range of 1 to 12 (minimum clarity to maximum clarity).

Table 3.6.1b shows the image clarity scores as affected by the thickness of the soil medium. Table 3.6.1c shows the image clarity scores as affected be the type of seed used.

Table 3.6.1b Effect of soil thickness on the clarity of the X-ray images.

Thickness	Image clarity score (1 to 12)
25 mm	9.3
50 mm	7.3
75 mm	5.7
100 mm	3.7
LSD (P 0.05)	0.8

See Appendix 7 for complete data.

Table 3.6.1c Effect of seed type on the clarity of the X-ray images.

Seed type	Image clarity score (1 to 12)
Soybeans	8.9
Barley	7.9
Rape	2.8
LSD (P 0.05)	0.5

See Appendix 7 for complete data.

It is clear from Table 3.6.1b that despite corresponding increases in X-ray source intensity, as soil thickness was increased from 25 mm to 100 mm, image clarity was reduced. More importantly in the case of soybeans, images at 100 mm soil thickness were still quite clear. Barley images were also visible at 100 mm but they were not as easily identified as soybean images. Rape, however, was rarely visible at 100 mm. Even at 75 mm, the rape seed images although visible, were difficult to locate.

Based on this imformation, it was decided to use a 75 mm sample thickness. It was felt that this would provide a reliable X-ray sample in which all seeds could be identified, albeit that rape would be marginal. The soil block was also considered to be large enough to contain all seeds sown in the row and would be relatively easy to sample and remove from the field.

3.6.2 Experiment 5: Evaluation of the effects of soil type and soil moisture content on X-ray image clarity

Objectives

1. To determine the effect of soil type on X-ray image clarity over three seed sizes.

2. To determine the effect of soil moisture content on X-ray image clarity over three seed sizes.

Materials and methods

A range of four soil types were selected from local surroundings. Beach sand was utilized to serve as a control as it had been used in Experiment four. A "Tokomaru Silt Loam" soil was selected as one of the common soil types at Massey University. "Rongotea Peat Loam" was selected as an example of a high organic matter peat soil. "Marton Silt Loam" subsoil was selected because it had a high clay content. Finally a "Carnarvon Black" soil was choosen because of its high iron content. This range was by no means exhaustive, but it was felt it would provide a spread of conditions as affected by texture and organic matter content.

Since X-rays travelling through water might be expected to behave differently than those through soil or air, (J. Kirkman, pers. comm., 1983) each soil was tested dry, at field capacity and at saturation. The experiment was designed to examine the extremes in order to determine if soil moisture content had any effect on the clarity of the X-ray images.

The experiment was conducted with three seed types; soybeans, barley and rape. 100 mm by 100 mm by 80 mm deep pots were half filled with soil and the red lead oxide coated seeds were placed on cards at this soil depth. The seeds were arranged in three rows with three of each seed type in each row. The pots were then filled with the same soil to a depth of 75 mm. Three pots of each soil type were perpared. One was dried and the other two were saturated with water and one of these was removed and allowed to drain to field capacity.

The experiment thus compared five soil types and three soil moisture contents with two replicates in a completely randomised block design for each seed type. The scoring system consisted of attributing a score to each of the 15 treatment within this experiment giving a range of 1 to 15 (minimum clarity to maximun clarity). Each seed type was analysed seperatly as a series of two factor experiments.

Pots were X-rayed using the procedure outlined in Section 3.5 with X-ray machine settings of 85 kVa and 4 mAs.

Results and discussion

Table 3.6.2a shows the image clarity scores as affected by soil type for each of the three seed types tested.

Table 3.6.2a Effect of soil type on the clarity of the X-ray images.

	Image clarity score (1 to 15)		
Soil type	Soybeans	Barley	Rape
Sand	6.0	7.8	4.5
"Tokomaro Silt Loam"	7.8	8.3	7.5
"Rongotea Peat Loam"	5.3	7.5	7.2
"Marton Silt Loam" subsoil	8.8	8.7	8.3
"Carnarvon Black Soil"	12.2	7.8	12.0
LSD (P 0.05)	4.0	6.6	4.3
(P 0.01)	5.6	-.-	6.0

See Appendix 8 for complete data.

From Table 3.6.2a it is apparent that the soil effect on image clarity was not consistent across the three seed types tested. In the case of soybeans the "Carnarvon Black" soil had a significantly (P 0.01) clearer image than did the Sand or "Rongotea Peat Loam". The "Carnarvon Black" soil was also significantly (P 0.05) clearer than the "Tokomaro Silt Loam".

Similarly in the case of rape the "Carnarvon Black" soil had significantly (P 0.01) clearer images than did the sand and was also significantly (P 0.05) clearer than the "Tokomaro Silt Loam" and the "Rongotea Peat Loam".

With barley there was no effect of soil type on image clarity.

Table 3.6.2b shows the image clarity scores as affected by soil moisture content over the three seed types tested.

Table 3.6.2b Effect of soil moisture content on the clarity of the X-ray image.

	Image clarity score (1 to 15)		
Soil moisture content	Soybean	Barley	Rape
Dry soil	9.2	7.5	6.9
Field capacity	9.1	10.0	10.3
Saturated	5.7	6.5	6.8
LSD (P 0.05)	3.1	5.1	3.3
(P 0.01)	4.3	--.-	4.6

See Appendix 8 for complete data.

From the table, the saturated soil condition in the soybean experiment appeared to have significantly (P 0.05) inferior image clarity compared to both the dry soil and the soil at field capacity which were not significantly different. There were no significant differences in image clarity between soil moisture levels with barley. In the case of rape the soil at field capacity appeared to have significanltly (P 0.05) clearer images than either the dry soil or the saturated soil.

In all treatments outlined above, the images were visible and identifiable. The scoring system gave some indication that soil conditions differed in their effects on X-ray clarity. It was concluded that the X-ray technique could be applied in all cases outlined above. The best results however could be expected from even-textured soil, such as the "Carnarvon Black" soil at a moisture content near field capacity.

3.7 EFFECT OF COATING LEVELS OF RED LEAD OXIDE AND RADIATION ON SEED GERMINATION (EXPERIMENTS 6, 7 AND 8)

Previous experiments indicated that red lead oxide was the best coating material of those tested, and apropriate coating levels were selected. It remained to establish whether or not the coating material or method of coating would adversely affect seed germination. Also, it was necessary to test whether or not the X-ray radiation would affect seed germination. If seed performance was not affected as suggested by Gilbert (1983), then, coated or radiated seed could be planted and evaluated in field or laboratory situations.

Objectives

1. To determine toxicity effects of red lead oxide seed coating on seed germination.

2. To determine the effect of X-ray radiation on seed germination.

Materials and methods

Based on results from Section 3.5, it was decided to use the following coating levels; 0%, 30% and 100% for soybeans and barley; and 0%, 100% and 150% for rape. This was expected to cover a workable range of coating levels.

Similarly, three levels of X-ray intensity were selected. These were: 1. No exposure to radiation (control); 2. two exposures to radiation, while the seed was protected by placement in the centre of a 75 mm soil mass; and 3. two exposures to radiation without soil protection. The X-ray equipment was set as for X-raying soil blocks from the field, i.e. 85 kVa and 4 mAs, as indicated in Table 3.6.1a.

Seeds were coated, using the procedures outlined in Section 3.4, and then exposed to the X-ray treatments. Four lots of 50 treated seeds were counted for each treatment. The soybeans and barley seeds were laid on germination paper, rolled and put in germination rooms set at 26 degrees C, and 20 degrees C, respectively, where they remained for seven days. The rape seeds were laid on germination cards and each card was placed in individual plastic containers which in turn were placed in a cabinet controlled at 30 degrees C, day, and 20 degrees C, night temperature, and left for seven days. After seven days germinated seeds were counted. Special note was made of abnormal seedlings located in each treatment.

The experiments thus contained two factors, amount of coating and (X-ray) radiation intensity. Each experiment was a completly randomised block design with four replications and each seed type was run as a separate experiment.

Results and discussion

Table 3.7a shows the percent germination as affected by the amount of red lead oxide seed coating applied to the seed.

Table 3.7a Effect of red lead oxide coating on percent germination.

	Percent germination		
Coating amount	Soybean	Barley	Rape
0%	91.1	98.0	93.6
30%	91.8	98.7	--.-
100%	91.8	98.3	95.3
150%	--.-	--.-	94.7
LSD (P 0.05)	2.8	1.8	3.2

See Appendix 9 for complete data.

Table 3.7b shows percent germination as affected by the amount of radiation the seed was exposed to.

Table 3.7b Effect of radiation on seed percent germination.

	Percent germination		
Radiation intensity	Soybean	Barley	Rape
No radiation	92.3	97.8	95.7
Radiation with soil	91.1	98.5	94.8
Radiation without soil	91.3	98.7	93.1
LSD (P 0.05)	2.8	1.8	3.2

See Appendix 9 for complete data.

From the tables, it is clear that neither the amount of coating nor radiation had any significant (P 0.05) effects on seed germination of any of the seed species tested.

Figures 3.7a, 3.7b and 3.7c illustrate treated and untreated seed lots. In laboratory examinations there were no visual differences between seed lots, with respect to seed vigor or seedling abnormalities.

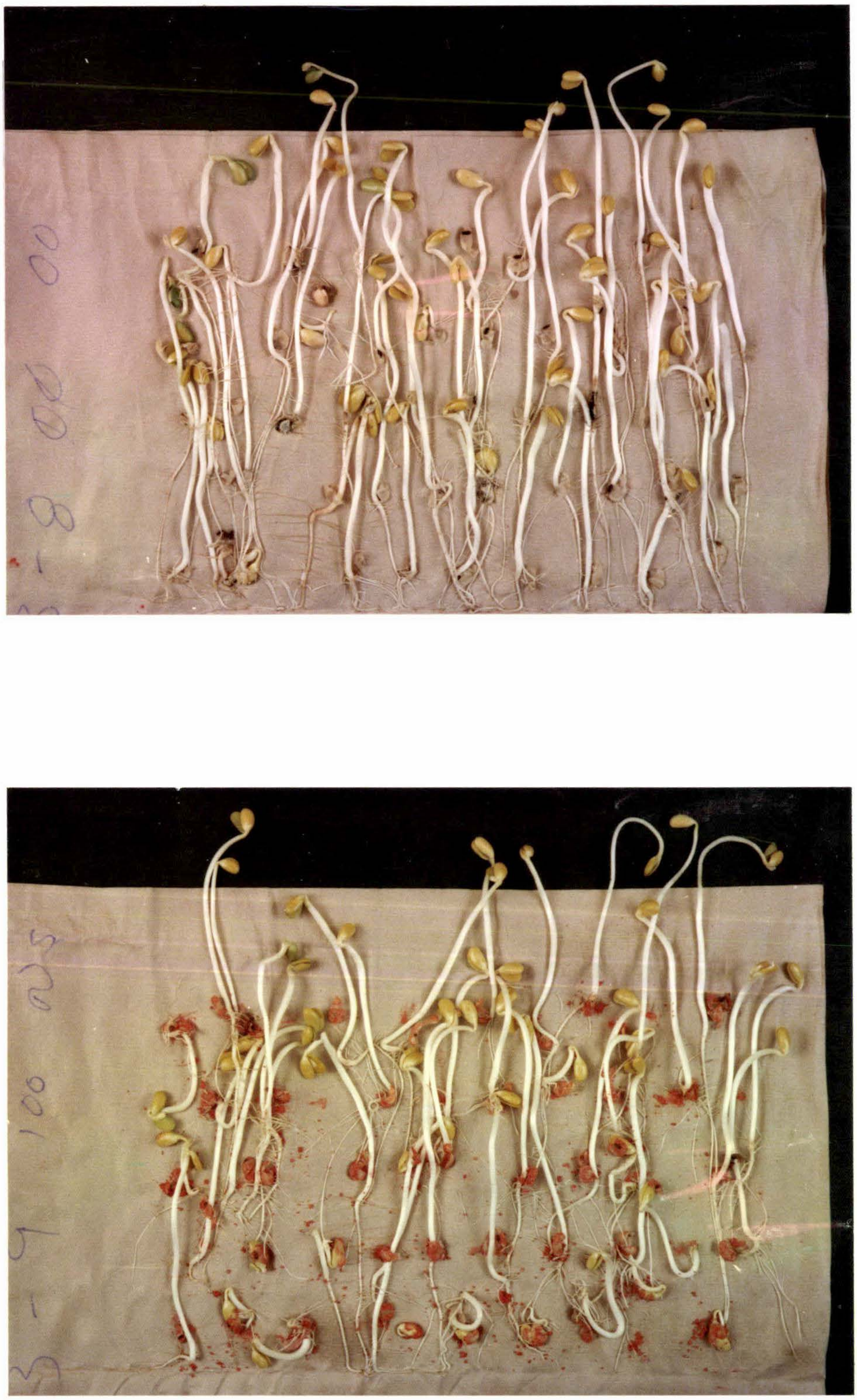


Figure 3.7a Soybean germination.

Top. Untreated soybean seed.

Bottom. Soybean seed coated with 100% red lead oxide by weight and X-rayed without soil protection.

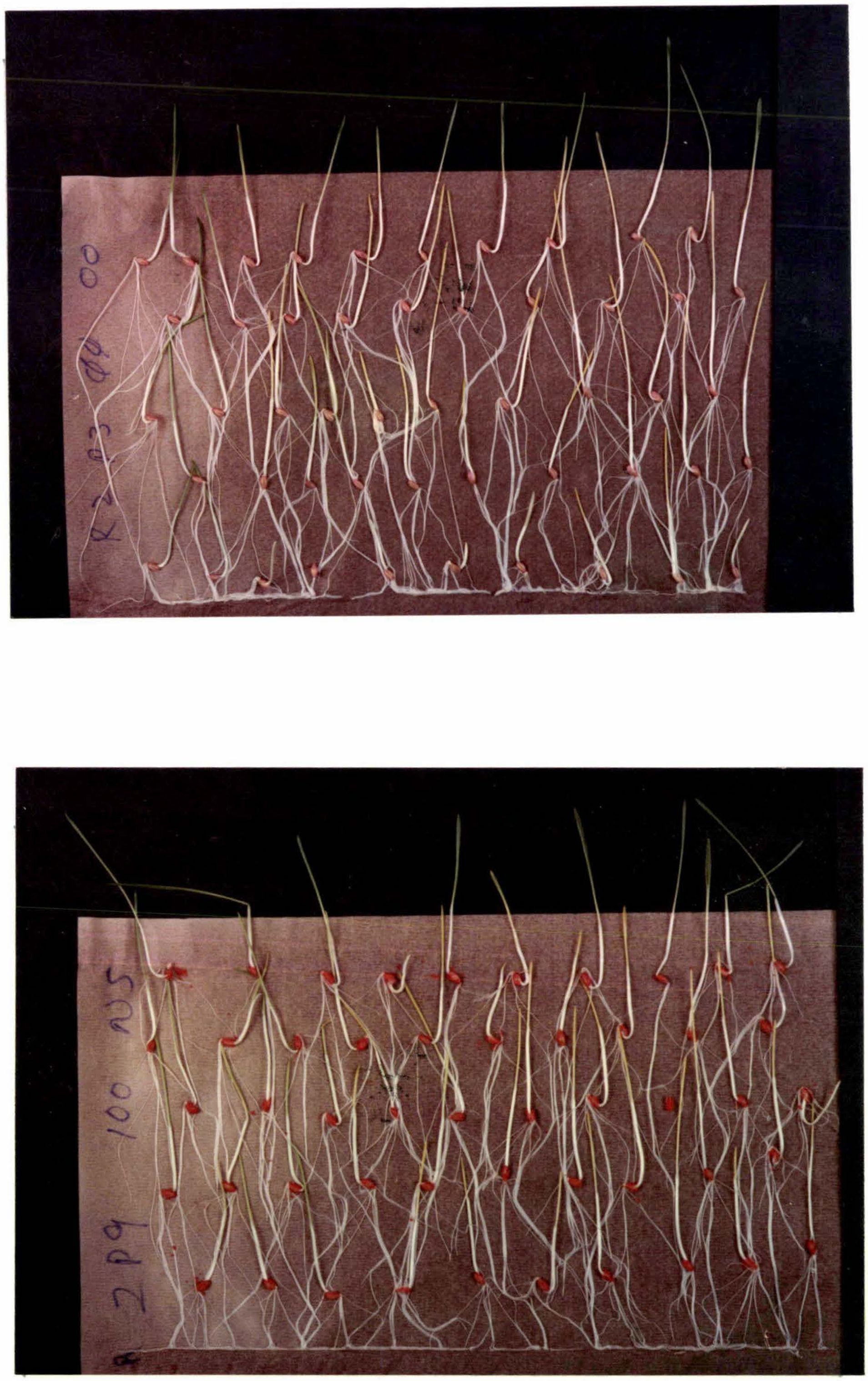


Figure 3.7b Barley germination.

Top. Untreated barley seed.

Bottom. Barley seed coated with 100% red lead oxide by weight and X-rayed without soil protection.

Figure 3.7c Rape seed germination.

Top left. Untreated rape seed.

Top right. Rape seed with no coating and X-rayed without soil protection.

Bottom left. Rape seed coated with a 100% read lead oxide by weight and X-rayed without soil protection.

Bottom right. Rape seed coated with a 150% red lead oxide by weight and X-rayed without soil protection.

3.8 EVALUATION OF SEED IN-SOIL-ELAPSED-TIME ON CLARITY OF X-RAY IMAGES AND SEED-IMAGE-MOVEMENT (EXPERIMENTS 9, 10 and 11)

Experiments in the previous section clearly showed that the ability of seeds to germinate was not affected by the coating material (red lead oxide) or radiation exposure. Experiments in this section were designed to determine the effects of germination and seedling growth on seed-image-clarity on the X-ray films. The major questions were, whether the seed images moved as the seeds germinated and emerged, and if so, when this occurred? A second question was, how long the images remained visible? It was felt that answering these questions would give some indication of the time constraints on sampling in the field.

Objectives

1. To determine any movement of seed-image-positions, as a function of the processes of seed germination and emergence.

2. To determine the visibilty of X-ray images as a function of elapsed-time-after-sowing.

3. To determine any correlations between measurements of seeding depth made by the X-ray-image technique, and the seedling tracing technique.

Materials and methods

In the previous experiments soybeans, barley and rape were used. Lupin (Lupinus angustifolius) was selected instead of soybean for this experiment because it was considered to be a more cold tolerant species than soybean but the seeds were similar in size and shape. This was important since the later field experiment was to be conducted in the cooler winter months. Potential germination of the lupin was found to be 95% for the coated seed and 92.5% for the uncoated seed.

Both lupin and barley seeds had a target seeding depth of 40 mm, while the rape was sown at 25 mm. Each experiment consisted of a single seed type and two treatments. In treatment one the seeds were placed in soil bins on top of undisturbed soil, and then were covered with loose soil (hard soil base). Treatment two had the seeds placed on loose soil and covered by loose soil (soft soil base). The experimental design was a completely randomised block with 4 replications.

The treatments were prepared by removing small soil blocks (in 200 mm long by 75 mm wide by 75 mm deep bins) from the field, along with a quanity of topsoil. In the laboratory the blocks had the top 40 mm of soil removed for both lupin and barley seeds, and the top 25 mm removed for rape seeds. A second set of bins were prepared by filling bins with loose topsoil up to a depth of 35 mm (for lupin and barley) and 50 mm for rape. All bins had a piece of solder wire fixed to the top of the bins to act as a soil surface reference marker when X-raying. Prior to X-raying, six coated seeds and two steel reference markers (40 mm long by 10 mm wide by 4 mm thick) were placed in each of the prepared bins and covered with loose soil.

Seed coating levels were 30% for lupins, 50% for barley and 150% rape. The barley seed coating level was increased from 30% to 50% as a result of the experience gained in Section 3.6. Although the barley seeds were visible in all treatments in Section 3.6, it was felt that increasing the coating level would make seed identification in future experiments more positive and easier.

The samples were then X-rayed in groups of four. The machine settings were 85 kVa and 4 mAs with standard speed X-ray film in a cassette with fast intensifying screens. The samples were then removed to a greenhouse and watered with a fine mist to avoid disturbing the soil surface.

The above procedure was repeated each day until images ceased to be visible or seed movement was detected. To slow down seed germination over the weekend period (due to difficulties in accessing the X-ray equipment) seed bins were placed in a cold room at 4 degrees C after X-raying on the Friday, and removed again to the greenhouse on the Monday. X-raying continued on the Tuesday.

X-ray films were examined to determine when the image of any seed type was no longer visible on the film. The daily X-ray films were examined to determine the distances from the seeds to the soil surface. Distances from the steel markers in the soil were also recorded daily. These markers were used to determine any soil settling which occurred during the experiment. The distance values were not corrected using the procedure outlined in Section 3.3 as only the differences in position were important and distortion by the X-ray for any one seed was considered to be almost constant. Finally, films from day one were examined and measurements of seed depth were made. These values were corrected using the procedures outlined in Section 3.3 so that they could be compared with the values obtained by seedling tracing.

Seed positions from the X-ray film were measured as follows: For the lupin seed the position on the film was determined by measuring both the distance from the base of the seed and the top of the seed to the surface marker. These values were then averaged to give the mid position of the seed. This was done because the seeds were of large size and the amount of swelling which took place as the seeds imbibed, may have increasingly altered the seed size. Positions for barley and rape were determined by measuring only from the top of the seed to the surface marker.

After seedling emergence had ceased, the soil bins were taken to the laboratory where visible seedlings were cut off at the soil surface and the remaining seedling portions which extended to the seed, were carefully removed from the soil (Figure 3.8a). In the

Figure 3.8a Seedling emergence blocks.

Back row. Rape seed.
Middle row. Barley.
Front row. Lupin.

case of lupins and rape, the distance from the soil surface to the begining of the root structure, was measured and taken as the seed depth. In the case of barley, the distance from the soil surface to the seed was measured. Measurements from each bin were bulked and averaged to give seed depth. The values were then compared to those obtained by the X-ray technique using a regression analysis.

Results and discussion

Table 3.8a shows the relative seed positions of germinating seeds as related to day 1 when placed on a hard soil medium as compared to a soft soil medium.

Table 3.8a Relative seed positions in the soil as related to day one.

Soil treatment	Lupin	Barley	Rape
Soft soil base	-0.41	0.47	1.05
Hard soil base	-0.23	0.37	0.66
LSD (P 0.05)	0.69	0.36	0.63

See Appendix 10 for complete data.

From Table 3.8a there were no differences in seed movement detected between soil compaction treatments for any of the three seed types tested. Subsequently, all data was accumulated.

Observation of the X-ray films revealed that the lupin seed images remained visible for at least five days after placement in the soil. X-raying was stopped at this point as seed movement in the soil was detected (Figure 3.8b).

Barley seed images remained visible for up to seven days after their placement in the soil with an undisturbed base. In the loose soil treatment the images were visible for nine days after placement. No movement of the seed images was detected up to day nine at which time X-raying ceased (Figure 3.8c).

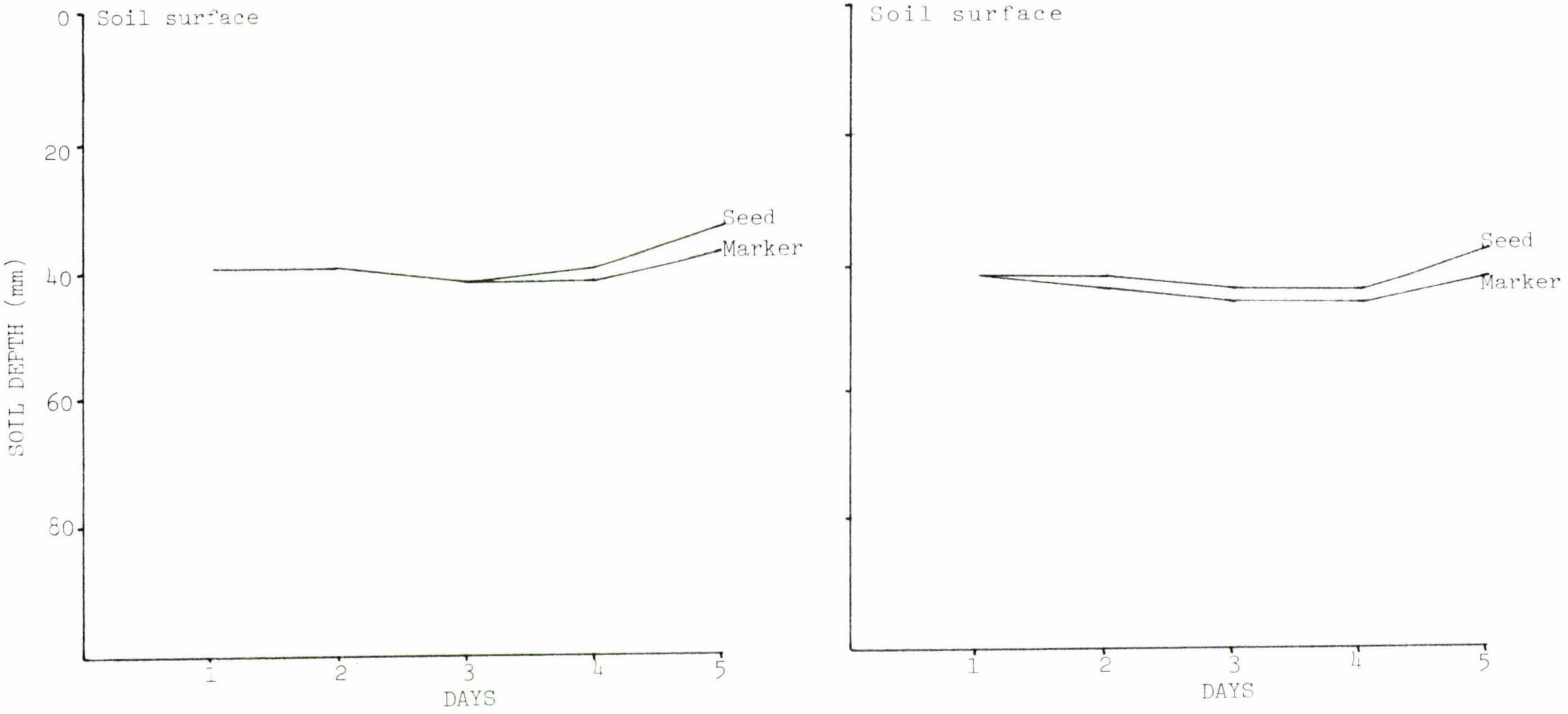


Figure 3.8b Curves of lupin seed position in the soil as time progressed.
Left; soft soil base. Right; hard soil base.

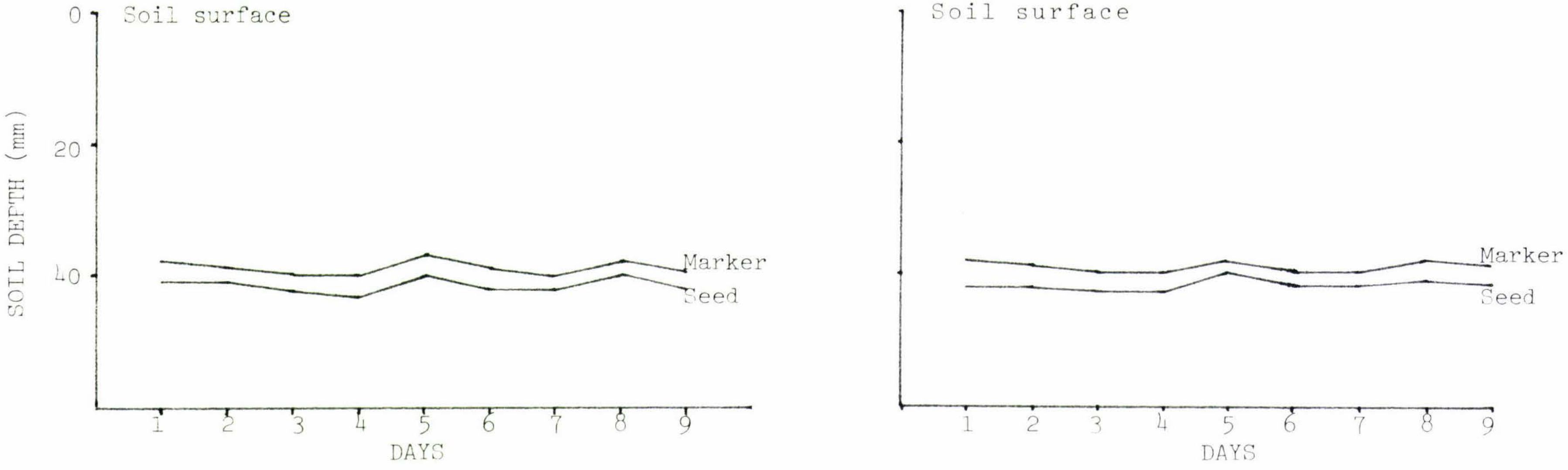


Figure 3.8c Curves of barley seed position in the soil as time progressed. Left; soft soil base. Right; hard soil base.

Rape remained visible for only three days after seed placement in the soil with an undisturbed base. Images in the loose soil base were visible for up to five days, at which time seed movement was detected and X-raying ceased (Figure 3.8d).

Table 3.8b shows the values for seed depth as determined by the X-ray technique and the seedling tracing technique along with the regression cofficients.

Table 3.8b Values for seed depth as determined by the X-ray technique and the seedling tracing technique.

	Barley depth (mm)		Lupin depth (mm)		Rape depth (mm)	
Sample	X-ray technique	Seedling tracing	X-ray technique	Seedling tracing	X-ray technique	Seedling tracing
1	35.9	41.8	31.6	46.4	22.8	29.2
2	35.9	43.0	32.4	50.8	23.9	31.3
3	34.5	41.0	31.9	--.-	22.2	28.8
4	35.4	41.2	33.4	44.7	24.5	29.8
5	38.0	44.7	34.0	46.2	24.4	30.0
6	36.2	43.0	32.5	48.8	25.8	30.0
7	36.1	43.0	32.9	46.4	22.3	29.0
8	33.4	40.8	35.3	52.0	25.3	32.8
R	0.914		0.344		0.655	

From the table it was found that in the case of seeds with hypogeal germination (barley) a reasonably strong positive correlation coefficient (r=0.91) existed between the values obtained by the X-ray technique and those of the seedling tracing technique. In the case of seed with epigeal germination (lupins and rape) the correlation coefficients were found to be weak (r=0.34 for lupins and r=0.66 for rape).

This would suggest that the seedling tracing technique might be successfully used with seeds having hypogeal germination such as barley, but not with seeds having epigeal germination, such as lupins or rape.

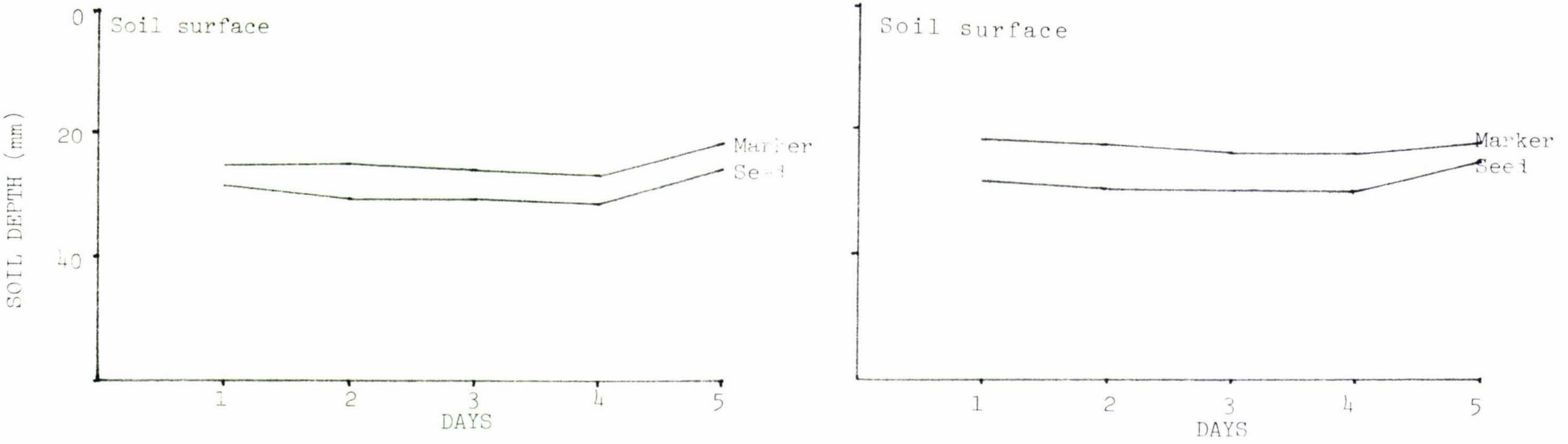


Figure 3.8d Curves of rape seed position in the soil as time progressed.
Left; soft soil base. Right; hard soil base.

In general, images were harder to detect in the bins using a layer of undisturbed soil covered by a layer of loose topsoil than where both layers were of consistent density (Figure 3.8e). This was probably a result of contrasts caused by the two soil densities.

Image movement was expected as epigeal germination started to push the cotyledons to the surface of the soil. This occurred five days after planting the seed. It might therefore be suggested that soil blocks containing lupin seeds should be removed from the field and X-rayed within the first 4 days after planting. Such a possibility, however, takes no account of differences that might be caused by field conditions, since these experiments were conducted in a glasshouse. Rape seed images, perhaps because of their small size, remained visible for only three days after seeding in the undisturbed soil treatment and therefore should be sampled, removed from the field and X-rayed as soon as possible after sowing.

The barley seeds provided the clearest results of those seed types tested. Images were visible for up to seven days after seeding in the undisturbed soil treatment, and there was no movement of the seed detected up to the ninth day, when X-raying ceased.

These experiments measured only visibility of the image. It should be noted that as time passed, image clarity was reduced. Therefore, it is recommended that to make the best use of the technique, sampling and X-raying should be done as soon as possible after seeding.

Figure 3.8e Radiograph of 2 soil blocks showing differences in soil density.

Top block. Uniform loose soil with 6 barley seeds, 2 steel markers and a sloder wire to mark the soil surface.

Bottom block. Layered soil densities with a cover of loose soil laid over an intact soil taken from the field. Six seeds, 2 steel markers and a solder wire to mark the soil surface are seen.

3.9 DEVELOPMENT OF EQUIPMENT FOR FIELD SAMPLING AND SUBSEQUENT X-RAYING

As outlined in Section 3.8 removal of in-row soil blocks and X-raying of these blocks had to be conducted as soon as possible after seeding, to preserve the clarity of the seed images. To facilitate this for large scale field experiments, the following three pieces of equipment were required:

1. A machine which could mechanically cut (or assist in the cutting of) rectangular blocks of soil centred on the sown rows.

2. Simple and inexpensive bins into which these soil blocks could be placed for transportation and subsequent X-raying.

3. A jig to hold multiple bins and their soil blocks while they were being X-rayed.

3.9.1. Development of a soil block cutting machine

Design criteria

1. The block size selected was 75 mm wide by 75 mm deep by 240 mm long (as suggested by the results of Section 3.6 and the X-ray facility).

2 The vertical sides and horizontial base of the sample should be mechanically cut in such a way as to cause minimum disturbance to the seeded row.

Machine construction

Two possiblities were considered for cutting the sides of the block. The first of these was to use vertical non-powered cutting discs to cut both sides. The second was to use powered cutting blades which would slice the sides of the block. The option of using unpowered discs was the simpler of the two but the downward compressive force would have required a heavy frame construction. It was also felt that the compressive cutting action of the discs could produce stresses in the soil and seed groove which might disturb the position of the seeds.

It was therefore decided to design a powered cutting machine which would cut by shearing action rather than compressive action. Since the desired depth was 75 mm, two suitable (235 mm diameter) circular saw blades were obtained. These were mounted on a shaft with a 75 mm wide spacing block between the two. Depth wheels were attached on the rear and set to provide a cutting depth of 75 mm (Figure 3.9.1). The blades were powered by a 1.0 kilowatt hydraulic motor through a chain drive system. The blades were arranged in such a manner that they rotated at 820 rpm in the same direction as the direction of travel, but the teeth on the saw blades were reversed so they provided a self cleaning action. The machine was mounted on a tractor three-point-hitch, and powered from the hydraulic system of the tractor.

Figure 3.9.1 Soil block cutting machine.

In an attempt to cut the base of the soil block at the same time as the sides, a pair of vertical arms were arranged to travel in the slots cut by the saw blades. At a depth of 75 mm, a length of piano wire was stretched between the two arms. This procedure worked well in some conditions, but if the wire became snagged on obstructions in the soil, the arms were drawn together, and the soil block was usually destroyed. Due to the narrow width of the slots cut by the saw blades the support arms for the piano wire could not be strengthened sufficently to prevent being drawn in from time to time. Thus, an alternative procedure was developed, in which the sides of the soil blocks were cut using the powered saw blades, and the base of the blocks were later cut by hand after first removing the block together with the surrounding soil using a spade.

3.9.2 Development of the soil block bins

Design criteria

1. In Section 3.6 it was concluded that an appropriate soil block size was 75 mm wide by 75 mm deep. The length of the block was determined by the limitations of the X-ray facilities available, and the possibility that larger blocks could be damaged during sampling. In this study the X-ray cartridge was 432 mm wide, so the bins were made 240 mm long in order that two bins could be placed, end-to-end, and X-rayed at one time with a small overhang (24 mm) on either end.

2. The bins should be constructed in such a way that soil blocks could be taken in the field, and left untouched in bins for transportation, X-raying and subsequent growth.

Bin construction

Because of the large number of bins required to sample a field experiment, construction time and material were kept to a minimum. Three possible materials were plastic, aluminum and steel. Steel sheeting was eliminated because it would have reduced the X-ray penetration and thus image clarity. Plastic was not available in a 75 mm by 75 mm box section or "U" section. Thus plactic bins would have had to be fabricated and this would have been difficult. Aluminum offered the best alternative. It would not noticeably block X-ray penetration, (M.W. O'Callghan, pers. comm., 1984) it was easily fabricated into small bins, it would not rust or deteriorate over time in the growth chamber or greenhouse and the bins were reusable.

Bins were fabricated 75 mm by 75 mm by 240 mm long with one end closed by folding the aluminum sheeting (Figure 3.9.2). The bin material cost was NZ $0.91 each, and fabrication time was about 8 minutes each.

Figure 3.9.2 Aluminium soil block sample bin.

3.9.3 Holding jig for X-raying soil blocks

Design criteria

1. The jig should be able to position a number of soil blocks in their bins for X-raying.
2. It should also be able to transfer reference marks to the X-ray film, for the correction technique.

Jig construction

The jig was designed to hold six soil blocks for each X-raying exposure. The sample bins were stacked directly on top of one another, and two blank bins full of soil, were placed over the top samples. This was done because at steep X-ray angles (such as those used in the stereo correction technique) it was possible to project an image of a shallow sown seed in the top bin, above the position of this bin. Where this occured, part of the X-ray beam would have passed through only air, and the film would have been over-exposed with the result that seed images would have not been visible (Figure 3.9.3).

The jig was constructed of a plexiglass sheet, mounted on a wooden base, with a steel box section located at the base to ensure the bins were at the proper height. The centres of the jig were marked, using lead tape, in such a way that these marks would be transferred to the X-ray film (Figure 3.9.3). This was required to provide reference marks on the film for use with the correction procedure outlined in Section 3.4.

Figure 3.9.3. Soil block positioning jig.

Top. In X-ray facility with bins in place.

Bottom. Empty jig with lead tape marks which are transferred to the X-ray film.

3.9.4 Field sampling procedure

Using the above equipment, the following procedure was developed for field sampling and subsequent X-raying of the soil blocks.

1. The locations of the potential blocks were marked in each row (selected at random).
2. A piece of twine was laid as a line, parallel to the row, to aid in positioning the tractor and cutter over the centre of the row.
3. The powered blades were operated and lowered to the ground, and the sides of a series of soil blocks were cut to the desired length.
4. One end of each block was cut with a sharp spade perpendicular to the row, and an aluminum bin was pressed over the block.
5. The aluminum bins containing the soil blocks were carefully removed by using a spade to dig out parcels of surrounding soil containing the soil blocks.
6. Waste soil was removed from the outside of the bins and the bases of the soil blocks were cut flush with the base of the bin using a sharp knife. The soil blocks were thus upside-down in their bins.
7. A second aluminum bin was placed inside each of the bins containing the soil blocks. They were then inverted to bring the soil block up-right, and the original bins were removed, thus leaving the blocks in the new bins with the grooves exposed along the top.
8. The bins with their blocks were labeled and removed from the field to a cold room for storage prior to X-raying.

9. Blocks were transferred to the X-ray facility.

10. The holding jig was set on the X-ray table and positioned so that the X-ray source was one meter from the film cassette (Figure 3.9.3).

11. Lengths of solder wire were laid over the soil surface of each block in order to provide a reference marker representing the soil surface.

12. The blocks were stacked three high on the jig and blank bins filled with soil were placed on top to provide a uniform soil mass through which the top blocks would be X-rayed.

13. The position of each block was recorded.

14. The X-ray beam was aimed at the centre mark of the jig, the film exposed, removed and processed (Figure 3.9.3).

15. The cassette was reloaded and placed at the back of the jig; the X-ray source was centred at the top of the jig, then tilted downward to centre on the original centre mark. The power setting was reduced by one half and the first stereo exposure was taken. The X-ray source was then lowered and centred at the bottom mark on the jig and tilted upward to centre again on the original centre mark, where the second stereo exposure was taken (Figure 3.3.2a). The film was removed from the cassette and processed. The distance between the two centreing positions was 360 mm.

The procedure described above represented the methodology leading to and including the stereo technique to determine the Z component. When using, instead, the X-raying method in two planes to determine the Z component, steps 1 to 14 were the same as outlined above and instead of step 15, steps 15a to 18a were substituted.

15a. The blocks were removed from the jig and laid groove up on the X-ray table, and their locations were recorded.

16a. The solder wire marker was moved to the rear of the bin but remained as a reference representing the soil surface and the rear edge of the sample.

17a. The X-ray source was positioned one meter above the centre of the bins and the film was exposed.

18a. The Z component was the distance from the solder marker (step 16a) to the seed image.

19. The X-ray films were then laid on a light table over an X-Y grid (Figure 3.9.4). From this grid the X and Y coordinates were measured for the seed locations and the surface reference marker directly above the seed. The Z components were determined from the stereo or second plane X-ray. These six values for each seed location (X, Y and Z seed; X, Y and Z reference) were then entered into a computer program (developed by the author: Appendix 1) where the X and Y coordinates were corrected using the procedure described in Section 3.3. The corrected Y values were then subtracted to provide the seeding depth. The corrected Z values for each seed were compared to determine width of spread within the row and the corrected X values for adjacent seeds were compared to obtain in-row spacing. All values and standard errors were caluated using the computer program in Appendix 1.

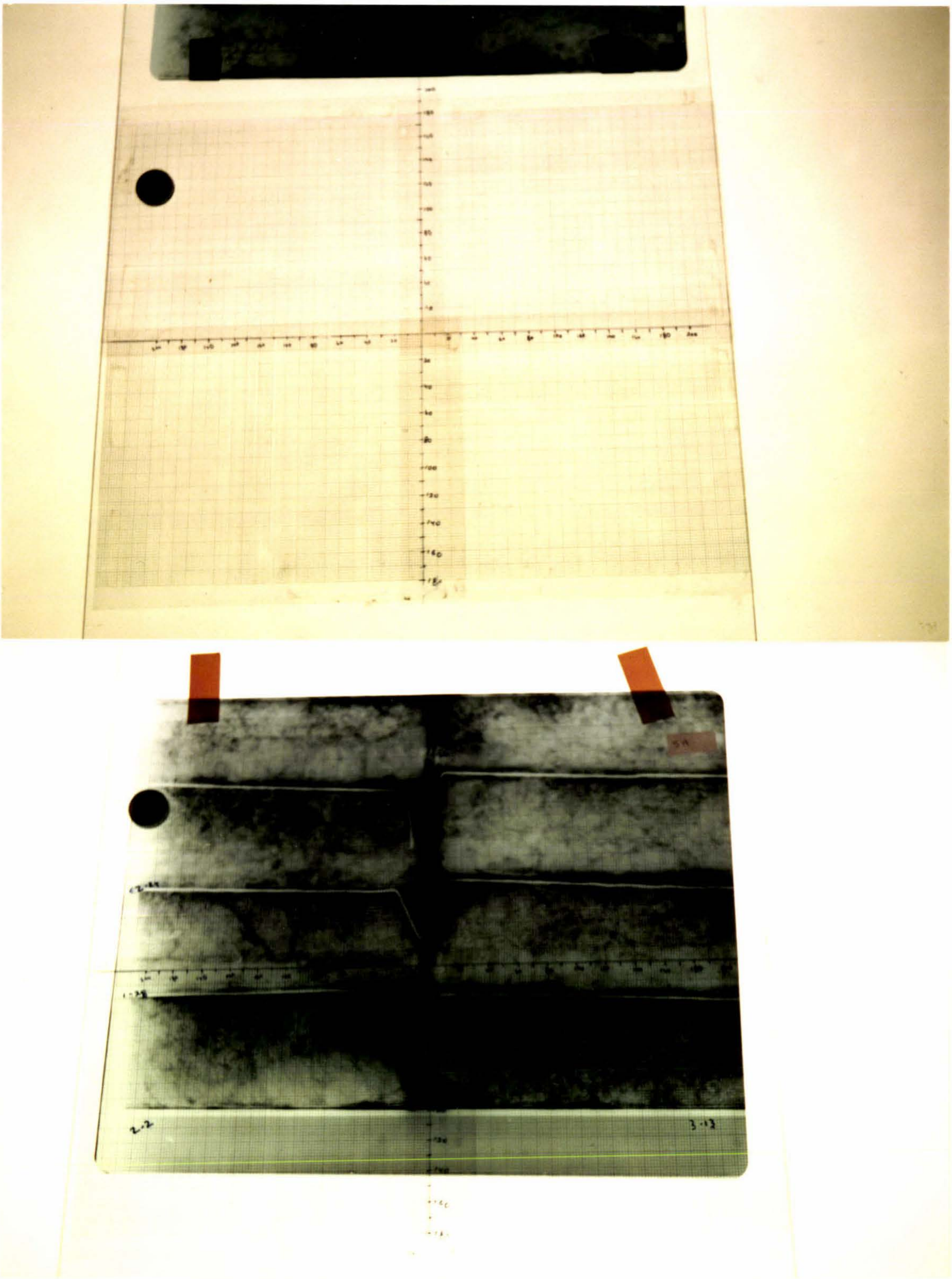


Figure 3.9.4 X-ray grid for measuring image positions.
(on light table)

Top. Grid alone.

Bottom. Grid with X-ray film over top.

3.10 SUMMARY OF THE X-RAY TECHNIQUE

The X-ray technique offered a new method for accurately determining seed placement in the soil; by planting seeds coated with a heavy metal compound, and measuring the distance between the seed images on an X-ray film. The procedure, in developing the technique, was to highlight factors which were likly to affect the performance of the technique. These factors were grouped, and comparative experiments were conducted. The aim for this major part of the project, was to develop a reliable X-ray technique which could be used in the field.

The first step in developing the technique was to develop a procedure for correcting the seed image positions on the film. Since the X-ray beam was emitted from a point source the images on the film were projected shadows, and not true representations of the seed positions in the soil. By using either an X-ray stereo technique or X-raying in two planes, the distances from the seeds to the film were determined. This value was used to correct the seed image positions so that accurate measurements could be obtained.

Two types of coating procedures were evaluated. The first involved soaking the seed in solutions containing heavy metals while the second entailed modifying a commercial seed coating procedure to apply a powdered coating of heavy metals to the outside of the seed. The first set of experiments was conducted to determine the effects of coating-type and amount on the image intensities, as measured by a microdensitometer. The results indicated that powdered red lead oxide gave the most intence images and thus was the best coating material. A 30% coating level was suggested as a satisfactory minimum standard coating for soybeans and barley, while rape seed required a coating level of 150%. The level of coating for barley was later increased to 50% to improve image clarity, when seeds were X-rayed in a soil medium. It was also concluded that there were differences in image clarity between seed sizes. As seed size was reduced, the level of coating had to be increased to maintain a suitable image.

The next set of experiments was conducted to determine the effect of soil types and soil moisture contents on image clarity. A soil sample thickness of 75 mm was found to be an acceptable size. It was small enough to be easily taken and transported, but it was also large enough to contain all seeds in the sown row. All soil types tested were acceptable, but those with even textures produced the clearest images. All soil moisture contents were acceptable, but it was suggested that in some cases soils at field capacity were more satisfactory than either dry or saturated soils.

Seeds which had been coated with red lead oxide and exposed to radiation were tested for germination. It was found that neither the coating nor the radiation had an adverse effect on seed germination. This result allowed for sown coated-seeds to be sampled for seedling emergence and establishment.

The final set of laboratory experiments was aimed at determining any time-elapse effects on the use of the X-ray technique in the field. These experiments showed that barley was the most reliable seed tested. There were no changes in the position of the seed images in the soil as germination and emergence proceeded. Images remained visible for up to seven days after placement in the soil. In the case of lupin seeds (with epigeal germination), image movement was detected at five days after placement in the soil in this laboratory experiment. This might suggest a sampling limit of four days or less, depending on the field conditions. Rape exhibited the shortest time-tolerance of the seed species tested. Images were visible for only three days after placement in the soil, even in laboratory conditions.

An attempt was made to correlate results obtained from a seedling tracing technique with those obtained by the X-ray technique. There was a moderate correlation between the two in the case of barley. In the case of lupins and rape the weak correlations indicated that seedling tracing was not a reliable technique. It was thus concluded that only seeds with hypogeal germination, such as barley, were suited to seedling tracing, and then only if ungerminated or unemerged seeds were ignored (which could be misleading if seed placement, per se had had an effect on seed/seedling performance). It appeared that the X-ray technique was the only realistic option available for locating epigeal seeds, such as lupins and rape, and the best available option for hypogeal seeds such as barley.

Based on information from the laboratory experiments and size of the X-ray cassette, a soil block size of 75 mm wide by 75 mm deep by 240 mm long was selected. Of these three dimensions, only the 75 mm measured in the direction of the X-ray beam was critical, provided the stereo technique was used for determining the correction value of the Z component. This meant that if a soil block was 75 mm in one plane, the other two dimensions could be varied. If such blocks were too large for the X-ray cassette it was possible that overapping X-rays could be taken.

For the purposes of this study three pieces of equipment were developed: An aluminium soil block bin 75 mm by 75 mm by 240 mm long; a soil cutting machine which sliced the sides of the soil blocks in situ; and a jig to hold the bins and their soil blocks and to transfer the reference marks to the X-ray film.

The second, more minor, phase of this study was to demonstrate the use of the X-ray technique for sampling from a field situation, and to determine its working guidelines and any possible shortcommings for future field experiments.

4. FIELD EVALUATION OF THE X-RAY TECHNIQUE

4.1 OBJECTIVES

A field experiment was undertaken with the objective of evaluating the X-ray technique in the field. A lesser objective was to determine the effects of a range of direct drilling openers on seed placement and seedling emergence.

4.2 MATERIALS AND METHODS

4.2.1 Site selection and preparation

The site, located at Massey University, was a fine sandy loam soil with a cover of permament pasture. The locations of the three replications are given in Figure 4.2.1. This layout appeared to provide the most uniform replications of the options possible. This portion of the field was sprayed with 6.0 l of Paraquat in 250 l of water per hectare, 3 weeks prior to sowing, although damage by grass grub (Phyllophaga sp. anxia (Les.)) meant that competition was weak. The experiment was conducted during the winter months of temperate New Zealand with a mean daily temperature for June, 1984 of 10.1°C (Source; Grasslands Division, DSIR, Palmerston North).

4.2.2 Selection of variables

Table 4.2.2 provides a list of the variables which were thought to possibly affect seed placement by direct drilling openers in the field. Opener type, depth control, forward speed and seed species were selected for this initial experiment because they were thought likely to have affects on seed placement. They also were easily controlled; and the equipment was readily available (with minor modifications).

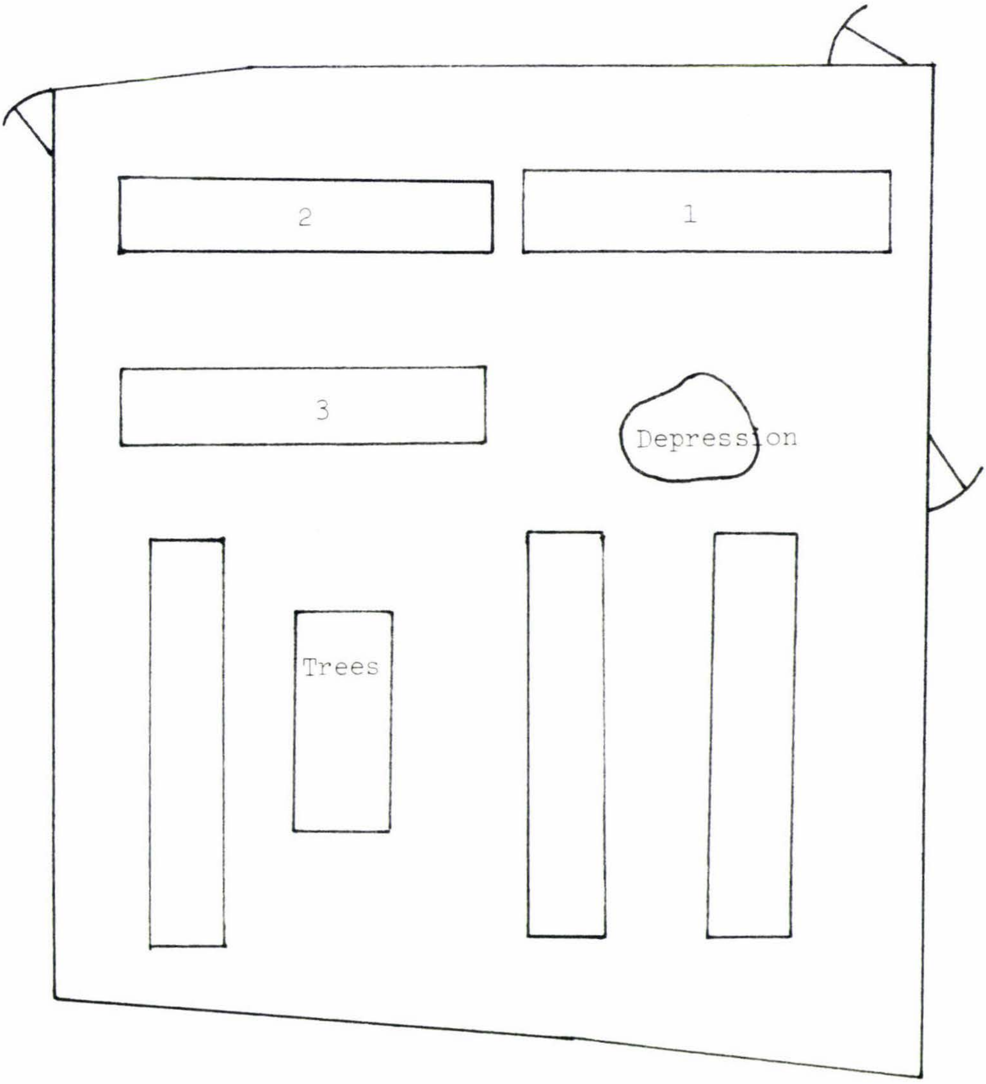


Figure 4.2.1 Layout of plots in the field experiment
1, 2, and 3 locations of replications.

Table 4.2.2 Factors thought likly to affect opener performance in the field.

Machine factors	Soil factors	Seed factors
Opener design	Texture	Size
Seed release velocity	Structure	Weight
Forward speed	Strength	Shape
Type of depth control	Organic matter	
Time of seed covering	Moisture content	
Method of covering	Surface condition	
Press wheel position	Residue level	
Press wheel pressure	Residue type	
Seeding depth	Residue distribution	

A brief description of each factor is given in Appendix 11.

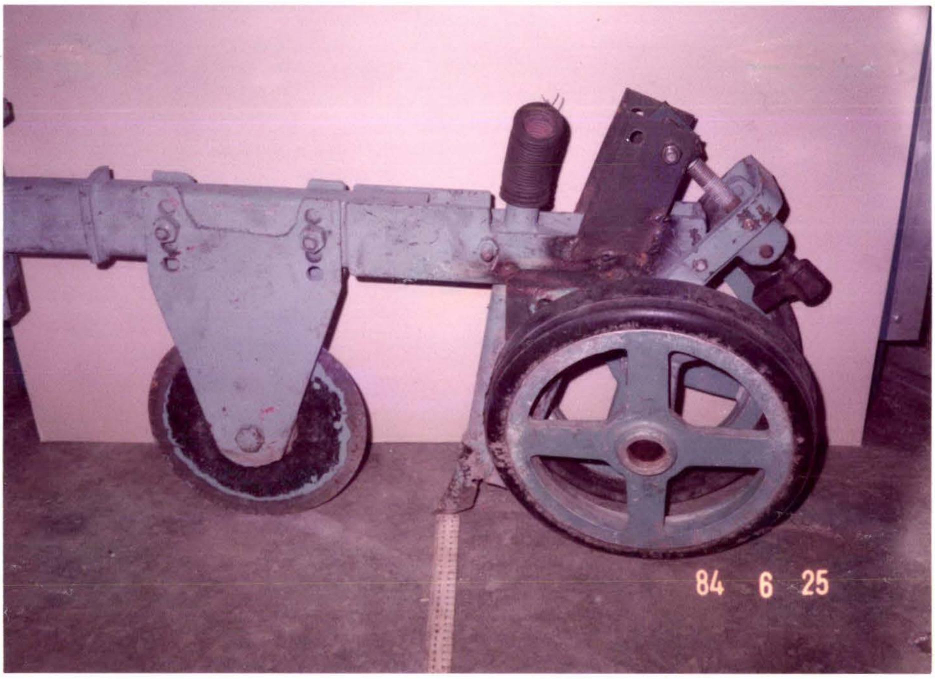
Method of depth control

Two common methods of controlling the depth of openers were, on the one hand, to establish a free equilibrium between the downward force applied to the openers and the soil resistance to penetration; and on the other hand, to use an excessive downward force, with depth wheels mounted on each opener to prevent the opener from going too deeply, and instead remaining at a preselected depth. Because the "2000 winged" opener under development at Massey University was designed with depth wheels located behind and to either side of the opener, it was decided to keep the same depth wheel configuration for all opener assemblies to be tested, as the other designs were normally operated without depth wheels.

Opener assemblies

Figures 4.2.2a,b,c,d show the selected opener assemblies. A hoe opener assembly was operated both with and without depth wheels attached (Figure 4.2.2a). This assembly also featured a 240 mm diameter cutting disc which preceded the opener.

A newly developed "2000 winged" opener assembly was operated with and without depth wheels (although in practice this opener did not



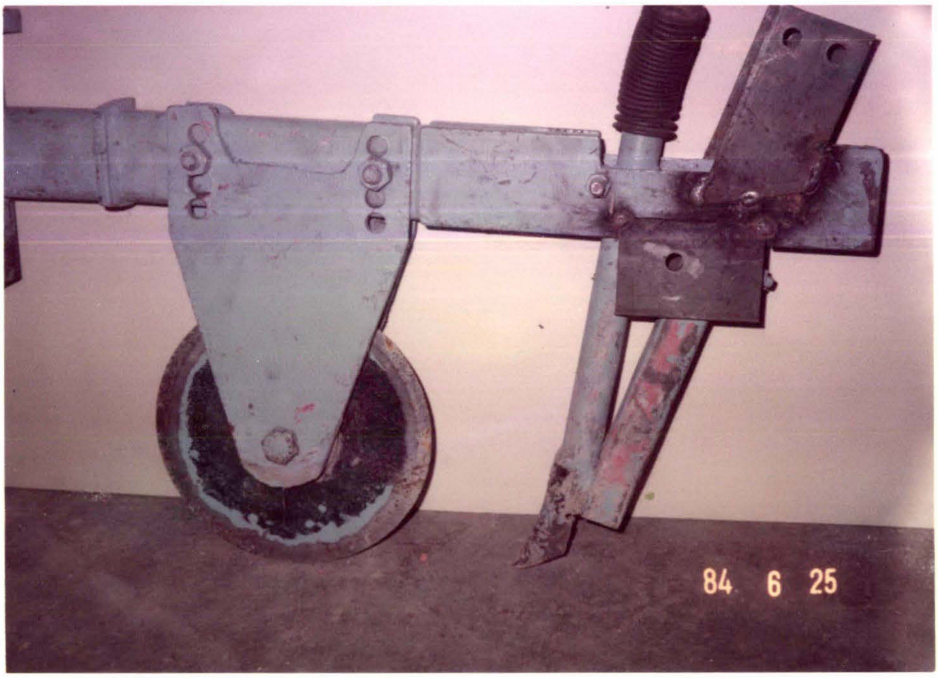
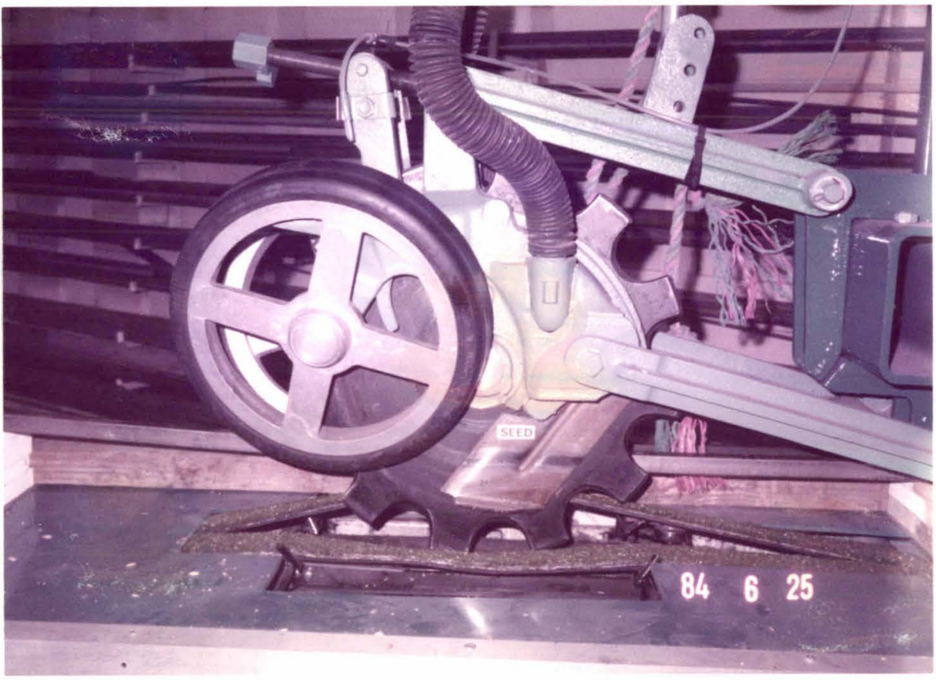


Figure 4.2.2a Hoe opener assembly.
Top. With depth control wheels.
Bottom. Without depth control wheels.



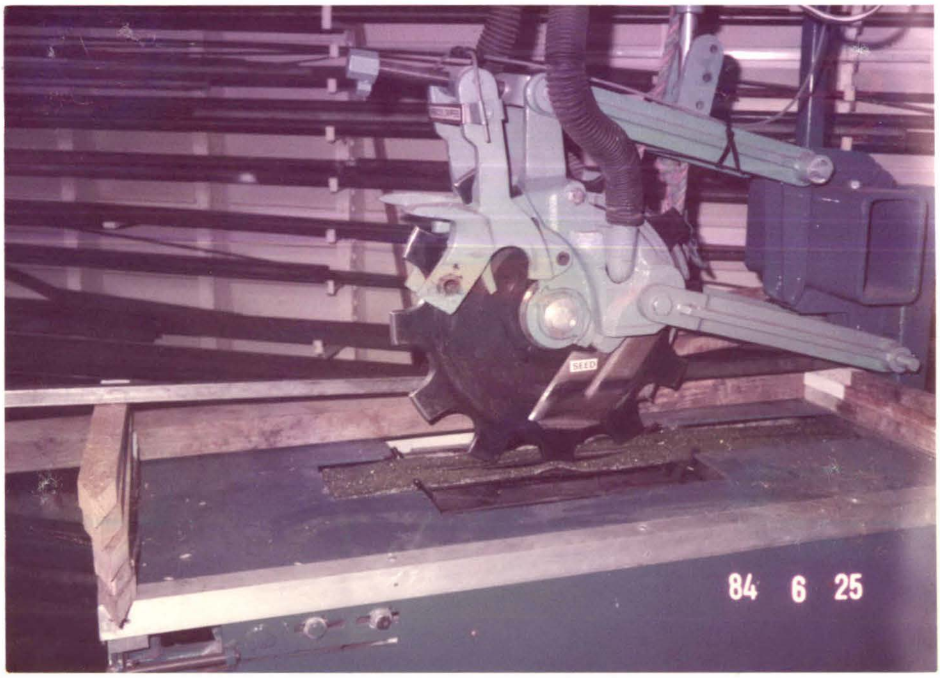
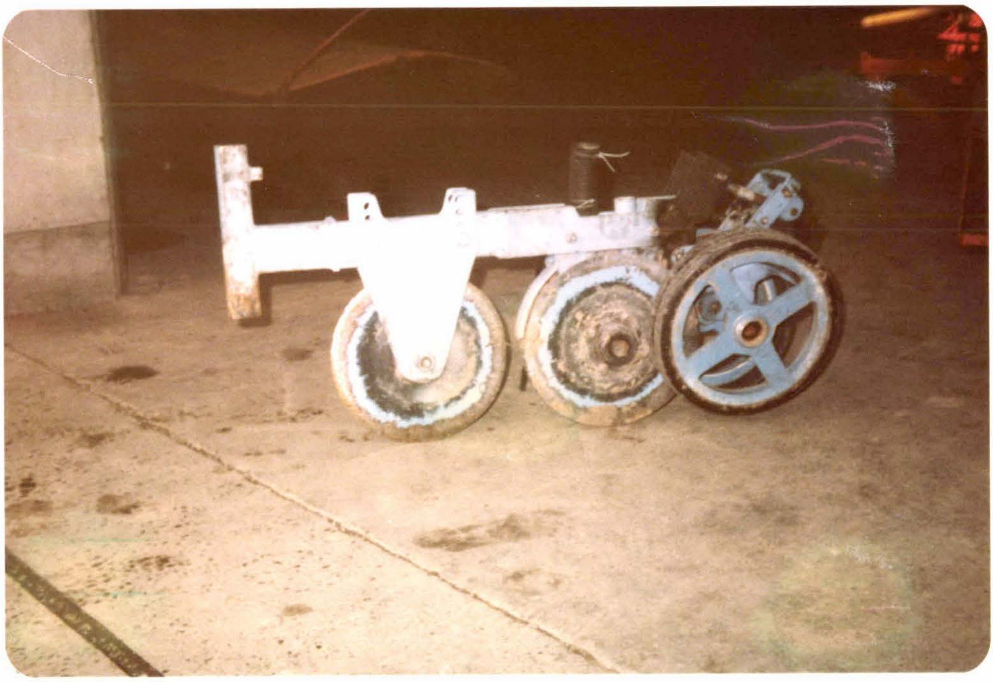


Figure 4.2.2b 2000 winged opener assembly.
Top. With depth control wheels.
Bottom. Without depth control wheels.



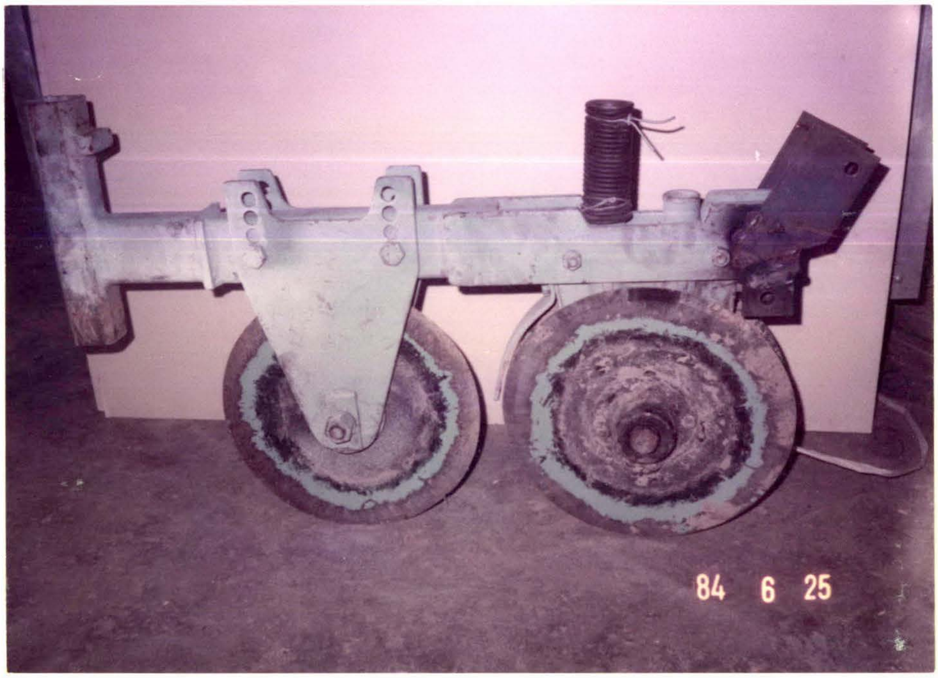
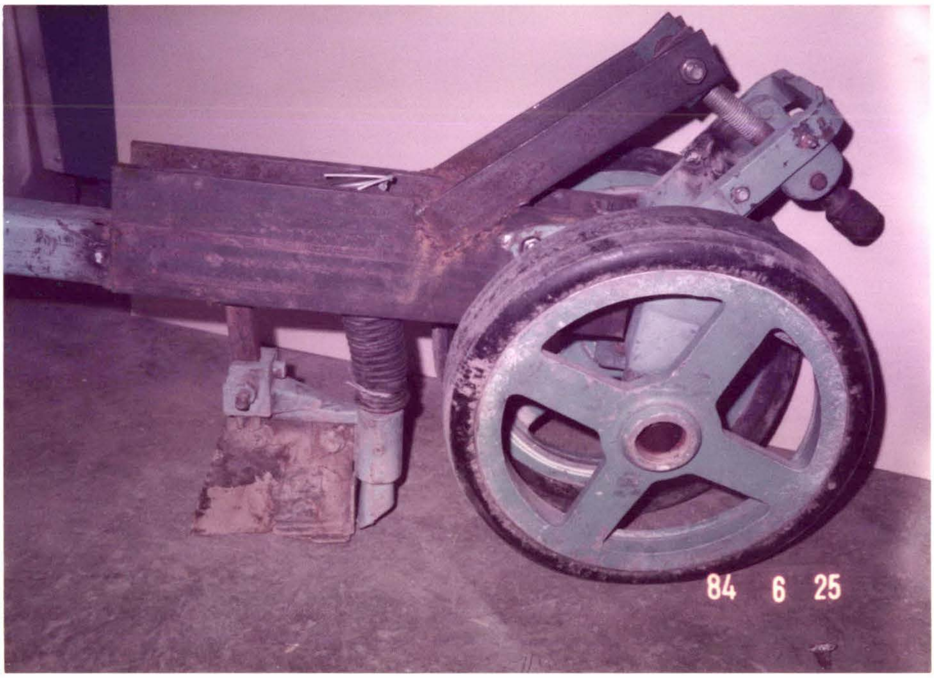


Figure 4.2.2c Triple disc opener assembly.
Top. With depth control wheels.
Bottom. Without depth control wheels.



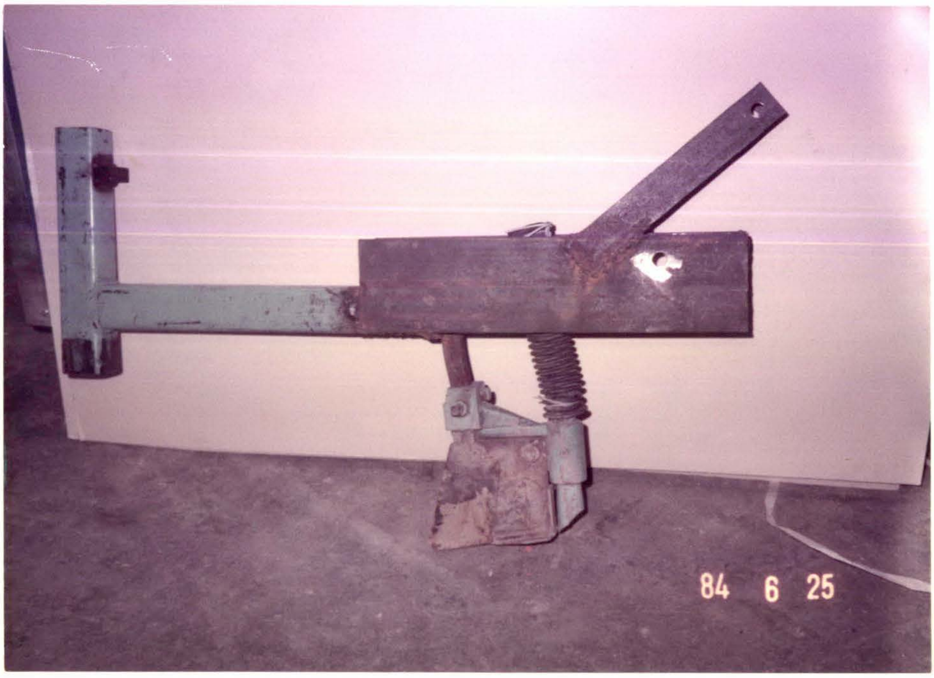


Figure 4.2.2d 1000 winged opener assembly.

Top. With depth control wheels.

Bottom. Without depth control wheels.

have a "without-press wheel" option). This is shown in Figure 4.2.2b. The assembly consisted of a notched cutting disc, 450 mm in diameter, with a pair of winged openers located on either side (one for seed and one for fertilizer) and a pair of depth wheels located to the rear and to one side of each opener blade. The position of the depth wheels also assisted in closing the seed groove with this opener.

A triple disc opener assembly was operated with and without depth wheels (Figure 4.2.2c). The assembly consisted of a 320 mm diameter cutting disc followed by a pair of 320 mm discs which formed a V at their bases, thus creating the seed groove.

A commercially available "1000 winged" opener assembly was also operated with and without depth wheels (Figure 4.2.2d). This opener had no cutting disc.

Figure 4.2.2e shows the field test rig with a single test opener fed by a single cone seeder unit.

Seed type

From results obtained in Section 3.8 two seed species were selected. Barley was chosen as a monocotyledonous type with hypogeal germination, and lupin was chosen as a dicotyledonous seed with epigeal germination. It was felt that using these two seed types would provide a suitible range for testing the X-ray technique for determining seed placement in the field. An in-row spacing of 20 mm between seeds was chosen as a compromise between normal seeding rates and a sufficent density within a row to be collected in a soil block. At this spacing, a 240 mm long soil block was expected to contain approximatly 12 seeds. Thus for each plot, sufficent seed to cover a 12 m length of row was prepared. This was to allow for a 1.0 m run-in on one side of the plot and a 1.0 m run-out on the other side of the 10 m plot. The cone seeder was calibrated in the field prior to seeding, so that it completed one nominal revolution in the 12 m length.

Figure 4.2.2e Test rig with a single opener and cone seeder assembly.

Forward speed

In direct drilling, work rate in the field is directly related to forward speed. Two speeds, 6 kph (representing a low operating speed) and a high speed of 12 kph were used. These forward speeds were checked in the field with an opener assembly in the ground, prior to sowing, to ensure that the speeds had been corrected for wheel slip.

The experimental design for each seed type was thus a two factor randomised block with three replications.

4.2.3 Field measurements

Seed placement

Using the X-ray technique developed in Section 3, it was proposed to measure the mean depth, variation of depth and variation of the in-row lateral spread of seeds.

Seedling emergence

From the day of first emergence, daily seedling counts were made over 5 m lengths of row until total seedling emergence had stabilized. From these data it was proposed to calculate total emergence, percent emergence at day 15, and emergence rate. Seedling emergence rate was defined as the time span, in days, from 20% emergence to 80% emergence.

Seed fate

Seed fate was an attempt to account for seeds which had not emerged. In this study seeds were classified as "emerged" and "unemerged". The procedure was to remove the soil blocks with a spade and count the seedlings in two 0.5 m row lengths. These large soil blocks were then taken to the laboratory where they were broken open and the unemerged seeds were found by dissection, and counted. Percent emergence was calculated by dividing the number of emerged seedlings by the total number of seeds in the sample.

Groove shape

It was proposed to measure the basic shape of the groove created by each of the opener treatments by measuring the width of spread at the top of the groove and the depth of the shattered zone.

4.2.4 Sampling times

The experiment was sown on the 1st and 2nd, June 1984. Soil blocks for the X-ray technique were taken on the 3rd, 4th and 5th, June 1984. Sampling time was approximatly 10 minutes for each block. Soil blocks were X-rayed using the stereo technique on the 7th and 8th, June 1984. Treatments with blocks which were found to contain less than 5 seeds had two additional soil blocks taken on the 9th, June 1984. These were X-rayed using the stereo technique on the 12th, June 1984. Destructive examination of the lupin blocks confirmed that seed movement had taken place and these blocks were discarded, and no future samplings were made of the lupin plots. A similar destructive examination of the barley soil blocks confirmed that all seeds in the blocks had been identified on the X-ray film and no movement had taken place. On 14th, June 1984, barley plots which had not been successfully sampled were resampled with four blocks taken from each plot. These were X-rayed on the 15th, June 1984, and bins with five seeds or more were X-rayed using the second plane system for determining the Z component. This technique was used because seed images were by then faint, and would not have been visible on the stereo film. This method also allowed for the soil blocks to be viewed from two planes, making cross referencing of the seed images possible. These blocks were destructively examined to confirm that all seeds had in fact been identified on the X-ray film.

Seedling emergence counts in situ were started on 12th, June 1984 when first emergence was detected. Counts were made on all plots, and values were later corrected to reflect the one day difference in planting dates. Values are reported from the day of first emergence.

4.2.5 Limiting conditions

In selecting the cone seeder as a seed metering system it was assumed that it would discharge a consistent in-row spacing with a known quanity of seed in each plot. Unfortunately, under the conditions of this experiment this was not the case. The cone seeder, as it rotated, was designed to move seed over an opening and seeds dropped through a delivery tube to the opener. This procedure often lead to a number of seeds falling off the edge at once, followed by a pause while the cone brought the next group of seeds to the opening. The second factor (which also compounded the intermittent seed-fall described above) was that two forward speeds were used. Both speeds were in excess of what would be considered normal for cone seeder operation. These higher speeds caused the cone to rotate faster than normal. Thus if seeds jammed in the throat or seed tube; the cone continued to move, thus extending the overall sowing length for the seeds to be discharged.

Because of the unpredictable and intermittent nature of the cone seeder malfunctions there was no way of determining the number of seeds sown in each plot, or of ascertaining that in-row spacing was consistent in any one plot. This was the reason why repeated soil blocks were required to obtain suffient numbers of seeds for the X-ray technique. This erratic seeding pattern also meant that there was an unknown number of seeds in each plot. Since the quantity of seed remaining in the seeder was not recorded at the time, measurements of total emergence, emergence on day 15, and emergence rate could not be calculated on a "percent of seeds sown" basis from the 5 m row lengths which were counted. In order to examine these data, curves of seedling emergence rates were plotted (using the actual field counts) so that at least the slopes of the curves could be compared, even if the magnitudes of the counts on any one day were meaningless.

Because it was not possible to take a full set of soil blocks from the lupin plots for the X-ray technique, these data were analysed separately from the barley (which had a full set of data). With the lupins, 18 of the 48 plots were not X-rayed because of the time constraint on repeated samplings.

4.3 RESULTS AND DISCUSSION

4.3.1 Barley experiment

Forward speed

Table 4.3.1a shows the average seeding depths, standard errors of seeding depth and standard errors of seeding width of direct drilled barley seeds as affected by forward speed. The seed placement data were collected using the X-ray technique. The table also shows the percent seedling emergence as affected by forward speed. These data were determined from the seed fate counts.

Table 4.3.1a Effect of forward speed on average sowing depth, standard error of sowing depth, standard error of sowing width and percent seedling emergence of direct drilled barley.

Speed	Average sowing depth (mm)	Standard error of depth	Standard error of width	Percent seedling emergence
6 kph	42.7	5.9	6.5	81.9
12 kph	37.0	7.2	6.4	83.0
LSD (0.10)	5.1	1.7	1.7	4.8
LSD (0.05)	6.2	2.1		

See Appendix 12 for complete data.

Table 4.3.1b lists the estimated percent seedling emergence of direct drilled barley given by covariate analyses with average depth, standard error of depth and standard error of seeding width as the covariates.

Table 4.3.1b Estimated percent seedling emergence as effected by forward speed determined by the covariate analyses in direct drilled barley.

Speed	Percent seedling emergences Covariate average depth	Covariate std. error depth	Covariate std. error width
6 kph	82.6	81.3	81.9
12 kph	82.3	83.6	83.0
LSD (0.10)	5.0	4.9	4.9

See Appendix 12 for complete data.

From Table 4.3.1a there appeared to be no significant differences (P 0.05) amongst any of the parameters listed. It is possible that there was a decrease in seeding depth as speed was increased from 6 to 12 kph, but this was significant only at the lower order of probability (P 0.10).

Table 4.3.1b shows that none of the covariate analyses caused any marked changes in the estimates of percentage emergence.

The absolute counts of seedling emergence are plotted in Figure 4.3.1a. The figure shows that the slopes of the lines were similiar for all treatments up to day 5 regardless of their absolute values. Between days 5 and 9 (and perhaps 10) the slope for the 6 kph speed was approximately twice that of the 12 kph speed. This change in slope might suggest that as emergence proceeded, the seeds planted at the 6 kph speed had a faster rate of emergence than those in the 12 kph plots even though (as described earlier) no importance could be placed on the absolute values of the comparision.

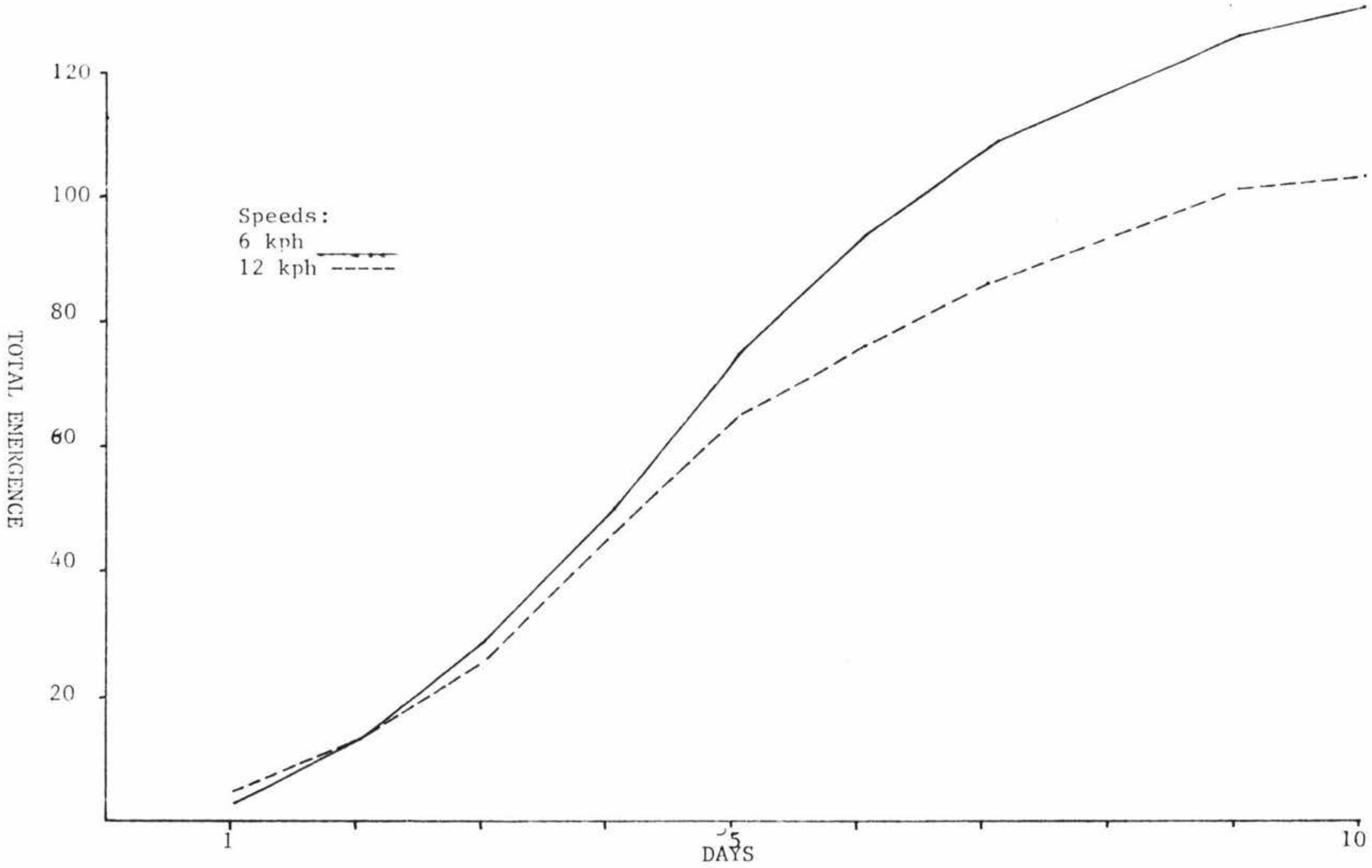


Figure 4.3.1a Effect of forward speed on seedling emergence of direct drilled barley.

Opener type

Table 4.3.1c shows the average seeding depths, standard errors of seeding depth and standard errors of seeding width of direct drilled barley, as affected by the different opener assemblies. These data were compiled by the X-ray technique. The table also presents the percent seedling emergence as determined by the seed fate counts, and affected by the opener assemblies.

Table 4.3.1c indicates that the triple disc, both with and without depth wheels, seeded significantly (P 0.01) shallower than the 2000 winged opener and the hoe opener, both without wheels. The triple disc opener with wheels seeded significantly (P 0.05) shallower than the 1000 winged opener with and without wheels and the 2000 winged opener with wheels. The triple disc opener without wheels seeded significantly (P 0.05) shallower than the hoe opener with wheels.

The triple disc opener with wheels showed a significantly (P 0.01) greater standard error of seeding depth than did the 2000 winged opener without wheels. The triple disc opener without wheels also showed a significantly (P 0.05) greater standard error of seeding depth than the 2000 winged opener with wheels, the hoe opener with wheels and the 1000 winged opener with wheels.

The 1000 winged opener without wheels had a significantly (P 0.05) greater standard error of seeding depth than did the 2000 winged opener without wheels.

Opener type had no effect on the standard error of seeding width in this study.

Table 4.3.1c shows that the triple disc opener with wheels and the 2000 winged opener with wheels significantly (P 0.01) improved seedling emergence, compared with the 2000 winged opener without wheels. These two openers were also significantly (P 0.05) better than the hoe opener without wheels. It can also be seen from the

Table 4.3.1c Effect of opener type on average sowing depth, standard error of sowing depth, standard error of sowing width and percent seedling emergence of direct drilled barley.

Opener type	Average sowing depth (mm)	Standard error of depth	Standard error of width	Percent emergence
Triple disc with wheels	20.8	11.1	7.1	92.6
Triple disc without wheels	28.5	7.9	7.3	89.0
2000 winged with wheels	40.5	4.6	6.4	92.2
2000 winged without wheels	53.5	3.2	7.4	70.1
Hoe with wheels	43.3	5.1	4.4	81.5
Hoe without wheels	55.6	7.7	6.6	72.2
1000 winged with wheels	36.2	4.3	5.0	80.3
1000 winged without wheels	40.6	8.2	7.2	81.7
LSD (0.05)	14.7	5.0	4.8	13.8
LSD (0.01)	22.2	7.6		20.9

See Appendix 12 for complete data.

table that the triple disc opener without wheels showed significantly (P 0.05) better seedling emergence than the 2000 winged opener without wheels and the hoe opener without wheels.

It was uncertain from the above results whether or not the differences in seedling emergence rates were caused by the design of the openers or were perhaps due to the other factors. It was therefore decided to perform a series of covariate analyses on percent seedling emergence with average seeding depth, standard error of seeding depth and standard error of seeding width as the covariates.

Table 4.3.1d lists the estimated percentage seedling emergence data as given by covariate analyses with average seeding depths, standard errors of seeding depth and standard errors of seeding width as the covariates.

Table 4.3.1d indicates that similar differences existed for all three covariates as shown by the LSD values. This table does not, however, reflect the change in the analysis of variance.

Table 4.3.1e lists the variance values for the opener factor of the original analysis of variance and the subsequence variances for the analyses of percent seedling emergence based on the covariates. From the table it is clear that average seeding depth as a covariate had a major effect, dropping the variance from 4.51 (highly significant P 0.01) to 1.74 (non-significant). This large change in variance strongly suggests that seeding depth, rather than opener type, affected percent seedling emergence in this experiment.

As stated earlier, the data for rates of seedling emergence collected from the 5 m row lengths could not be directly compared due to the unpredictable seeding pattern of the cone seeder. The absolute values for seedling emergence for each opener type are plotted in Figure 4.3.1b and a comparison of the slopes may give some indication as to differences in seedling emergence rates.

Table 4.3.1d Estimated percent seedling emergence as effected by opener type determined by covariate analyses in direct drilled barley.

	Percent seedling emergence		
Speed	Covariate average depth	Covariate std. error depth	Covariate std. error width
Triple disc with wheels	87.5	96.1	92.7
Triple disc without wheels	85.9	90.1	89.1
2000 winged with wheels	92.4	90.7	92.2
2000 winged without wheels	73.7	67.5	70.2
Hoe with wheels	82.4	80.4	81.2
Hoe without wheels	76.4	73.1	72.2
1000 winged with wheels	79.3	78.6	80.1
1000 winged without wheels	81.9	83.1	81.9
LSD (0.05)	15.1	14.2	14.2
LSD (0.01)	22.9	21.5	21.5

See Appendix 12 for complete data.

Table 4.3.1e A comparision of the variances for the opener factor as computed for the original analysis and the subsequent corvariate analyses.

Analysis	Variance	Significance level
Original analysis	4.51	P 0.01
Covariate depth	1.74	N.S.
Covariate standard error of depth	5.06	P 0.01
Covariate standard error of width	4.38	P 0.01

From the figure it appears that all the wheeled openers, the triple disc opener without wheels and the hoe opener without wheels had similiar rates of seedling emergence, with a sharp rise in rate, followed by a gradual reduction in rate. The 1000 and 2000 winged openers without wheels appeared to have somewhat flatter seedling emergence curves. This suggests a slower rate of seedling emergence for the latter two openers.

Speed and opener assemblies interactions

Table 4.3.1f shows barley percent emergence data as affected by forward speed and opener type. Table 4.3.1g gives the estimated percent barley seedling emergence data for the interactions as determined by the covariate analyses.

Table 4.3.1f indicates some inconsistent performances of opener types when operated at the two speeds. For example the hoe opener without wheels responded to an increase in speed with a corresponding increase in seedling emergence. On the other hand the 2000 opener without wheels significantly decreased its seedling emergence count at the higher speed. All other opener-depth wheel combinations were unaffected by the speed change.

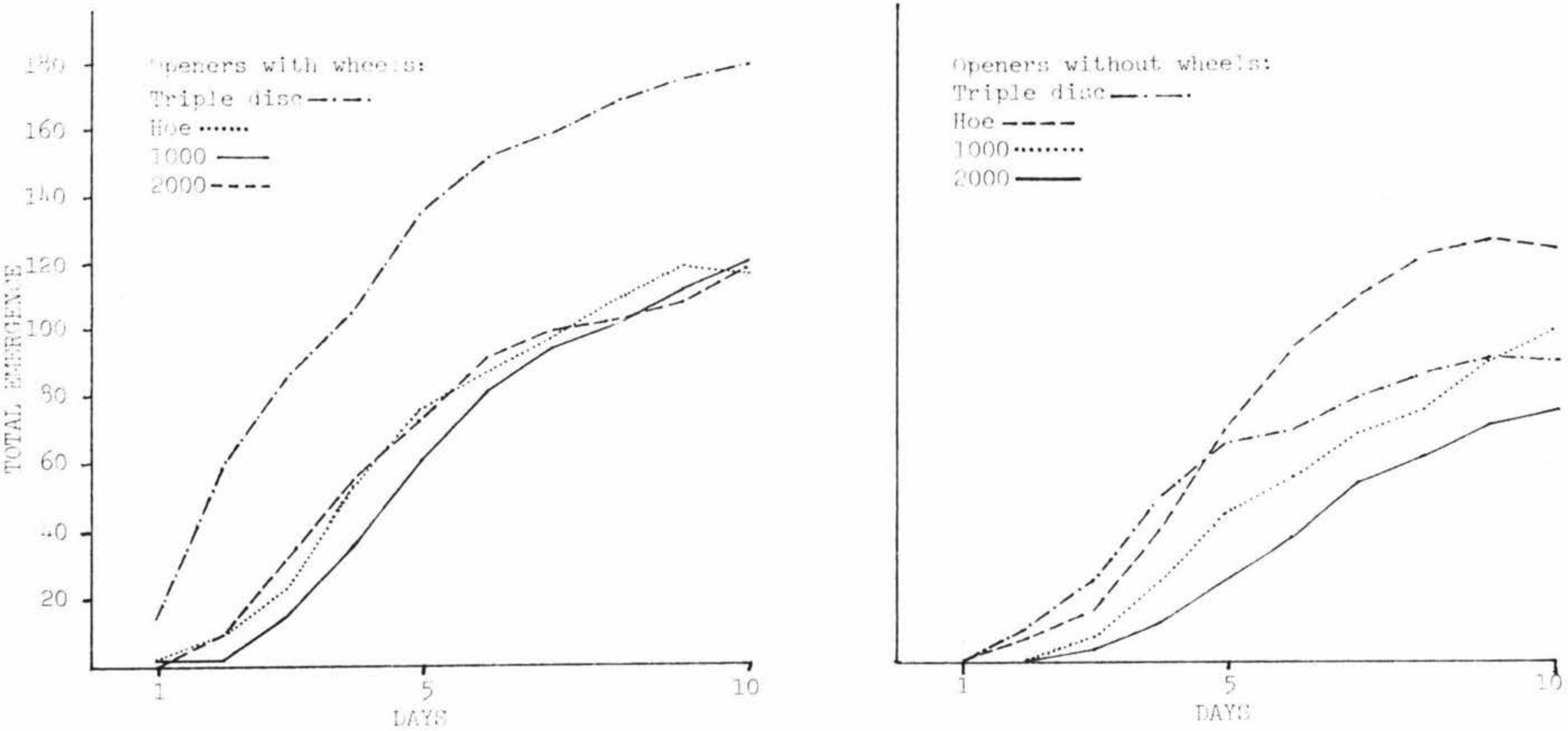


Figure 4.3.1b Effects of opener type on seedling emergence of direct drilled barley.

Table 4.3.1f Effect of opener type and forward speed on percent seedling emergence of direct drilled barley.

Opener type	Percent seedling emergence	
	6 kph	12 kph
Triple disc with wheels	93.3	91.9
Triple disc without wheels	86.2	91.8
2000 winged with wheels	92.6	91.8
2000 winged without wheels	81.5	58.7
Hoe with wheels	82.2	80.8
Hoe without wheels	58.6	85.6
1000 winged with wheels	82.1	78.1
1000 winged without wheels	78.4	85.9
LSD (0.05)	25.4	

See Appendix 12 for complete data.

Table 4.3.1g Effect of opener type and forward speed on the estimated percent seedling emergence based on covariate analyses of direct drilled barley.

	Estimated percent seedling emergence					
	Covariate depth		Covariate std. error depth		Covariate std. error width	
Opener type	6 kph	12 kph	6 kph	12 kph	6 kph	12 kph
Triple disc with wheels	89.3	85.2	95.9	96.3	93.4	92.0
Triple disc without wheels	83.3	88.0	87.0	93.1	86.4	91.8
2000 winged with wheels	92.6	91.4	91.2	90.1	93.0	91.4
2000 winged without wheels	86.3	61.8	77.8	57.2	81.7	58.8
Hoe with wheels	84.2	80.0	80.1	80.8	81.8.	80.6
Hoe without wheels	63.1	88.8	59.5	86.8	58.6	85.8
1000 winged with wheels	86.0	76.1	79.8	77.3	81.8	78.3
1000 winged without wheels	78.8	84.3	79.3	86.8	78.2	85.5
LSD (0.05)	25.4		25.6		26.1	

See Appendix 12 for complete data.

Table 4.3.1g indicates that the estimated seedling emergence interactions still highlighted the sensitivity of the hoe opener without wheels and the 2000 winged opener without wheels with regard to variations in speed. However the analysis with depth as the covariate appeared to influence the data more than the other factors as covariates. This strengthens the possibility described earlier that depth was the dominant covariate.

4.3.2 Lupin experiment

As pointed out in Section 4.2.5 a full set of seed placement data was not obtained for the lupin experiment. Reported below is the partial data and an analysis using missing plot values as determined by a "Genstat" analysis package. Because of the large number of missing plots (18 of 24) covariate analyses were not conducted.

These data are presented primarily to supplement the barley experiment and to further illustrate the use of the X-ray technique with large round seeds.

Forward speed

Table 4.3.2a shows the effects of forward speed on average seeding depth, standard error of seeding depth and standard error of seeding width of direct drilled lupin. These data are based on partial data determined by using the X-ray technique. Also shown in the table is the percent emergence as affected by forward speed. These data were complete and were determined by seed fate counts taken from each treatment.

Table 4.3.2a Effect of forward speed on average sowing depth, standard error of sowing depth, standard error of sowing width and percent seedling emergence of direct drilled lupin.

Speed	Average sowing depth (mm)*	Standard error of depth *	Standard error of width *	Percent seedling emergence
6 kph	35.3	6.4	4.8	80.3
12 kph	32.4	6.7	6.0	85.3
LSD (0.05)	6.1	2.5	1.2	4.4

* Data based on missing plot values.

See Appendix 13 for complete data.

Table 4.3.2a suggests that there were no significant (P 0.05) differences in average seeding depth or standard error of seeding depth as a function of speed, although there may have been a significant (P 0.05) increase in standard error of seeding width as speed increased.

There was a small but significant (P 0.05) increase in percent seedling emergence as forward speed was increased from 6 kph to 12 kph.

Figure 4.3.2a shows the seedling emergence rate curves for lupin seeds at both the 6 kph and 12 kph forward speeds. These curves were plotted from the 5 m counts of seedling emergence. The slopes of the two curves appear very similar indicating no difference in seedling emergence rates between the two speeds.

Opener types

Table 4.3.2b lists the effects of opener type on average seeding depth, standard error of seeding depth and standard error of seeding width of direct drilled lupin seeds. These partial data were determined from the X-ray technique using a "missing plot" analysis. The table also lists percent seedling emergence as affected by opener type, which represents complete data obtained from seed fate determinations.

The table shows that, based on the partial data, the triple disc with wheels seeded significantly (P 0.01) shallower than did the 2000 winged opener with and without wheels, the hoe opener with and without wheels and the 1000 winged opener with wheels. This opener also seeded significantly (P 0.05) shallower than the triple disc without wheels and the 1000 winged opener without wheels. The 1000 winged opener without wheels seeded significantly (P 0.05) shallower than the 1000 winged opener with wheels and the 2000 winged opener without wheels.

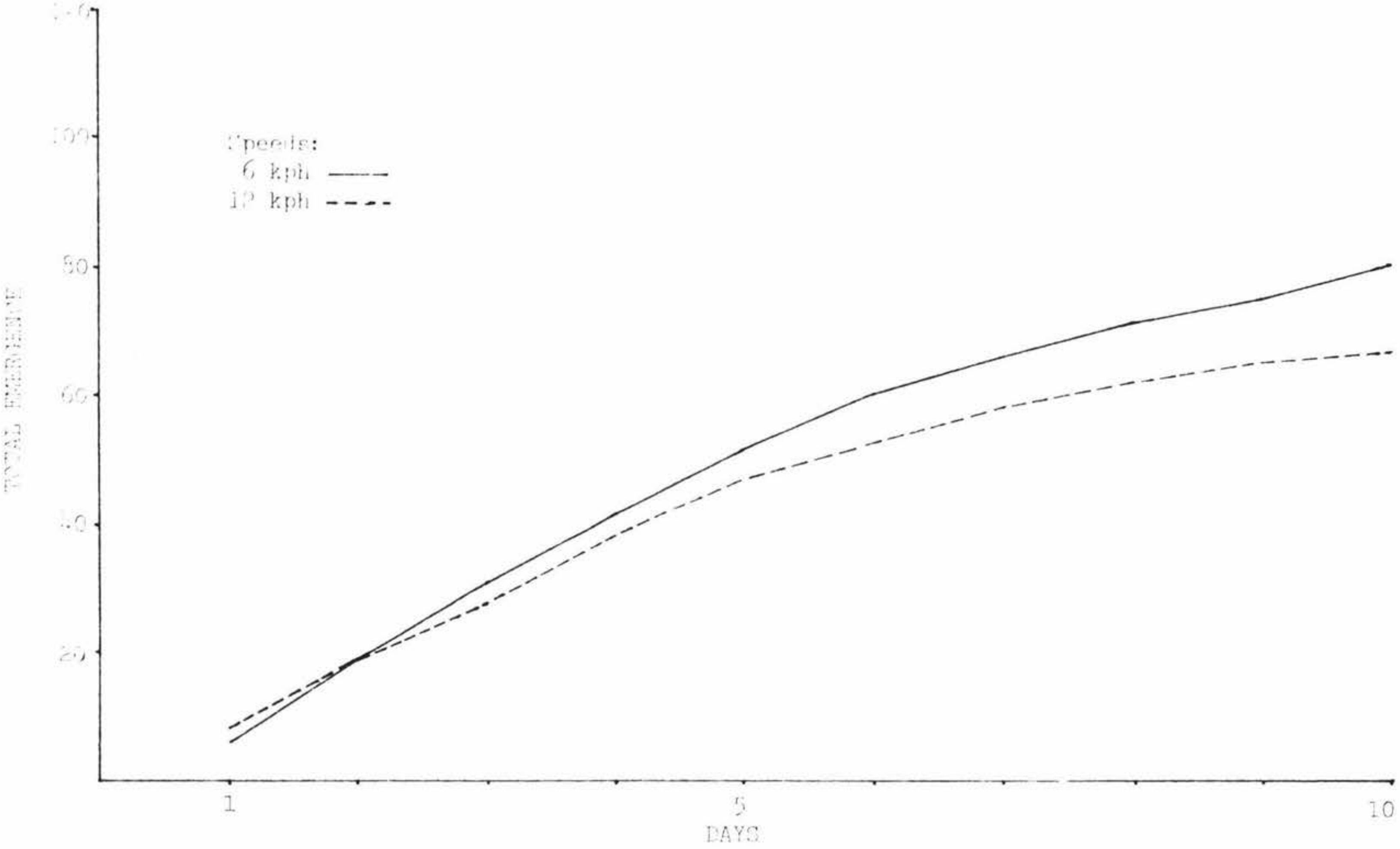


Figure 4.3.2a Effects of forward speed on seedling emergence of direct drilled lupins.

Table 4.3.2b Effects of opener type on average sowing depth, standard error of sowing depth, standard error of sowing width and percent seedling emergence of direct drilled lupin.

Opener type	Average sowing depth (mm) *	Standard error of depth *	Standard error of width *	Percent seedling emergence
Triple disc with wheels	12.3	11.8	3.0	89.1
Triple disc without wheels	30.6	6.7	5.1	88.0
2000 winged with wheels	34.5	4.1	6.6	80.7
2000 winged without wheels	43.3	5.5	5.6	58.8
Hoe with wheels	35.8	4.3	3.9	90.6
Hoe without wheels	42.3	7.1	5.8	86.1
1000 winged with wheels	43.0	5.9	5.3	84.7
1000 winged without wheels	28.4	7.3	7.7	84.3
LSD (0.05)	14.5	6.0	2.9	10.4
LSD (0.01)	22.0	9.1	4.3	15.8

* Data based on missing plot values.

See Appendix 13 for complete data.

The triple disc opener with wheels had a standard error of seeding depth significantly (P 0.05) greater than the 2000 winged opener with and without wheels and the hoe opener with wheels.

The 1000 winged opener without wheels had a significantly (P 0.01) wider standard error of seeding width than did the triple disc with wheels and a significantly (P 0.05) wider width of spread than the hoe opener with wheels. The table also shows that the 2000 winged opener with wheels had a significantly (P 0.05) wider standard error of spread than did the triple disc opener with wheels.

Table 4.3.2b shows that the 2000 winged opener without wheels promoted a significantly (P 0.01) lower seedling emergence than all other types with and without depth wheels.

Figure 4.3.2b shows curves of the seedling emergence rate for the eight openers tested. The figure appears to illustrate that the seedling emergence rates for the triple disc opener, with or without wheels were more rapid during days 1 to 3 than those of the other 6 openers. The seedling emergence curve for the 2000 winged opener without wheels appeared to have a lower slope than the other openers tested indicating a slower rate of seedling emergence.

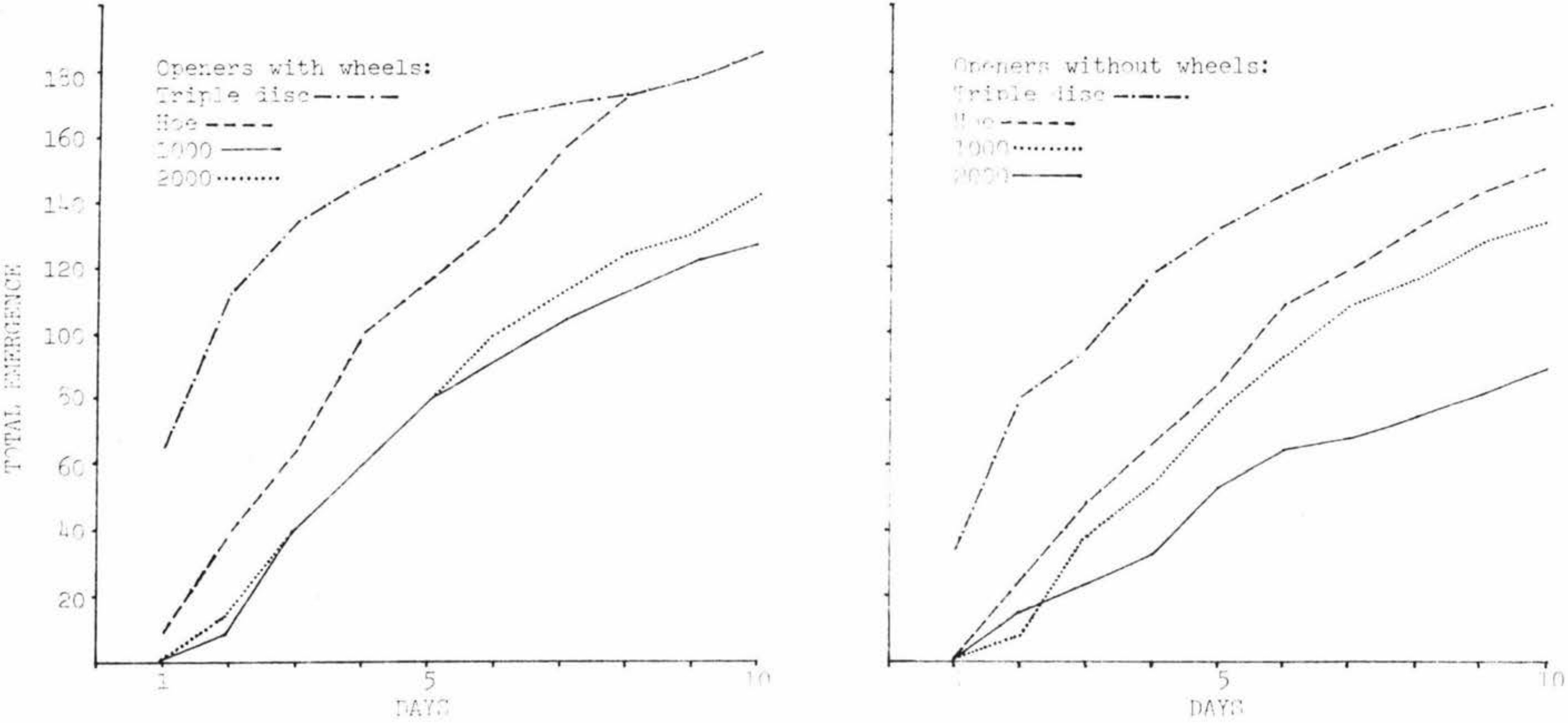


Figure 4.3.2b Effect of opener type on seedling emergence of direct drilled lupins.

4.4 DISCUSSION OF THE FIELD EXPERIMENTS

The objectives of the field experiments were primarily to provide a means for field testing the X-ray technique and then to determine the effect of direct drilling opener assemblies, depth wheels and forward speed on aspects of seed placement and seedling emergence in the field.

4.4.1 X-ray technique

Both of the field experiments clearly demonstrated the benefits and limitations of the X-ray technique for determining seed placement in the soil. The major advantage of the X-ray technique was that it provided an accurate measure of seed placement for all seeds sown (regardless of germination). In these experiments seeding depth, standard error of seeding depth and standard error of seeding width were all determined from the sown field plots. The technique also had the ability to determine in-row spacing and the standard error of in-row spacing, although these were not measured in the two experiments described. The X-ray technique allowed the operation of field equipment and openers under field conditions and then later plots were sampled to determine the accuracy of the seed placement arising therefrom. After X-raying, the sample blocks could be removed to the greenhouse or controlled climate rooms where the seeds could be closely monitored. The procedure also allowed for the samples to be taken, frozen and stored, and tested at a later time.

The limitiation of the X-ray technique was that when soil blocks were removed immediately after sowing it was not possible to know how many seeds were in each block until they were X-rayed. This necessitated that repeated samples were taken from a number of plots before a suitable sample was obtained. In the lupin experiment seed movement occurred before all plots were successfully sampled and as a consequence 18 plots were not sampled.

A number of possiblities existed for correcting this situation. The first of these would be to use a precision seed metering system and/or a seed counting monitor to ensure a more even (or at least predictable) seed selection. Alternatively, an increase in the cone size of the cone seeder (so that a thinner layer of seed was distributed around its circumference) would probabaly have made it better able to cope with the bulky coated seed lots. A further alternative would have been to use multiple cones with smaller seed lots in each, and bulk the seed going to the openers. When testing commercial seed drills the seeding rate might have to be increased above normal field rates to provide sufficient seed in each soil block sample. It should be noted that should seeding rates become excessive, it might become overly difficult to locate and position individual seed images due to image overlapping on the X-ray film. Recourse to longer soil blocks would also help but size limitations would be imposed by the X-ray facility. Regardless of the above suggestions, it is necessary to check the in-row spacing in the laboratory before attempting a field experiment.

Not withstanding the limitations outlined above the X-ray technique proved very successful in identifing barley seed placement in the soil. With attention to above details the technique will be successful for identifying lupin seed placement. From the above experiments it appears that there are no restrictions on using the technique for other seed types.

4.4.2 Opener performance

Although the major objective of the field experiments was to demonstrate the X-ray technique, these experiments also provided some interesting results with regard to comparisons between openers.

In the case of the barley experiment, as forward speed was increased from 6 kph to 12 kph the average seeding depth appeared to be reduced, although this was not duplicated in the lupin experiment. The lupin experiment did, however, show a 6 percent increase in total emergence as speed was increased from 6 kph to 12 kph. Such an effect is difficult to explain. Also in the lupin experiment there was a 25 percent increase in the standard error of width of spread as speed was increased, which was perhaps not surprising considering the increased velocity of soil movement that would be expected at the higher forward speed. Seedling emergence rate for barley appeared to increase as forward speed was increased from 6 kph to 12 kph. This difference did not appear in the lupin experiment where the seedling emergence curves appeared to be similar at both speeds. The inconsistencies between the barley and lupin experiments would seem to indicate that each seed type responded differently as forward speed increased, confirming the need to test different seed shapes and/or to avoid generalizations based on a specific seed type.

As stated in Section 4.2, an attempt was made to drill each plot at a depth of 40 mm. It is clear from the results of the field experiments that this target depth was not achieved. It would appear that the openers without wheels were more difficult to control, and thus achieve the desired target depth. In fact there may have been a trend towards deeper seeding without wheels with all openers except the 1000 winged opener in the lupin experiment, which was significantly shallower without wheels. In the case of the barley experiment particularly, the triple disc opener with and without wheels seeded shallower than the other opener assemblies tested. By contrast, the 2000 winged opener and the hoe opener, both without wheels, seeded deeper than some of the other opener assemblies. Field observations indicated that because the depth wheels were positioned slightly behind and to either side of all openers they tended to close the seed groove and forced soil back into the slot (which indeed they were designed to do). The effect might have been to trap seeds before they reached the bottom of the groove or had finished bouncing; thus leaving them placed shallower than at the base of the groove. Positioning of the depth wheels in this manner (which,as previously explained, was to standardise wheel assemblies with the 2000 winged opener design) may have adversely affected the seed placement of the other openers by prematurely closing the seed groove and trapping the seed.

Overall, the seedling emergence results seemed to reflect mainly the depths of seeding, in that the shallow seeded plots generally had a higher seedling emergence than the deeper plots. A covariate analysis confirmed that average seeding depth rather than opener assemblies explained the differences in seedling emergence.

The triple disc opener with wheels had a larger standard error of seeding depth than most of the other opener assemblies (by a factor of two). Because of the shallow mean seeding depth of this opener, however, this variation in seeding depth was not reflected in low emergence counts. It is conceivable that because of the importance of seeding depth in determining seedling emergence in these experiments, such large variations in depth caused by this opener might have had an adverse effect on performance if the target depth of 40 mm had been achieved. No consistent trends in standard error of seeding depth appeared between opener assemblies when operated with and without depth wheels. Similarly, depth wheels appeared to have no effect on the standard error of width of spread with any of the opener assemblies.

In the lupin experiment, there were similar trends in the performance of opener assemblies. The triple disc opener with wheels again appeared to seed shallower than all other opener assemblies tested. The 2000 winged opener without wheels had a lower seedling emergence than the other opener assemblies tested. Due to the incomplete seed placement data, covariate analyses were not conducted in this experiment and thus it is not possible to confirm whether the differences in seedling emergence were as a result of opener assemblies or the depth at which the seeds were placed. The barley data, however, would make the latter seem more likely.

Again, as in the barley experiment, the triple disc with wheels had a large standard error of seeding depth in the lupin experiment.

In the case of the lupin experiment, there were significant differences in sowing width amongst treatments. The triple disc and hoe openers, both with wheels, had the lowest values of standard error of width (3.0 mm and 3.9 mm respectively). The highest values were recorded with the 1000 winged opener without wheels and the 2000 winged opener with wheels. It was not clear from the data in what manner the depth control wheels affected this factor with the 2000 winged opener.

In general, the effects of opener assemblies and forward speeds followed a similar trend for both the barley and lupin experiments, the exception being the significant differences in the standard error of width of spread as affected by both the opener assemblies and forward speeds for the lupin experiment. Perhaps this reflected the more spherial nature of the lupin seeds and thus their tendency to move within the seed groove.

The interactions between forward speed and opener type were highlighted in the barley experiment by two opener assemblies which had opposite responses to increases in speed. The 2000 winged opener without wheels experienced a substantial drop in seedling emergence as speed was increased, while the hoe opener without wheels showed a substantial increase in seedling emergence as forward speed increased. It should be noted that again these inconsistencies in opener performance were with openers without depth control wheels. Nevertheless it is difficult to see why these two openers should behave so differently in terms of seedling emergence.

The important treatment effects of the field experiments were that although there appeared to be differences in the seedling emergence between opener assemblies, these differences (at least in the barley experiment) were later explained by the fact that not all openers seeded at the target depth. It also appeared that forward speed and opener assemblies did not perform consistently across both experiments; with the lupin experiment showing differences in standard error of width, while the barley experiment showed no such differences. It was also clear that when openers operated without depth wheels, it was more difficult to acheive a particular target depth and the openers performed inconsistently as forward speed was increased.

5 SUMMARY AND CONCLUSIONS

The X-ray technique for determining seed placement in the soil by field or experimental equipment provided a facility for identifying the position of individual seeds in terms of a three dimensional space. These three dimensions were seeding depth, lateral width of spread and in-row spacing. Hitherto no previous technique allowed for all these measurements to be made on the total seed pool, without the risk of seed disturbance.

The X-ray technique is based on the principle that seeds coated with a heavy metal powder, when X-rayed within a soil mass appeared as white or grey images on an X-ray film. The main objectives of this study were: To develop and document a reliable, workable X-ray technique for identifying seed placement in the soil; to examine those factors which might influence this procedure; and to demonstrate the use of the technique in a field experiment with a view to outlining its advantages and shortcomings.

The X-ray technique neccessitated the development of a number of special, but inexpensive peices of equipment and procedures, together with a number of laboratory experiments.

The first step was to develop both the equipment and procedures for applying powder and liquid coatings to the seeds. Secondly, as the seed images on the X-ray film were to be shadow representations of the actual seed positions in the soil mass, a correction procedure to eliminate the parallax error was developed to locate the seeds in their true position.

Laboratory experiments found red lead oxide to be the most appropriate coating material and that small seed sizes required greater coating levels than larger seeds. The most appropriate coating levels were, for large seeds (soybean and lupin), 30% by weight; for medium seeds (barley), 50%; and for small seeds (rape) 150%.

Experiments indiciated that an adequate soil block size for removal from the field was 75 mm by 75 mm by 240 mm, and that neither soil type (which ranged from pure sand to high clay and organic matter soils), nor soil moisture content had a marked influence on X-ray image clarity.

Seed germination was unaffected by the amount of coating material, coating procedure or radiation exposure at the levels used in these experiments. X-ray intensity was standardized at 85 kVa and 4 mAs using a Triplex Optimatic 1023 Vetinerary Science X-ray machine.

Greenhouse studies indicated that as time elapsed after seed placement in the soil, seed image identification became more difficult. Seeds with hypogeal germination (barley) projected images which remained visible for up to 7 days after placement in the soil. Seeds with epigial germination (lupin) projected images which changed position on day 5 due to movement of the cotyledons. Small seed (rape) projected images which were visible only until day 3. These facts suggested that soil block sampling should be conducted as soon as possible after the sowing procedure.

Further equipment development included a soil-block-cutter for field sampling, re-useable individual sampling bins, and a holding jig for X-raying the soil blocks.

The field experiments clearly demonstrated the benefits and limitations of the X-ray technique. The technique was used to provide the means of accurately determining sowing depth, standard error of sowing depth and standard error of sowing width. A limitation resulted from poor in-row spacing obtained with the particular cone seeder used in these experiments. As a result, some soil blocks had insufficient seed numbers for measurement, and several plots had to be resampled, although this was not possible where seeds remained detectable by the X-ray for only a short time particularly in the case of the lupins. To ensure success in future field experiments, in-row spacing would need to be checked in the laboratory prior to conducting field experiments and perhaps a precision seeder used instead of a plot-type cone seeder.

Notwithstanding, the field experiments did provide interesting results. It appeared from the data that in the case of barley, opener assemblies had a marked effect on total seedling emergence. Seeding depth data provided by the X-ray technique indicated that although the target depth was 40 mm not all openers achieved this. A covariate analysis of these two factors indicated that seeding depth rather than opener assemblies explained the differences in total seedling emergence. Similar trends appeared in the lupin experiment but because of incomplete seed placement data, a covariate analysis was not conducted in that experiment.

Opener forward speed possibly decreased seeding depth in the case of barley but not in the case of lupins. By contrast this also caused small differences in total seedling emergence in the lupins but not in the barley experiment. These differences were unexplained.

In the lupin experiment there appeared to be differences in the standard error of sowing width, both as opener speed increased, and between the various opener assemblies. This trend was not seen in the barley experiment.

Opener assemblies did not perform consistently as forward speed was increased in the case of the barley experiment, with two of the opener assemblies without wheels showing contrasting trends in total seedling emergence as speed was increased from 6 kph to 12 kph.

This confirmed the trend throughout the field experiments that openers without wheels were more difficult to set at a target depth, and were more difficult to control.

Future considerations

The most important consideration when using the X-ray technique would be to ensure a known in-row seed spacing and number, thus improving the field sampling of the seeded rows. When conducting tests of opener assemblies (for seed placement and seedling emergence) particular care must be taken to ensure plots are seeded at the target depth. An alternate solution would be to have depth as a variable in studies of future opener assemblies.

Aside from these two points the X-ray technique for determining seed placement offers a substantial range of possiblies for future work. For example, Table 4.2.1a listed 21 factors which might affect seed placement by direct drilling openers. Subsequently other factors not listed in the table became apparent. These included the ability to examine the effects on seed placement of both micro and macro soil surface contours. It may also be possible to examine seed groove shape by examining the cross sections of the drilled row as reflected by density changes of the X-ray image. The technique may need to be further developed to reflect changes in the soil density around the seed groove. Still another possibility would be to add a separate tracer to fertilizer sown with the openers so that both seed and fertilizer placement might be determined.

In conclusion, the X-ray technique developed had the ablity to examine three dimensional seed placement in the soil by direct drilling openers. This technique will permit a new area of research into direct drilling opener design to be undertaken, centering on those factors which affect seed placement in the soil.

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APPENDICES

Appendix 1: Computer program to caluate the average depth, average width, and average in-row spacing along with the standard error of each for each soil block taken.*

```
100 REM TO CALUATE CORRINATES OF SEEDS IN SOIL IF GIVEN CORRINATES
X,Y,Z ON THE X-RAY FILM
110 REM X-RAY FOCAL LENGTH SET AT 1000 MM
115 REM DISTANCE BETWEEM X-RAY SOURCES FOR X-RAY STEREO TECHNIQUE
360 MM
120 REM PROGRAM TO CALUATE THE AVERAGE DEPTH, WIDTH AND IN-ROW
SPACING ALONG WITH THE STANDARD ERROR OF EACH
151 DIM X (50)
152 DIM W1 (50)
155 DIM W (50)
156 DIM L (50)
160 INPUT "DATAFILE ",A$
165 REM THE DATA LINE FOR EACH SEED CONTAINS THE VALUES:  PLOT
NUMBER, X,Y,Z SEED; AND X,Y,Z FOR THE SURFACE REFERENCE OF THAT
SEED (7 VALUES).  VALUES ARE SEPERATED BY COMMAS.
170 INPUT "OUT PUT FILE ",B$
180 PRINT A$,B$
190 DEFINE FILE #1 =A$
200 DEFINE FILE #2 =B$
210 A1$=" #######  #######  #######  #######  #######  #######
#######  #######"
220 WRITE #2 USING A1$,"PLOT #","# SEED","AV DEP","AV WID","AV
INR","SE DEP","SE WID","SE INR"
235 J=1
240 K=1
250 K1=2
255 REM P IS THE PLOT NUMBER
260 READ #1,P
265 REM 999 IS THE END OF THE DATA FILE
270 IF P=999 THEN GO TO 530
275 REM CORRINATES FOR SEED AND REFERENCE READ BELOW
280 READ * #1,X(K);Y(K);W(K);X(K1);Y(K1);W(K1)
290 IF J=1 THEN R=P
300 IF P IS NOT EQUIL TO R  GO TO 530
310 FOR I= 1 TO 2
315 REM PROCEDURE FOR CALUATEING THE CORRECTED X,Y,Z CORRINATES
FOR THE SEED AND REFERENCE MARKER
320 Z(I)=W(I)
321 C1=1000
322 REM C1 IS THE X-RAY FOCAL DISTANCE
323 C2=360
330 REM C2 IS THE DISTANCE BETWEEN THE X-RAY SOURCES IN THE STEREO
TECHNIQUE
335 REM IF THE X-RAY IN TWO PLANES IS USED INSTEAD OF THE STEREO
TECHNIQUE ADD THE FOLLOWING LINE TO THIS PROGRAM -339 GO TO 350
340 Z(I)=(C1*W(I))/(C2+W(I))
350 N7(I)=Y(I)*C1-Z(I))/C1
360 N8(I)=X(I)*C1-Z(I))/C1
380 NEXT I
390 REM PROCEDURE FOR CALUATING THE AVERAGES OF DEPTH, WIDTH AND
IN-ROW SPACING
```

```
391 L(J)=N8(I)
392 W1(J)=Z(1)
400 D5=N7(2)-N7(1)
410 D1=D1+D5
420 W1=W1+Z(1)
430 D2=D1/J
440 D3=D3+D5*D5
450 W2=W1/J
460 IF J=1 THEN GO TO 480
465 REM PROCEDURE FOR CALUATING THE STANDARD ERROR OF DEPTH FOR
EACH BLOCK
470 S1= SQR ((D3-D1*D1/J)/(J-1))
480 J1=J
490 P1=P
500 J=J+1
510 A$="#######   ####.##   ####.##   ####.##   ####.##   ####.##
####.##  ####.##"
520 GO TO 260
530 FOR I =1 TO J1
535 REM PROCEDURE FOR CALUATING THE STANDARD ERROR OF IN-ROW
SPACING FOR EACH BLOCK
540 IF I=J1 GOTO 590
550 L1= (L(I+1)-L(I))
560 L2= L2+L1
570 L3= L3+L1*L1
575 L4= L2/(J1-1)
580 S2= SQR((L3-((L2*L2)/(J1))/(J1-1))
590 NEXT I
600 FOR I=1 TO J1
605 REM PROCEDURE FOR CALUATING THE STANDARD ERROR OF WIDTH FOR
EACH BLOCK
610 W3=(W2-W1(I))
620 W4=W4+W3
630 W5=W5+W3*W3
640 S3= SQR((W5+W4*W4/(J1))/(J1-1))
650 NEXT I
660 WRITE #2 USING A$,P1,J1,D2,W2,L4,S1,S2,S3
665 REM VALUES OF PLOT #, # OF SEEDS, AVERAGE DEPTH, WIDTH, AND IN
-ROW SPACING ALONG WITH THE STANDARD ERROR OF EACH ARE WRITTEN TO
THE OUTPUT FILE
670 D1=0
680 W1=0
690 D3=0
700 W3=0
701 L2=0
702 L3=0
704 W4=0
705 W5=0
710 J=1
720 IF P= 999 GOTO 750
729 REM 999 IS THE END OF DATA VALUE
730 GO TO 290
740 CLOSE #1,2
750 STOP
```

* Program written in basic by the author.

Appendix 2: Computer program to convert the microdensitometer values from numbers to letters.*

```
      PROGRAM SEEDSCAN
      COMMON IREC (200,100)
      CHARACTER*100 IOUT
      CHARACTER*1 IRECL(772,100),ALF(27)
      CHARACTER*32 FILIN,FILOUT
      CHARACTER*28 IALF/'ABCDEFGHIJKLMNOPQRSTUVWXYZ .'/
      EQUIVALENCE (IREC,IRECL),(IALF,ALF)
      IOBUFFER = 2000
      WRITE (1,100)
  100 FORMAT("ENTER NAME OF INPUT FILE')
      READ(1,110) FILIN
  110 FORMAT(A32)
      OPEN (10,FILE=FILIN, STATUS='OLD', FORM='UNFORMATTED')
      WRITE(1,120)
  120 FORMAT(' ENTER NAME OF OUTPUT FILE')
      READ(1,110) FILOUT
      OPEN(6,FILE=FILOUT,STATUE='NEW')
      WRITE(6,130) FILIN
  130 FORMAT(///'DATA FROM FILE   ',A32)
C
C
      JYMAX = 772
      IYMAX = 772/4
      KYMAX = JYMAX + 1
      REWIND (10)
      WRITE (1,131)
  131 FORMAT('ENTER COORDINATES OF ORGIN ')
      READ (1,*) NXO,NYO
      NXO=NXO-1

      IF (NXO.GT.0) READ(10,END=32) ((IRECL(J,I), J=1, JYMAX)
,I=1,NXO)
   30 DO 31 I = 1,100
      READ(10,END=32) (IRECL(J,I),J = 1,JYMAX)
   31 CONTINUE
   32 IL=I
      IF(IL.GE.100) IL=100
      DO 33 K = 100,IL,-1
      IOUT(K:K) =ALF(27)
   33 CONTINUE
      L = NYO
      LL = L + 99
      DO 40 I =L,JYMAX,100
      WRITE (6,300) I
      WRITE (1,300) I
  300 FORMAT(//,1H,10('#'),I5,10('#'),1H1)
      DO 41 J =L,LL
      DO 42 K =1,IL
      KK = ICHAR(IRECL(J,K))/10 +1
      IF (KK.GE.26) KK=26
      IOUT(K:K) = ALF(KK)
   42 CONTINUE
      WRITE (6,310) IOUT
```

```
 310 FORMAT(1H,A100)
  41 CONTINUE
     L=L+100
     LL=LL+100
     IF (LL.GE.JYMAX) LL = JYMAX
  40 CONTINUE
     IF(IL.GE.100) GOTO 30
     REWIND (10)
     CLOSE (10)
     STOP
     END
```

* Fortran program supplied by Mr. Brian Anderson, Chemistry Department, Massey University, Private Bag, Palmerston North, New Zealand.

Appendix 3: Computer program to locate the seed and caluate the average image intensity of each seed from the microdensitometer output file.*

```
100 REM PROGRAM TO CALUATE THE FREQUENCY OF EACH POINT FROM THE
MICRODENSITOMETER OUTPUT
110 INPUT "INPUT FILE NAME  ",C$
115 PRINT "SEED NUMBER", "TOTAL NUM OF PT.", "TOTAL INTENSITY",
"AVE.INTENSITY"
120 DEFINE FILE #1=C$
130 X$="YXWVUTSRQPONMLKJIHGFEDCBA"
140 D$="ZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZ
ZZZZZZZZZZZZZZZZZZZZZZ"
160 REWIND #1
180 READ LINE #1,A$
190 IF A$="%" GOTO 480
200 I1=I1+1
210 IF I1= 1 THEN DO
215 REM SEED NUMBER COUNTER
220 C3=C3+1
240 DO END
250 IF I1= 5 GO TO 180
255 REM COMMAND TO SKIP THE FIRST FIVE LINES OF EACH FILE AS THESE
WERE HEADER LINES
260 IF A$=D$ GO TO 330
265 REM TO SKIP LINES WITH ALL Z
270 FOR I= 1 TO LEN(A$)
275 REM PROCEDURE FOR CALUATING THE THE VALUES FOR TOTAL INTENSITY
OF EACH SEED
280 B$= MID(A$,I,1)
290 T= INDEX(X$,B$)
300 IF T 0 THEN C1=C1+1
310 T1=T1+1
320 NEXT I
330 IF A$=" " THEN DO
335 REM A BLANK LINE REPRENSENTED THE END OF A SECTION WITH A SEED
340 READ LINE #1,A$
370 IF C1=0 THEN C1=1
380 C2 =T1/C1
390 PRINT C3,C1,T1,C2
391 REM C3= NUMBER OF SEED
392 REM C1= TOTAL NUMBER OF POINTS COUNTED IN EACH SEED
393 REM T1= TOTAL INTENSITY FOR EACH SEED
394 REM C2= AVERAGE INTENSITY VALUE FOR EACH SEED
410 GO TO 440
420 DO END
430 GO TO 180
440 T1=0
450 I1=0
460 C1=0
470 GO TO 180
480 CLOSE #1
490 STOP
```

* Program written in basic by the author.

Appendix 4: Intensity values for coated soybean and barley seed (complete data).

Seed	Coating Type	Level*	Intensity readings		
			Rep 1	Rep 2	Average
Soybean	Red lead oxide	0	2.8	2.1	2.5
		1	14.8	15.1	15.0
		2	17.2	16.6	16.9
		3	17.8	18.2	18.0
	Barium sulphate	0	2.2	2.4	2.3
		1	8.7	9.5	9.1
		2	12.6	12.2	12.4
		3	13.3	15.0	14.2
	Iodine	0	2.3	1.0	1.7
		1	5.5	3.8	4.7
		2	6.0	5.9	6.0
		3	8.8	6.6	7.7
	Bariun choride	0	1.0	1.0	1.0
		1	1.0	2.6	1.8
		2	2.8	2.2	2.5
		3	1.0	2.0	1.5
Barley	Red lead oxide	0	1.4	1.5	1.5
		1	9.5	10.1	9.8
		2	14.3	13.2	13.8
		3	13.9	15.5	14.7
	Barium sulphate	0	1.2	1.5	1.4
		1	6.3	6.8	6.6
		2	9.8	7.9	8.9
		3	11.3	10.7	11.0
	Iodine	0	1.6	1.0	1.3
		1	1.0	1.0	1.0
		2	1.0	3.5	2.3
		3	4.5	1.0	2.8
	Barium cloride	0	1.0	1.0	1.0
		1	1.0	1.6	1.3
		2	1.6	1.5	1.6
		3	1.0	1.0	1.0

* Levels for red lead oxide and barium sulphate powders were 0= no coating, 1= 50% by weight, 2= 100% by weight, and 3= 150% by weight.
Levels for iodine and barium chloride liquids were 0= no soaking, 1= 1 soaking (24 hours), 2= 2 soakings (24 hours each) and 3= 3 soakings (24 hours each).

Appendix 5: Intensity values for powder coated soybean and barley using low coating levels (complete data).

Seed	Coating type	Level*	Rep 1	Rep 2	Rep 3	Average
Soybean	Red lead oxide	0	3.3	1.0	1.0	1.8
		1	7.7	9.7	8.6	8.7
		2	11.9	13.4	12.8	12.7
		3	14.1	15.4	14.7	14.7
	Barium sulphate	0	2.0	1.0	1.0	1.3
		1	8.1	5.7	6.3	6.7
		2	7.4	7.5	7.5	7.5
		3	9.6	8.3	9.1	9.0
Barley	Red lead oxide	0	2.8	1.0	1.0	1.6
		1	5.6	5.9	5.8	5.8
		2	10.5	7.9	8.7	9.0
		3	9.9	9.8	10.6	10.1
	Barium sulphate	0	1.0	1.0	1.0	1.0
		1	4.9	5.1	5.8	5.3
		2	4.8	5.7	5.7	5.4
		3	6.7	6.9	6.7	6.8

* Levels are as followes 0= no coating, 1= 10% coating by weight, 2= 30% coating by weight and 3= 50% coating by weight.

Appendix 6: Intensity values for red lead oxide coated rape seed (complete data).

Coating level	Rep 1	Rep2	Average
0%	1.0	2.0	1.5
50%	9.8	10.7	10.3
100%	13.4	12.5	13.0
150%	15.3	14.8	15.1

Appendix 7: Image clarity rating for three seed types and four soil thicknesses (complete data).

Seed type	Soil thickness (mm)	Rep 1	Rep 2	Average
Soybean	25	12	12	12
	50	10	10	10
	75	8	8	8
	100	5	6	5.5
Barley	25	11	11	11
	50	9	9	9
	75	7	7	7
	100	4	5	4.5
Rape seed	25	6	4	5
	50	3	3	3
	75	2	2	2
	100	1	1	1

Rating system used above 12 best image, 1 worst image.

Appendix 8: Image clarity ratings (1 minimun clarity, 15 maximun clarity) for each of three seed types in five soils at three moisture conditions (complete data).

Seed type	Soil* type	Moisture content	Clarity ratings		
			Rep 1	Rep 2	Average
Soybean	Sand	Dry	14	9	11.5
		Field capacity	4	7	5.5
		Saturated	1	1	1.0
	TSL	Dry	6	5	5.5
		Field capacity	8	11	9.5
		Saturated	9	8	8.5
	RPL	Dry	2	4	3.0
		Field capacity	10	10	10.0
		Saturated	3	3	3.0
	MSL	Dry	7	14	10.5
		Field capacity	5	13	9.0
		Saturated	11	2	6.5
	CAR	Dry	15	15	15.0
		Field capacity	12	12	12.0
		Saturated	13	6	9.5
Barley	Sand	Dry	4	7	5.5
		Field capacity	11	15	13.0
		Saturated	1	8	4.5
	TSL	Dry	13	4	8.5
		Field capacity	9	13	11.0
		Saturated	8	3	5.5
	RPL	Dry	6	9	7.5
		Field capacity	3	12	7.5
		Saturated	14	1	7.5
	MSL	Dry	5	10	7.5
		Field capacity	10	12	11.0
		Saturated	2	11	6.5
	CAR	Dry	15	2	8.5
		Field capacity	7	6	6.5
		Saturated	12	5	8.5
Rape seed	Sand	Dry	4	1	2.5
		Field capacity	6	13	9.5
		Saturated	1	2	1.5
	TSL	Dry	9	3	6.0
		Field capacity	12	6	9.0
		Saturated	7	8	7.5
	RPL	Dry	5	7	6.0
		Field capacity	2	9	5.5
		Saturated	8	12	10.0
	MSL	Dry	3	10	6.5
		Field capacity	14	11	12.5
		Saturated	11	4	7.5
	CAR	Dry	13	14	13.5
		Field capacity	15	15	15.0
		Saturated	10	5	7.5

* Key for soil types
Sand- Washed beach sand
TSL- "Tokomaro silt loam"
RPL- "Rongotea peat loam"
MSL- "Marton silt loam" (Subsoil with high clay content)
CAR- "Carnarvon black soil"

Appendix 9: Percent germination for each seed type as affected by amount of seed coating and X-ray radiation (complete data).

Seed type	Coating amount*	Radiation **	Percent germination Rep 1	Rep 2	Rep 3	Rep 4	Aver
Soybean	0%	None	93.3	91.8	90.0	86.0	90.3
		With soil	94.0	89.8	98.0	84.0	91.5
		No soil	94.0	86.0	96.0	90.0	91.5
	30%	None	90.0	90.0	96.0	92.0	92.0
		With soil	91.8	90.0	90.0	90.0	90.5
		No soil	94.0	91.8	94.0	92.0	93.0
	100%	None	92.0	94.0	100.0	92.0	94.5
		With soil	98.0	88.0	87.5	92.0	91.4
		No soil	89.8	88.0	88.0	92.0	89.5
Barley	0%	None	98.0	96.0	100.0	97.9	98.0
		With soil	100.0	100.0	96.0	96.0	98.0
		No soil	94.0	98.0	100.0	100.0	98.0
	30%	None	-	98.0	100.0	96.0	98.0
		With soil	100.0	100.0	96.0	100.0	99.0
		No soil	100.0	100.0	100.0	96.0	99.0
	100%	None	98.0	98.0	98.0	95.9	97.5
		With soil	96.0	100.0	98.0	100.0	98.5
		No soil	100.0	98.0	100.0	98.0	99.0
Rape seed	0%	None	95.8	97.9	96.0	93.8	95.9
		With soil	92.0	95.7	96.0	95.9	94.9
		No soil	93.6	-	81.6	93.8	89.7
	100%	None	98.0	98.0	98.0	93.9	97.0
		With soil	90.0	100.0	89.8	95.8	93.9
		No soil	91.8	95.9	100.0	92.0	94.0
	150%	None	87.5	96.0	98.0	95.9	94.4
		With soil	94.0	95.8	100.0	92.0	95.5
		No soil	95.9	92.0	95.9	93.8	94.4

Key * Coating amounts were in percent coating by weight

** Radiation treatments were seeds with no radiation, seeds radiated with soil protection and seeds radiated without soil protection.

Appendix 10: Seed positions relative to day one in the soil as given by the X-ray technique for soft and hard soil bases.

Seed type	Time	Soil type	Rep 1	Rep 2	Rep 3	Rep 4	Average
Lupin	Day2-Day1	Soft	-1.9	-2.0	1.3	0.4	-0.55
		Hard	-1.6	-2.4	0.8	2.2	-0.25
	Day3-Day1	Soft	1.7	1.8	2.1	1.1	1.68
		Hard	0.9	2.4	1.6	2.0	1.73
	Day4-Day1	Soft	2.0	0.0	2.1	0.7	1.60
		Hard	0.8	2.0	0.8	1.9	1.38
	Day5-Day1	Soft	-2.8	0.0	-5.1	-4.8	-4.23
		Hard	-1.3	-4.0	-4.8	-5.0	-3.78
Barley	Day2-Day1	Soft	0.3	1.2	-0.3	0.1	0.33
		Hard	0.7	1.0	0.0	0.0	0.43
	Day3-Day1	Soft	0.7	1.7	1.2	1.6	1.30
		Hard	1.7	1.5	0.7	1.6	1.38
	Day4-Day1	Soft	2.2	2.7	0.7	1.0	1.65
		Hard	1.5	1.7	-0.1	1.8	1.23
	Day5-Day1	Soft	-0.7	0.0	-2.6	-1.2	1.13
		Hard	-0.2	-1.0	-2.8	-1.0	-1.25
	Day6-Day1	Soft	0.3	0.5	1.2	0.6	0.65
		Hard	0.8	0.9	1.2	1.0	0.98
	Day7-Day1	Soft	1.2	1.5	-0.3	0.0	0.60
		Hard	0.0	0.9	-1.0	1.0	0.23
	Day8-Day1	Soft	-0.5	0.5	-2.0	-0.4	-0.60
		Hard	0.3	0.0	-3.8	0.0	-0.88
	Day9-Day1	Soft	1.7	2.0	0.0	0.0	0.93
		Hard	2.1	1.7	-1.8	1.3	0.83
Rape	Day2-Day1	Soft	1.2	-0.3	1.8	2.1	1.20
		Hard	0.7	1.2	1.6	2.0	1.38
	Day3-Day1	Soft	2.0	0.5	1.3	2.8	1.65
		Hard	0.1	1.4	0.8	1.9	1.05
	Day4-Day1	Soft	2.5	1.2	2.8	3.0	2.38
		Hard	3.0	0.2	2.0	1.7	1.73
	Day5-Day1	Soft	0.0	-3.2	-.-	0.0	0.75
		Hard	0.5	-2.6	-.-	-2.5	-1.15

Appendix 11: Definitions of factors possibly affecting seed placement in the soil.

Opener design may affect seed placement in the soil by: 1. The method of creating the slot, 2. the type of slot created, 3. the way the seed is placed in the slot.

Seed release velocity is the speed and direction the seed is travelling when released from the opener.

Forward speed refers to the forward speed of the opener relative to the soil.

Type of depth control refers to the mechanism which controls the penetration depth of the opener.

Time of covering refers to the time the seed is covered in the seed slot (at seeding versus a seperate operation).

Method of covering refers to the mechanism used to cover the seed after it has been placed in the seed slot.

Press wheel position refers to the point at which the press wheel acts (on the seed versus on the soil surface).

Press wheel pressure refers to the amount of pressure applied by the press wheel.

Seeding depth refers to the target depth at which the opener is set to place the seed.

Texture is the proportion of sand, silt and clay in the soil.

Structure is the way and shape the textural particles are joined to form aggregates in the soil.

Strength refers to the strength of the bonds which hold the aggregates together.

Organic matter is the amount of organic material located in the soil profile.

Surface contition refers to the smoothness of the soil surface.

Residue level refers to the amount of residue on the soil surface.

Residue type refers to the kind of residues (pasture versus straw versus stover).

Residue distribution refers to the way the residue is spread over the paddock.

The size, weight and shape of the seed is a function of the seed lot selected.

Appendix 12: Values for average sowing depth, standard error of depth, standard error of width and percent emergence for direct drilled barley (complete data).

		Seed depth in mm			
Opener* type	Speed (kmh)	Rep 1	Rep 2	Rep 3	Aver
SPTD	6	28.3	27.3	34.6	30.1
	12	20.3	28.5	31.8	26.9
WHTD	6	25.0	32.6	20.9	26.2
	12	19.0	7.8	19.8	15.5
SPHOE	6	76.8	42.8	55.7	58.4
	12	45.5	53.0	59.8	52.8
WHHOE	6	58.6	45.9	41.6	48.6
	12	42.8	31.0	39.7	37.8
SP1000	6	60.1	37.8	30.2	42.7
	12	45.9	28.0	41.4	38.4
WH1000	6	32.5	45.6	43.1	40.4
	12	31.9	32.3	31.5	31.9
SP2000	6	59.4	46.4	55.5	53.8
	12	45.3	81.1	33.0	53.1
WH1000	6	45.0	36.4	41.9	41.1
	12	44.9	43.4	31.4	39.9

		Std. err of seeding depth in mm			
Opener* type	Speed (kmh)	Rep 1	Rep 2	Rep 3	Aver
SPTD	6	8.3	12.8	1.6	7.5
	12	9.4	8.0	7.3	8.2
WHTD	6	9.3	10.6	10.0	10.0
	12	16.3	3.9	15.8	12.2
SPHOE	6	7.2	13.9	2.1	7.7
	12	5.6	6.3	11.4	7.8
WHHOE	6	3.3	3.9	4.1	3.8
	12	5.6	6.0	7.7	6.4
SP1000	6	11.3	3.6	8.2	7.7
	12	8.2	3.0	15.3	8.8
WH1000	6	3.4	4.7	2.7	3.6
	12	4.0	6.6	4.4	5.0
SP2000	6	2.1	1.2	1.9	1.7
	12	3.6	5.6	4.8	4.7
WH1000	6	4.7	4.1	5.4	4.7
	12	4.2	4.4	4.6	4.4

		Std. err. of seeding width in mm			
Opener* type	Speed (kmh)	Rep 1	Rep 2	Rep 3	Aver
SPTD	6	13.0	8.4	2.1	7.8
	12	7.5	3.9	8.7	6.7
WDTD	6	8.4	6.1	7.5	7.3
	12	4.6	5.2	11.1	7.0
SPHOE	6	4.4	10.9	4.7	6.7
	12	6.5	3.4	9.9	6.6
WHHOE	6	2.7	5.1	3.7	3.8
	12	6.8	4.5	3.9	5.1
SP1000	6	8.5	1.3	6.2	5.3
	12	6.6	7.5	13.2	9.1
WH1000	6	4.6	3.9	5.7	4.7
	12	7.1	7.6	1.4	5.4
SP2000	6	7.5	6.4	9.3	7.7
	12	6.0	11.2	4.0	7.1
WH1000	6	4.7	5.4	16.2	8.8
	12	3.2	3.9	5.1	4.1

		% seedling emergence			
Opener* type	Speed (kmh)	Rep 1	Rep 2	Rep 3	Aver
SPTD	6	94.4	83.3	80.8	86.2
	12	95.5	91.3	88.6	91.8
WHTD	6	88.1	93.8	97.9	93.3
	12	94.6	94.6	86.7	92.0
SPHOE	6	63.2	47.4	65.2	58.6
	12	88.3	83.3	85.7	85.8
WHHOE	6	88.9	69.6	88.2	82.2
	12	91.2	77.3	74.3	80.9
SP1000	6	74.3	85.3	75.7	78.4
	12	68.4	100.0	86.7	85.0
WH1000	6	97.0	66.0	83.3	82.1
	12	89.7	70.8	75.0	78.5
SP2000	6	91.2	91.7	61.5	81.5
	12	59.4	52.3	64.4	58.7
WH1000	6	93.2	87.5	97.1	92.6
	12	80.0	100.0	95.4	91.8

* Key for opener type.
SPTD Triple disc opener without depth wheels.
WHTD Triple disc opener with depth wheels.
SPHOE Hoe opener without depth wheels.
WHHOE Hoe opener with wheels.
SP1000 1000 Winged opener without wheels.
WH1000 1000 Winged opener with wheels.
SP2000 2000 Winged opener without wheels.
WH2000 2000 Winged opener with wheels.

Appendix 13: Values for average sowing depth, standard error of depth, standard error of width and percent emergence for direct drilled lupins (complete data).

Seed depth in mm

Opener* type	Speed (kmh)	Rep 1	Rep 2	Rep 3	Aver
SPTD	6	28.6	38.5	29.2	32.1
	12	-.-	-.-	-.-	-.-
WHTD	6	1.1	8.6	-.-	4.9
	12	8.3	-.-	-.-	8.3
SPHOE	6	37.8	56.9	-.-	47.4
	12	23.4	46.8	37.5	35.9
WHHOE	6	15.8	54.4	-.-	35.1
	12	-.-	41.0	35.8	38.4
SP1000	6	19.4	-.-	38.1	28.8
	12	-.-	34.9	26.5	20.5
WH1000	6	39.6	47.1	53.9	46.9
	12	40.2	32.5	-.-	36.4
SP2000	6	39.7	-.-	-.-	39.6
	12	-.-	26.2	59.6	42.9
WH1000	6	21.4	32.3	-.-	26.9
	12	30.6	-.-	-.-	30.6

Std. err. of seeding depth in mm

Opener* type	Speed (kmh)	Rep 1	Rep 2	Rep 3	Aver
SPTD	6	6.0	5.6	8.0	6.5
	12	-.-	-.-	-.-	-.-
WHTD	6	3.2	17.0	-.-	10.1
	12	10.9	-.-	-.-	10.9
SPHOE	6	4.0	4.9	-.-	4.5
	12	6.1	3.3	17.3	8.9
WHHOE	6	5.9	4.0	-.-	5.0
	12	-.-	3.4	4.1	3.8
SP1000	6	4.9	-.-	8.3	6.6
	12	-.-	8.0	9.4	8.7
WH1000	6	6.0	5.1	6.4	5.8
	12	2.8	7.7	-.-	5.3
SP2000	6	4.2	-.-	-.-	4.2
	12	-.-	10.9	1.1	6.0
WH1000	6	3.8	3.2	-.-	3.5
	12	2.0	-.-	-.-	2.0

		Std. err. of seeding width in mm			
Opener* type	Speed (kmh)	Rep 1	Rep 2	Rep 3	Aver
SPTD	6	7.4	1.9	4.3	4.5
	12	-.-	-.-	-.-	-.-
WHTD	6	2.1	2.0	-.-	2.1
	12	3.2	-.-	-.-	3.2
SPHOE	6	2.0	4.9	-.-	3.5
	12	8.5	6.8	8.0	7.8
WHHOE	6	5.4	4.3	-.-	4.9
	12	-.-	3.2	2.6	2.9
SP1000	6	1.9	-.-	7.6	4.8
	12	-.-	13.0	9.0	11.0
WH1000	6	4.5	4.0	6.2	4.9
	12	4.2	6.5	-.-	5.4
SP2000	6	5.9	-.-	-.-	5.9
	12	-.-	3.5	6.9	5.2
WH1000	6	6.0	7.1	-.-	6.6
	12	6.1	-.-	-.-	6.1

		% seedling emergence			
Opener* type	Speed (kmh)	Rep 1	Rep 2	Rep 3	Aver
SPTD	6	78.3	85.7	88.9	84.3
	12	75.0	100.0	100.0	91.7
WHTD	6	80.0	92.0	100.0	90.7
	12	75.0	87.5	100.0	87.5
SPHOE	6	72.2	89.7	84.0	82.0
	12	90.9	80.0	100.0	90.2
WHHOE	6	90.9	84.6	96.4	90.6
	12	85.7	86.1	100.0	90.6
SP1000	6	90.5	75.0	89.5	85.0
	12	90.9	85.0	75.0	83.6
WH1000	6	76.9	85.0	85.7	82.5
	12	83.3	87.5	90.0	86.9
SP2000	6	44.4	46.2	56.3	49.0
	12	72.7	66.7	66.7	68.7
WH1000	6	77.8	78.6	78.3	78.2
	12	90.0	75.0	84.6	83.2

* Key for opener type.
SPTD Triple disc opener without depth wheels.
WHTD Triple disc opener with depth wheels.
SPHOE Hoe opener without depth wheels.
WHHOE Hoe opener with wheels.
SP1000 1000 Winged opener without wheels.
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SP2000 2000 Winged opener without wheels.
WH2000 2000 Winged opener with wheels.