THE REQUIREMENTS OF DRY FERTILIZER PLACEMENT IN DIRECT DRILLED CROPS BY IMPROVED CHISEL COULTER

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ABSTRACT

This study was conducted to evaluate the effects of dry fertiliser placement as a function of design criteria for direct drills.

The study was conducted in three parts.

1. Rectangular turf blocks (140 x 140 x 200 mm) of undisturbed soil were taken from a Tokomaru concretionery silt loam soil, site of permanent pasture. Seed and fertiliser placement was achieved by removing 2.5 mm diameter soil cores at 20% (d.b.) soil moisture content. Ammonium sulphate (21-0-0) was applied at the rate of 60 kg N ha^{-1}. It was either mixed with rape seed (*Brassica napus* L. c. Tower) or separated from the seed by 10 or 20 mm of soil, horizontally or vertically. A control treatment had no fertiliser. Where seed and fertiliser were mixed or separated vertically by a 10 mm soil core, seedling emergence was reduced significantly ($P < 0.01$) compared to control. Where separated horizontally by either 10 or 20 mm of soil, or vertically by 20 mm of soil, emergence counts were similar to no fertiliser placement. Initiation of emergence was significantly ($P < 0.05$) more rapid with 20 mm separation than with only 10 mm or no separation (mixed) of seed and fertiliser. Maximum seedling emergence counts were significantly ($P < 0.05$) delayed when seed and fertiliser were either mixed or horizontally separated by 10 mm or vertically separated by 10 or 20 mm. Horizontal separation of fertilizer by 20 mm from seed produced significantly more height, weight and total yield than the mixed or 10 mm placements, harvested 5 weeks after sowing ($P < 0.05$).

2. An improved chisel coulter was used for drilling rape seed with simultaneous fertiliser placement in cultivated and uncultivated Tokomaru silt loam soil under field conditions. Ammonium sulphate (75kg-N ha^{-1}) was placed along with the seed, horizontally separated by 20mm of soil. Significantly greater plant populations ($P < 0.01$) were obtained with direct drilled plots compared to plots cultivated a week before drilling. This trend was more pronounced at lower soil moistures (19-20% db) at the time of drilling than higher ones (23-37%).

3. Direct drilling of large turf blocks (1.8 m x 660 mm x 200 mm) was carried out in the laboratory using both the improved chisel coulter and the modified version. The blocks were extracted from the same pasture as in 1 above. Horizontal and vertical placements of ammonium sulphate and mono-ammonium phosphate fertilisers at 20mm from the rape seed and at rates of either 30 or 60 kg-N ha^{-1} largely resulted in higher germination and fewer dead seeds compared to mixed seed and fertiliser placements. Placements of fertiliser in wet soil and horizontal placements in dry soil tended to produce higher germination percentages and fewer viable seeds. The interaction of fertiliser x placement indicated that mono-ammonium phosphate (16-9-0) mixed with rape seed was likely to cause more dead seeds than at 20mm placement.

It appears from the results of these 3 experiments that the horizontal separation of fertiliser by 20mm from rape seed was desirable from the point of view of germination, seedling emergence, initiation of emergence, delay in maximum seedling emergence and yield characteristics of plants. With this fertiliser placement arrangement plant populations in uncultivated soil were greater (up to 30%) than in cultivated soil. The improved direct drilling chisel coulter was capable of achieving this fertiliser placement objective without modification.

1 INTRODUCTION

Interest in direct drilling in many parts of the world is growing as farmers and researchers experiment with this newly discovered, but anciently principled concept. The technique offers a number of advantages over conventional tillage practices, especially in the areas of conservation of energy, time, water and soil (Phillips *et al* 1980).

Inorganic fertilisers are an essential input in modern agriculture. In conventional cultivation techniques, the fertilisers can be applied through various implements and at different times of seedbed preparation, sowing or crop establishment. The easily manipulated soil after tillage offers easy machinery penetration and thereby increases flexibility of fertiliser placement. In direct drilling fertiliser application at present is limited to surface broadcasting or mixing of fertiliser with the seed in the soil (if not in the seed hopper) during sowing.

Some surface applied fertilisers are at risk from volatilization or fixation losses and often depend on rain or irrigation water for their downward movement. There may also be preferential movement of water soluble nutrients down cracks and worm channels, thus distributing the nutrients unevenly (Scotter 1978; Kanchanasut *et al* 1978). Mixed fertiliser and seed may risk adverse effects on germination and seedling emergence (Carter 1969; Baker 1979; Olson and Dreier 1956; and Cooke 1960).

Direct drilling, on the other hand, has often resulted in accumulation of nutrients near the soil surface (Triplett and Van Doren 1969; Drew and Saker 1975; and Ketcheson 1980). The technique has given either poorer (Ketcheson 1980; Riley *et al* 1975), similar (Baeumer 1970) or increased (Triplett and Van Doren *loc cit*) yields compared to conventionally cultivated crops in response to applied fertilisers. Uncultivated soils have also been reported to be more resistant to structural damage (Hughes and Baker 1977), and have resulted in increased soil moisture, earthworm population and improved soil temperature regimes (Triplett and Van Doren 1969; Soane *et al* 1974)

Despite evidence of the positive effects of direct drilling on soil physical properties, which might or might not indirectly affect soil fertility, there have been few reported experiments to examine the relationships between different methods of applying fertiliser and seed, and plant responses in direct drilling.

At the same time the recent development of a chisel coulter with the claimed capability of placing seed and fertiliser simultaneously, (but separated by 20mm) in the soil, offered promise of greater flexibility in fertiliser application during direct drilling (Baker *et al* 1979). It was by no means clear though whether or not horizontal placement of seed and fertiliser was superior to vertical placement by the same distance, or indeed mixing of the two together. The experiments reported here were therefore conducted to explore some basic aspects of dry fertiliser placement, mainly in uncultivated soil, under semi-controlled and field conditions. The primary objective of the study was to ascertain the design criteria for simultaneous seed and fertiliser placement equipment in the direct drilling of cereals and brassicas.

2 LITERATURE REVIEW

2.1 Introduction

It is now well known that tillage is not absolutely necessary for crop production. Crops can be grown without cultivation and even without soil. Cultivation is made unnecessary by using herbicides to control unwanted weeds and grasses, thus substituting chemical energy for mechanical power widely used for tillage operations.

The terms "no-till", "no-tillage", "zero-tillage" and "chemical fallow" are commonly used in the literature. All these terms are synonomous and represent a description of the state of soil which has not been tilled. For the purposes of this text the terms "no-till", "no-tillage" will be used to describe such a soil. The term "direct drilling" as used in the text describes the drilling of seed, directly into such untilled ground where the weeds may have been pre-sprayed to reduce competition.

General aspects of direct drilling

The technique of direct drilling has been claimed to offer many advantages over conventional tillage. These have included: increased trafficability (Bakerman 1970); reduced soil erosion due to wind and water (Unger *et al* 1971); decreased water evaporation, and increased infiltration into the soil (Phillips and Young 1973); reduced investment in farm power and equipment due to reduced energy requirements (Allen *et al* 1977); and improved timing of planting and harvesting operations (Phillips and Young *loc lit*; Phillips *et al* 1980).

Bramley (1962) and Phillips *et al* (*loc cit*) considered that direct drilling also had uses in areas where conventional cultivation was difficult or impossible because of rough topography, high rainfall, erosion, stony soils or in low-lying water-logged conditions.

Crop residues, left on the surface in no-till farming, contribute to many of the advantages mentioned above. Phillips & Young (1973) stated that the residues reduced the hammering impact of raindrops, reduced the effective force of wind in dislodging dry soil particles and increased water infiltration, resulting in reduced surface run-off. In this respect they felt that the residues compared in effectiveness to that of growing weeds or plants.

Mathews (1972) considered that reduced evaporation from no-till soils may have been helped by a decrease in temperature of up to $5^{O}C$ compared with cultivated soils. Burrows & Larson (1962) found that corn stalks reduced soil temperatures as much as $4^{O}C$ at the hottest part of the day at soil depths down to 6mm. Similar temperature reductions down to a soil depth of 25mm were also reported by Phillips (1974). Lillard & Jones (1964) found $2.8^{O}C$ lower average maximum temperatures, and $2.3^{O}C$ to $3.4^{O}C$ less fluctuations between day and night averages, with little difference in daily minimum temperatures. Phillips *et al* (1980) considered that lower temperatures could be a disadvantage when they delayed spring planting in areas such as the central and northern United States, or where the soil temperature in the no-tilled soil was below the optimum temperature required for maximum plant growth. In the tropics, however they considered that lower temperatures could be advantageous, where the soil temperatures were frequently above the optimum required for maximum plant growth.

There are also several disadvantages associated with direct drilling. The populations of insects and disease producing organisms, and the resulting crop damage could be higher than in conventional cultivation practices, because of a more favourable habitat, according to Ivens (1977), Carpenter *et al*. (1978) and Phillips *et al*. (1980). These authors also stated that most pesticides used in direct drilled corn and soyabeans did not move appreciably in the environment except by soil erosion. Because soil erosion was greatly decreased by direct drilling, the authors expected less movement of pesticides compared with conventional tillage practices.

Triplett *et al* (1978) found the transport of herbicides in run-off water from direct drilled fields to be no greater than from conventionally tilled seedbeds. Some pesticides were degraded to harmless components in the soil in a shorter period of time under no-tillage than under conventional tillage (Slack *et al* 1978) Thus although more pesticides were used for direct drilling, similar or lesser pollution was expected compared to conventional tillage (Triplett *et al, loc cit*; Slack *et al, loc cit*).

The lack of suitable drills for no-tillage farming had been a major factor limiting its wider adaptation by the farming community according to Leonard & Hart (1977) and Phillips & Young (1973), but a considerable amount of research work has been carried out to overcome this problem (Allen 1977; Baker 1979; Koronka 1973; Logan & Gowman 1977).

2.2 Design requirements of direct drills

The terms "coulter" and "opener" are sometimes used in the literature to describe different components of a drill. At other times they are used synonomously. For descriptive purposes of this text the term "coulter" is used by the author to describe the assembly on a drill which creates a seed groove. In this context a "coulter" may or may not include a pre-disc in its assembly.

A seed drill is the only machine required in direct drilling; substituting for the tillage and drilling equipment commonly used for conventional cultivation and drilling practices. Because of this elevated importance of a single implement it is not surprising that some workers have suggested that the greatest factor limiting direct drilling has been the lack of a commercially available drill that would place seed properly in varying soil moisture and crop residue conditions (Phillips & Young 1973). Other workers (Logan & Gowman 1977) tested the potential of several conventional drills for direct drilling. The coulter systems they investigated included Suffolk hoe, single disc, and double disc types. The authors reported encountering the following problems:

(a) penetration into unprepared soil was difficult,

(b) blockage from trash was unacceptable, and

(c) contour following ability was inadequate.

A similar problem of penetration with a hoe coulter was earlier noticed by Taylor (1967). He modified the coulter by fitting narrow tips to improve penetration and also to minimise soil disturbance. This author found, however, that the modified hoe coulter was unable to cope with loose trash and the drill as a whole lacked in necessary weight and robustness. Thus it became clear that specialist drills were required for this exacting task, and many potential coulter types were tried. Krall *et al* (1979) evaluated several seeding methods and drills for comparison in recropping small grains. They tested various combinations of rolling coulters and furrow openers. They found that a flat (disc) coulter followed by a double disc proved to be the best combination when drilling into standing stubble. The coulter system tended to plug less and created less straw bunching. Earlier, Koronka (1973) had also noticed that this triple disc coulter was superior to disc-and-knife coulters except in stony soils. Krall *et al* concluded that in rocky soils the (disc) coulter and (following) opener must act independently to avoid stone problems.

Even the criteria for comparison of direct drills have varied amongst research workers. For example, Koronka (1973) measured;

(i) the load requirements to hold the coulter at a desired depth

(ii) tractor force required for pull, and coulter loading, and

(iii) wear characteristics on the soil working implements.

Krall *et al* (1979) used the term "performance rating" for the comparison of direct drills, based on the following criteria;

(a) soil movement rating;

(b) depth of penetration;

(c) amount of cut stubble;

(d) bunching of straw;

(e) seedling emergence;

(f) plant stand; and

(g) volunteer plants between rows.

Baker (1976) on the other hand compared the performance of direct drilling coulters in terms of seed and seedling responses under different soil moisture regimes.

Similarly a wide range of views existed regarding the design requirements of a direct drill. Phillips & Young (1973) stated that a direct drill must fulfil the following basic requirements:

(i) Be heavy enough and strong enough to plant under adverse soil conditions, and cut through previous crop residues.

(ii) Provide a narrow band of tillage for receiving the seed (50-75mm wide, 75-150mm deep).

(iii) Plant seed at different depths with an accurate control of planting depth from 25mm to 75mm.

(iv) Cover and firm soil around seed.

In drawing attention to the limitations of existing drills to perform in untilled soils, Koronka (1973) and Phillips & Young (*loc cit*) stated that direct drills had to be capable of performing in all types of soils and tillage systems. This clearly indicated to Koronka (*loc cit*) that a completely new drill with a new frame and soil working elements needed to be developed. That author further suggested special design criteria as follows:

1. Combined seed and fertiliser drill.
2. Row spacing 150 to 180mm.
3. Superior trash control and cutting ability.
4. Positive seed insertion with firm seed/soil contact.
5. Seed/soil contact to be maintained under very hard or wet soil conditions.
6. Wear of the soil working elements must not interfere with efficient trash cutting or seed deposition, or increase load requirement.
7. Long life of soil working elements under hard working conditions.

8. Good seed handling characteristics for small or large seeds at any seeding rate.
9. Good contour following by coulters.
10. Working rate at least equal to conventional drilling rates.
11. Power requirements within current tractor's range.
12. Simple operation.
13. Reasonable price.
14. Low maintenance requirements.
15. Large adjustable hopper.

Although Koronka (*loc cit*) indicated the need for a firm seed/soil contact, he did not specify the seed requirements in more detail. Baker (1976 a, b) and Choudhary (1979) laid increased emphasis on the need to recognise the importance of the soil physical environment in relation to seeds and seedlings as a basis for direct drill coulter design, rather than to rely heavily on mechanical expediency alone.

Fertiliser placement, as a design characteristic for direct drills, appears to have been one of the least considered criteria by research workers, although, Baker *et al* (1979) drew attention to the ability of an improved chisel coulter to place fertiliser horizontally separated from seed in the untilled soil.

2.3 Tillage, fertilisation and crop yields

The literature contains some confusing accounts of tillage or no-tillage as the main treatment effects on soil nutrient status. Kupers & Ellen (1970) conductrd experiments with minimum tillage, and found that soil tillage (ploughing) had a favourable effect on yield levels. Jones *et al* (1968) however observed that plant growth and yield of corn generally increased with decreasing degrees of tillage, while Triplett & Van Doren (1963) found no yield differences between direct drilled and conventionally cultivated corn. Baeumer (1970) observed lesser yields with direct drilling but concluded that the reason for yield depression in direct drilled crops was often the failure of seeding techniques and weed control. He further added that lower stand densities were caused by inadequate performance of drills.

Kupers & Ellen (*loc cit*) found that the response to nitrogen of crops sown on uncultivated soils decreased with increases in nitrogen levels. Bakerman (1970) measured the yields of potatoes on a light sandy loam; and rye on a sandy loam soil in response to both nitrogen levels and method of seedbed preparations. He found that at low nitrogen levels the yields were lower under direct drilling than in cultivated ground, but that at higher nitrogen levels yields were similar. Ketcheson (1980) found that increased nitrogen, phosphorus or potassium applications gave similar response patterns on different tillage treatments and direct drilling. Triplett *et al* (1969) observed that grain yields were higher for direct drilling than for conventional tillage at all nitrogen levels. Similarly Jones *et al* (1977) obtained larger fertiliser responses from direct drilled wheat than from where the soil had been cultivated.

Low (1972) observed that the total nitrogen content decreased in various soil types when old grassland was ploughed. The nitrogen level showed a greater drop in the first few years after ploughing than in later years. This author predicted a drop of 75% of total nitrogen after 20 years of cultivation. Gillespie (1980) also concluded that tillage resulted in reduced soil mineral nitrogen at seeding and increased leaching. He found that direct drilling conserved over 100kg of nitrogen per hectare, mainly because of reduced losses.

2.4 Effect of tillage on germination and seedling emergence

The type of tilth produced in a soil may depend on the implement. Shiekh *et al* (1978) found that different tillage implements had different effects on the emergence and subsequent yield of wheat. Comparing the mean establishment of ten cultivars of wheat in no-till and conventional tillage, Felton *et al* (1980) found lesser numbers of plants in the conventionally cultivated soil than in that which was direct drilled. McCown *et al* (1980) observed that the establishment of both maize and sorghum was more than 40% greater with direct drilling. Damour *et al* (1973) found that the seedling emergence of rape and maize was poorer after conventional cultivation than direct drilling. Plant populations of cereals on ploughed land was lower than on direct drilled or shallow time cultivated plots, and the yields were 22% lower than after direct drilling according to Cannell *et al* (1976).

The favourable response of seedling emergence to direct drilling was attributed to greater bulk density and earth worm populations found after direct drilling than after ploughing (Ellis *et al* 1977). Certainly no-tillage had resulted in improvment in soil structural stability over a three year period, according to Marston (1979). Hughes & Baker (1977) also found that a direct drilled silt loam soil was more resistant to structural damage than when it had been cultivated or rotary hoed for two seasons.

On the other hand, Triplett & Van Doren (1963) and Baeumer (1970) found that direct drilling resulted in reduced stand densities, although these did not result in yield differences. Baeumer (*loc cit*) pointed out that lower stand densities were caused by the poor performance of direct drills. This has subsequently been confirmed by Baker (1976 a, b), Choudhary & Baker (1981 a, b, c) who have demonstrated differences in seedling emergence as high as 14 fold when comparing different coulter designs. These authors also pointed out that the effects of coulter design could be expected to be more pronounced with seedling emergence than seed germination, especially in a dry soil.

2.5 Nutrient and moisture distribution in direct drilled and cultivated soils

There appears to have been limited work aimed specifically, at studying the nutrient and moisture distribution in the soil profile of no-till and conventionally cultivated soils. The distribution of nutrients under a crop of spring barley on land, which had been either ploughed or direct drilled for three years, was investigated by Drew & Saker (1975). After ploughing, concentrations of phosphate and potassium were relatively uniform down to 200mm, the approximate depth of ploughing. In contrast, the authors found that direct drilling resulted in a higher concentration of phosphate and potassium in the top 50mm and a marked decrease in the concentration of phosphate below 100mm. Similar effects have been reported by Baeumer & Bakerman (1973), Drew & Saker (1976) and Drew & Saker (1980).

Earlier, Power *et al* (1961) had concluded that the value of soil phosphate for wheat depended on water held in the soil at seeding plus rain falling between tillering and earing. These authors suggested that cultivations which altered the water holding capacity of soils might therefore have altered the value of fertilisers. Black & Siddoway (1979), Jones *et al* (1968), Tripplet *et al* (1968) and Soane *et al* (1974) found that the average soil moisture content was higher under no-till than under conventional tillage. Jones *et al* (*loc cit*) attributed the increased moisture storage in no-till to the killed sod on the soil surface, which reduced evaporation losses and aided recharge by maintaining good surface infiltration.

2.6 Nutrient movement in soil and availability to the plant roots

Barber *et al* (1963) described three principal mechanisms by which plant nutrients in the soil could reach the surface of a growing root:

(a) The root may grow to the nutrient.

(b) The nutrients may be carried to the root as a result of water absorption by the root.

(c) The nutrients may diffuse from soil to the root.

Weirsum (1962) stated that average distances over which nutrients were extracted from water-saturated soil were 2.5mm for phosphorous; 5mm for calcium, manganese and magnesium; 7.5mm for potassium and sodium; and 20mm for mobile ions. This author also mentioned that in the field only 2% to 5% of the whole volume of soil explored by roots was fully used by plants in reaching immobile nutrients.

Barber (1976) stated that the efficiency of uptake usually reported for nitrogen, phosphorus and potassium agreed closely with the distances these nutrients could diffuse to get to the plant roots (nitrogen 10mm, phosphorus 0.2mm and potassium 2mm).

Ulysses (1979) observed that the source, which referred to the carrier of the nutrient as well as the method of application, influenced nutrient availability. This author found that the volume of soil contacted by a highly soluble phosphate fertiliser was eight time that of low solubility source.

Welch *et al* (1966) reported that placement was critical with phosphorous because it was a relatively immobile nutrient. Efficiency of phosphorous utilisation was greater where the fertiliser was mixed with only a portion of soil than compared to broadcast application (Singh & Black 1964). Placement of nitrogen together with phosphorous promoted branching of the roots of maize in the fertilised volume of soil (Duncan & Ohlragge 1958).

2.7 Effect of fertiliser on germination and seedling emergence in conventionally cultivated soils

Seeds varied in their susceptibility to damage by fertilisers in the order: rape linseed oats wheat barley (Mason 1971). Germination damage from fertilisers decreased as moisture levels increased according to Smith & Woodward (1968). Carter (1967) observed a number of important differences in percentage establishment between plant species, fertilisers and rates of fertiliser application. These were summarised as follows:

(a) Ammonium sulphate was associated with the lowest percentage establishment.

(b) Fertilisers had marked delaying effects on seedling emergence.

(c) Fertilisers caused slower rates of seedling growth and death of young embryos.

(d) Crucifers were most sensitive, legumes intermediate and grasses and cereals least sensitive to fertilisers.

Seed germination and seedling establishment could also be greatly reduced, particularly by nitrogenous fertilisers banded with the seed (Olson & Dreier 1956; Brage *et al* 1960; Chapin & Smith 1960). Phosphate sources such as superphosphate reduced germination and emergence of small grains (Guttay 1957), and turnips and rape (Carter 1969). Guttay (*loc cit*) observed that the severity of injury to seeds depended to a large extent on the following factors:

(i) Soil moisture content at the time of sowing.

(ii) The rate of fertiliser applied.

(iii) The components of fertiliser used.

Cooke (1960) found that with peas, beans, sugarbeet and certain vegetable crops, fertiliser in contact with the seeds often had severe negative effects on germination, early growth and final yields. Heavy applications of highly soluble fertiliser placed in contact with wheat seed prevented or delayed germination and drastically reduced emergence (Olson & Dreier 1956). Those authors concluded that nitrogen and potassium components of fertiliser were more detrimental than others. Snyder (1957) observed that on sugar-beet, for a given fertiliser rate and placement, as the soil moisture level was decreased, emergence was progressively delayed, and the percentage of emergence was lower at lower moisture levels.

2.8 Fertiliser placement in conventionally cultivated soils

The distances over which fertilisers may be accessible to the plant roots are narrow, so their placement is very critical. Fertiliser placed too far from the seed/plant may not be within its reach when needed, while fertiliser placed too close to the seed may injure young seedlings.

Cooke (1951) observed that the heavy dressings of fertiliser normally used for sugarbeet were extremely dangerous when placed either in contact or directly beneath the seed. This author found that single-band placement, 25mm to the side of seed and 75mm below the soil surface was not practicable due to drill limitations at that time. Fertiliser placed at 50mm to the side at the same level as the seed caused no damage to germination.

Nelson (1956) stated that 224 kg ha^{-1} of fertiliser in the row was frequently as effective as 448 kg ha^{-1} broadcast for increasing corn yield. Experiments at Jealott's Hill Research Station (Anon. 1966) indicated that narrow rows (9.5cm) of barley showed a greater response to combine drilling with fertiliser than when in 19cm rows. The overall response to placement in the 19cm rows was 4%, while with the narrow row drilling it was 8%.

Rich & Odland (1947) in a 3 year comparison of eight different methods of fertiliser placement, found only small variations in terms of silage corn yield. The authors observed that band application (2 bands; 50mm either side of the seed at the same depth) was as effective as plough-sole or other deep placement of either all or part of the fertiliser. However there was more rapid early growth and less weed competition from band placement. Cooke (1967) also observed a positive response of barley to band placement of ammonium sulphate, but calcium nitrate had no such effect.

Ulysses (1979) emphasised the importance of an ample supply of water-soluble phosphorous in the soil zone of germinating seeds. In this respect he stated that:

"When a seed in the presence of moisture begins to germinate, the starch grains surrounding the endosperm begin to break down and are converted to sugar to provide quick energy. During this conversion from starch to sugar, phosphorous in the form of insoluble organic compounds in the seed is converted into water soluble forms. There is competition between the young seedling and the soil for the phosphorus that nature supplies in the seed to get the young seedling off to a quick and vigourous start."

Choudhary and Gupta (1974) observed that the highest dry matter yield of maize at the jointing and tasselling stages; and the total phosphorous and fertiliser phosphorous uptake was with phosphorous applied below the seed. The next best treatment to that was where phosphorous was applied at both sides of the seed. The authors recorded the least yield, total phosphorous and fertiliser phosphorous uptake with phosphorous broadcast at the time of sowing. Ham & Caldwell (1978) found that soybean seed yield and total plant phosphorous were increased significantly by addition of phosphorous fertiliser, but found no differences amongst a number of placement treatments.

Band application of phosphorous was more effective at lower temperatures for corn (Ketcheson 1957), and clover (Robinson *et al* 1959) compared to when it was mixed with the seed. Robinson *et al* (*loc cit*) concluded that band application was particularly important:

(i) for seedlings growing during periods of lower temperatures;

(ii) for crops which made most of their growth during cold weather; and

(iii) on soils low in available phosphorous, particularly those high in phosphorous fixing capacity.

Sims & Andrew (1958) observed that where crops responded to the application of superphosphate, drilling with the seed gave the greatest yield increases. Where superphosphate was top-dressed before (Rudd 1972) or after (Smith 1967) sowing, the nearer the application was made to the time of sowing, the more closely the yield increase approached to that obtained with combine drilling.

Proliferation of a barley root segment greatly increased, when it was exposed to a high phosphorous concentration (Drew & Saker 1978). Roots of flax and wheat in contrast to that of rape, did not proliferate extensively around pellets of phosphorous fertiliser (Strong & Soper 1973). On the other hand, Aboulroos & Nielsen (1979) observed a high correlation between root density and phosphorous recovery but fineness and density of barley roots did not increase in the phosphorous fertilised soil.

Lawton & Davis (1960) found that contact-placement of wheat seed with 5-20-20 fertiliser at the rate of 560 kg ha^{-1} was more detrimental to seedling emergence and subsequent growth than was similar placement with 5-20-0 fertiliser. These authors also observed that a compound fertiliser in a band either directly below, or 38mm to the side and 38mm below the seed was most desirable from the standpoint of emergence, growth and uptake of fertiliser phosphorous by wheat.

2.9 Fertiliser placement in direct drilling

The literature available on fertiliser placement in direct drilling appears to be very limted and unspecific, compared to data available on fertiliser placement in conventionally cultivated soils. Jeater (1966) observed no differences in direct drilled barley yield between combine drilled and broadcast fertiliser applications. Cornish & Fettel (1977) concluded that direct drilling would not increase phosphorous fertiliser requirements of young wheat plants, because of high mechanical resistance observed in the soil due to no-tillage. Experiments in Illinois, U.S.A. (Anon. 1979) and the findings of Gard & McKibben (1973) showed that surface applied nutrients in direct drilling maintained yield levels similar to conventionally cultivated crops, despite their limited downward movement.

3 EXPERIMENTAL METHODS AND MATERIALS

3.1 Introduction

Three experiments (A, B and C) were designed to evaluate the effects of fertiliser placement on rape (*Brassica napus*) in field and laboratory conditions. Rape seed was selected because of its reported germination sensitivity to fertilisers (Mason, 1971).

Germination, seedling emergence, fresh and dry matter yields, and leaf and stem analysis for macro and micro nutrients were considered to be important parameters in relation to this study. The separate experiments were as listed below:

A. Small pot experiment

B. Field experiment

C. Large bin experiment

Experiments A and C were conducted in a Tokomaru concretionary silt loam soil in controlled climatic conditions. Experiments B used a Tokomaru silt loam soil in field conditions.

Different experimental techniques were used in each experiment in an attempt to answer specific questions related to the main objective, having regard to limitations imposed by facilities and time. The experimental methods and materials are described separately for each experiment as follows.

3.2 A. <u>Small Pot Experiment</u>

3.2.1 Experimental design and layout

A complete randomised plot design, with six treatments and three replicates was selected, because apparently there were no identifiable sources of variation among the experimental units other than treatment effects. The treatments were as follows:

1. Seed sown without fertiliser (0)
2. Seed mixed and sown with fertiliser (M)
3. Seed sown simultaneously, but horizontally separated from the fertiliser by 10mm (H_1).
4. Seed sown simultaneously, but horizontally separated from the fertiliser by 20mm (H_2).
5. Seed sown simultaneously but vertically separated from the fertiliser by 10mm (V_1).
6. Seed sown simultaneously but vertically separated from the fertiliser by 20mm (V_2).

The plot layout was as shown on Fig. 1.

2.2.2 Collection of undisturbed small soil blocks

Rectangular soil blocks of 140x 140mm and 200mm depth were extracted from a pasture covered field with a knife and spade. Each soil block was placed inside a plastic pot of 150x 150x 200mm size. Soil moisture at the time of extraction was 50% on a dry weight basis (50% d.b.).at 25^{o}C.

The pots were transported to a glasshouse and dried to 30% m.c. at 25^{o}C. Vegetation from the pots was removed with hand clippers, cutting as close to the soil surface as practicable.

Fig. 1. Plot layout of small pot experiment. Each plot is a separate unit, consisting of a pot of surface dimensions 150mm x 150mm.

1 R_1 V_1	2 R_3 V_1	3 R_3 H_2
4 R_2 H_1	5 R_1 0	6 R_3 M
7 R_1 M	8 R_1 H_1	9 R_3 0
10 R_2 V_1	11 R_2 M	12 R_1 H_2
13 R_2 0	14 R_2 V_2	15 R_2 H_2
16 R_3 H_1	17 R_1 V_2	18 R_3 V_2

3.2.3 "Pre-drilling" treatment of pots

The pots were sprayed with equal volumes of Paraquat and Dicamba at the rate of 6 litres in 300 litres of water per hectare (2% solution) to suppress any weed growth on the soil surface.

An aluminium plate of 0.5mm thickness and 120mm dia. was perforated with 20 holes of 3.5mm dia. at each of 30, 40 and 50mm radii from the centre, (Fig. 2). An additional hole at the centre, and three smaller diameter holes were drilled for marking and locating the plate on the soil surface during "drilling"*.

Copper tubes of 2.5mm i.d. and 3mm o.d. were sharpened on the outer leading edges with a round file. Copper washers of 3.2mm i.d. and 6mm o.d. were welded near the leading edges in order to control the depth of the holes in soil, formed by pushing in the sharpened tubes.

One of the tubes was used to fix the plate in the soil through a specially predrilled hole. A copper wire of 2mm dia. was inserted inside the tube from the top end to the washer, in order to reinforce the tube strength and to assist with subsequent removal of the soil core by pushing it out after extraction. A loop was fashioned at the outer end of the wire to facilitate handling.

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* As seeds were in fact placed in small holes rather than by the more accepted definition of drilling involving creation of a continuous seed slot, the word "drilling" is used here in a broad context.

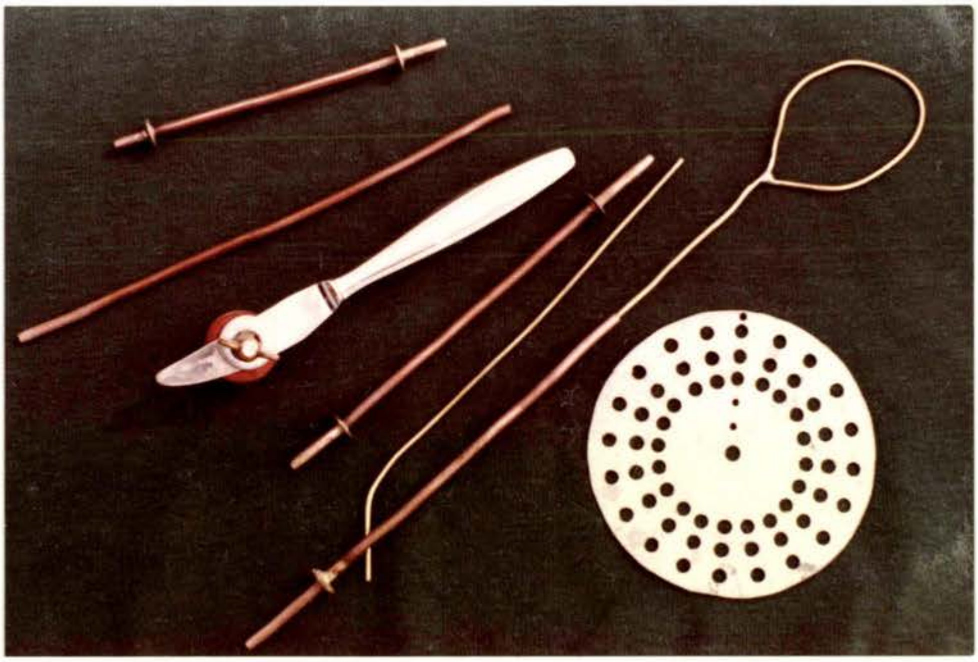


Fig. 2 Tools designed and used in small pot experiment.

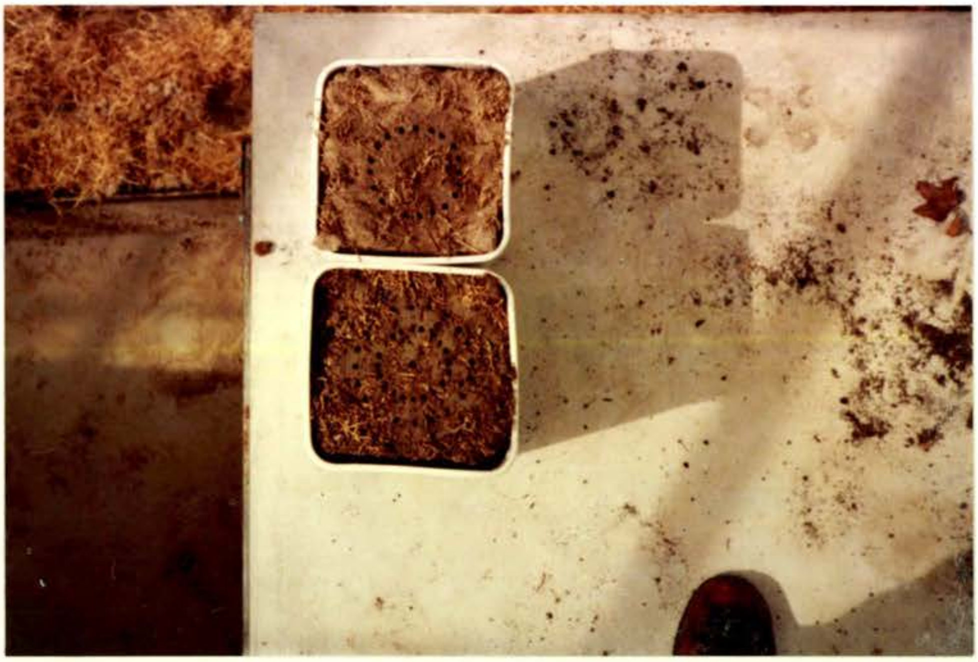


Fig. 3 A typical view of the pattern of holes drilled for horizontal placements (front pot) and vertical or mixed placements (top rear pot).

Twenty equidistant holes at 40mm radius were drilled in each plot for placement of seed except for the H_2 treatment, where horizontal placement of fertiliser was required at 20mm from the seed. In H_2 plots the seed holes were drilled at 30mm radius, and the fertiliser holes at 50mm radius as shown in Fig. 3.

3.2.4 "Drilling" of plots

After pre "drilling" treatments, the pots were kept in a glasshouse at 20^{0}C for air drying to 20% m.c. During the drying process some holes were completely or partially filled by either earthworm activity or soil contraction or both (Fig. 4). Such holes were re-cleared at the same locations (Fig. 5) just prior to seed and fertiliser placement. In the separated placements (H_1 and H_2) the seed was placed in the outer circle holes while the fertiliser was placed in the inner circle holes.

3.2.5 Placement of seed and fertiliser

Rape seeds of variety "Tower", having 86% germination (tested in the Seed Technology Laboratory Massey University) were placed with a forcep; one seed to each hole; twenty seeds to each plot of 0, M, H_1 and H_2 treatments. Ammonium Sulphate (21-0-0) granules (which were sieved to a uniform granule size of 0.686 to 1.270mm) were placed at the rate of 60 kg -N ha^{-1} in all the treatment holes except 0 (no fertiliser). In plots V_1 and V_2 a pre-cut soil core of appropriate length was placed above the fertiliser, followed by a seed in each hole. All the plot holes were then filled with loose soil extracted from a spare pot reserved for this purpose. No post-drilling soil pressure was applied. After the "drilling" and covering of the seeds, the pots were placed in a glasshouse at 20^{o}C.

3.2.6 Counts of seedling emergence, irrigation and harvest

Daily counts of seedling emergence were recorded for one month after "drilling". Negligible additional emergence occurred after 3 weeks, so the pots were then irrigated to field capacity. A final count of plants established was made on day 37 after drilling, and the crop was harvested the same day. The plants were cut individually at the soil surface with a pair of scissors. The numbers of leaves and height of each plant harvested were measured. All the plants from each plot were weighed together for fresh yield, dried in an oven at 80^{o}C and were again weighed for drymatter yield.

Fig. 4 The filling of "pre-drilled" holes and earthworm activity. Some holes have completely disappeared.

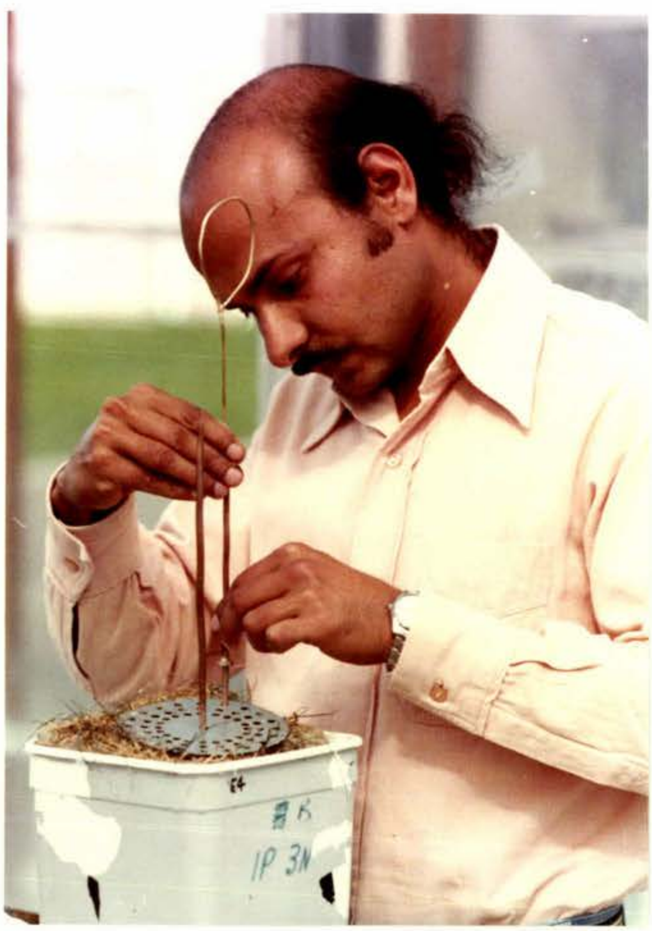


Fig. 5 "Pre-drilling" and clearing of the holes.

3.3 B. Field Experiment

3.3.1 Experimental design and layout

The trials were conducted in a Tokomaru silt loam soil from which a barley crop had been recently harvested. The field, had been in green feed oats and barley in the preceding years.

A randomised complete block design was used for two drillings and seven time-of-sowing treatments with four replicates. The times of sowing were sequential at about one week's interval beginning on 14th March 1980. The drilling treatments were as follows:

1. Seed and fertiliser horizontally separated by 20mm, drilled with the improved chisel coulter into cultivated (rotary hoed) soil.
2. Seed and fertiliser horizontally separated by 20mm, direct drilled with the improved chisel coulter into uncultivated soil.

Each plot was 0.75 meters wide and 15m long. The layout of plots is shown in Fig. 6.

3.3.2 Herbicide spray and cultivation treatment

A blanket spray of paraquat and dicamba (2% solution) was applied one week prior to the first drilling on the whole experimental area.

The cultivation treatment plots were rotary hoed one week before the respective drilling. A strip of soil 350mm wide and 15m long was twice rotary hoed with a self-propelled machine to a depth of 80mm in the centre of the plot.

Fig. 6 Plot layout of field experiment

Treatment	Plot No.	Block No.
4D	1	
3C	2	
6D	3	
5C	4	
1D	5	
2D	6	
1C	7	I
6C	8	
3D	9	
4C	10	
5D	11	
2C	12	
7D	13	
7C	14	
2C	1	
6D	2	
3C	3	
5C	4	
6C	5	
2D	6	
4D	7	II
5D	8	
1D	9	
3D	10	
7D	11	
1C	12	
7C	13	
4C	14	

Plot width: 0.75 m; plot length: 15 m

(Continued)

Treatment	Plot No.	Block No.
4C	1	
1D	2	
3C	3	
2C	4	
7D	5	
6C	6	
5C	7	III
4D	8	
6D	9	
2D	10	
3D	11	
5D	12	
1C	13	
7C	14	
1D	1	
5D	2	
2C	3	
6C	4	
5C	5	
1C	6	
4D	7	IV
2D	8	
4C	9	
7D	10	
3C	11	
6D	12	
7C	13	
3D	14	

0.75 m

15 m

C - Cultivated

D - Direct drilled

3.3.3 Drill coulter and fertiliser placement

An improved chisel coulter, developed at Massey University, was used for direct drilling, and drilling in cultivated plots. The coulter consisted of a rolling scalloped 460mm diameter disc (4mm thick) in the centre. Two detachable winged blades, hinged from the frame, were positioned on either side of the disc (Fig 7). The blades created a subsurface groove about 30mm wide as shown in Fig. 8. A pair of press wheels joined together by an axle were attached to the coulter assembly frame (Fig 9). The press wheels served to close the groove to retain moisture vapour, and to establish a positive seed soil contact. The press wheels also controlled the depth of drilling.

The coulter assembly was bolted to a testing rig, especially designed to test the coulters (Fig 10). Adjustable external forced feed mechanisms were provided for separate seed and fertiliser metering. The metering units were driven by a ground-drive spoked wheel. The test rig was fully mounted on a tractor with a conventional category one three point linkage (Fig 10).

The coulter assembly drilled seed on one side and placed fertiliser on the other side of the scalloped disc (separated by 20mm) as shown in Fig. 11. The position of seed and fertiliser in the experimental field after drilling was similar to as shown in Fig. 12.

3.3.4 Seed and fertiliser rates

Rape seed (*Brassica napus*) was drilled at a rate of 7 kg ha^{-1} at 25mm depth. Ammonium sulphate (21-0-0), at the rate of 360 kg

Fig. 7 Improved chisel coulter (side view).

Fig. 8 Cross section of a groove formed with the improved chisel coulter showing seed (right) and fertiliser (left) placement.

Fig. 9 Rear view of the press wheels and test rig, drilling in a rotary hoed plot.

Fig. 10 Test rig and tractor, direct drilling.

Fig. 11 Chisel coulter and cross section of the groove showing the separate seed and fertiliser distribution.

Fig. 12 Seed and fertiliser placement after direct drilling. The position of the small rape seed is shown with a straw beside the fertiliser, above tape.

ha^{-1} (75 kg N ha^{-1}) was placed at 20mm to the side of seed at the same depth. Before each drilling, fertiliser was dried for one hour in an over at 70^{o}C to standardize its flow characteristics. The drill was calibrated for seed and fertiliser separately before commencement of the experiment.

3.3.5 Measurement of soil moisture

After each drilling, soil samples of approximately 200 g were extracted with a core sampler to a depth of 30mm. Moisture content was measured by oven drying through gravimetric methods.

3.3.6 Plant counts and harvesting

Daily counts of plants were taken up to three weeks after each drilling. After this period changes in daily counts were negligible.

Yield harvests were taken at the flowering stage from the plots sown at the first and second drillings. The last five drillings grew very slowly due to the onset of lower winter temperatures. They were therefore not considered for harvesting.

Ten meter lengths from each plot were harvested at random with an "Allen" gasoline-powered walking-type mechanical harvester. The harvested crop was collected manually and weighed on a spring balance in the field.

A subsample of approximately 600 g weight was taken at random from the harvested crop of each plot, and was separated into leaf and stem, Leaf and stem fractions were weighed fresh and dried in an oven at 80^{o}C for 24 hours. The dried leaf and stem were weighed separately for each plot to determine the dry matter yield.

3.3.7 Chemical analysis of leaf and stem for major elements

The dried sub-samples of fractions of leaf and stem from each plot were despatched to Ruakura Agricultural Research Station for analysis. The analysis report listed the proportions of the macro and micro nutrients: N, P, K, Ca, Mg, Na, and S.

3.4 C. Large Bin Experiment

3.4.1 Experimental design and layout

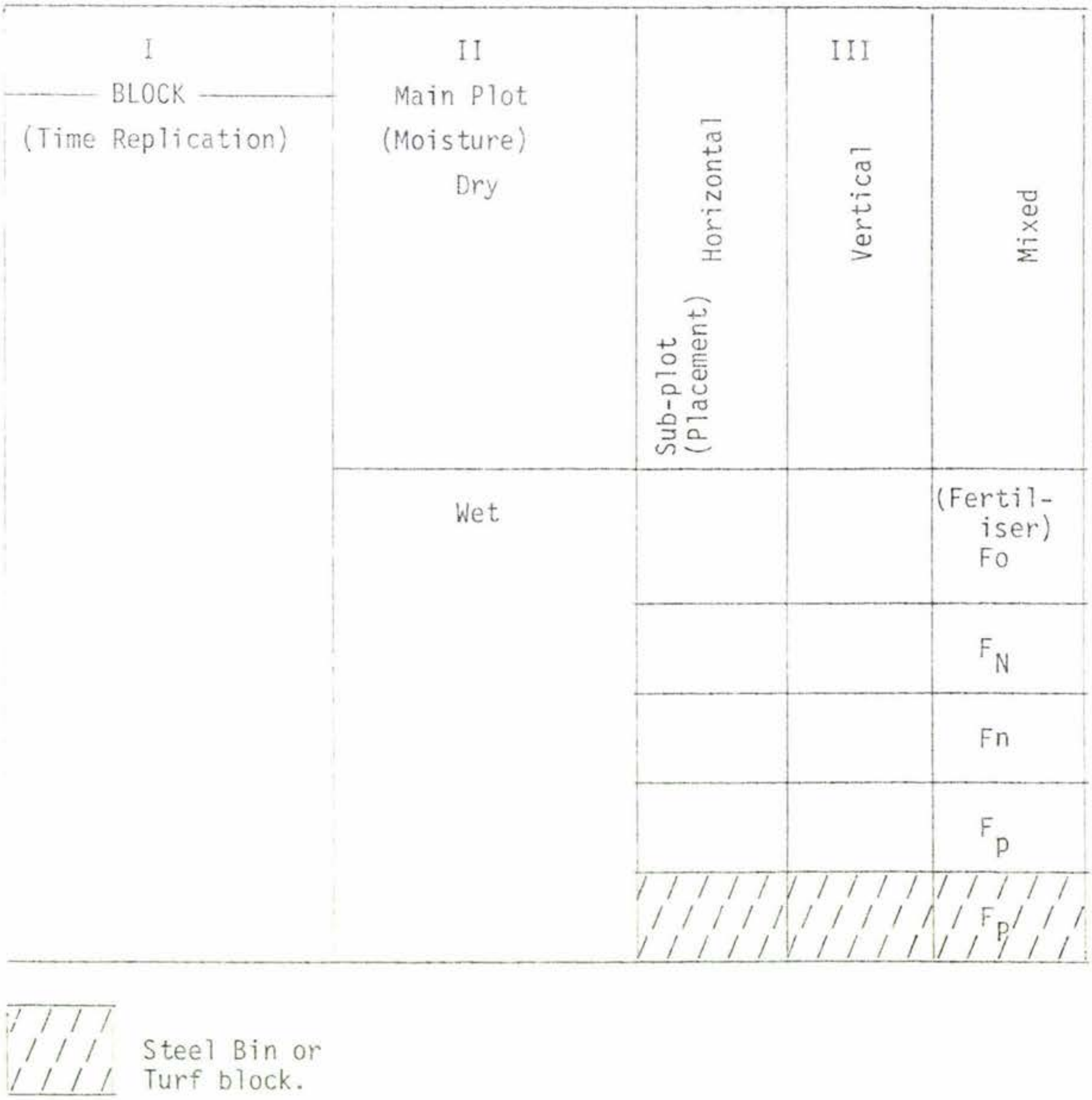
A laboratory tillage bin technique developed especially for direct drilling research (Baker 1969, 1972, 1976) was utilised. Large undisturbed soil blocks (measuring 1.8 m long, 660 mm wide and 200mm deep) were extracted from the field. These were subjected to drying conditions, and were drilled on a special support bed straddled by a tool testing apparatus. The use of such tillage bin technique allowed an effective control of soil moisture, timely seed and fertiliser drilling with reasonably accurate adjustments of rate of the seed and fertiliser. It also permitted the use of several prototype coulter arrangements to be compared with constant rates of fertiliser and seed. It allowed for more accurate control of depth and speed of drilling than possible on the field rig.

The extracted turf blocks were randomly divided into two main plots for dry (20% d.b.) and wet (30% d.b.) moisture treatments. Each main plot was given three placement treatments (sub-plot), and each of the placements had two rates of two fertilisers and zero fertiliser (sub-sub plot). Thus a split-split plot design was used. The experiment was replicated 3 times in blocks at one month intervals. The experimental layout is shown in Fig 13 and the Treatments (denoted by letters in parenthesis) were as follows:

1. Main plot; soil moisture content; two treatments, dry (D) and wet (W).
2. Sub-plot; three fertiliser placements; horizontally separated (H), vertically separated (V) and mixed (M) in relation

The experimental design and layout of the large bin experiment.

Fig. 13 (Split-Split Plot Design)



to seed.

3. Sub-sub plot; two fertilisers; ammonium sulphate and ammonium phosphate with two rates of each and zero treatment as control (Fn, F_N, Fp, F_P and Fo).

   Fn - low rate ammonium sulphate.

   F_N - high rate ammonium sulphate.

   Fp - low rate mono-ammonium phosphate.

   F_P - high rate mono-ammonium phosphate.

   Fo - seed sown without fertiliser (control).

3.4.2 Selection of site

Turf blocks were collected from a gently sloping field of Tokomaru concretionary silt loam soil, situated near the main south highway at Massey University. The field was covered with a dense pasture of rye grass (*Lolium perenne*) and white clover (*Trifolium repens*), and had not been tilled during the previous two years. The field was grazed by sheep one week before bins were extracted.

3.4.3 Collection of turf blocks

Undisturbed soil blocks were extracted from the field using a special tractor drawn cutter according to the procedure described by Baker (1976 a, b). The sites for bins were randomly selected. Uneven soil surface and tractor wheel marks were avoided. Fig 14, 15, 16 and 17 illustrate the bin collection technique.

3.4.4 Preparation of turf blocks

The turf blocks were transported to and housed behind a large glass wall in a boiler house for the first and second replicates. Because of the unavailability of this facility for the third replicate a glasshouse was used for air drying instead (Fig 18). The use of

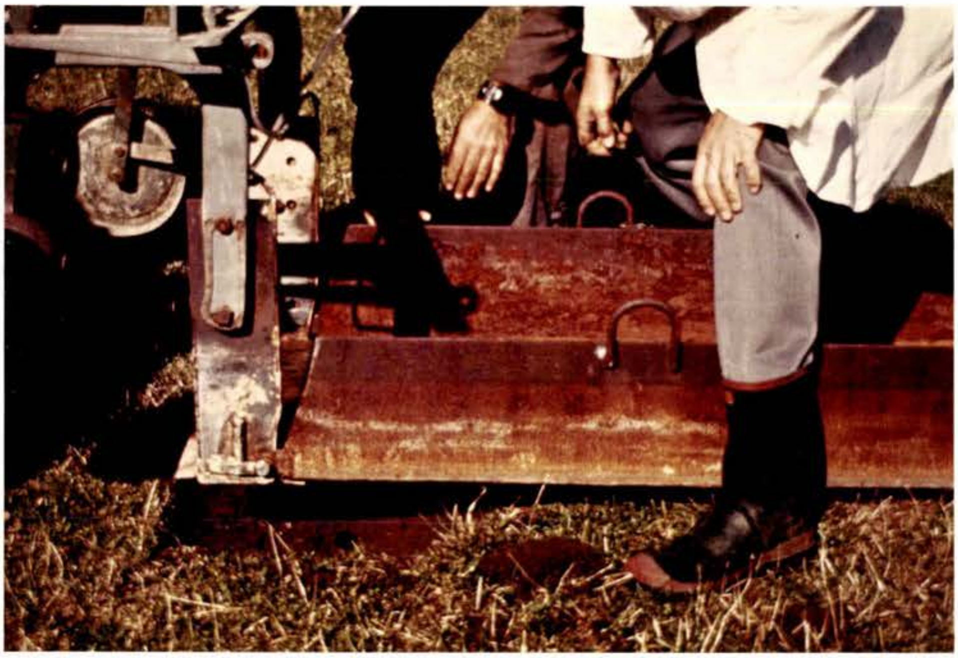


Fig. 14 Bin collection technique;

Bin is connected to turf cutter.

Fig. 15 Bin collection technique;

Initial penetration of bin into soil.

Fig. 16 Bin collection technique;
tillage bin at full depth.

Fig. 17 Bin collection technique;
tillage bin removed with a front end loader.

the boiler house and glasshouse was to dry the turf blocks to a required moisture content. Both places had similar aeration and temperature regimes and access to sunlight. It was, therefore considered that the change in drying place, particularly insofar as it was used prior to treatments being imposed, was unlikely to have effected the subsequent treatments. A specially constructed lowbed trolley was used to move the turf blocks in and out of the glasshouse (Fig 19).

The exposed ends of the turf blocks were coated with parafin wax (Fig 20) to prevent moisture loss from these areas. Thus, to all intents and purposes, the soil in the extruded bins was encouraged to behave as if it was in a field situation.

Wet and dry bins were removed from the drying areas at 32% and 21% moisture content respectively. After drying, the bins were transported to the tillage bin facility for final preparations before drilling.

3.4.5 Soil moisture measurement

Soil samples of 25mm depth were taken randomly at intervals varying from three to five days before and after drilling. The sampling utilised a 15mm long, 6.25mm diameter core sampler, described by Choudhary (1979). Care was taken while sampling that the soil was not removed from the expected rows, which in turn might have affected the drilling treatments. Soil moisture was determined by gravimatric methods with oven drying at 105^{o}C for 14 hours.

Fig. 18 Turf block samples in the glasshouse during drying.

Fig. 19 A specially constructed lowbed wheeled trolley straddling a turf block.

Fig. 20 Open end of a turf block, after coating with paraffin wax.

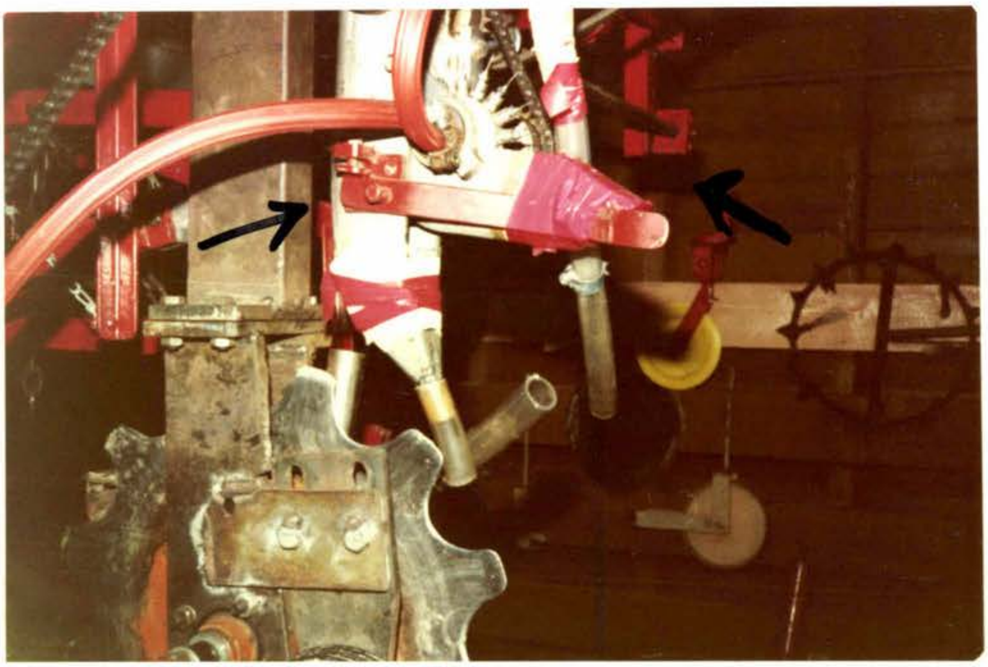


Fig. 21 Seed metering unit of the vacuum operated seeder (upper centre) on tillage bin.

3.4.6 Herbicide and pesticide application

Herbicides, paraquat and dicamba, in equal volumes were applied with a knapsack sprayer at a combined rate of 6 litres/300 litres of water ha^{-1}. The herbicides were sprayed 3-4 days before drilling.

The molluscicide Mesurol in the form of slug-snail pellets, at the rate of 10 kg ha^{-1} were hand placed in the rows after drilling to control slugs.

3.4.7 Seed and fertiliser metering

Rape seed was drilled at a rate of 10 kg ha^{-1} through a vacuum-operated seeder previously described by Baker (1976 a) and shown in Fig. 21.

Ammonium sulphate (21-0-0) was metered at the rates of 150 kg ha^{-1} (31. 5 kg - N) and 300 kg ha^{-1} (63 kg - N), and mono-ammonium phosphate (16-9-0) at the rates of 200 kg ha^{-1} (33 kg - N & 18 kg - P), and 400 kg ha^{-1} (64 kg - N & 36 kg - P). Both fertilisers were placed either with the seed, or horizontally or vertically separated from the seed.

An external forced feed fertiliser metering unit (Fig 22) was attached to the gantry of the tool testing apparatus. The fertiliser metering unit was movable in the horizontal plane within the width of each turf block and was operated by a V-belt drive. The V-belt was rotated by a rectangular shaft, which also operated the seed metering unit. It was itself driven by a rubber-tyred adjustable ground wheel, running on the steel track of the tillage bin support bed.

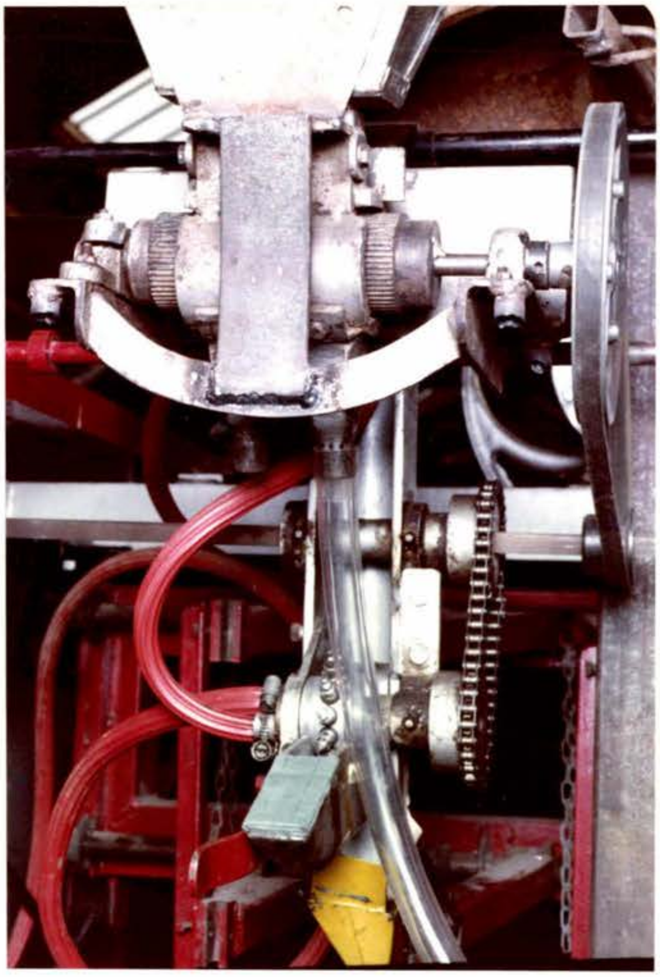


Fig. 22 An external forced feed fertiliser metering unit attached above the seed metering unit on tillage bin.

Fig. 23 Direct drilling in progress on the tillage bin, showing gantry and tool testing apparatus.

Seed and fertiliser metering units were calibrated separately before the commencement of the experiment.

3.4.8 Direct drilling of turf blocks

The turf blocks were placed end to end with polystyrene packing in between to level the surfaces on the support beds and were drilled using a gantry and tool testing apparatus (Baker, 1976 a, b) which travelled at controlled speeds along the support bed (Fig 23). Dry and wet bins were direct drilled separately in sets of two and three to avoid having to alter penetration forces for the coulter repeatedly. The turf blocks resting on the support beds are shown in Fig. 24 along with the grantry and tool testing apparatus, immediately after direct drilling three bins.

Two smaller length turf blocks were also extracted with each replicate and were placed on either end of the treatment blocks at the time of drilling. The depths of seed and fertiliser placement were adjusted in the smaller bin attached in the front. The smaller bin on the back was used to avoid any damage to the last block and for subsequent support of the gantry at the far end. Changes in fertiliser application position and rate were made with the coulter stationary at the junction between adjacent turf blocks.

Two related designs of an improved chisel coulter were used. These are described insection 3.4.8.1 to 3.4.8.3 below. One was for horizontal and mixed placement of fertiliser and seed, and the other was for vertical placement of fertiliser and seed. After direct drilling the soil flaps above the groove were gently pressed

Fig. 24 The turf blocks resting on the support beds after direct drilling (with the gantry at the far end of its travel).

Fig. 25 A top view of the groove formed by the improved chisel coulter, seed and fertiliser are arrowed. (Note: - covering flaps of groove have not yet been pressed into place)

down by hand to encourage retention of moisture vapour in the grooves (Choudhary & Baker 1981 a, b).

3.4.8.1 Horizontal placement of fertiliser

For horizontal placement of fertiliser, the coulter assembly used was identical to that which was used in the field experiment (Fig 7). Fertiliser was horizontally separated from the seed in the soil by 20mm. A top view of an open groove is shown in Fig 25. Seed and fertiliser can be seen to be separated. The configuration of groove, disc cut and rape plants are shown in Fig 26. In this figure the overlying flaps of soil have been removed for clarity.

3.4.8.2 Seed and fertiliser, mixed placement

In the mixed placement of seed and fertiliser, one winged blade of the coulter assembly was removed and seed and fertiliser were allowed to discharge from one side of the disc only. Thus seed and fertiliser were placed together at the same depth with a single winged blade. The groove formed by this arrangement of the coulter assembly is shown in Fig 27. The soil flap has been lifted on the right hand side and plants are shown deflected to the left.

3.4.8.3 Vertical placement of fertiliser

For the vertical placement of fertiliser, the coulter was modified. Both the blades were located on the same side of the disc (Fig 28). The front blade was winged while the rear blade was longer and with no horizontal wing. It was adjustable for depth. A depth control wheel was attached on the opposite side of the blades (Fig 29).

Fig. 26 The groove configuration of horizontal placement. Soil flaps have been lifted off either side, exposing the disc cut and horizontal slice regions created by the wings on either side.

Fig. 27 (Left, Centre). The groove shape after mixed placement of seed and fertiliser. The soil flap has been lifted on the right and plants are shown deflected (arrow) towards the opposite side.

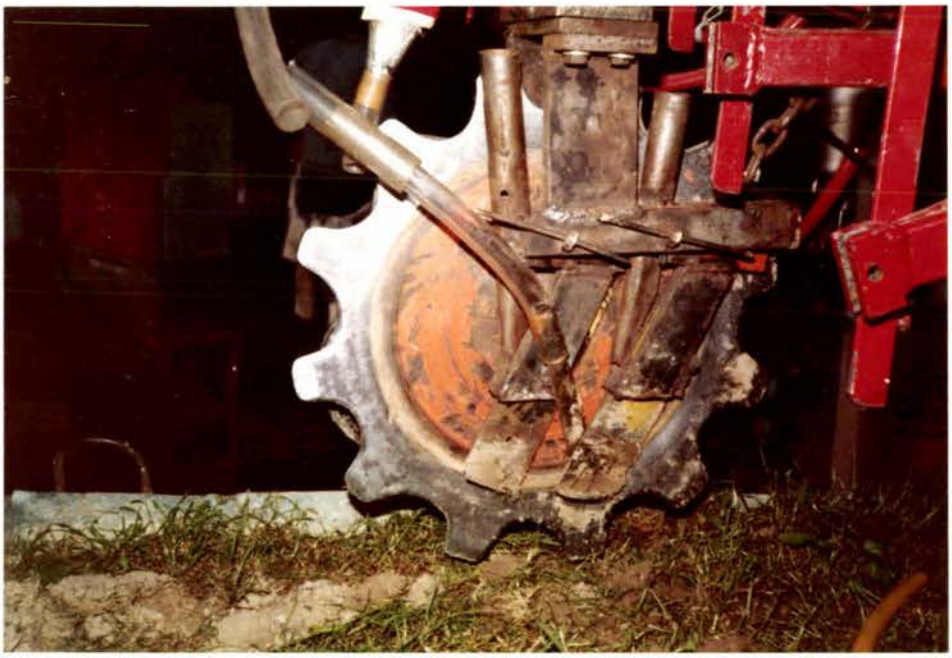


Fig. 28 A side view of the improved chisel coulter, modified for vertical fertiliser placement. Note: Seed coulter (front on right) and fertiliser coulter (rear on left).

Fig. 29 The depth control wheel attached on the modified improved chisel coulter.

Seed was placed on a small horizontal ledge by the front blade. The rear blade which followed, pressed the seed aside slightly and then dropped the fertiliser beneath as shown in Fig 30. The fertiliser position was 20mm below the seed. A side view of the modified improved chisel coulter, illustrating its action in the soil is shown in Fig 31. The appearance of the groove after plant establishment is shown in Fig 32.

3.4.9 Seedling emergence counts and germination

After direct drilling, turf blocks were placed in a glasshouse at 20^{o}C and whole plot daily counts of seedling emergence were recorded for 3 weeks. After three weeks, increases in counts were negligible.

On days 11-13 and 18-21 horizontal soil samples were randomly collected from the grooves with a 300mm long semi-cylindrical stainless steel scoop. These samples were opened by hand and examined individually for germinated and ungerminated seeds. The ungerminated seeds were tested for viability in a seed testing laboratory. After this germination test, the seeds were classified as viable or dead (including dormant, dead and injured by fertiliser). This sampling procedure was first described by Baker (1976 a). Fig 33 shows successive scoop divots left after the sampling.

Fig. 30 A cross sectional rear view of modified chisel coulter for vertical placement: Wheat seed (at 60mm level on scale) and fertiliser at 40mm level.

Fig. 31 A side view of vertical placement coulter assembly in the soil after removal of soil to expose wheat seed and fertiliser.

Fig. 32 The groove appearance and plant establishment after the vertical placement of fertiliser.

Fig. 33 (Foreground) The divots formed by the scoop sampler in the turf blocks.

3.5 Statistical Analyses of Results

The number of emerged seedlings were recorded daily over a considerable period of time. Statistical analyses were confined to weekly or other specified time intervals. All data is however included in appendices.

Statistical analyses were processed by a B6700 computer using "CANDE" through a standard "Teddybear" programme by J.B. Wilson (version 80 Oct 6, Manual 2.5).

3.6 Definitions

The following definitions are applied to the results in this text:

GERMINATION: This refers to the first sign of sprouting of seed.

SEEDLING EMERGENCE: This refers to emergence of any part of a growing plant above the soil surface, observable with the naked eye. Daily counts of seedling emergence recorded only the cumulative figure. The criterion of seedling emergence was used in the small pot and bin experiments.

PLANT COUNTS: In the field experiment a number of seedlings were apparently destroyed by unknown pests (as some emerged plant counts actually decreased with time). It was not always possible to identify the destroyed seedlings (which vanished without trace). Thus there was no positive record of plants which had disappeared. For this reason data in the field experiment are referred to as plant counts rather than seedling emergence or seedling establishment.

INITIATION OF SEEDLING EMERGENCE: This refers to the first appearance of seedlings above the surface in a plot, and is counted in days from sowing.

DELAY IN MAXIMUM SEEDLING EMERGENCE OR PLANT COUNTS: This refers to the time in days from sowing taken by the plants of a treatment to attain their maximum number.

4 RESULTS AND DISCUSSIONS

The results of each of the three experiments are discussed separately in the following sections:

4.1 A - Small Pot Experiment

4.1.1 Seedling Emergence

Results

Fig. 34 and Table 1 summarises the seedling emergence data for 37 days after drilling, as effected by the fertiliser placement.

TABLE 1 Effect of fertiliser placement on rape seedling emergence

	Treatment	Percent seedling emergence day from sowing				
		7	14	21	31	37
	Seed sown without fertiliser	75 A a	88.3 A a	88.3 A a	88.3 A a	88.3 A a
	Mixed	0 B d	31.7 B b	31.7 B b	46.7 B c	40 B c
Seed and fertiliser	Horizontally separated by 10mm	15 B cd	68.3 AB ab	68.3 AB ab	73.3 AB ab	73.3 AB a
Seed and fertiliser	Horizontally separated by 20mm	51.7 A b	66.7 AB ab	66.7 AB ab	68.3 AB abc	68.3 AB ab
Seed and fertiliser	Vertically separated by 10mm	0 B d	40 AB b	41.7 AB b	53.3 B bc	48.3 B bc
Seed and fertiliser	Vertically separated by 20mm	21.7 B c	65 AB ab	66.7 AB ab	66.7 AB abc	66.7 AB ab

Unlike letters in a column indicate significant differences (Capitals $P < 0.01$; lower case $P < 0.05$)

Rape seed sown without fertiliser produced significantly more seedling emergence on day 7 than any of the placement treatments. However at all subsequent readings the only treatment which suffered significantly in comparison with the no fertiliser treatment was where the fertiliser was either mixed with, or vertically separated from the seed by 10mm.

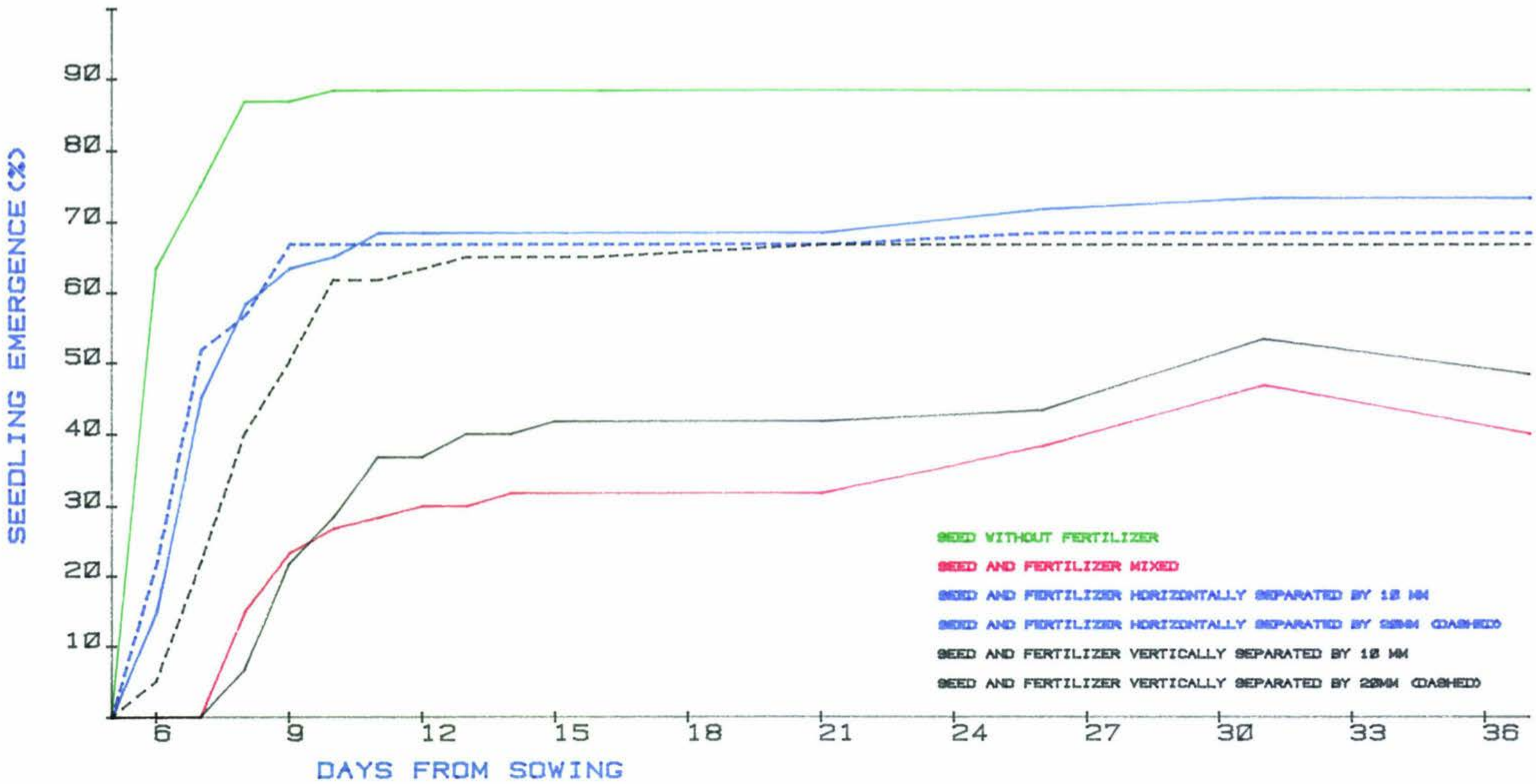


FIG 34 THE EFFECTS OF FERTILIZER PLACEMENT ON SEEDLING EMERGENCE OF RAPE

There was no seedling emergence on day 7 where the fertiliser was mixed with the seed and when the fertiliser was vertically separated by 10mm (Fig 34). At subsequent counts, while some seedling emergence occured with these treatments their maxima rose to only 46.7% and 53.3% respectively which were significantly less than all other treatment maximas (mean 74.1%).

From Fig 34 it is apparent that seedling emergence from day 14 to 21 remained almost unchanged except possibly for very minor increases in both of the vertical placements.

On day 21 all plots were irrigated. On that day the pre-irrigation seedling emergence counts showed a 57% difference between the no fertiliser treatment and the mixed treatment, and a 47% difference from vertical 10mm treatment. Following irrigation, these differences (relative to the no fertiliser treatment) were reduced to 42% and 35% respectively but as noted previously, they remained statistically significant ($P < 0.01$). Similarly most of the other fertiliser treatments were also increased in seedling emergence counts slightly by irrigation but they all remained not significantly different from each other and the control which involved no fertiliser.

Discussion

The seedling emergence data suggests that the effects of fertiliser placement were more pronounced during the earlier period of development, and also possibly, the later period, compared to the intermediate (days 13-21) period. Fig 35 and 36 illustrate the differences between treatments during the early (day 7) and intermediate

Fig. 35 Typical seedling emergence patterns on day 7.
Note: Greater number of emerged seedlings in the centre front pot (no fertiliser).

Fig. 36 Typical seedling emergence on day 13.
Mean percentages are shown.

(day 13) period. In Fig 35 it can be seen that there was no noticeable seedling emergence in any of the treatments except in the central front pot (no fertiliser). In Fig 36 relatively more plants are seen to have emerged in all the treatments as compared to Fig 35.

Fertiliser either mixed or placed with seed but vertically separated by 10mm appeared to have reduced seedling emergence because of its toxicity. Such an effect is similar to those reported by Olson and Dreier (1956), Cooke (1960) and Carter (1967) for conventionally cultivated soils.

The effect of placing fertiliser 10mm vertically beneath the seed was similar to that of the mixed treatment. Surprisingly, however, it was different from horizontal placement at the same distance from the seed. The specific cause of this difference in effect was not identified. It is possible that it may have been the result of ammonia vapour rising from the ammonium sulphate. It is also possible that during placement of seed and fertiliser a small space may have been left at the base of the hole while filling with a smaller diameter soil core or loose soil. This would have facilitated the movement of ammonia vapour to the seed, compared to the horizontal placement where the soil in between fertiliser and seed was undisturbed. On the other hand, a similar effect must have also existed with the 20mm vertical placement. Perhaps the greater distance compensated for any loose fitting of the core.

The mean effect of all fertiliser placement treatments on seedling emergence of rape, compared with the no fertiliser placement is shown in Fig 37 and Table 2.

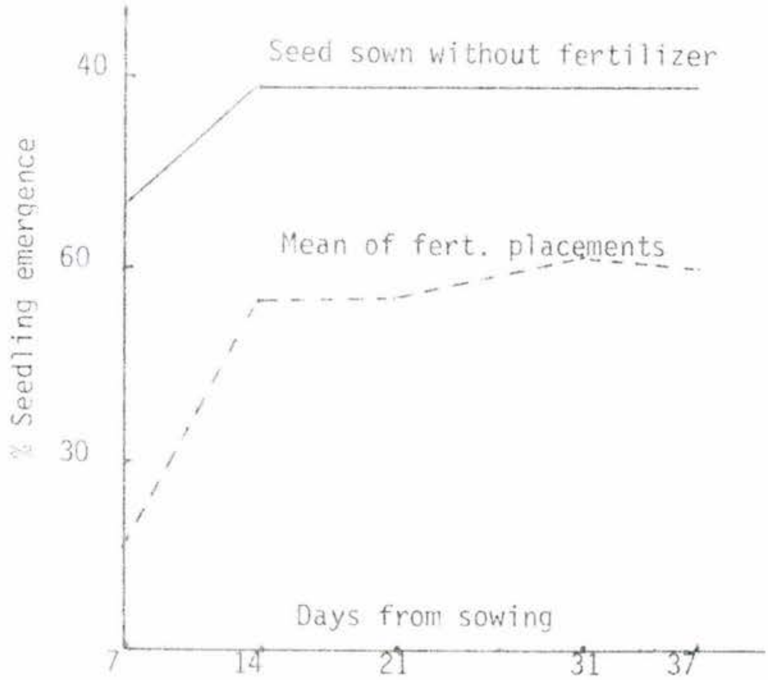


Fig 37 The effect of no fertiliser and fertiliser placement on seedling emergence of rape.

TABLE 2 The effect of fertiliser placement at drilling on rape seedling emergence

Fertiliser Treatment	day 7	14	21	31	37
Seed sown without fert.	75 **	88.3 **	88.3 **	88.3 **	88.3 **
Fert. placements (mean)	17.7	54.3	55	61.7	59.3

** Significant differences at $P < 0.01$

It is apparent from Fig 37 and Table 2 that the overall effect of placing fertiliser with the seed was to lower seedling emergence counts. These differences were highly significant ($P < 0.01$) throughout the whole sampling period.

4.1.2 Initiation of seedling emergence and maximum seedling emergence delay

Results

Table 3 lists the data of initiation of seedling emergence and maximum seedling emergence delay as effected by the fertiliser treatment.

TABLE 3 Effect of fertiliser placement on initiation and delay to reach maximum seedling emergence of rape.

Treatment	Time in days					
	To initiate seedling emergence (Control = 1)			Maximum seedling emergence delay (prior to irrigation)		
Seed sown without fertiliser	1	A	a	8.7	A	a
Mixed	3	C	bc	12	AB	c
Horizontally separated by 10mm	2.3	BC	b	11.7	AB	bc
Horizontally separated by 20mm	1	A	a	9	AB	ab
Vertically separated by 10mm	3.3	C	c	13	B	c
Vertically separated by 20mm	1.3	AB	a	11.7	AB	bc

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

It is apparent from Table 3 that the no-fertiliser treatment and both of the fertiliser placements at 20mm from seed had similar effects on the initiation of seedling emergence. They were, however, significantly ($P < 0.05$) more rapid than all of the other placement treatments.

The horizontal placement of fertiliser at 10mm from the seed was again significantly ($P < 0.05$) better than the vertical placement at the same distance, if rapid initiation of emergence is considered to be desirable. The mixed treatment and vertical separation by 10mm were the worst treatments in this respect.

The time delays for maximum seedling emergence of rape under a dry regime showed some significant differences amongst treatments. Table 3 indicates that the no-fertiliser and horizontal 20mm placements were not significantly different in the delay until reaching maximum seedling emergence. The no-fertiliser treatment achieved its maximum seedling emergence 4.3 days earlier than the slowest of the other treatments (vertical 10mm). Fig 38 further illustrates the differences in initiation and maximum seedling emergence delay between horizontal and vertical placements of fertiliser as compared to no fertiliser placement.

Discussion

From Table 3 and Fig 38 it appears that the fertiliser placements at 20mm from the seed were more rapid in initiating seedling emergence than any of the other treatments involving fertiliser placement. The delay in initiation of seedling emergence generally appeared to have increased as the distance between fertiliser and seed decreased, from 20mm to zero (mixed). The overall mean delay for horizontal placement (2.11 days) may have differed slightly from that for vertical placements (2.44 days), but this difference was significant only at the lower order of probability, $P < 0.08$.

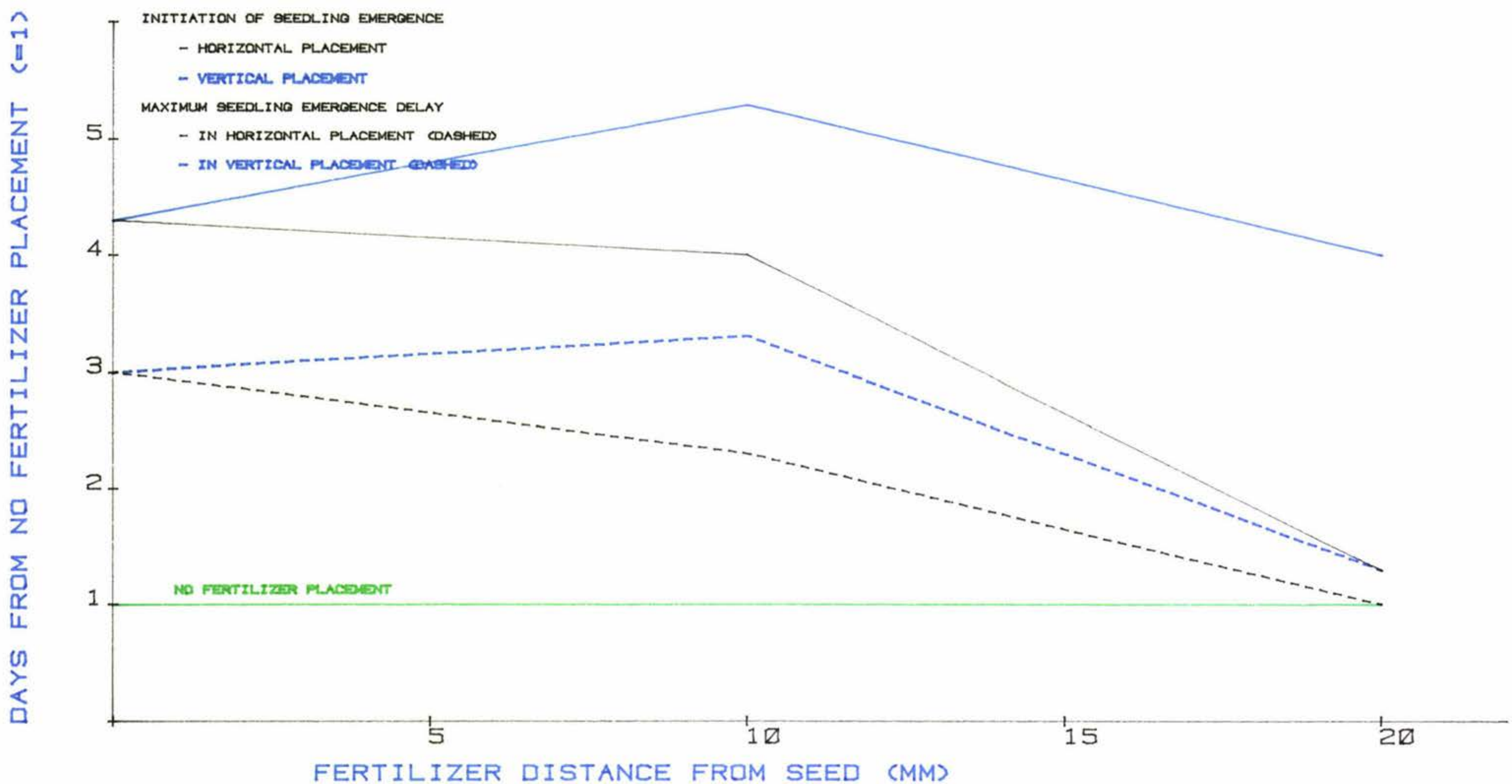


FIG 38 EFFECT OF HORIZONTAL AND VERTICAL PLACEMENT OF FERTILIZER ON INITIATION AND DELAY OF MAXIMUM SEEDLING EMERGENCE OF RAPE

The time delays until maximum seedling emergence appeared to have been affected by the fertiliser treatments in a similar manner to the delay of initiation of seedling emergence.

Although the actual counts of seedling emergence have not been taken into account in the data of initiation and maximum seedling emergence delays, it is interesting to note that both of these latter parameters did respond to the effects of fertiliser placements in a similar manner to the respective counts of seedling emergence (Sec 4.1.1).

4.1.3 Yield

Results

Table 4 and Fig 39 show the effects of fertiliser placements on rape yield at 5 weeks from sowing.

TABLE 4 The effects of fertiliser placement on yield of rape, 5 weeks after sowing

		Per plant				Total yield	
	Treatment	No. of leaves	Height (mm)	Fresh weight (gm)	Dry weight (gm)	Fresh weight (gm)	Dry weight (gm)
	Seed sown without fertiliser	4.06 ab	63 ab	0.43 ab	0.046 ab	8.2 ab	0.812 ab
Seed and fertiliser	Mixed	3.26 a	36 a	0.23 a	0.022 a	2.0 a	0.205 a
Seed and fertiliser	Horizontally separated by 10mm	3.31 ab	34 a	0.16 a	0.019 a	2.6 a	0.286 a
Seed and fertiliser	Horizontally separated by 20mm	4.31 b	71 b	0.83 b	0.080 b	11.4 b	1.065 b
Seed and fertiliser	Vertically separated by 10mm	3.27 a	38 a	0.16 a	0.025 a	2.2 a	0.264 a
Seed and fertiliser	Vertically separated by 20mm	4.21 ab	60 ab	0.50 ab	0.054 ab	7.4 ab	0.760 ab

Unlike letters in a column indicate significant differences $P < 0.05$.

From 'the Table 4' it is apparent that horizontal placement of fertiliser at 20mm from the seed produced significantly ($P < 0.05$) more height, weight and total yield than the mixed and 10mm horizontal or vertical placements. The dry matter yield per plant from the horizontally placed fertiliser at 20mm was 3 times greater than that of either of the horizontal or vertical placements at 10mm or the mixed seed and fertiliser.

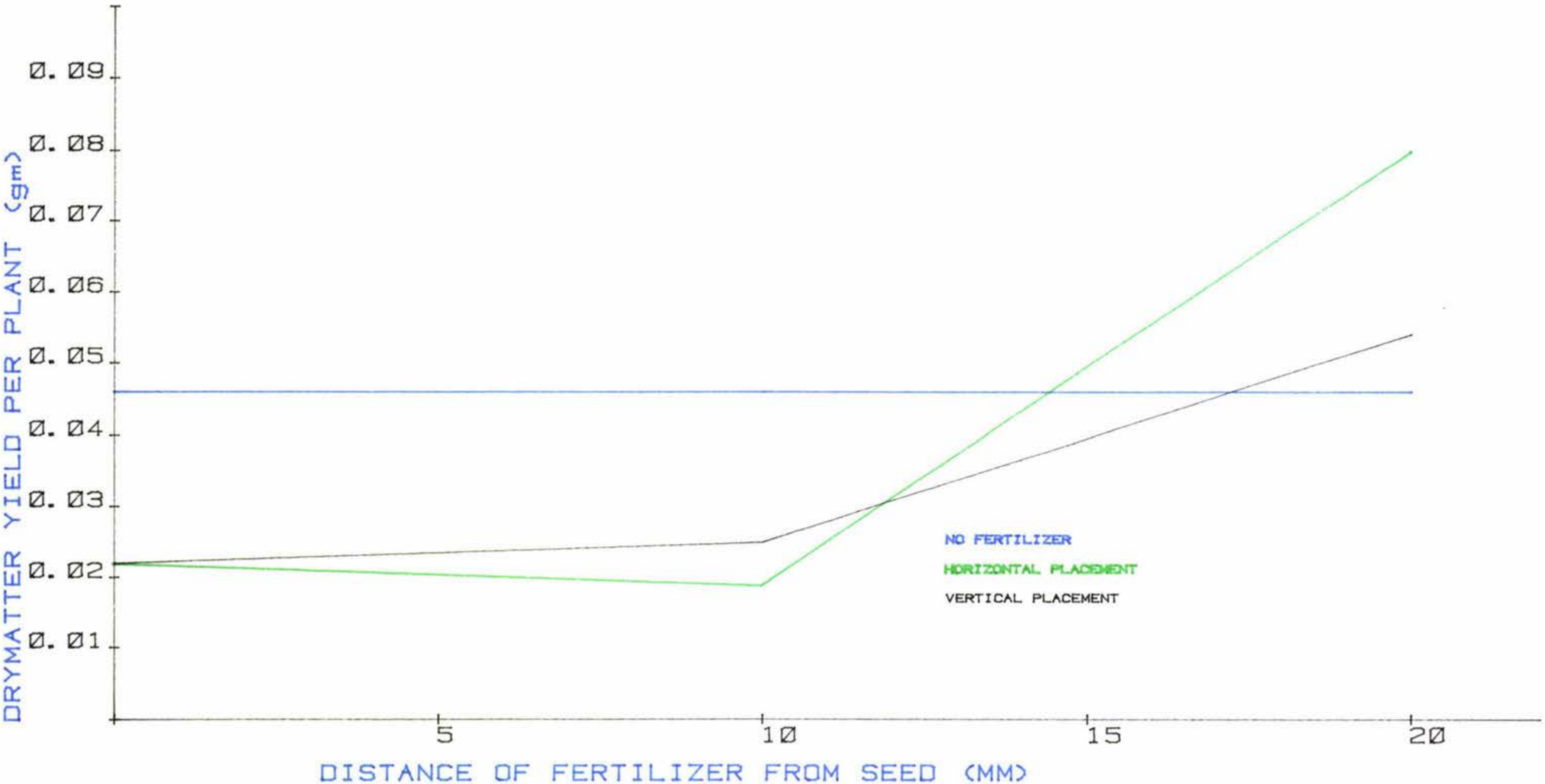


FIG 39 THE EFFECTS OF FERTILIZER PLACEMENT ON DRYMATTER YIELD OF RAPE

5 WEEKS AFTER SOWING

Discussion

The results in Table 4 and Fig 39 show that fertiliser placement at 20mm from the seed produced significant gains in yield parameters of rape compared to the mixed seed and fertiliser and in most respects to the 10mm fertiliser placements.

Early initiation of emergence and a shorter delay until maximum seedling emergence of the rape plants was reached in 20mm horizontal placement of fertiliser, which may have contributed to the superior yield. This may have provided a longer growing period than the mixed and 10mm fertiliser placements, which could have compensated for any detriment arising from the fact that the roots and/or fertiliser had further to travel to intersect each other; and from intra-specific competition amongst the larger number of seedlings present. The 20mm horizontal placement was not significantly different in growth vigour from the no-fertiliser and 20mm vertical placement of fertiliser (Fig 40) treatments, which had similar initiation and maximum seedling emergence delays. The latter however did not differ significantly in growth vigour from both of the 10mm placements and mixed placement. It is probable that in the case of the no-fertiliser treatment, a simple nutrient deficit is reflected but is difficult to explain the situation with the 20mm vertical placement. Moreover it was beyond the scope of this study to fully explain the mechanisms by which fertiliser affected growth parameters.

It is conceivable that the fertiliser effects could have been different in each case. This is not considered to be a shortcoming of the study however as the prime objective was to establish design

Fig. 40 Typical growth patterns of seedling emergence and growth.

criteria for machines rather than explain the manner in which fertiliser affects germination, germinated seeds or seedlings.

4.1.4 Summary

Rape seed sown without fertiliser produced significantly ($P < 0.05$) more seedling emergence on day 7 (from sowing) than all other treatments. At all subsequent measurements (days 14, 21, 31 and 37) the fertiliser mixed with the seed or vertically separated by 10mm suffered significantly ($P < 0.01$) in comparison with no fertiliser treatment.

Seed sown without fertiliser or separated either horizontally or vertically by 20mm, were similar in initiation of seedling emergence, but significantly ($P < 0.05$) more rapid in initiation. Mixed seed and fertiliser; horizontal or vertical separation by 10mm; or vertical separation by 20mm, significantly ($P < 0.05$) delayed the maximum seedling emergence as compared to no fertiliser treatment.

Horizontal separation of fertiliser by 20mm from seed produced significantly ($P < 0.05$) more height, weight and total yield than the mixed or horizontal or vertical placements at 10mm from the seed, harvested 5 weeks after sowing.

4.2 B. Field Experiment

The results of the field experiment are discussed in three sections:

a. Overall trends (across the 7 drillings).

b. Mean trends (across the selected drillings; numbers 1 and 2).

c. Individual results of each of the drillings 1 - 7 (this includes time-of-drilling effects).

4.2.1 Overall trends

4.2.1.1 Plant counts

Results

Table 5 and Fig 41 illustrate the effects of cultivation treatment on the plant counts of rape on days 10, 15 and 20 from sowing.

TABLE 5 Effects of cultivation treatment on plant counts of rape

Cultivation	Plant counts m^{-2} day from drilling		
Treatment	10	15	20
Cultivated	19.4	41.6	44.8
Uncultivated	25.1 *	50.7 **	55.2 **

* significantly different at $P< 0.05$

** significantly different at $P< 0.01$

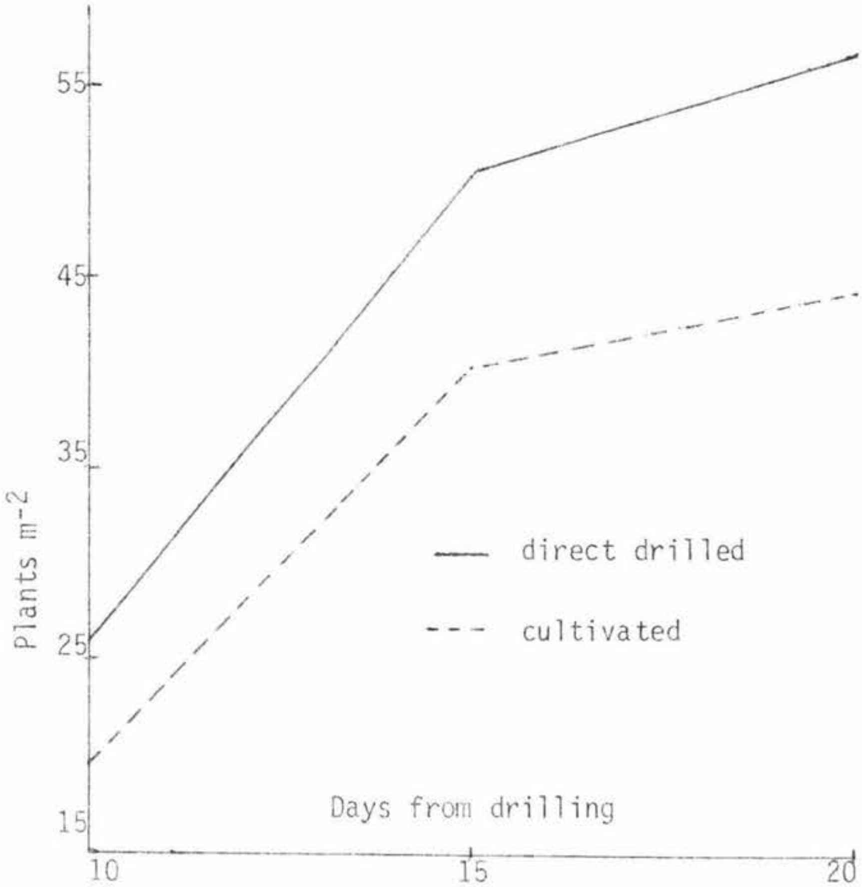


Fig 41. The effect of cultivation treatment on plant counts of rape, drilled with an improved chisel coulter.

Fertiliser was horizontally separated from seed by 20mm at the time of drilling in both of the cultivation treatments. From the table and figure it can be seen that the effects of cultivation treatments on the plant counts of rape were significant on each of the days 10 through 20. In fact the differences between the two treatments increased with time. At all samplings the number of plants counted was greater in the uncultivated soil (by up to 30%).

Discussion

The relative superiority of the uncultivated soil (in terms of plant counts) suggests, either that the fertiliser was more toxic to plant emergence in cultivated soil than in uncultivated soil, or that other features of the cultivated soil resisted emergence. Snyder (1957), Smith and Woodward (1968) found that the toxic effect of fertiliser on seedling emergence was increased with reduced soil moisture. The mean soil moisture content prior to each drilling was significantly ($P < 0.01$) lower (25.8% db) in the cultivated soil than in the uncultivated soil (27.4%). This reduction may have been partly responsible for any increased fertiliser toxicity in the cultivated soil, although at no time did the soil moisture content fall below wilting point.

Similar effects on soil moisture content in conventionally cultivated and uncultivated soils have been observed by a number of authors (Black & Siddoway 1979; Jones *et al* 1968, Triplett *et al* 1968, and Soane *et al* 1974).

4.2.1.2 Delay in maximum plant counts

Results

Table 6 lists the delays in maximum rape plant counts in cultivated and uncultivated soil.

TABLE 6 Effect of cultivation treatments on delay in maximum plant counts.

Cultivation treatment	Delay in max. plant counts (days) from sowing	
Cultivated	19.3	
Uncultivated	18.9	NS

NS: Not significantly different ($P < 0.05$).

It appears from the table that there was no significant difference between the two treatments in terms of delay in maximum plant counts.

4.2.2 Mean trends

4.2.2.1 Fresh and dry weight yield

Results

Table 7 lists the data (from number 1 and 2 drillings) of fresh and dry matter yields of rape plants harvested at the flowering stage, from the cultivated and uncultivated treatments.

TABLE 7 Effect of cultivation treatment on the fresh and dry matter yield of rape (Numbers 1 and 2 Drillings).

	Yield m^{-2}	
Cultivation Treatment	Fresh (kg)	Dry (gm)
Cultivated	4.6	583
Uncultivated	5.5 NS	670 NS

NS: Not significantly different ($P < 0.05$).

It appears from the table that there were no differences in the fresh and dry matter yields of rape attributable to the cultivated and uncultivated treatments in combination with horizontal placement of fertiliser.

Discussion

Ammonium sulphate is a water soluble nitrogenous fertiliser. The soil moisture measurements and rainfall data during the growth period of the rape crop indicate that moisture was present in ample supplies in both of the soil conditions. It is therefore not surprising that there were no significant effects on the yield (fresh and dry) of rape at flowering between the cultivation treatments. Baeumer (1970) also observed a similar response from the applied nitrogen on yield of maize and wheat in cultivated and uncultivated soils.

4.2.2.2 Major elements

Results

Table 8 lists the data of the major elements of leaves and stems of rape, as affected by the cultivation treatments when ammonium sulphate was placed 20mm horizontally from the seed during drilling (Number 1 and 2 Drillings).

TABLE 8 The effects of cultivation treatment on the major elements of rape (leaf and stem) at flowering stage (Numbers 1 and 2 Drillings)

Plant Fraction	Cultivation Treatment	Major elements % of weight						
		N	P	K	Ca	Na	Mg	S
Leaf	Cultivated	3.72	0.46	3.32	1.66	0.17	0.21	0.80
	Uncultivated	3.58	0.47	3.49	1.67	0.15	0.21	0.81
		NS	NS	NS	NS	NS	NS	NS
Stem	Cultivated	1.94	0.40	4.05	0.63	0.13	0.15	0.47
	Uncultivated	1.76	0.39	4.21	0.63	0.10	0.15	0.46
		NS	NS	NS	NS	NS	NS	NS

NS: Not significantly different ($P < 0.05$)

It is apparent from the table that neither of the cultivation treatments produced any differences in the percentage weights of major elements in plant fractions of the rape plants.

Discussion

It was earlier observed by Riley *et al* (1975) that uptake of calcium, magnesium and microelements by direct drilled and conventionally cultivated crops did not differ greatly. They reported that the concentration of phosphorus and potassium in shoots of wheat were also little effected by the method of cultivation.

Although little information concerning differences due to fertiliser placement is available in the literature, Triplett & Van Doren (1969) found that phosphorus and potassium concentration at all levels of applied nitrogen were similar in no-tillage and conventional tillage in the leaves of maize, sampled at tasseling. Similarly Ketcheson (1980) observed adequate nitrogen, phosphorous and potassium levels in corn tissue in response to nitrogen, phosphorus or potassium application in conventional cultivation and no-tillage.

4.2.2.3 Dry matter yield and drillings

Results

Table 9 lists the data of dry matter yields from the first and second drillings of the rape crop, harvested at the flowering stage from the cultivated and uncultivated soil.

TABLE 9 Effect of time of drilling and cultivation treatment on the dry matter yield of rape at flowering

Cultivation Treatment	Yield gm m^{-2} Drilling 1		Yield gm m^{-2} Drilling 2	
Cultivated	616		551	
Uncultivated	703	NS	637	NS
Mean	659	NS	594	

NS: Not significantly different ($P < 0.05$)

There appeared to be no effect on dry matter yield of rape, either from the two cultivation treatments or the two drilling times.

Discussion

It is logical to expect that the time of drilling would not effect the yield of rape unless it was associated with environmental changes (temperature, moisture etc). Moreover the time between the first and second drilling was only one week, which did not undergo sufficient environmental change to have had measurable effect on the dry matter yield of rape measured at the flowering stage.

4.2.2.4 Major elements and drillings

Results

Table 10 lists the analyses of major elements in leaves and stems of rape, as effected by the two cultivation treatments in the two drillings (number 1 and 2).

TABLE 10 The effect of time of drilling and cultivation treatment on the major elements of rape (leaf and stem) at flowering stage (Drilling Numbers 1 and 2)

Element Symbol	Cultivation Treatment	Major elements % weight LEAF Drilling time 1		LEAF Drilling time 2	STEM Drilling time 1		STEM Drilling time 2
N	C	3.66	NS	3.77	1.90	NS	1.97
	D	3.76	NS	3.39	1.71	NS	1.81
	Mean	3.71	NS	3.58	1.81	NS	1.89
P	C	0.43	NS	0.50	0.37	NS	0.43
	D	0.45	NS	0.48	0.36	NS	0.42
	Mean	0.44	*	0.49	0.37	*	0.42
K	C	3.30	NS	3.33	3.79	NS	4.31
	D	3.75	NS	3.24	4.36	NS	4.05
	Mean	3.53	NS	3.29	4.08	NS	4.18
Ca	C	1.69	NS	1.62	0.61	NS	0.66
	D	1.75	NS	1.58	0.66	NS	0.60
	Mean	1.72	NS	1.60	0.63	NS	0.63
Na	C	0.20	NS	0.14	0.14	NS	0.12
	D	0.16	NS	0.13	0.12	NS	0.09
	Mean	0.18	NS	0.14	0.13	NS	0.10
Mg	C	0.21	NS	0.21	0.15	NS	0.16
	D	0.23	NS	0.20	0.14	NS	0.15
	Mean	0.22	NS	0.21	0.14	NS	0.15
S	C	0.85	NS	0.76	0.45	NS	0.49
	D	0.82	NS	0.81	0.45	NS	0.48
	Mean	0.83	NS	0.79	0.45	NS	0.48

* Significantly different ($P < 0.05$)
NS: Not significantly different ($P < 0.05$)
C: Cultivated
D: Uncultivated

It is apparent from the table that the cultivation treatments did not effect the percentage of major elements in either leaf or stem of rape in any of the drillings. The time of drilling (one week difference between drilling 1 and 2) had no effect on the mjaor elements except phosphorus. The phosphorus percentage in both leaf and stem was significantly ($P < 0.05$) lower in the first than second drilling.

Discussion

The only difference found in the percentage of phosphorus in the two drillings may have been caused by the difference in the number of plants (counted on day 20 from sowing - Sec 4.2.3.2). There was a significantly ($P < 0.01$) greater number of plants in the second drilling than in the first drilling. This greater number of plants may have resulted in greater root and shoot competition. Leaf to stem ratio of dry weight was found greater in second drilling (1.88) than the first drilling (1.06) and this difference was highly significant ($P < 0.01$). The greater competition in drilling 2 may have caused extensive root growth. As phosphorus is a relatively immobile nutrient (Welch *et al* 1966), extensive root growth may have resulted in an increased uptake by these plants.

4.2.3 Individual results of each of the drillings 1 - 7, including time of drilling effects

4.2.3.1 Soil moisture

Results

Table 11 lists the soil moisture data at the time of the seven drillings and the effect of the cultivation treatments.

TABLE 11 Effect of time of drilling on the soil moisture content due to cultivation treatment.

Cultivation Treatment	Soil moisture (% db) Drilling time						
	1	2	3	4	5	6	7
Cultivated	17.5	25.5	38.6	29.7	21.9	16.7	34.5
Uncultivated	20.2 *	26.0 NS	35.5 NS	29.2 NS	24.7 NS	23.2 **	34.5 NS
Mean	18.8 Aa	25.7 Bb	37.0 Cc	29.4 Dd	23.3 Be	19.9 Aa	34.5 Cf

* Denotes significant differences between treatments for any one drilling at $P < 0.05$.

** Denotes significant differences at $P < 0.01$.

Unlike letters alongside means denote significant differences amongst times of drilling (capitals P 0.01; lower case letters P 0.05).

NS: Not significantly different at $P < 0.05$.

It is apparent from the table that the only significant differences in soil moisture content due to cultivation treatments were in drilling 1 and drilling 6. There were highly significant ($P < 0.01$) differences amongst the mean moisture contents at the different drilling times.

Discussion

The results indicate that only two of the seven drillings showed significant soil moisture differences which were attributable to the cultivation treatments. In both cases the soil moisture was lower in the cultivated soil than in the uncultivated soil. Both the drillings experienced the lowest soil moisture means amongst all of the drillings. This indicates that as soil moisture content was reduced the response to cultivation treatment increased. The differences found amongst the soil moisture means of the various drillings were mainly the result of random occurrence of rainfall and are therefore not surprising.

4.2.3.2 Plant count

Results

Table 12 lists the data of plant counts in the seven drillings, as affected by the cultivation treatments, when the fertiliser was placed at 20mm horizontally from the seed with the improved chisel coulter. Fig 42 - 48 illustrate the effect of cultivation treatment on the plant counts of rape for each drilling.

TABLE 12 Effect of time of drilling and cultivation treatment on plant counts of rape on day 20 from sowing.

Cultivation Treatment	No. of plants M^{-2} Drilling time						
	1	2	3	4	5	6	7
Cultivated	41.6	77.4	10.7	70.2	62.6	35.6	37.2
Uncultivated	64.8 *	86.2 NS	5.6 NS	72.2 NS	88.2 NS	59.2 *	45.1 NS
Mean	53.2 BCb	81.8 Aa	8.1 Dc	71.2 ABa	75.4 ABa	47.4 Cb	41.1 Cb

* Denotes significant differences between treatments for any one drilling at $P < 0.05$.

NS: Not significantly different at $P < 0.05$.

Unlike letters alongside means denote significant differences amongst times of drilling (capitals $P < 0.01$); lower case letters $P < 0.05$).

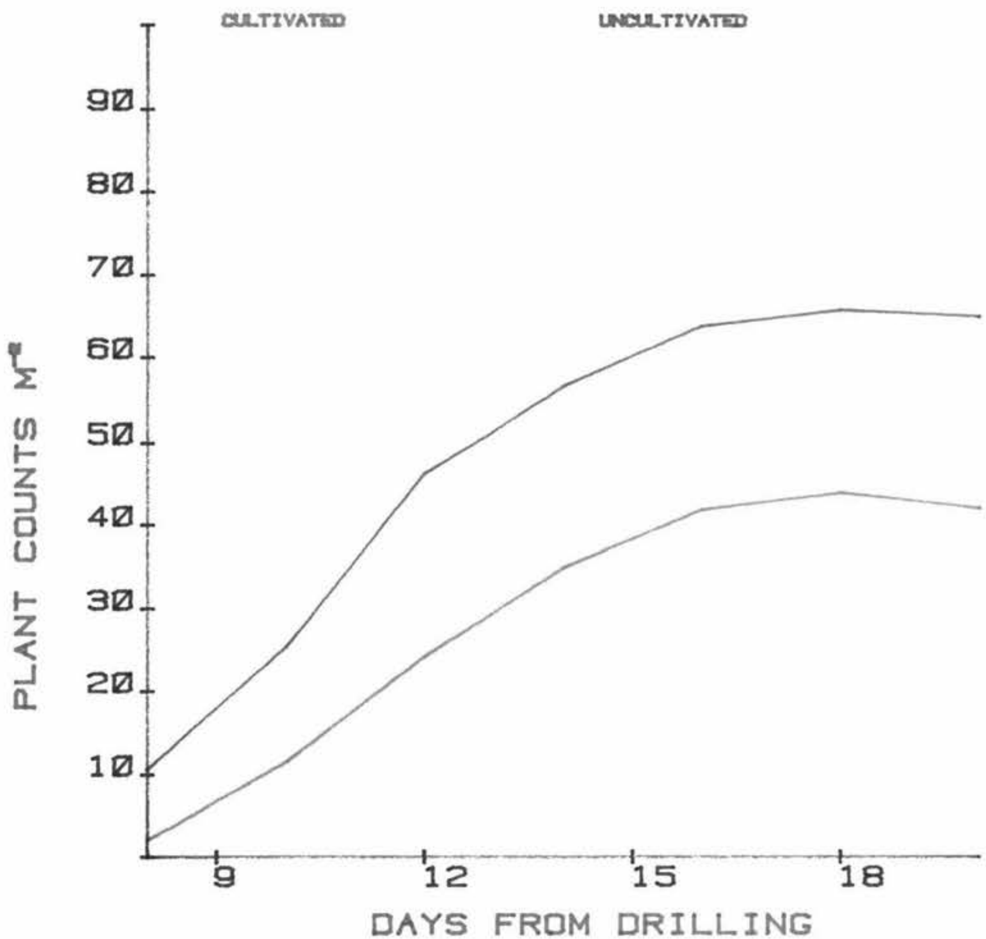


FIG 42 DRILLING 1

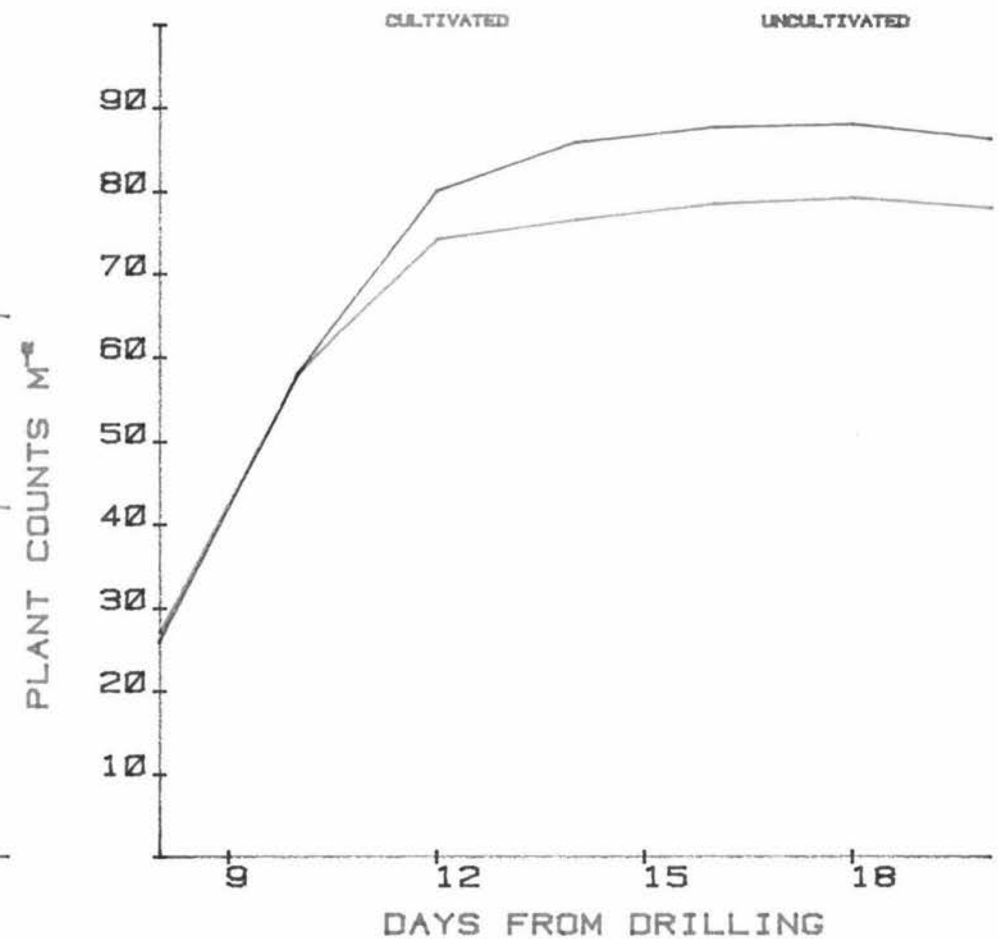


FIG 43 DRILLING 2

THE EFFECTS OF CULTIVATION TREATMENT ON PLANT COUNTS OF RAPE

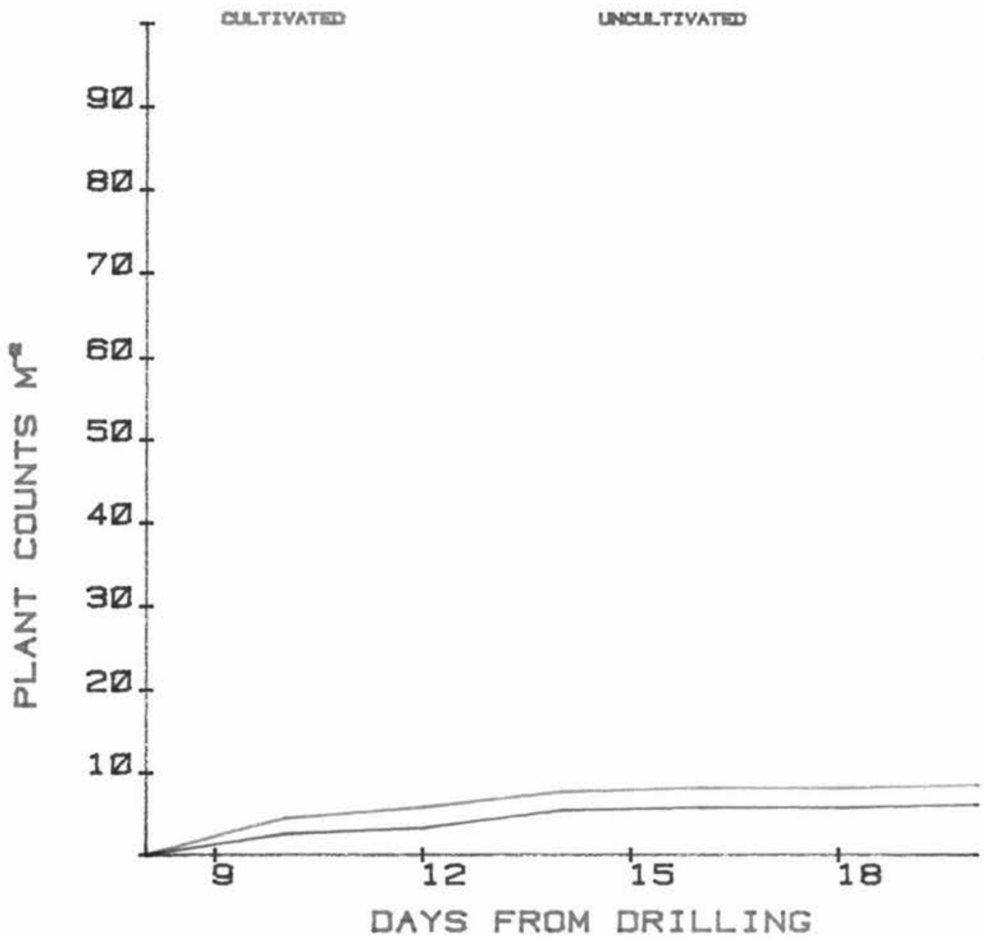


FIG 44 DRILLING 3

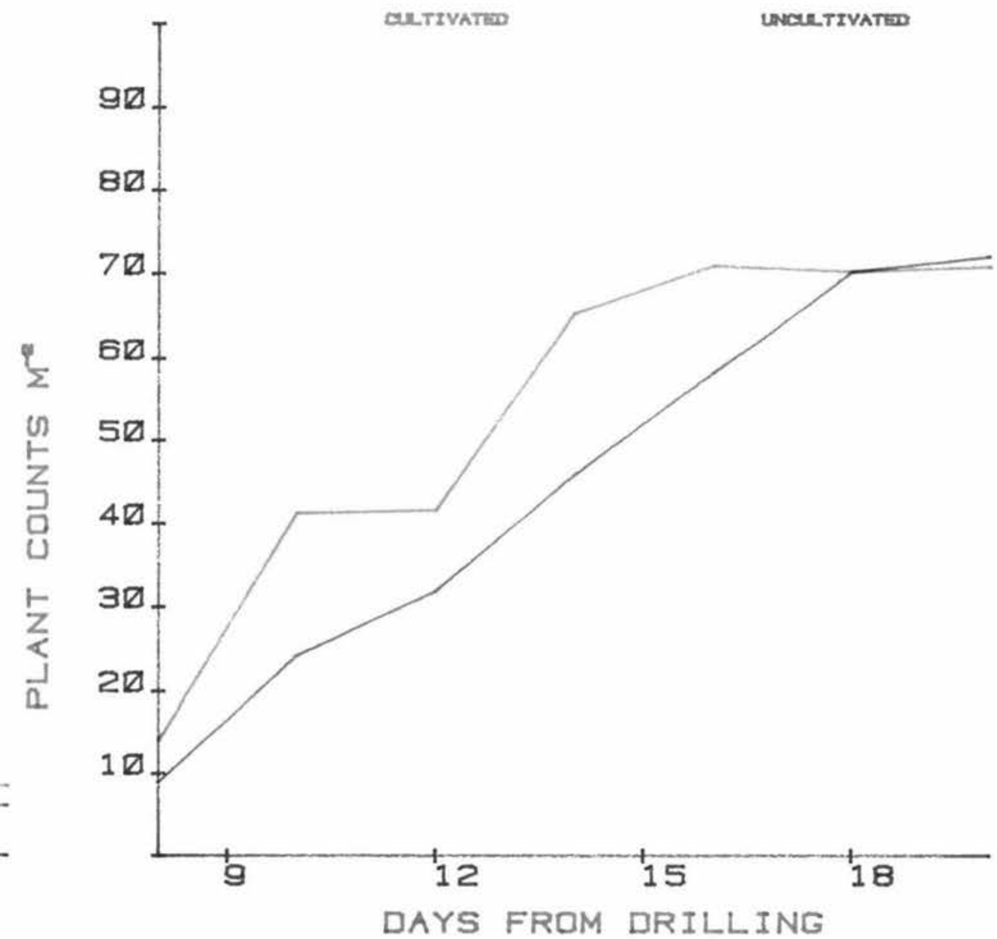


FIG 45 DRILLING 4

THE EFFECTS OF CULTIVATION TREATMENT ON PLANT COUNTS OF RAPE

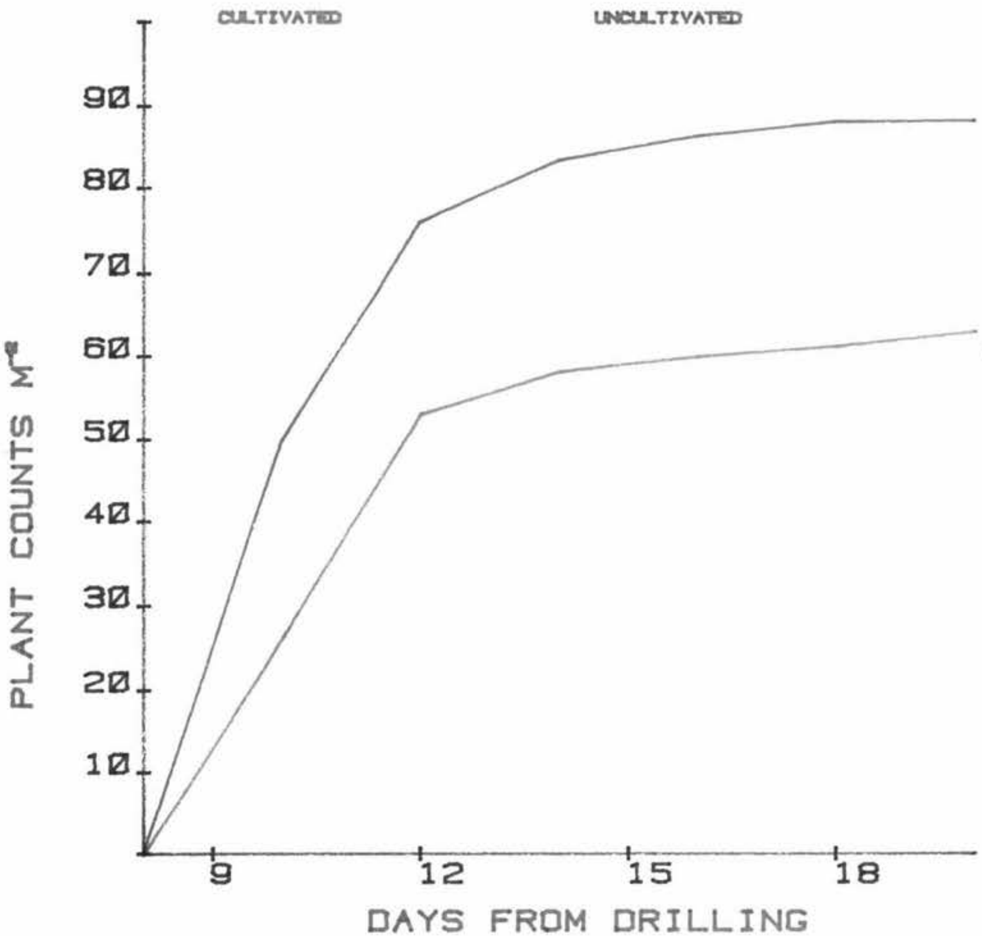


FIG 46 DRILLING 5

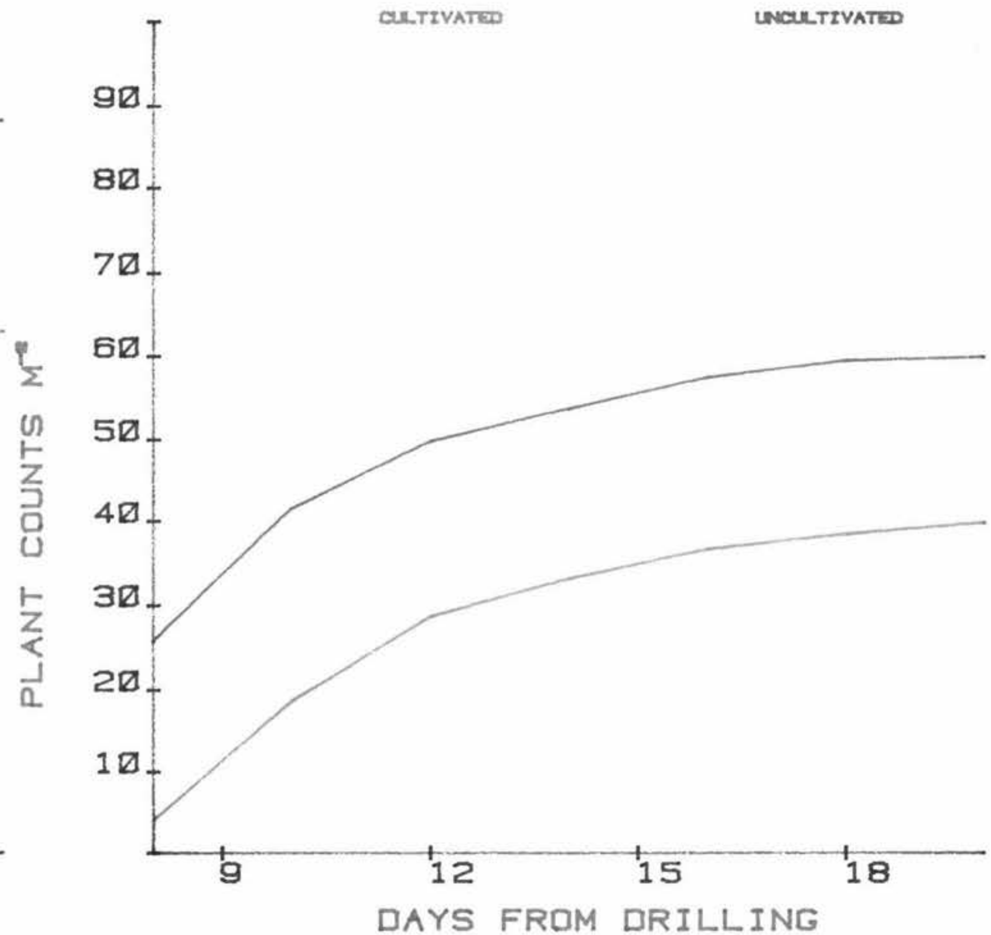


FIG 47 DRILLING 6

THE EFFECTS OF CULTIVATION TREATMENT ON PLANT COUNTS OF RAPE

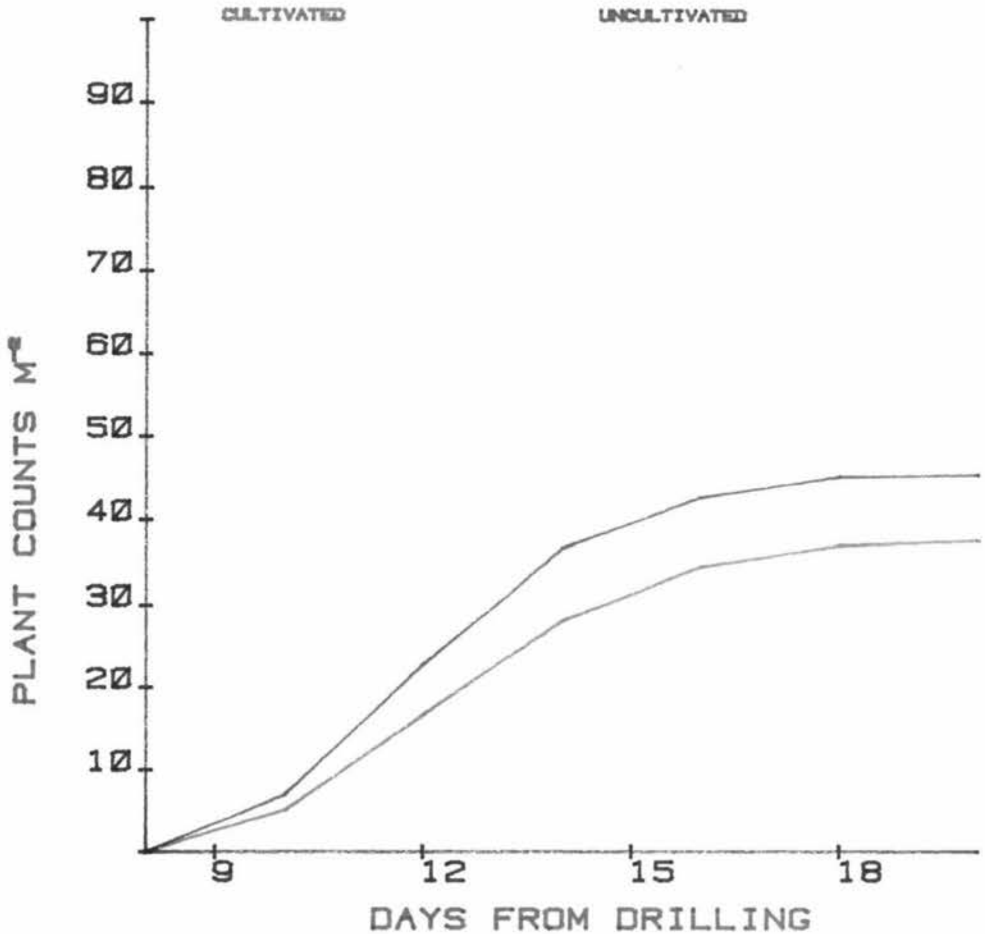


FIG 48 DRILLING 7

THE EFFECTS OF CULTIVATION TREATMENT ON PLANT COUNTS OF RAPE

It is evident from Table 12 that the cultivation treatments significantly ($P < 0.05$) effected the plant counts on day 20 from sowing in only the first and sixth drillings. There were also significant ($P < 0.01$) differences amongst the means of the various drillings, while the greatest overall plant numbers being recorded on the second, fourth and fifth drillings.

Discussion

It is noteworthy that the two drillings (numbers 1 and 6), which indicated significant effects of cultivation treatment on plant numbers, both had similar means. It is also noteworthy that those two drillings also showed significant differences in soil moisture due to the cultivation treatments. Their soil moisture means were also similar.

Clearly the cultivation treatments interacted both with the mechanism of moisture loss from the soil, and the effects of the fertiliser placement on plant numbers. It seems likely therefore that these two mechanisms were themselves related. The lower soil moisture level of the cultivated treatments (during drillings 1 and 6) appear to have contributed to the greater seed or seedling mortality in the cultivated plots, compared with the uncultivated plots.

4.2.3.3 Delay in maximum plant counts.

Results

Table 13 lists the delays in maximum plant counts in each drilling as a function of cultivation treatments.

TABLE 13 The effects of drilling time and cultivation treatment on delay in maximum plant counts of rape.

Cultivation Treatment	Delay in maximum plant counts (days)						
	Drilling time						
	1	2	3	4	5	6	7
Cultivated	18.2	18.2	19.6	18.1	20.5	20.0	20.5
Uncultivated	17.5 NS	17.0 NS	18.6 NS	20.2 NS	20.0 NS	19.7 NS	20.0 NS
Mean	17.8 a	17.6 a	19.1 ab	19.1 ab	20.2 b	19.8 b	20.2 b

NS: Not significantly different P< 0.05.

Unlike letters indicate significant differences P 0.05 within a row.

It is apparent from the table that the delay in maximum plant counts was not effected by the two cultivation treatments in any of the drillings. The drilling means of delay in maximum plant counts for the first two drllings were significantly ($P< 0.05$) less than the last three drillings.

Discussion

It is interesting to note that the last three drillings (numbers 5, 6 and 7) delayed the maximum plant counts by significantly ($P< 0.05$) more days than the first two drillings (number 1 and 2). The 3rd and 4th drillings were not significantly different from any of the other drillings. A high positive correlation ($R=0.92$) was found between the drilling time and mean delay in maximum plant counts as illustrated in Fig 49. A gradual decrease in soil temperature was observed between the first and seventh drillings as a result of climatic change (Autumn to Winter 1980). This probably was responsible for the increasing delay until the number of plants had maximised.

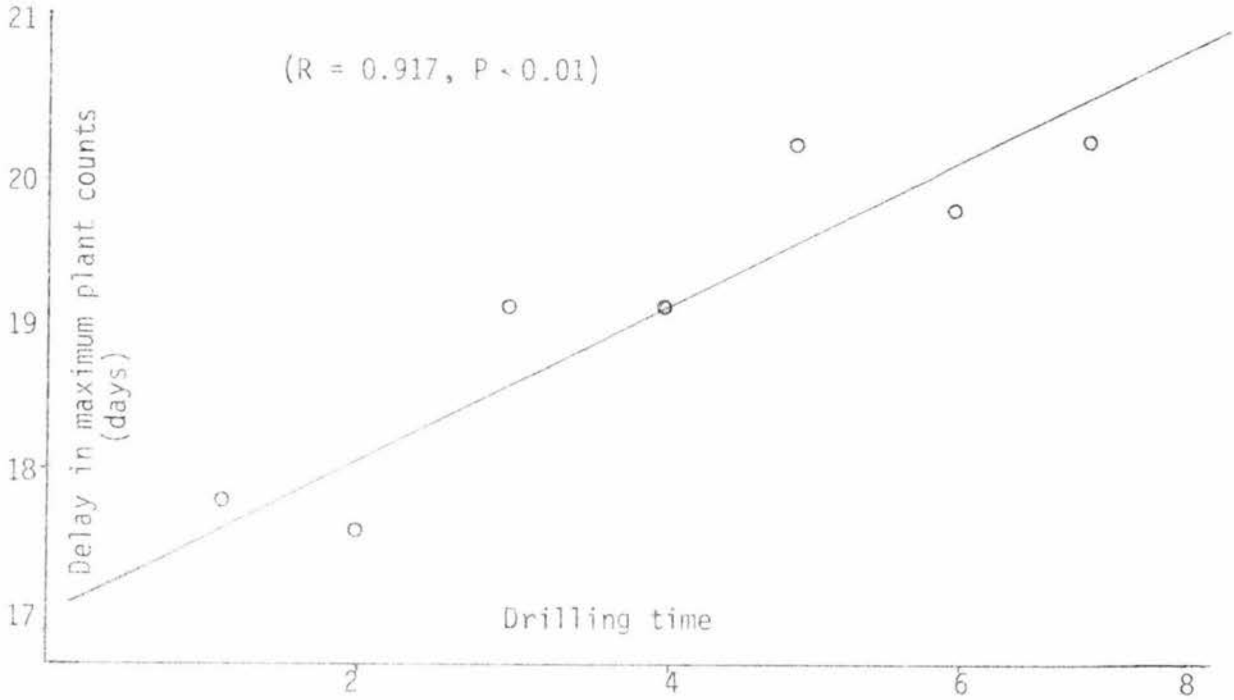


Fig 49. Correlation between drilling time and delay in maximum plant counts.

4.2.4 Summary

The overall effect of cultivation treatments in conjunction with fertiliser placement (20mm, horizontally separated from the seed) by an improved chisel coulter, was to promote greater rape plant populations in uncultivated soil compared with cultivated soil. These differences were up to 30% in magnitude. The trend was more pronounced when soil moisture conditions at the time of drilling were drier (19-20% db) rather than wetter (23-37%).

4.3 C LARGE BIN EXPERIMENT

4.3.1 Fertiliser placement effects

Results

Table 14 summarises the effects of position of fertiliser placement on seedling emergence, in-groove seed status, and delay in maximum seedling emergence of rape direct drilled with an improved chisel coulter.

TABLE 14 The effects of fertiliser placement on seedling emergence, status of seed in the groove and delay in maximum seedling emergence.

Particulars of Measurements			Fertiliser Placement		
			Horizontal	Vertical	Mixed
Seedling emergence on day from sowing (plants m^{-1} row)		7	0.05 Aa	0.11 Aa	0.03 Aa
		14	2.69 Aab	3.36 Ab	1.82 Aa
		21	3.33 Aa	4.20 Aa	2.46 Aa
In-groove seed status on day from sowing (% seeds)	Germinated	12	53 Aa	48 Aab	36 Ab
		20	59 Aa	59 Aa	44 Ab
	Viable	12	15 Aa	15 Aa	13 Aa
		20	6 Aa	9 Aa	12 Aa
	Dead	12	7 Bb	12 Bb	24 Aa
		20	9 Bb	10 ABb	19 Aa
Delay in maximum seedling emergence (days from sowing)			16 Aa	18 Aa	17 Aa

Unlike letters on a single line denote significant differences (capitals $P < 0.01$; lower case $P < 0.05$)

On day 14 after drilling the plant population was significantly ($P < 0.05$) higher with the vertical placement of fertiliser than with the mixed placement of seed and fertiliser. There was no difference between vertical and horizontal placement on day 14, nor were there any differences amongst any of the placement treatments on days 7 and 21.

Mixed placement significantly ($P < 0.05$) reduced the percentage of germinated seeds compared with the horizontal placement on day 12 but was similar to both the horizontal and vertical placements on day 20. There were no significant differences between horizontal and vertical placements on either of these sampling days.

The percentage of viable seeds recovered from the grooves was not effected by the placement treatments when sampled on days 12 and 20 after drilling. The percentage of dead seeds was significantly ($P < 0.05$) higher with the mixed placement than with either the horizontal or vertical placements on both of the sampling days (12 and 20). There appeared to be no difference between horizontal and vertical placements with respect to the percentages of dead seeds recovered from the grooves.

There were no significant effects of placement treatments on the delays until maximum seedling counts of rape.

Discussion

The counts of seedling emergence, and the percentage of germinated and dead seeds, indicate that the mixed placement of seed and fertiliser was the most disadvantageous in most respects compared to both the horizontal or vertical placement treatments. It is reasonable to expect this to have been caused by a toxic effect of the fertiliser on rape seed. This trend also confirms a similar effect observed in the small pot experiment.

4.3.2 Soil moisture effects

Results

Table 15 summarises the effects of the two soil moisture treatments on seedling emergence, in-groove seed status, and delay in maximum seedling emergence of rape, direct drilled with fertiliser, using an improved chisel coulter.

TABLE 15 Effects of soil moisture (dry, wet) on seedling emergence, in-groove seed status and delay in maximum seedling emergence of rape.

Particulars of Measurements			Soil moisture treatment	
			Dry	Wet
Seedling emergence on day 21 from drilling (plants m^{-1} row)			2.17 Aa	4.66 Aa
In-groove seed status on day from sowing (% seeds)	Germinated	12	30.7 Aa	63.7 Aa
		20	45.1 Aa	64.1 Aa
	Viable	12	23.5 Aa	7.4 Aa
		20	17.3 Aa	3.3 Aa
	Dead	12	15.9 Aa	11.3 Aa
		20	10.3 Aa	13.8 Aa
Delay in maximum seedling emergence (days from sowing)			17 Aa	16 Aa

Unlike letters on a single line denote significant differences (capitals $P < 0.01$; lower case $P < 0.05$).

It is apparent from Table 15 that the rape seedling emergence, in-groove seed status on days 12 and 20 from sowing, and delay in maximum seedling emergence were not effected by dry and wet soil moisture status.

4.3.3 Fertiliser treatment effects

Results

The effects of fertiliser treatments on seedling emergence, in-groove seed status and delay in maximum seedling emergence of rape are summarized in Table 16.

TABLE 16. The effects of fertiliser treatments on direct drilled rape.

Particulars of Measurements			Fertiliser Treatments				
			Fo	Fn	F_N	Fp	F_P
Seedling emergence on day 21 from sowing (plants m^{-1} row)			3.7 Aa	4.6 Aa	2.4 Aa	4.0 Aa	2.0 Aa
In-groove seed status on day from sowing (% seeds)	Germinated	12	45 Aa	47 Aa	47 Aa	45 Aa	44 Aa
		20	49 Aa	56 Aa	56 Aa	57 Aa	52 Aa
	Viable	12	12 Aa	12 Aa	16 Aa	17 Aa	15 Aa
		20	9 Aa	9 Aa	9 Aa	10 Aa	8 Aa
	Dead	12	12 Aa	14 Aa	13 Aa	11 Aa	18 Aa
		20	11 Aa	11 Aa	12 Aa	9 Aa	17 Aa
Delay in maximum seedling emergence from sowing (days)			17ABabc	16 Bbc	15 Bc	18 ABab	19 Aa

Unlike letters in a single line denote significant differences (capitals $P < 0.01$; lower case $P < 0.05$).

Fo - seed without fertiliser

Fn - low rate ammonium sulphate

F_N - high rate ammonium sulphate

Fp - low rate mono-ammonium phosphate

F_P - high rate mono-ammonium phosphate

There appeared to be no significant ($P < 0.05$) effects of fertiliser treatments on seedling emergence, and seed status of rape seeds recovered from the grooves.

The high rate of mono-ammonium phosphate however, caused a highly significant ($P< 0.01$) delay in maximum seedling emergence of rape compared with both of the rates of ammonium sulphate. Both of the mono-ammonium phosphate treatments were significantly ($P< 0.05$) different from the high rate of ammonium sulphate in causing a greater delay in maximum seedling emergence.

Discussion

The relatively greater effect of mono-ammonium phosphate compared to sulphate of ammonia may have been caused by the presence of both nitrogen and phosphorus in the former formulation while the latter contained nitrogen alone. Such an effect was noticed by Olson & Dreier (1956), who found that fertilisers containing both nitrogen and phosphorous were more toxic to wheat germination than those containing only nitrogen, when banded with the seed.

4.3.4 Soil moisture and fertiliser placement interactions

Results

Table 17 summarises the effects of dry (20% db) and wet (30% db) soil moistures, and horizontal, vertical and mixed fertiliser placements on seedling emergence, in-groove seed status and delay in maximum seedling emergence of direct drilled rape.

TABLE 17. The effects of soil moisture and fertiliser placement treatments on rape seedling emergence, seed status and delay in maximum seedling emergence.

Particulars of Measurements			Soil Moisture Treatment					
			Dry			Wet		
			Placement			Placement		
			Horizontal	Vertical	Mixed	Horizontal	Vertical	Mixed
Seedling emergence day from sowing plants m^{-1} row		7	0.01 Aa	0.01 Aa	0.02 Aa	0.13 Aa	0.33 Aa	0.04 Aa
		14	1.8 Aa	1.5 Aa	1.4 Aa	3.7 Aa	5.9 Aa	2.2 Aa
		21	2.4 Aa	2.1 Aa	2.0 Aa	4.4 Aa	6.9 Aa	3.0 Aa
In-groove seed status on day from sowing (% seeds)	Germinated	12	41 ABCbc	29 ABab	23 Aa	67 CDd	71 Dd	53 BCDcd
		20	65 BCcd	42 ABab	31 Aa	54 BCbc	80 Cd	60 BCbcd
	Viable	12	19 ABbc	34 Bc	19 ABbc	11 Aab	4 Aa	9 Aab
		20	6 Aa	26 Bb	25 Bb	6 Aa	1 Aa	4 Aa
	Dead	12	9 ABab	13 ABCab	28 Cc	5 Aa	11 ABab	20 BCbc
		20	5 Aa	10 ABab	17 ABb	13 ABab	9 ABab	21 Bb
Delay in maximum seedling emergence from sowing (days)			16 Aa	19 Aa	17 Aa	17 Aa	17 Aa	16 Aa

Unlike letters in a single line denote significant differences (capitals $P < 0.01$; lower case $P < 0.05$).

There appeared to be no significant ($P < 0.05$) effect from soil moisture or fertiliser placement on seedling emergence on day 7, 14 or 21 after sowing, and in delaying the maximum seedling emergence of rape.

The mixed placement of fertiliser in a dry soil produced significantly ($P < 0.01$) fewer germinated seeds than any of the placement treatments in wet soil. On the other hand, vertical placement in the dry soil was also significantly ($P < 0.05$) inferior to all treatments in the wet soil, but this difference occurred only on day 12 and had disappeared by day 20. Vertical placements of fertiliser in the wet soil gave significantly (P 0.01) higher counts of germination than the mixed and vertical placements of fertiliser in dry soil.

On both days (12, 20) vertical placement of fertiliser in dry soil gave significantly ($P < 0.01$) higher percentages of viable seeds than any of the placements in wet soil. On day 20 the horizontal placement of fertiliser in dry soil produced significantly (P 0.01) fewer viable seeds in the groove than both of the vertical and mixed placements in the same soil moisture.

Mixed placement of fertiliser in dry soil gave significantly ($P < 0.05$) more dead seeds in the groove on day 12 than any of the other treatments in either soil except the mixed seed and fertiliser in wet soil. By day 20, all of these differences had disappeared except in the dry soil the horizontal placement of fertiliser gave a significantly ($P < 0.05$) lower percentage of dead seeds than either of the mixed placements.

Discussion

Most of the fertiliser placements in wet soil and the later (day 20) horizontal placement of fertiliser at 20mm from the seed in dry soil produced higher percentages of in-groove germinated seeds than the mixed or vertical placement of fertiliser at 20mm below the seed in dry soil. It appears that mixed or vertical placements of fertiliser in dry soil had more adverse effects on germination of rape seed (either death or delayed germination) than horizontal placement in similar soil moisture regimes or most of the fertiliser placements in wet soil. Moreover it was clear that these adverse effects on germination did not always result in seed death. For example, although it was not surprising that vertical placement of fertiliser in the dry soil gave a higher percentage (30%) of viable seeds than vertical placement in the wet soil (2%). The percentage of viable seeds from the dry soil vertical placement was not significantly different from the mixed placement in dry soil. By comparison on day 12 at least, the percentage of dead seeds in the dry soil mixed treatment was larger than the corresponding vertical placement. Mixed placement in a dry soil had the effect of killing seeds whereas the vertical placement tended to delay their germination rather than kill the seeds.

It is interesting to note that while the overall soil moisture data reported in section 4.3.2 above, indicated no mean differences between the two moisture regimes, there were some interactions amongst treatments in this respect. The horizontal placement of fertiliser was little effected by soil moisture. It is probable that the horizontal placement of fertiliser in dry soil may have been helped by retention of soil moisture vapour due to the configuration of its groove (Fig 8, 10, 16) compared with mixed (Fig 27) or vertical (Fig 30) placement in dry soil. Certainly Choudhary & Baker (1981 a, b) have indicated that such a groove does retain soil moisture vapour, but unfortunately no comparable data exists to characterise the vertical placement groove.

There was a greater percentage of dead seeds in the mixed placement of seed and fertiliser in the dry soil on day 12 compared with the horizontal placement in the wet soil. Later, on day 20 this difference seemed to have been extended. The mixed placement of seed and fertiliser in either dry or wet soil at that time appeared to have caused significantly more seed deaths compared with the horizontal placement in the dry soil. It is probable that fertiliser in contact with seed (mixed) may be at risk compared to horizontal placements, where seed and fertiliser were 20mm apart. In this respect, however, it is difficult to explain why the relative superiority of horizontal placement compared with mixing, was less in a wet soil than in a dry soil.

4.3.5 Soil moisture and fertiliser interactions.

Results

Table 18 summarises the effects of soil moisture (dry and wet) and fertiliser treatments (Fo, Fn, F_N, Fp and F_P) on seedling emergence, seed status and delay in maximum seedling emergence of rape.

TABLE 18. The effects of soil moisture and fertiliser treatments on the seedling emergence, in-groove seed status and delay up to maximum seedling emergence.

Particulars of Measurements			Soil Moisture Treatment									
			Dry					Wet				
			Fertiliser					Fertiliser				
			Fo	Fn	F_N	Fp	F_P	Fo	Fn	F_N	Fp	F_P
Seedling emergence on day 21 from sowing (plants m^{-1} row)			2.2 NS	3.7 NS	2.4 NS	2.2 NS	0.9 NS	5.8 NS	5.7 NS	2.5 NS	6.2 NS	3.6 NS
In-groove seed status (% seeds) on day from sowing	Germinated	Day 12	24 NS	31 NS	45 NS	27 NS	28 NS	73 NS	65 NS	50 NS	67 NS	65 NS
		20	35 NS	56 NS	56 NS	42 NS	39 NS	66 NS	56 NS	57 NS	75 NS	67 NS
	Viable	12	29 NS	19 NS	20 NS	24 NS	26 NS	2 NS	7 NS	12 NS	12 NS	6 NS
		20	21 NS	17 NS	13 NS	21 NS	15 NS	2 NS	3 NS	6 NS	3 NS	3 NS
	Dead	12	14 NS	20 NS	9 NS	17 NS	21 NS	10 NS	9 NS	17 NS	7 NS	16 NS
		20	13 NS	10 NS	6 NS	9 NS	16 NS	9 NS	15 NS	19 NS	9 NS	18 NS
Delay in maximum seedling emergence (days) from sowing			17 NS	16 NS	14 NS	18 NS	20 NS	17 NS	15 NS	16 NS	17 NS	17 NS

NS: Not significant differences in a row at $P < 0.05$.

It is evident from the table that there were no significant differences ($P < 0.05$) or interactions amongst any soil moisture and fertiliser treatments.

4.3.6 Placement and fertiliser interactions.

Results

The effects of position of placement and fertiliser treatment on seedling emergence, seed status and delay in maximum seedling emergence of direct drilled rape are summarised in Table 19.

TABLE 19. Effect of fertiliser and placement treatments on the seedling emergence, in-groove seed status and delay in maximum seedling emergence of rape.

Particulars of Measurement			Placement Treatment														
			Horizontal					Vertical					Mixed				
			Fertiliser					Fertiliser					Fertiliser				
			Fo	Fn	F_N	Fp	F_P	Fo	Fn	F_N	Fp	F_P	Fo	Fn	F_N	Fp	F_P
Seedling emergence plants m^{-2} on day 21 from sowing			4.4 NS	2.7 NS	1.6 NS	5.6 NS	3.1 NS	5.2 NS	5.8 NS	3.9 NS	3.1 NS	3.3 NS	2.1 NS	5.8 NS	2.1 NS	3.4 NS	0.5 NS
In-groove seed status (% seeds) on day from sowing	Germinated	12	47 NS	55 NS	53 NS	56 NS	56 NS	49 NS	46 NS	54 NS	41 NS	51 NS	40 NS	39 NS	35 NS	38 NS	29 NS
		20	42 NS	62 NS	57 NS	67 NS	71 NS	66 NS	61 NS	48 NS	65 NS	60 NS	43 NS	47 NS	64 NS	43 NS	29 NS
	Viable	12	19 NS	15 NS	12 NS	11 NS	17 NS	10 NS	11 NS	20 NS	26 NS	11 NS	8 NS	11 NS	16 NS	18 NS	16 NS
		20	9 NS	2 NS	11 NS	6 NS	3 NS	7 NS	9 NS	14 NS	11 NS	7 NS	10 NS	22 NS	4 NS	12 NS	17 NS
	Dead	12	5 NS	8 NS	13 NS	4 NS	8 NS	10 NS	10 NS	6 NS	16 NS	18 NS	24 NS	27 NS	22 NS	16 NS	33 NS
		20	11 NS	11 NS	11 NS	4 NS	8 NS	10 NS	17 NS	13 NS	3 NS	10 NS	12 NS	10 NS	12 NS	27 NS	42 NS
Delay in maximum seedling emergence (days) from sowing			15 NS	15 NS	14 NS	17 NS	19 NS	18 NS	16 NS	17 NS	19 NS	18 NS	17 NS	16 NS	15 NS	16 NS	19 NS

NS: Not significant ($P < 0.05$) in a row.

Although the table indicates that there were no significant differences or interactions amongst the treatments at $P < 0.05$, the interactions in counts of dead seeds on day 20 were significant at the lower order of probability $P < 0.07$. These are re-analysed separately and summarised in Table 20.

TABLE 20 The effect of placement and fertiliser treatments on dead seeds of rape on day 20 after sowing.

Fertiliser Treatment	% dead seeds		
	Placement Treatment		
	Horizontal	Vertical	Mixed
Fo	11 Aa	10 Aa	12 Aa
Fn	11 Aa	17 Aa	10 Aa
FN	11 Aa	13 Aa	12 Aa
Fp	4 Aa	3 Aa	27 Bb
FP	8 Aa	10 Aa	42 Bb

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

It appears from Table 20 that with no fertiliser (Fo) and both of ammonium sulphate (Fn, FN) there were no significant effects attributable to placement treatments. On the other hand with both of the mono-ammonium phosphate treatments (Fp, FP) there were significant ($P < 0.01$) differences due to position of placement. The mixed placement of mono-ammonium phosphate with seed caused more death of seeds than either the horizontal or vertical placements on day 20.

Discussion

It is interesting to note that the adverse effect of mono-ammonium phosphate, mixed with the seed did not appear until day 20. Moreover it has previously been noted (Section 4.3.3) that the high rate of mono-ammonium phosphate had also caused more delay in the maximum seedling emergence than the corresponding rate of ammonium sulphate. Therefore it appears, that the mixed placement of mono-ammonium phosphate exerted its effect over a period of time, delaying maximum emergence and also causing permanent damage to the seed. The horizontal and vertical separation of mono-ammonium phosphate (where the distance between seed and fertiliser was 20mm) not only helped to reduce the total toxic effect of fertiliser, but also reduced the delays apparently associated with seed damage.

4.3.7 Summary

From the results of large bin experiment, it appears that soil moisture status, as a main treatment was not influential in affecting any of the rape parameters observed. In comparisons of fertiliser placements, most of the horizontal or vertical placements resulted in greater percentages of germinated seeds and fewer dead seeds recovered from the groove than was the case with the mixed placements. Fertiliser may have delayed maximum seedling emergence of rape, especially when the two were close together, but these results were not conclusive.

Amongst the interactive effects of treatments, soil moisture and placement had some effect on the seed status. Most of the placements in wet soil and most of the horizontal placements in dry soil gave better percentages of germinated seeds and lesser viable seeds than the remaining treatments. Most of the mixed placements appeared to have caused more dead seeds than the majority of horizontal placements.

Soil moisture *per se* and fertiliser *per se* showed no effects on rape parameters. The interaction of fertiliser and placements, indicated that mono-ammonium phosphate mixed with the seed was likely to increase the percentage of dead seeds more than when it was placed horizontally or vertically separated from the seeds.

5 DISCUSSION AND CONCLUSIONS

Cultivation

It is evident from the field experiment that the placement of ammonium sulphate, separated by 20mm from the seed with an improved chisel coulter, produced greater numbers of rape plants in uncultivated soil than in soil which had been rotary hoed. This response was more pronounced in the drier ranges of soil moisture than in more moist conditions at the time of drilling. The greater sensitivity at lower soil moisture levels may have been due to the in-groove moisture retention properties of the coulter. This property of the coulter was outlined in detail by Baker & Choudhary (1981 a, b, c). The authors found that the groove formed by the coulter in uncultivated soil, had good potential for retaining soil moisture in the vapour form, which was desirable from the standpoint of germination and subsequent seedling emergence. It is possible that the cultivated soil did not retain sufficently the boundaries of the groove, to enable it to exploit the vapour moisture as effectively as in uncultivated soil. It is unclear though whether or not the improved chisel coulter exerted its influence in uncultivated soil by promoting germination and seedling emergence or by reducing the toxic effect of ammonium sulphate on the seeds because of the higher moisture regime in the groove in the uncultivated soil as compared to cultivated. Both explanations are possible. Perhaps a combination of the two occurred. Because even the drier soil moisture regimes of this experiment could not be considered to be limiting, it is possible that there is another explanation. The groove formation by the improved chisel coulter also included the formation of a deep narrow vertical cut by the disc which passed between the seed and fertiliser and extended 75-100mm below either. In the uncultivated soil this cut remained well defined and may have effectively interrupted the horizontal liquid movement of water or solutes between the seed and fertiliser. In the cultivated soil this slit was noticeably less distinct and gave the appearance of having collapsed or crumbled. No unreasonably crumbling of this nature could be expected to be greater in a drier soil than a moist soil, thus exaggerating the difference in the drier situation. This explanation too, however, was not fully supported by the small pot experiment where no central deep slit occurred.

Fertiliser placement

In the small pot experiment the horizontal separation of fertiliser by 20mm from the rape seed proved advantageous in terms of seedling emergence, initiation and maximum seedling emergence delays as well as in yield characteristics of the plants.

Mixed seed and fertiliser, and horizontal or vertical placements at 10mm adversely effected the initiation and maximum seedling emergence delays, and yield parameters as compared to horizontal placement of fertiliser at 20mm from the seed. This appears to have been as a direct result of the toxicity of ammonium sulphate as there were no other functions involved which could be attributed to actual coulter operation. The adverse treatment effects mainly resulted in:

(i) delayed germination and subsequent seedling emergence, and/or

(ii) permanent injury to seeds or seedlings.

The superiority of at least the horizontal, and in some respects also the vertical placements of fertiliser at 20mm from the seed in terms of seedling emergence, germination and death of seeds was partially confirmed in the large bin experiment with the improved and modified versions of chisel coulter. However, amongst the interactive effects, most of the placements in wet soil and most of the horizontal placements in dry soil promoted better germination and viability of seeds. The majority of mixed placements caused greater seed deaths than most of the horizontal placements. It is logical to expect more dead seeds in the mixed placements because of close proximity of seeds and fertiliser, but the superior performance of the horizontal 20mm placement compared to the vertical 20mm placement casts some doubt on whether the fertiliser effect on seed can be explained as a simple function of distance between the two. It is possible that the greater overall depth of the fertiliser in the soil with the vertical placement (40mm), compared to the horizontal placement (20mm), may have provided more moisture from the soil profile. However an analysis of the ungerminated seeds recovered from the groove did not confirm this. Moreover in the dry soil the horizontal placement proved to be better than the vertical placement, which suggests that the shape of groove might have played a more major role than previously thought. The vertical placement groove contained sub-surface shattering to one side of the disc only, while in the horizontal placement this shattering was on both sides of the disc. The other notable difference was that in the horizontal placement, seed and fertiliser were separated by the disc cut in the centre as discussed previously. With the vertical placement the seed and fertiliser were on the same side of the disc slit and were therefore likely to experience more uninterrupted moisture movement in a similar manner to the cultivated soil. A similar superiority of the horizontal over the vertical placement at 10mm was observed in the small pot experiment, even though no coulter was used. The soil between seed and fertiliser was undisturbed in the former, while in the latter the separating soil was in the form of a replaced core and thus may not have been as intact as in the horizontal placement.

Whatever the explanation, it seems that there is an added reason why the horizontal placement has an advantage in mechanical terms. Compared to the vertical placement the penetration forces are equally distributed on both sides of disc and are equidistant from the axle of disc in the horizontal placement. This would be expected to result in the avoidance of uneven wear and stresses on the assembly. It also provides less chance of physical contact between seed and fertiliser and has the added flexibility of allowing selection of either side for fertiliser or seed delivery.

Conclusion

This study was confined to rape seed (C. "Tower"), mainly ammonium sulphate, limited moisture ranges and soil types, and with few placement distances. Since all three experiments came to similar conclusions, using different techniques, the validity of the results was strengthened. The following conclusions were drawn:

1. Mixed placement of rape seed with ammonium sulphate or mono-ammonium phosphate fertilisers at the rates $\geq$30kg-N ha^{-1} should be avoided. The effects of lower application rates of these fertilisers should be further investigated.
2. Ammonium sulphate and mono-ammonium phosphate at the rates $\geq$30kg-N ha^{-1} require horizontal separation from rape seed by a minimum of 20mm distance.
3. With this separation configuration, uncultivated soils give better seed survival than cultivated soils, especially at the lower end of the "available" soil moisture range.
4. The improved chisel direct drilling coulter is capable of achieving the objective of 20mm horizontal separation. This is not to say that the tolerance of this or any other direct drilling coulter is incapable of improvement.

6 BIBLIOGRAPHY

1 Aboulroos, S.A; and Nielsen, N.E. 1979. Effect of phosphorus placement in varying, confined volumes of soil on fineness and density of barley roots and the mean rate of nutrient uptake per root unit. *Acta Agriculturae Scandinavica*: XXIX(4) : 331-36.

2 Allen, H.P. 1977. Direct drilling: Its contribution towards conservation of time, energy, and labour in crop planting. *Energy Conservation in Crop Production, Proceedings of the International Conference*, Massey University, New Zealand. 129-36.

3 Allen, R.R; Stewart, B.A. and Unger, P.W. 1977. Conservation tillage and energy. *Journal of Soil and Water Conservation*. 32 : 84-7.

4 Anon. 1966. *Guide to Field Experiments*. (Jealotts Hills Research Station).

5 Anon. 1979. Tillage Systems for Illinois. University of Illinois. *Cooperative Extension Service Circular No.1172*.

6 Baeumer, K. 1970. First Experiences with Direct Drilling in Germany. *Neth. J. Agric. Sci*: 18 : 283-292.

7 Baeumer, K. and Bakermans, W.A.P. 1973. Zero Tillage. *Advances in Agronomy*: 25 : 77-123

8 Baker, C.J. 1969. A tillage bin and tool testing apparatus for turf samples. *J. of Agric. Eng. Res.* 14 : 357-60.

9 Baker, C.J. 1972. The mechanised collection of turf blocks and their utilization in field experimentation. *Proc. 3rd Int. Conf. on Mech. of Field Expts.* (Brno) 282-93.

10 Baker, C.J. 1976a. An investigation into the techniques of direct drilling seeds into undisturbed, sprayed pasture. Ph.D Thesis, Massey University.

11 Baker, C.J. 1976b. Experiments relating to the techniques of direct drilling of seeds into untilled dead turf. *J. Agric. Eng. Res.* 21(2): 133-45.

12 Baker, C.J. 1979. Equipment impact and recent developments. *Proc. Consvtn. Tillage Tech. Sem.* Christchurch, N.Z.

13 Baker, C.J; McDonald, J.H; Rix, C.S; Seebeck, K; Griffiths, P.M. 1979. Developments with seed drill coulters for direct drilling: 3 An improved chisel coulter with trash handling and fertiliser placement capabilities. *N.Z. J. Exp. Agric.* 7 : 189-96.

14 Bakerman, W.A.P. 1970. Crop husbandry on naturally compacted soils. *Neth. J. Agric. Sci.* 18 : 225-46.

15 Barber, S.A. 1976. Efficient fertiliser use - Agronomic Research for Food. *Americ. Soc. Agron. Special Publication* No. 26.

16 Barber, S.A; Walker, J.M; Vasey, E.H. 1963. Mechanisms for the movement of plant nutrients from the soil and fertiliser to the plant root. *Agricl. and Food Chemistry* 11 : 204-7.

17 Black, A.L. and Siddoway, F.H. 1979. Influence of tillage and wheat straw residue management on soil properties in the great plains. *J. Soil and Water Cons.* 34 (5) : 220-23.

18 Brage, B.L; Zich, W.R; and Fine, L.O. 1960. The germination of small grains and corn as influenced by urea and other nitrogenous fertilisers. *Proc. Soil Sci. of Amerc.* 24 : 294.

19 Bramley, P. 1962. New developments in the weed-killer field. *N.Z. Weed Control Conf. Proc.* 14 : 41-47.

20 Burrows, W.C; and Larson, W.E. 1962. Effect of amount of mulch on soil temperature and early growth of corn. *Agron. J.* 54 : 19-23.

21 Carpenter, A; Kain, W.M; Baker, C.J. and Sims, R.E.H. 1978. The effect of tillage technique on insects pests of seedling maize. *Proc. 31st Weed and Pest Control Conf.* 89-91.

22 Cannel, R.Q; Ellis, F.B; Barnes, B.T. 1976. Effects of reduced cultivation on soil conditions and root development of cereals. Agri. Res. Council, *Letcombe Lab. Ann. Report.*

23 Carter, O.G. 1967. The effect of chemical fertilisers on seedling establishment. *Aust. J. of Exptl. Agri. and Animal Husb.* 7 : 174-80.

24 Carter, O.G. 1969. The effect of fertilisers on germination and establishment of pastures and fodder crops. *Wool Tech. and Sheep Breeding.* 16 (1) : 69-75.

25 Chapin, J.S. and Smith, F.W. 1960. Germination of wheat at various levels of soil moisture as affected by application of NH_4NO_3 and KCl. *Soil Science* 89 : 322.

26 Choudhary, M.A. 1979. Interrelationships between performance of direct drilled seeds, soil micro-environment and drilling equipment. Ph.D Thesis, Massey University N.Z.

27 Choudhary, M.A. and Baker, C.J. 1981 a. Physical effects of direct drilling equipment on undisturbed soils: 1. Wheat seedling emergence from a dry soil under controlled climates. *N.Z. J. Agric. Res.* - in press.

28 Choudhary, M.A. and Baker, C.J. 1981 b. Physical effects of direct drilling equipment on undisturbed soils: 2 Seed groove formation by a "triple disc" coulter and seedling performance. *N.Z. J. Agric. Res.* - in press.

29 Choudhary, M.A. and Baker, C.J. 1981 c. Effects of direct drill coulter design and soil moisture status on emergence of wheat seedlings. *Soil and Tillage Res.* - in press.

30 Choudhary, M.L; Gupta, A.P. 1974. Relative efficiency of different methods of P application on fertiliser P uptake by maize. *In use of radiations and radioisotopes in studies of plant productivity Symp.* Pantnagar, India.

31 Cooke, G.W. 1951. Placement of fertiliser for sugar beet. *J. Agric. Sci.* 41 : 176.

32 Cooke, G.W. 1960. *'Fertilisers and Profitable Farming'*, London.

33 Cooke, G.W. 1967. *'The Control of Soil Fertility'*, London.

34 Cornish, P.S; Fettell, N.A. 1977. Root growth and phosphorus nutrition of wheat seedlings in soil of high mechanical resistance. *Energy Cons. in Crop Prod. Proc. of the Intl Conf. Massey University, N.Z.* 100-106.

35 Damour, L; Camus, P; Garreau, J; Lesage, B. and Jeannin, B 1973. Research into farming techniques applicable to the marshland soils of western France. *Outlook on Agric.* 7 (4) : 162-7.

36 Drew, M.C; Saker, L.R. 1975. Effect of different cultivation treatments on root distribution and on the concentrations of extractable phosphorus and potassium, at different depths. *Agri. Res. Council Letcombe Lab. Annual Report.* 24.

37 Drew, M.C; Saker, L.R. 1976. Effect of direct drilling and ploughing on concentration gradients of extractable phosphate and potassium. *Agri. Res. Council Letcombe Lab. Annual Report.* 37-39.

38 Drew, M.C; Saker, L.R. 1978. Nutrient supply and the growth of the seminal root system in barley. *J. Exp. Bot.* 29 : 435-451.

39 Drew, M.C: Saker, L.R. 1980. Direct drilling and ploughing: Their effects on the distribution of extractable P and K, and the roots, in the upper horizons of two clay soils under winter wheat and spring barley. *J. Agric. Sci. Camb.* 94 : 411-23.

40 Duncan, W.G; and Ohlrogge, A.J. 1958. Principles of nutrient uptake from fertiliser bands: II. Root development in the band. *Agron. J.* 50 : 605-8.

41 Ellis, F.B; Elliot, J.G; Barnes, B.T. and House, K.R. 1977. Comparison of direct drilling, reduced cultivation and ploughing on the growth of plants. 2. Spring barley on a sandy loam soil: soil physical conditions and root growth. *J. Agric. Sci. Camb.* 89 : 631-42.

42 Felton, W.L; Doyle, A.D. and Holland, J.F. 1980. No Tillage Wheat Production in Northern New South Wales. *Proc. Aust. Agron. Conf. Queensland Agri. College, Lawes.* 213.

43 Guttay, J.R. 1957. The effects of fertiliser on germination and emergence of wheat and oats. *Michigan Agri. Exp. Sta. Quart. Bult.* 40 (1) : 193.

44 Ham, G.E; Caldwell, A.C. 1978. Fertiliser placement effects on soybean seed yield, N_2 fixation and ^{33}P uptake. *Agron. J. 70.* 70 : 779-83.

45 Hughes, K.A; Baker, C.J. 1977. The effects of tillage and zero tillage systems on soil aggregates in a silt loam. *J. Agri. Eng. Res.* 22 : 291-301.

46 Ivens, G.W. 1977. The latest developments in weed and pest aspects of low energy cropping. *Proc. Intl. Conf. Energy Cons. in Crop Prod. Massey University, N.Z.* 231-3.

47 Jeater, R.S.L. 1966. Agronomic aspects of direct drilling. *Proc. 8th Brit. Weed Control Conf.* 3 : 874-83.

48 Jones, J.N; Moody, J.E; Shear, G.M; Moschler, W.W; and Lillard, J.H. 1968. The no-tillage system for corn. *Agron. J.* 60 (1) : 17-20.

49 Jones, D.B; Hicks, J.S; Hutchings, R.J. and Ibrahim, Z. 1977. Tillage methods and wheat yields after pasture. *Proc. Intl. Conf. Energy Cons. in Crop Prod. Massey University, N.Z.*

50 Kanchanasut, P; Scotter, D.R; Tillaman, R.W. 1978. Preferential solute movement through larger soil voids. II Experiments with saturated soil. *Aust. J. Soil Res.* 16 : 269-76.

51 Ketcheson, J.W. 1957. Some effects of soil témperature on phosphorus requirements of young corn plants in the green house. *Can. J. Soil Sci.* 37 : 41-7.

52 Ketcheson, J.W. 1980. Effect of tillage on fertiliser requirements for corn on silt loam soil. *Agron. J.* 72 (3) : 540-42.

53 Krall, J; Dubbs, A; Larson, W. 1979. No-till drills for recropping. *Montana Agr. Expt. St. Bult.* 716.

54 Koronka, P. 1973. Machinery development for direct drilling. *Outlook on Agri.* 7 (4) : 190-5.

55 Kupers, .J.P; and Ellen, J. 1970. Experiments with minimum tillage and nitrogen fertilisation. *Neth. J. Agri. Sci.* 18 : 270-76.

56 Lawton, K; Davis, J.F. 1960. Influence of fertiliser analysis and placement on the emergence, growth and nutrient absorption by wheat seedlings. *Agron. J.* 52 : 236-8.

57 Leonard, W.F: and Hart, R.I.K. 1977. Direct drilling: Progress under New Zealand Conditions. *Proc. Intl. Conf. Energy Cons. in Crop Prod. Massey University, N.Z.*

58 Lillard, J.H; and Jones, J.N. 1964. Planting and seed environment problems with corn in killed seed beds. *Trans. ASAE.* 7 (3) : 204-8.

59 Logan, I.C. 1979. Direct drilling: Some thoughts on machine performance. *Ag. Eng. Aust.* 8 (2) : 60-5.

60 Low, A.J. 1972. The effects of cultivation on the structure and other physical characteristics of grassland and arable soils (1945-70). *J. Soil Sci.* 23 : 363-81.

61 McCown, R.L; Jones, R.K; Peake, D.C.I. 1980. Short-term benefits of zero-tillage in tropical grain production. *Proc. Aust. Agron. Conf. Queensland Agri. College, Lawes.* P. 220.

62 Marston, D. 1979. Effects of five tillage practices on soil structure. *Ag. Eng. Aust.* 8 (2) : 69-75.

63 Mason, M.G. 1971. Effects of urea, ammonium nitrate and superphosphate on establishment of cereals, linseed and rape. *Aust. J. Exp. Agri. and Animal Husb.* 11 : 662-9.

64 Mathews, L.J. 1972. No-tillage cropping. *N.Z. J. Agric. Sci.* 7 : 15-19.

65 Nelson, L.B. 1956. The mineral nutrition of corn as related to its growth and culture. *Adv. Agron.* 8 : 321-75.

66 Olson, R.A; and Dreier, A.F. 1956. Fertiliser placement for small grains in relation to crop stand and nutrient efficiency in Nebraska. *Soil Sci. Soc. Amer. Proc.* 20 : 19-24.

67 Phillips, R.E. Ed. 1974. *No Tillage Research Conf. Proc.* (College of Agri., Univ. of Kentucky).

68 Phillips, S.H; and Young, H.M. 1973. *No-tillage Farming* (Rieman, Milwaukee, Wis.).

69 Phillips, R.E; Blevins, R.L; Thomas, G.W; Frye, W.W; and Phillips, S.H. 1980. No-tillage Agriculture. *Science.* 208 (4448) : 1108-1113.

70 Power, J.F; Brown, P.L; Army, T.J; and Klages, M.G. 1961. Phosphorus responses by dryland spring wheat as influenced by moisture supplies. *Agron. J.* 53 : 106-8.

71 Rich, A.E; Odland, T.E. 1947. Fertiliser placement for silage corn. *Soil Sci. Soc. of Amer. Proc.* 12 : 253-4.

72 Riley, D; Coutts, J; and Gowman, M.A. 1975. Placement, mobility and plant uptake of nutrients in no-tillage systems. *No-tillage Forage Symp.* Ohio State University. 15-28.

73 Robinson, R.R; Sprague, V.G; Gross, G.F. 1959. The relation of temperature and phosphate placement to growth of clover. *Soil Sci. Soc. Amer. Proc.* 23 : 225-28.

74 Rudd, C.L. 1972. Effect of method of application of superphosphate on wheat yield. *Dep. Agric. S. Aust. Exp. Rec.* No. 7 : 4-9.

75 Scotter, D.R. 1978. Preferential solute movement through larger soil voids. I Some computations using simple theory. *Aust. J. Soil. Res.* 16 : 257-67.

76 Sheikh, G.S; Ahmed, S.I; Chaudhry, A.D. 1978. Comparative performance of tillage implements. *A.M.A. Autumn.* 57-60.

77 Sims, H.J; Andrew, R.A. 1958. Superphosphate on wheat. *J. Agri.* Melbourne . 56 : 9-10.

78 Singh, R.M; Black, C.A. 1964. Test of the De Wit compensation function for estimating the value of different fertiliser placements. *Agron. J.* 56 : 572-4.

79 Slack, C.H; Blevins, R.L; Rieck, C.E. 1978. Effect of soil pH and tillage on persistance of Simazine. *Weed Sci.* 26 : 145-8.

80 Smith, A.N. 1967. Late applications of superphosphate to wheat are ineffective. *Agric. Gaz. N.S.W.* 78 : 539-40.

81 Smith, A.N; and Woodward, H.A. 1968. Care needed in the use of new concentrated fertilisers. *Agric. Gaz. N.S.W.* 79 : 150-1.

82 Snyder, F.W. 1957. Effect of moisture and fertilisation of sugar beet seedlings. *J. Am. Soc. Sugarbeet Tech.* 9 : 450-6.

83 Soane, B.D; Butson, M.J; Pidgeon, J.D. 1974. Soil/machine interactions in zero-tillage for cereals and raspberries in Scotland. *Outlook on Agric. Special Number:* 222.

84 Strong, W.M; and Soper, R.J. 1973. Utilization of pelleted phosphorus by flax, wheat, rape, and buckwheat from a calcerious soil. *Agron. J.* 65 : 18-21.

85 Taylor, R. 1967. Bipyridyl herbicides and the direct establishment of crops in uncultivated soil. 1. Cereals. *Proc. 20th N.Z. Weed and Pest Control Conf.* P. 74.

86 Triplett, Jr, G.B; Van Doren, Jr, D.M. 1963. Chemicals make possible no tillage corn. *Ohio Farm and Home Res.* Jan-Feb: 6-7.

87 Triplett, Jr, G.B; Van Doren, Jr, D.M. 1969. Nitrogen, phosphorus and potassium fertilisation of non-tilled maize. *Agron. J.* 61 : 637-9.

88 Triplett, Jr, G.B; Johnson, W.H; and Van Doren, Jr, D.M. 1963. Performance of two experimental planters for no-tillage corn culture. *Agron. J.* 55 ; 408-9.

89 Triplett, Jr, G.B; Van Doren, Jr, D.M; Schmidt, B.L. 1968. Effect of corn stover mulch on no-tillage corn yield and water infiltration. *Agron. J.* 60 : 236-9.

90 Triplett, Jr, G.B; Conner, B.J; Edwards, W.M. 1978. Herbicide runoff from conventional and no-tillage corn fields. *Ohio Report on Research and Development* (Ohio Agri. Res and Dev. Centre, Wooster). 63 : 70-73.

91 Ulysses, S.J. 1979. *Fertilisers and Soil Fertility.* (Reston Pub. Co. Virginia. U.S.A.). P 108.

92 Unger, P.W; Allen, R.R; Wiese, A.F. 1971. Tillage and herbicides for surface residue maintenance weed control and water conservation. *J. Soil and Water Cons.* 26 : 147-50.

93 Weirsum, L.K. 1962. Uptake of nitrogen and phosphorus in relation to soil structure and nutrient mobility. *Plant and Soil.* 16 : 62-70.

94 Welch, L.F; Mulvaney, D.L; Boone, L.V; Mckibben, G.E; and Pendelton, J.W. 1966. Relative efficiency of broadcast vs banded P for corn. *Agron. J.* 58 : 283-7.

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APPENDIX 1

Results of seedling emergence - Small Pot Experiment.

Treatment	Replicate	6	7	8	9	10	11	12	13	14	15	16
		% Seedling emergence										
		Day from sowing										
Seed Sown	1	80	85	95	95	95	95	95	95	95	95	95
Without Fertiliser	2	50	65	75	75	80	80	80	80	80	80	80
	3	60	75	90	90	90	90	90	90	90	90	90
	Mean	63	75	87	87	88	88	88	88	88	88	88
Seed and Fertiliser												
Mixed	1	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	20	35	45	45	45	45	45	45	45
	3	0	0	25	35	35	40	45	45	50	50	50
	Mean	0	0	15	23	27	28	30	30	32	32	32
Horizontally	1	0	0	15	35	40	40	45	45	45	45	45
separately by	2	0	35	70	80	80	85	85	85	85	85	85
10mm	3	0	10	50	60	70	70	75	75	75	75	75
	Mean	0	15	45	58	63	65	68	68	68	68	68
Horizontally	1	15	55	60	70	70	70	70	70	70	70	70
separately by	2	25	50	60	65	65	65	65	65	65	65	65
20mm	3	25	50	50	65	65	65	65	65	65	65	65
	Mean	22	52	57	67	67	67	67	67	67	67	67
Vertically	1	0	0	15	35	45	55	55	60	60	65	65
separated by	2	0	0	0	20	30	40	40	45	45	45	45
10mm	3	0	0	5	10	10	15	15	15	15	15	15
	Mean	0	0	7	22	28	37	37	40	40	42	42
Vertically	1	10	30	65	75	85	85	85	90	90	90	90
separated by	2	5	30	40	50	55	55	55	55	55	55	55
20mm	3	0	5	15	25	45	45	50	50	50	50	50
	Mean	5	22	40	50	62	62	63	65	65	65	65

APPENDIX 2

Results of seedling emergence - Small Pot Experiment.
% seedling emergence on day from sowing.
After irrigation (on day 21 from sowing)

Treatment		Replicate	21	22	23	24	25	26	27	28	29	30	31	37
Seed Sown		1	95	95	95	95	95	95	95	95	95	95	95	95
Without Fertiliser		2	80	80	80	80	80	80	80	80	80	80	80	80
		3	90	90	90	90	90	90	90	90	90	90	90	90
		Mean	88	88	88	88	88	88	88	88	88	88	88	88
Seed and Fertiliser	Mixed	1	0	0	0	0	10	15	20	25	30	35	40	25
		2	45	45	50	50	50	50	50	50	50	50	50	50
		3	50	50	50	50	50	50	50	50	50	50	50	45
		Mean	32	32	33	33	37	38	40	42	43	45	47	40
	Horizontally separated by 10mm	1	45	45	50	55	55	55	55	55	55	55	60	60
		2	85	85	85	85	85	85	85	85	85	85	85	85
		3	75	75	75	75	75	75	75	75	75	75	75	75
		Mean	68	68	70	72	72	72	72	72	72	72	73	73
	Horizontally separated by 20mm	1	70	70	70	70	70	70	70	70	70	70	70	70
		2	65	65	65	65	65	65	65	65	65	65	65	65
		3	65	65	65	70	70	70	70	70	70	70	70	70
		Mean	67	67	68	68	68	68	68	68	68	68	68	68
	Vertically separated by 10mm	1	65	65	65	65	65	65	65	65	65	65	65	60
		2	45	45	45	45	45	45	45	45	45	50	50	40
		3	15	15	20	20	20	20	20	20	35	40	45	45
		Mean	42	42	43	43	43	43	43	43	48	52	53	48
	Vertically separated by 20mm	1	90	90	90	90	90	90	90	90	90	90	90	90
		2	60	60	60	60	60	60	60	60	60	60	60	60
		3	50	50	50	50	50	50	50	50	50	50	50	50
		Mean	67	67	67	67	67	67	67	67	67	67	67	67

APPENDIX 3

Yield characteristics of rape plants, harvested on day 37 from sowing (Small Pot Experiment).

			Per Plant				Total	
Treatment		Replicate	No. of Leaves	Height (cm)	Fresh Weight (g)	Dry Weight (mg)	Fresh Weight (g)	Dry Weight (mg)
Seed Sown Without Fertiliser		1	3.9	5.8	0.40	40	7.6	770
		2	4.1	6.7	0.51	49	8.2	790
		3	4.2	6.5	0.49	49	8.7	878
		Mean	4.1	6.3	0.47	46	8.2	813
Seed and fertiliser	Mixed	1	2.4	1.9	0.04	5	0.2	26
		2	3.5	3.8	0.21	22	2.1	223
		3	3.9	5.2	0.41	41	3.7	368
		Mean	3.3	3.6	0.22	23	2.0	206
	Horizontally separated by 10mm	1	3.4	3.6	0.25	23	3.0	280
		2	3.6	4.1	0.21	22	3.6	380
		3	2.9	2.8	0.09	13	1.4	200
		Mean	3.3	3.5	0.18	19	2.7	287
	Horizontally separated by 20mm	1	3.9	5.4	0.55	55	7.7	768
		2	4.1	5.4	0.40	36	5.2	472
		3	4.9	10.5	1.64	150	21.3	1955
		Mean	4.3	7.1	0.86	80	11.4	1065
	Vertically separated by 10mm	1	3.7	4.1	0.31	35	3.7	426
		2	3.7	4.3	0.16	27	1.3	213
		3	2.4	3.1	0.17	15	1.7	153
		Mean	3.3	3.8	0.21	26	2.3	264
	Vertically separated by 20mm	1	4.3	7.0	0.69	73	12.4	1310
		2	4.0	4.7	0.30	34	3.6	410
		3	4.3	6.4	0.61	56	6.1	562
		Mean	4.2	6.0	0.53	54	7.4	761

APPENDIX 4

Initiation of seedling emergence and delay in maximum seedling emergence prior to irrigation.

(Small Pot Experiment)

Treatment		Replicate	Days from Sowing: Initiation of Seedling Emergence	Days from Sowing: Maximum Seedling Emergence
Seed sown without fertiliser		1	6	8
		2	6	10
		3	6	8
		Mean	6	8.7
Seed and fertiliser	Mixed	1	8 *	12 *
		2	8	10
		3	8	14
		Mean	8	12
	Horizontally separated by 10mm	1	8	12
		2	7	11
		3	7	12
		Mean	7.3	11.7
	Horizontally separated by 20mm	1	6	9
		2	6	9
		3	6	9
		Mean	6	9
	Vertically separated by 10mm	1	8	15
		2	9	13
		3	8	11
		Mean	8.3	13
	Vertically separated by 20mm	1	6	13
		2	6	10
		3	7	12
		Mean	6.3	11.7

* Calculated as a missing value

APPENDIX 5

Meteorological Data * --- Massey University Station

		1980			
		March	April	May	June
1.	Mean monthly temperature (C^o)	15.3	13.4	11.5	8.4
2.	Range of mean temperature (C^o)	7.7	8	7.5	8
3.	Mean daily rain (mm)	4.6	3.4	1.2	2
4.	Mean daily bright Sun hours	3.3	3.3	3.4	2.6

* Agronomy Department, Massey University Records.

APPENDIX 6

Drilling 1 Results (Field experiment)

Date of drilling 14.3.1980

Date of harvesting 1.7.1980

Particulars		Cultivated Replicates					Uncultivated Replicates				
		1	2	3	4	Mean	1	2	3	4	Mean
Soil moisture at drilling (% db)		19.1	15.6	17.4	18.5	17.6	23.6	20.2	20.0	17.1	20.2
Rape plant counts/m^2 on day from sowing	8	1.7	2.7	2.3	2.7	2.3	16.3	11.0	10.7	5.0	10.7
	9	2.3	5.7	6.7	4.7	4.8	20.0	17.0	22.0	5.7	16.2
	10	7.0	11.7	15.0	13.3	11.7	30.7	25.3	31.3	13.7	25.2
	11	11.7	18.0	23.0	22.3	18.7	43.0	39.0	40.3	22.0	36.1
	12	17.3	22.0	30.3	26.7	24.1	52.0	51.0	46.0	35.7	46.2
	13	21.7	29.0	35.3	30.0	28.0	53.3	55.7	48.3	41.0	49.6
	14	25.3	36.7	42.7	35.3	35.0	56.7	65.0	55.3	50.0	56.7
	15	28.3	40.3	44.3	40.0	38.2	61.0	70.7	58.7	51.7	60.5
	16	31.0	43.3	48.0	44.7	41.7	64.7	70.0	58.7	61.7	63.7
	17	29.3	45.0	51.3	45.7	42.8	67.7	69.3	56.0	62.7	63.9
	18	30.0	46.0	52.7	46.7	43.8	69.3	69.7	58.3	65.0	65.6
	19	31.0	43.3	48.7	44.0	41.7	64.0	70.0	60.0	62.7	64.2
	20	30.0	43.3	48.7	45.7	41.9	65.3	70.0	60.0	64.0	64.8
	21	30.0	44.7	48.3	46.0	42.2	65.3	66.0	60.0	64.0	63.8
Yield	Fresh weight (kg)	5.5	3.6	4.6	5.3	4.7	7.7	3.8	5.8	6.4	5.9
	Dry weight (g)	650	493	638	686	617	867	484	681	783	704
Dry weight leaf/stem ratio		1.4	0.9	1.1	1.1	1.1	1.2	1.0	1.0	0.9	1.0
Days to maximum plant counts		19	18	18	18	18.2	18	15	19	18	17.5

APPENDIX 7

Plant analysis for major elements (Field experiment) Drilling 1.

% weight

Plant fraction	Major element	Cultivated Replicates 1	2	3	4	Mean	Uncultivated Replicates 1	2	3	4	Mean
Leaf	N	3.45	3.40	4.20	3.60	3.66	4.00	4.00	3.75	3.30	3.76
	P	0.45	0.45	0.40	0.41	0.43	0.48	0.51	0.45	0.36	0.45
	K	4.23	2.85	2.28	3.85	3.30	4.35	3.18	3.84	3.64	3.75
	Ca	1.91	1.38	1.75	1.74	1.69	1.97	1.52	1.54	1.97	1.75
	Na	0.21	0.08	0.27	0.24	0.20	0.17	0.13	0.15	0.20	0.16
	Mg	0.22	0.20	0.23	0.19	0.21	0.23	0.20	0.25	0.23	0.23
	S	0.88	0.78	0.90	0.83	0.85	0.74	0.74	0.89	0.90	0.82
Stem	N	1.60	1.50	2.65	1.85	1.90	1.50	2.00	1.60	1.75	1.71
	P	0.40	0.38	0.33	0.38	0.37	0.32	0.44	0.36	0.32	0.36
	K	4.53	3.72	3.10	3.80	3.79	4.44	4.24	4.73	4.05	4.36
	Ca	0.38	0.55	0.78	0.72	0.61	0.78	0.55	0.59	0.72	0.66
	Na	0.08	0.07	0.25	0.16	0.14	0.15	0.09	0.11	0.13	0.12
	Mg	0.13	0.12	0.17	0.15	0.15	0.12	0.13	0.14	0.18	0.14
	S	0.45	0.41	0.51	0.44	0.45	0.39	0.45	0.46	0.51	0.45

APPENDIX 8

Drilling 2 Results (Field experiment)

Date of drilling 21.3.1980

Date of harvesting 1.7.1980

Particulars		Cultivated Replicates					Uncultivated Replicates				
		1	2	3	4	Mean	1	2	3	4	Mean
Soil moisture at drilling (% db)		26.1	25.0	25.7	25.0	25.5	27.2	25.4	25.0	27.5	26.3
Rape plant counts/m^2 on day from sowing	7	13.3	12.3	8.0	5.3	9.7	8.7	10.0	7.0	12.7	9.6
	8	38.3	34.3	18.7	16.7	27.0	24.7	29.3	24.7	25.3	26.0
	9	55.3	51.7	36.7	32.0	43.9	39.3	37.3	46.7	45.0	42.1
	10	63.3	71.7	46.7	50.7	58.1	56.7	51.7	62.0	62.3	58.2
	11	79.0	88.0	54.0	60.7	70.4	77.7	69.0	75.0	83.3	76.2
	12	82.0	92.0	60.0	63.3	74.3	80.7	74.0	79.3	86.7	80.2
	13	81.3	94.0	60.0	63.3	74.7	83.3	69.3	80.0	88.3	80.2
	14	84.0	96.0	60.0	67.0	76.7	88.3	83.3	80.0	92.3	86.0
	15	85.0	96.0	60.7	71.7	78.3	90.0	83.3	80.3	92.7	86.6
	16	85.3	96.7	60.3	72.0	78.6	91.7	84.0	80.7	95.0	87.8
	17	86.0	97.0	60.7	72.7	80.0	92.7	82.7	80.0	96.7	88.0
	18	86.0	95.0	61.0	73.3	79.3	93.3	81.7	80.3	97.3	88.2
	19	88.3	94.7	60.0	70.7	78.5	93.3	81.0	78.7	93.7	88.7
	20	88.0	95.0	59.3	70.0	78.0	92.7	80.7	78.7	93.3	86.3
	21	87.3	95.0	59.3	69.3	77.7	91.7	80.0	78.3	93.3	85.8
Yield	Fresh Weight (kg)	7.2	5.2	2.3	3.1	4.5	5.2	4.2	4.4	6.2	5.0
	Dry Weight (g)	862	635	312	398	552	642	594	583	730	637
Dry weight leaf/stem ratio		1.5	1.8	1.8	1.9	1.7	2.0	1.7	2.4	2.1	2.0
Days to maximum plant counts		19	18	18	18	18.2	18	16	16	18	17.0

APPENDIX 9

Plant analysis for major elements (Field experiment) Drilling 2

% weight

Plant	Major	Cultivated Replicates					Uncultivated Replicates				
fraction	element	1	2	3	4	Mean	1	2	3	4	Mean
Leaf	N	3.60	4.20	3.40	3.90	3.77	3.75	2.30	3.20	4.30	3.39
	P	0.47	0.53	0.48	0.51	0.50	0.54	0.48	0.43	0.49	0.48
	K	3.25	3.27	3.55	3.27	3.33	3.39	3.12	3.29	3.15	3.24
	Ca	1.98	1.65	1.41	1.44	1.62	1.62	1.38	1.64	1.70	1.58
	Na	0.24	0.11	0.10	0.13	0.14	0.10	0.08	0.13	0.22	0.13
	Mg	0.22	0.20	0.21	0.20	0.21	0.21	0.17	0.19	0.23	0.20
	S	0.74	0.71	0.72	0.87	0.76	0.73	0.77	0.87	0.88	0.81
Stem	N	1.50	2.10	1.85	2.45	1.97	1.35	1.70	2.00	2.20	1.81
	P	0.34	0.48	0.43	0.47	0.43	0.40	0.43	0.42	0.41	0.42
	K	4.42	4.27	4.20	4.35	4.31	4.44	3.75	3.77	4.25	4.05
	Ca	0.72	0.64	0.64	0.65	0.66	0.48	0.49	0.75	0.68	0.60
	Na	0.21	0.09	0.09	0.11	0.12	0.09	0.07	0.09	0.11	0.09
	Mg	0.13	0.15	0.17	0.17	0.16	0.13	0.13	0.17	0.16	0.15
	S	0.43	0.49	0.51	0.52	0.49	0.44	0.45	0.52	0.50	0.48

APPENDIX 10

Drilling 3 Results (Field experiment)

Date of drilling 2.4.1980

Particulars		Cultivated Replicates					Uncultivated Replicates				
		1	2	3	4	Mean	1	2	3	4	Mean
Soil moisture at drilling (% db)		32.0	41.0	42.0	40.0	38.7	37.0	36.0	35.0	34.0	35.5
Rape plant counts/m^2 on day from sowing	10	0	0.6	9.0	8.3	4.5	0.6	4.0	1.7	4.0	2.6
	11	0	1.0	10.3	9.3	5.1	1.0	4.0	3.0	4.0	3.0
	12	0	1.0	12.0	10.3	5.8	1.0	4.0	3.7	4.3	3.2
	13	0	1.0	15.0	11.3	6.8	1.0	4.0	4.3	7.3	4.1
	14	0	2.0	15.7	13.0	7.7	1.3	5.3	5.3	10.0	5.5
	15	0	2.0	16.3	13.3	7.9	1.3	6.7	5.7	10.3	6.0
	16	0	2.3	17.3	12.7	8.1	1.3	6.7	5.0	10.3	5.8
	17	0	2.7	17.7	13.3	8.2	1.3	6.7	5.3	10.3	5.9
	18	0	2.3	16.7	13.3	8.1	1.3	6.0	5.7	10.3	5.8
	19	0	2.3	16.7	13.3	8.1	1.3	6.0	5.7	10.7	5.9
	20	0	2.7	16.7	14.7	8.5	1.3	6.7	6.0	10.7	6.2
	21	0	3.0	16.7	15.0	8.7	1.3	7.3	6.3	10.7	6.4
Days to maximum plant counts		19.6 *	21	17	21	19.6	14	21	21	19	18.7

* Calculated as a missing value.

APPENDIX 11

Drilling 4 Results (Field experiment)

Date of drilling 14.4.1980

Particulars		Cultivated Replicates					Uncultivated Replicates				
		1	2	3	4	Mean	1	2	3	4	Mean
Soil moisture at drilling (% db)		29.0	26.0	33.0	31.0	29.7	30.0	30.0	31.0	26.0	29.2
Rape plant counts/m^2 on day from sowing	8	15.0	14.0	13.3	13.7	14.0	9.0	8.3	7.3	11.3	9.0
	9	32.7	28.3	19.7	32.3	28.2	13.0	16.7	14.7	22.3	16.7
	10	48.0	45.7	27.7	43.3	41.2	29.0	24.3	19.7	23.3	24.1
	11	58.7	52.0	31.3	51.7	48.4	34.3	27.3	24.0	26.7	28.1
	12	68.7	58.7	35.3	60.0	55.7	39.3	30.3	28.0	30.0	31.9
	13	75.7	61.0	40.7	65.0	60.6	41.3	32.3	31.3	33.3	34.6
	14	80.0	67.3	44.7	69.3	65.3	57.3	42.0	41.7	41.7	45.7
	15	84.7	73.3	48.3	73.7	70.0	72.7	51.7	51.7	50.0	56.5
	16	86.3	74.7	49.3	73.3	70.9	79.3	51.7	51.7	50.0	58.2
	17	85.3	71.0	46.7	73.3	69.1	95.0	60.7	53.3	52.3	65.3
	18	85.0	72.3	50.0	73.3	70.2	103.3	62.7	61.7	53.3	70.2
	19	86.0	73.3	51.0	73.3	70.9	96.7	66.3	60.7	56.7	70.1
	20	86.7	72.0	51.3	73.3	70.8	98.7	67.7	62.3	59.3	72.0
	21	87.0	70.7	51.7	73.3	70.7	100.7	68.0	63.7	60.0	73.1
Days to maximum plant counts		21	16	21	15	18.2	18	21	21	21	20.2

APPENDIX 12

Drilling 5 Results (Field experiment)

Date of drilling 17.4.1980

Particulars		Cultivated Replicates					Uncultivated Replicates				
		1	2	3	4	Mean	1	2	3	4	Mean
Soil moisture at drilling (% db)		20.0	24.0	24.0	20.0	22.0	25.0	24.0	26.0	24.0	24.7
Rape plant counts/m^2 on day from sowing	9	6.7	5.3	10.7	10.7	8.3	37.3	14.0	33.3	23.3	27.0
	10	10.7	25.0	28.0	41.3	26.2	55.0	33.3	55.7	56.0	50.0
	11	22.0	41.7	40.0	55.0	39.7	67.3	50.0	68.7	69.3	63.8
	12	33.3	58.0	51.7	69.0	53.0	80.0	66.7	81.3	82.3	76.0
	13	38.0	61.3	52.7	70.0	55.5	81.3	67.3	84.7	81.7	78.7
	14	44.0	64.7	52.7	71.7	58.2	84.7	72.7	89.3	87.0	83.4
	15	44.3	67.3	52.7	71.7	59.0	86.7	75.7	89.3	88.0	84.9
	16	46.0	69.0	52.7	72.3	60.0	88.7	77.0	91.7	88.3	86.4
	17	48.7	69.3	54.0	72.0	61.0	88.0	78.3	92.7	90.0	87.2
	18	50.7	69.0	53.3	71.7	61.1	88.7	79.0	94.0	91.0	88.2
	19	51.0	70.0	54.3	73.3	62.2	88.3	78.3	94.3	91.7	88.2
	20	51.3	71.0	55.0	74.7	63.0	88.3	77.7	94.7	92.7	88.3
	21	53.3	69.7	55.7	74.0	63.2	89.7	79.0	94.7	94.3	89.4
Days to maximum plant counts		21	20	21	20	20.5	21	18	20	21	20

APPENDIX 13

Drilling 6 Results (Field experiment)

Date of drilling 22.4.1980

Particulars		Cultivated Replicates					Uncultivated Replicates				
		1	2	3	4	Mean	1	2	3	4	Mean
Soil moisture at drilling (% db)		15.0	19.0	17.0	16.0	16.7	23.0	25.0	23.0	22.0	23.2
Rape plant counts/m² on day from sowing	7	4.7	0	0.3	0.3	1.3	12.3	20.0	9.0	7.3	12.2
	8	14.3	0.3	1.0	1.7	4.3	28.3	35.3	14.7	24.7	25.7
	9	31.7	3.7	2.0	11.7	12.2	40.0	44.0	23.3	33.3	35.2
	10	45.0	5.7	5.7	18.3	18.7	46.7	55.3	25.7	38.3	41.5
	11	56.0	8.0	7.7	30.3	25.5	47.7	60.0	34.3	47.3	47.3
	12	60.3	9.3	10.7	34.7	28.7	49.0	65.3	37.7	47.3	49.8
	13	64.3	10.3	12.3	39.0	31.5	50.3	70.7	40.7	47.3	52.2
	14	66.7	11.7	14.0	40.0	33.1	50.7	74.7	45.3	44.0	53.7
	15	68.3	13.0	15.3	40.7	34.3	52.7	78.3	50.0	44.3	56.3
	16	73.7	14.0	16.3	42.7	36.7	53.3	78.7	53.3	44.7	57.5
	17	71.3	13.3	17.7	42.7	36.2	51.7	80.0	52.3	44.3	57.1
	18	76.3	13.7	18.3	45.7	38.5	54.0	82.0	56.7	45.3	59.5
	19	78.0	15.0	18.7	48.3	40.0	54.3	83.3	55.0	45.7	59.6
	20	78.7	14.0	19.3	47.3	39.8	54.3	83.3	55.0	47.3	60.0
	21	79.3	14.0	20.0	47.0	40.1	54.3	83.7	55.3	49.3	60.7
Days to maximum plant counts		21	19	21	19	20	19	21	18	21	19.7

APPENDIX 14

Drilling 7 Results (Field experiment)

Date of drilling 29.4.1980

Particulars		Cultivated Replicates					Uncultivated Replicates				
		1	2	3	4	Mean	1	2	3	4	Mean
Soil moisture at drilling (% db)		35.0	35.0	33.0	35.0	34.5	35.0	32.0	35.0	36.0	34.5
Rape plant counts/m^2 on day from sowing	9	1.7	4.0	1.7	1.7	2.3	4.3	4.7	4.3	2.3	3.9
	10	3.3	8.7	4.7	4.0	5.2	6.0	8.3	8.3	6.0	7.1
	11	10.3	16.0	9.0	10.3	11.4	13.6	15.3	15.0	13.0	14.2
	12	15.7	21.7	13.7	15.7	16.7	20.7	26.3	24.0	20.0	22.7
	13	21.3	28.7	19.7	19.0	22.2	27.0	32.0	31.0	24.0	28.5
	14	26.3	38.7	24.7	22.3	28.0	35.7	43.0	38.7	29.3	36.7
	15	31.0	40.7	28.3	25.0	31.2	38.3	46.7	42.7	31.3	39.7
	16	35.7	43.0	31.7	27.3	34.4	41.0	50.0	46.3	33.3	42.6
	17	38.0	44.3	33.3	28.3	36.0	42.7	51.7	48.0	34.7	44.3
	18	39.0	45.0	34.3	29.3	36.9	43.3	52.7	48.7	35.7	45.1
	19	39.3	45.0	34.7	29.3	37.1	43.7	52.7	48.3	36.0	45.2
	20	39.3	45.3	35.0	30.0	37.4	43.3	53.0	49.0	36.0	45.3
	21	39.7	45.3	35.0	30.3	37.6	43.7	53.3	49.3	36.0	45.6
Days to maximum plant counts		21	20	20	21	20.5	19	21	21	19	20.0

APPENDIX 15 Large Bin Experiment: Seedling Emergence Results.

Treatments			Replicate	Seedling emergence m^{-1} on day from sowing															
Moisture	Placement	Fertiliser		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Dry	Horizontal	Fo	1	0	0	0	0.5	0.5	0.5	3	3	3	3	3	3	3	3	3	3
			2	0	0	0	0.5	1	1.5	2.5	4	5	5.5	6	6.5	8	8	8	8
			3	0	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
			Mean	0	0	0	0.3	0.7	0.8	2	2.5	2.8	3	3.2	3.3	3.8	3.8	3.8	3.8
		Fn	1	0	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
			2	0	0	0.5	0.5	1	2	2.5	3	3.5	3.5	3.5	3.5	4	4	4	4
			3	1.5	2.5	3.5	3.5	3.5	4	4.5	4.5	5	5.5	5.5	5.5	6	6	6.5	6.5
			Mean	0.5	0.8	1.3	1.3	1.7	2.2	2.5	2.7	3	3.2	3.2	3.2	3.5	3.5	3.7	3.7
		F_N	1	0	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
			2	0	0	0	0	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
			3	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
			Mean	0	0	0	0.2	0.3	0.3	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Continued..

Treatments			Replicate	Seedling emergence m^{-1} on day from sowing															
Moisture	Placement	Fertiliser		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Dry	Horizontal	Fp	1	0	0	0	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
			2	0	0	0	1	2.5	5	8	10	12	14	14.5	16	18	18	19	19.5
			3	0	0	0	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1
			Mean	0	0	0	0.3	0.8	1.7	3	3.3	4.3	5	5.2	5.7	6.3	6.5	6.8	7
		F_p	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0.5	3.5	6	9	11.5	11.5	14.5	16.5	17.5	18	18	19	19.5	20
			3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			Mean	0	0	0.2	1.2	2	3	3.8	3.8	4.8	5.5	5.8	6	6	6.3	6.5	6.7
	MEAN			0.1	0.2	0.3	0.7	1.1	1.6	2.3	2.6	3.1	3.4	3.6	3.7	4.0	4.1	4.3	4.3
	Vertical	Fo	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	1	3	6	7.5	10	11.5	12.5	13.5	14	14.5	14.5	15	15.5	16
			3	0	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
			Mean	0	0	0.3	1	2.2	2.7	3.5	4	4.3	4.7	4.8	4.8	4.8	5.2	5.2	5.5

Continued..

Treatments			Replicate	Seedling emergence m^{-1} on day from sowing															
Moisture	Placement	Fertiliser		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	Vertical	Fn	1	0	0	0	0	0	0	1.0	1.0	1.5	1.5	2.5	4	4	4	4	4
			2	0	0	0	0.5	1	1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2	2.5
			3	3	1	3	3	3	3	3	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
			Mean	0.3	1	1	1.2	1.3	1.7	2	2.2	2.2	2.5	3	3	3	3	3.2	3.2
		F_N	1	0	0	1.5	1.5	2	3.5	3.5	3.5	4	4	4	4	4	4	4	4
			2	0	0	0.5	5	12.5	15.5	16	18	20	20	21	21.5	21.5	22	22	22
			3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			Mean	0	0	0.7	2.2	4.8	6.3	6.5	7.2	8	8	8.3	8.5	8.5	8.7	8.7	8.7
		Fp	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0.5	1.5	1.5	1.5	1.5	2	2.5	2.5	3	3.5	3.5	4	4.5
			3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			Mean	0	0	0	0.2	0.5	0.5	0.5	0.5	0.7	0.8	0.8	1	1.2	1.2	1.3	1.5

Continued..

Treatments			Replicate	Seedling emergence m^{-1} on day from sowing															
Moisture	Placement	Fertiliser		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	Vertical	F_P	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0.5	0.5	2	4.5	5.5	5.5	7	7	7	7	7.5	8.5	9
			3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			Mean	0	0	0	0.2	0.2	0.7	1.5	1.8	1.8	2.3	2.3	2.3	2.3	2.5	2.8	3
	MEAN			0.1	0.2	0.4	1	1.8	2.4	2.8	3.1	3.4	3.7	3.8	3.9	4	4.1	4.2	4.4
	Mixed	Fo	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	1	2	3	4.5	5	5	8.5	8.5	9	9	9.5	10	10.5
			3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			Mean	0	0	0	0.3	0.7	1	1.5	1.7	1.7	2.8	2.8	3	3	3.2	3.3	3.5
		Fn	1	0	0	0	0	0	0	0	0.5	0.5	0.5	1	1	1	1	1	1
			2	0	0	0.5	1	1.5	3	3.5	4.5	6	7	7	7	7	7	7	7
			3	3	4	5	5	6	7	7	7	7.5	7.5	7.5	8	8.5	8.5	8.5	8.5
			Mean	1	1.3	1.8	2	2.2	3.3	3.5	4	4.7	5	5.2	5.3	5.5	5.5	5.5	5.5

Continued..

Treatments			Replicate	Seedling emergence m^{-1} on day from sowing															
Moisture	Placement	Fertiliser		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
		F_N	1	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2
			2	0	0	0.5	2.5	4	4.5	5	5.5	6.5	8	8	8	8	8	8	8.5
			3	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
			Mean	0	0	0.2	1	1.5	1.7	2.5	2.7	3	3.5	3.5	3.5	3.5	3.5	3.5	3.7
		Fp	1	0	0	0	0	0.5	0.5	1	2	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
			2	0	0	0	0	0.5	0.5	0.5	1	1.5	1.5	1.5	1.5	1.5	2	2.5	3
			3	0	0	0	1.5	1.5	1.5	2.5	3	3	3.5	3.5	3.5	3.5	3.5	3.5	3.5
			Mean	0	0	0	0.5	0.8	0.8	1.3	2	2.3	2.5	2.5	2.5	2.5	2.7	2.8	3
		F_P	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	0	0	0	0.5	0.5	1	1	1	1	1	1
			3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			Mean	0	0	0	0	0	0	0	0	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3
	MEAN			0.2	0.3	0.4	0.8	1	1.4	1.8	2.1	2.4	2.8	2.9	2.9	3	3	3.1	3.2
M E A N				0.1	0.2	0.4	0.8	1.3	1.8	2.3	2.6	3	3.3	3.4	3.5	3.7	3.7	3.9	4

contd....

Treatments			Replicate	Seedling emergence m^{-1} on day from sowing															
Moisture	Placement	Fertiliser		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Wet	Horizontal	Fo	1	0	0	0	1.5	2.5	3	4	4	4	5	5	5	5	5	5	5
			2	0	0	2.5	4	5	8.5	9	11.5	11.5	11.5	11.5	12	12	12	12	12.5
			3	0.5	0.5	0.5	1	1	1	1.5	1.5	2	2	2.5	2.5	2.5	2.5	2.5	2.5
			Mean	0.2	0.2	1	2.2	2.5	4.2	4.8	5.7	5.8	6.2	6.3	6.5	6.5	6.5	6.5	6.7
		Fn	1	0	0	0	2	2.5	2.5	3	3.5	3.5	5	5	5	5.5	5.5	5.5	5.5
			2	0	0	0	0	0.5	0.5	1	1.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
			3	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
			Mean	0	0.2	0.2	0.8	1.2	1.2	1.5	1.8	2.2	2.7	2.7	2.7	2.8	2.8	2.8	2.8
		F_N	1	0	0	0	1	1	2	2.5	2.5	2.5	3	3	3	3	3	3	3
			2	0	0	0.5	1	1.5	2	2	2.5	3	3	3.5	3.5	4	4	4	4.5
			3	0	0	0	0	0	0	0.5	1	1.5	2	2	2	2	2.5	2.5	2.5
			Mean	0	0	0.2	0.7	0.8	1.3	1.7	2	2.3	2.7	2.8	2.8	3	3.2	3.2	3.3

Continued..

Moisture	Placement	Fertiliser	Replicate	Seedling emergence m^{-1} on day from sowing: 6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
		Fp	1	0	0	0	0.5	1	1	2.5	2.5	2.5	3	3	3	3	3	3	3
			2	0	0	2.5	4.5	8	8	11.5	11.5	12.5	13.5	14	14	14.5	14.5	14.5	15
			3	1.5	2.5	3	4.5	5	5	5	5	5.5	6	6	6	6	6	6	6
			Mean	0.5	0.8	1.8	3.2	4.7	4.7	6.3	6.3	6.8	7.5	7.7	7.7	7.8	7.8	7.8	8
		F_P	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	1.5	3	4.5	4.5	5	5.5	5.5	5.5	5.5	6	6	6	6
			3	1.5	5.5	7.5	8	9	11	12	13	13	13	13	13	13	13	13	13
			Mean	0.5	1.8	2.5	3.2	4	5.2	5.5	6	6.2	6.2	6.2	6.2	6.3	6.3	6.3	6.3
	MEAN			0.2	0.6	1.1	2	2.6	3.3	4	4.4	4.7	5.1	5.1	5.2	5.3	5.3	5.3	5.4
	Vertical	Fo	1	0	0	0	0.5	1	1	1	1.5	2	2.5	2.5	2.5	2.5	2.5	2.5	2.5
			2	0	0	1.5	5	11	13	15	15.5	16	16	16	16	16	17	17.5	17.5
			3	2	3	5	6.5	7	8	8.5	8.5	9	9	9	9	9	9.5	10	10
			Mean	0.7	1	2.2	4	6.3	7.3	8.2	8.5	9	9.2	9.2	9.2	9.2	9.7	10	10

Continued..

Treatments			Replicate	Seedling emergence m^{-1} on day from sowing															
Moisture	Placement	Fertiliser		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
		Fn	1	0	0	0	0.5	0.5	1.5	1.5	2	2	2	3	3	3	3	3	3
			2	0	0	2.5	4	6	10	11	12	13	14	15	15.5	16	16	16	16
			3	3	7	7	8	9	9	9.5	10.5	11	11	11	11	11	11	11	11
			Mean	1	2.3	3.2	4.2	5.2	6.8	7.3	8.2	8.7	9	9.7	9.8	10	10	10	10
		F_N	1	0	0	0	0	0	0	0	0.5	0.5	0.5	1.5	1.5	1.5	1.5	1.5	1.5
			2	0	0	1	3	4.5	4.5	7	7	8	8.5	9	9.5	10	10	10	10.5
			3	0	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
			Mean	0	0	0.5	1.2	1.7	1.7	2.5	2.7	3	3.2	3.7	3.8	4	4	4	4
		Fp	1	0	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	1	1
			2	0	0	2	4	6	7	8	8	8	8.5	8.5	8.5	9	9.5	9.5	10
			3	5.5	9	13	14	16	17.5	18.5	18.5	18.5	18.5	18.5	19	19	19	19	19
			Mean	1.8	3	5	6	7.5	8.3	9	9	9	9.2	9.3	9.5	9.7	9.8	9.8	10

Continued..

Treatments: Moisture	Treatments: Placement	Treatments: Fertiliser	Replicate	Seedling emergence m^{-1} on day from sowing: 6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
		F_P	1	0	0	0	1	1.5	4	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
			2	0	0	0	1	2.5	4	5.5	5.5	7	7	7.5	7.5	7.5	8	8	8
			3	0.5	1.5	4	5.5	6.5	7	7	7	7.5	8	8.5	8.5	8.5	8.5	8.5	8.5
			Mean	0.2	0.5	1.3	2.5	3.5	5	5.7	5.7	6.3	6.5	6.8	6.8	6.8	7	7	7
	MEAN			0.7	1.4	2.4	3.6	4.8	5.8	6.5	6.8	7.2	7.4	7.7	7.8	7.9	8.1	8.2	8.2
	Mixed	Fo	1	0	0	0	1	1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2	2	2
			2	0	0	1	2	3	4	5.5	6.5	6.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
			3	0	0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
			Mean	0	0	0.8	1.5	1.8	2.3	2.8	3.2	3.2	3.5	3.5	3.5	3.5	3.7	3.7	3.7
		Fn	1	0	0	0	0	0.5	1	1	1.5	1.5	2	2.5	2.5	2.5	2.5	2.5	2.5
			2	0	0	0.5	3.5	5	5.5	7	7	7.5	8	8	8.5	9	9.5	10	11
			3	3.5	4.5	6	7.5	8.5	9	9	9	9	9	9	9	9	9	9	9
			Mean	1.2	1.5	2.2	3.7	4.7	5.2	5.7	5.8	6	6.3	6.5	6.7	6.8	7	7.2	7.5

Continued..

Treatments: Moisture	Treatments: Placement	Treatments: Fertiliser	Replicate	Seedling emergence m^{-1} on day from sowing: 6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
		F_N	1	0	0	0	0	0	0.5	0.5	0.5	0.5	1	1.5	1.5	1.5	1.5	1.5	1.5
			2	0	0	0	0	0	0.5	0.5	1	1	1.5	1.5	1.5	1.5	1.5	1.5	1.5
			3	0	0	0	0	0	0.5	0.5	0.5	1	1	1	1.5	1.5	1.5	1.5	1.5
			Mean	0	0	0	0	0.2	0.5	0.7	0.7	1	1.2	1.3	1.5	1.5	1.5	1.5	1.5
		Fp	1	0	0	0	0	0	0	0.5	0.5	0.5	1	1	1	1.5	1.5	1.5	1.5
			2	0	0	0.5	2.5	4	5	6	7	8	9.5	10	10.5	10.5	10.5	10.5	10.5
			3	1	1	1	1.5	2	2	2	2	2	2	2	2	2	2	2	2
			Mean	0.2	0.3	0.5	1.2	1.8	2.3	2.8	3.2	3.5	4.2	4.3	4.5	4.7	4.7	4.7	4.7
		F_P	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			2	0	0	0.5	1.5	1.5	1.5	2	2	2.5	3	3	3.5	3.5	3.5	4	4
			3	0	0	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1.5	1.5	1.5	1.5	1.5
			Mean	0	0	0.3	0.7	0.7	0.7	0.8	0.8	1.2	1.3	1.3	1.7	1.7	1.7	1.8	1.8
	MEAN			0.3	0.4	0.8	1.4	1.8	2.2	2.6	2.7	3	3.3	3.4	3.6	3.6	3.7	3.8	3.8
MEAN				0.4	0.8	1.4	2.3	3.1	3.8	4.4	4.6	5	5.3	5.4	5.5	5.6	5.7	5.8	5.8

APPENDIX 16 Large Bin Experiment: Results of in-groove seed status and days to maximum seedling emergence of rape.

Treatments			Replicate	In-groove seed status (% seeds) on day from sowing						Days to maximum seedling emergence from sowing
				12			20			
Moisture	Placement	Fertiliser		Germinated	Viable	Dead	Germinated	Viable	Dead	
Dry	Horizontal	Fo	1	43	43	14	87	7	6	12
			2	94	6	0	96	0	4	18
			3	0	94	6	0	83	17	10
			Mean	46	48	7	61	30	9	13
		Fn	1	60	0	40	94	0	6	10
			2	71	29	0	89	0	11	18
			3	11	67	22	91	0	9	20
			Mean	47	32	21	91	0	9	16
		F_N	1	75	0	25	100	0	0	10
			2	87	0	13	88	0	12	13
			3	33	58	9	30	60	10	9
			Mean	65	19	16	73	20	7	14

Continued..

Treatments: Moisture	Treatments: Placement	Treatments: Fertiliser	Replicate	In-groove seed status (% seeds) on day from sowing: 12			20			Days to maximum seedling emergence from sowing
				Germinated	Viable	Dead	Germinated	Viable	Dead	
		Fp	1	75	0	25	90	0	10	12
			2	94	0	6	100	0	0	21
			3	0	100	0	16	83	0	19
			Mean	56	33	10	69	28	3	17
		F_P	1	35	41	24	100	0	0	21
			2	59	5	36	95	0	5	21
			3	24	48	28	25	50	25	21
			Mean	39	31	29	73	17	10	21
	Mean			41	19	9	65	6	5	16
	Vertical	Fo	1	22	33	44	56	33	11	21
			2	79	14	7	80	7	13	21
			3	0	92	8	11	61	28	10
			Mean	34	46	20	49	34	17	17

Continued..

Moisture	Placement	Fertiliser	Replicate	12 Germinated	12 Viable	12 Dead	20 Germinated	20 Viable	20 Dead	Days to maximum seedling emergence from sowing
				In-groove seed status (% seeds) on day from sowing						
		Fn	1	71	7	21	78	11	11	16
			2	88	0	12	40	40	20	21
			3	0	87	13	25	62	13	12
			Mean	53	31	15	48	38	15	16
		F_N	1	56	44	0	62	13	25	15
			2	83	17	0	100	0	0	19
			3	14	71	14	6	82	12	21
			Mean	51	44	5	56	32	12	18
		Fp	1	37	56	11	75	25	0	21
			2	50	42	8	67	33	0	21
			3	0	50	50	5	48	47	21
			Mean	29	49	23	49	35	16	21

Continued..

Moisture	Placement	Fertiliser	Replicate	In-groove seed status (% seeds) on day from sowing: 12 Germinated	12 Viable	12 Dead	20 Germinated	20 Viable	20 Dead	Days to maximum seedling emergence from sowing
		F_P	1	67	22	11	71	18	11	21
			2	69	13	18	100	0	0	21
			3	0	69	31	0	71	29	21
			Mean	45	35	20	57	30	13	21
	MEAN			29	34	13	42	26	10	19
	Mixed	Fo	1	0	0	100	25	12	63	21
			2	88	6	6	90	0	10	21
			3	28	64	8	0	100	0	21
			Mean	39	23	38	38	37	24	21
		Fn	1	25	25	50	40	40	20	16
			2	67	0	33	71	29	0	15
			3	0	78	22	14	71	15	18
			Mean	31	34	35	42	47	12	16

Continued..

Moisture	Placement	Fertiliser	Replicate	In-groove seed status (% seeds) on day from sowing 12: Germinated	12: Viable	12: Dead	20: Germinated	20: Viable	20: Dead	Days to maximum seedling emergence from sowing
		F_N	1	80	0	20	83	8	9	12
			2	54	15	31	100	0	0	21
			3	0	94	6	8	75	17	9
			Mean	45	36	19	64	28	4	14
		Fp	1	62	0	38	76	6	18	14
			2	50	17	33	50	14	36	21
			3	0	78	22	0	62	38	15
			Mean	37	32	31	42	27	31	17
		F_P	1	75	0	25	43	14	43	21
			2	14	43	43	38	31	31	16
			3	0	57	43	0	39	61	21
			Mean	30	33	37	27	28	45	19
	MEAN			23	19	28	31	25	17	17
MEAN				31	24	17	46	19	11	17

Continued..

Moisture	Placement	Fertiliser	Replicate	Day 12 Germinated	Day 12 Viable	Day 12 Dead	Day 20 Germinated	Day 20 Viable	Day 20 Dead	Days to maximum seedling emergence from sowing
Wet	Horizontal	Fo	1	100	0	0	91	0	9	15
			2	90	0	10	100	0	0	21
			3	29	57	14	0	40	60	16
			Mean	73	19	8	64	13	23	17
		Fn	1	100	0	0	71	0	29	18
			2	86	14	0	100	0	0	15
			3	33	33	33	0	71	29	7
			Mean	73	16	11	57	24	19	13
		F_N	1	43	29	29	75	0	25	15
			2	100	0	0	71	21	8	21
			3	13	60	27	12	59	29	19
			Mean	52	30	19	36	27	21	18

Treatments: Moisture, Placement, Fertiliser. In-groove seed status (% seeds) on day from sowing.

Continued..

Treatments: Moisture	Treatments: Placement	Treatments: Fertiliser	Replicate	In-groove seed status (% seeds) on day from sowing: 12			20			Days to maximum seedling emergence from sowing
				Germinated	Viable	Dead	Germinated	Viable	Dead	
		Fp	1	85	8	8	80	0	20	15
			2	94	0	6	100	0	0	21
			3	57	43	0	44	37	19	15
			Mean	79	17	5	75	12	13	17
		F_P	1	62	25	13	43	14	43	21
			2	100	0	0	100	0	0	18
			3	70	20	10	87	0	13	13
			Mean	77	15	8	77	5	19	17
	MEAN			67	11	5	54	6	13	17
	Vertical	Fo	1	80	0	20	89	0	11	15
			2	100	0	0	100	0	0	20
			3	92	0	8	89	0	11	20
			Mean	91	0	9	93	0	7	18

Continued..

Treatments			Replicate	In-groove seed status (% seeds) on day from sowing						Days to maximum seedling emergence from sowing
				12			20			
Moisture	Placement	Fertiliser		Germinated	Viable	Dead	Germinated	Viable	Dead	
		Fn	1	100	0	0	71	0	29	16
			2	93	0	7	91	0	9	18
			3	11	67	22	75	0	25	14
			Mean	68	22	9	79	0	21	16
		F_N	1	84	0	16	70	0	30	16
			2	87	0	13	90	5	5	21
			3	29	57	14	11	63	26	8
			Mean	67	19	14	57	23	20	15
		Fp	1	55	36	9	100	0	0	16
			2	90	0	10	100	0	0	21
			3	67	14	19	86	7	7	17
			Mean	71	17	13	95	2	2	18

Continued..

Treatments: Moisture	Treatments: Placement	Treatments: Fertiliser	Replicate	In-groove seed status (% seeds) on day from sowing: 12 Germinated	12 Viable	12 Dead	20 Germinated	20 Viable	20 Dead	Days to maximum seedling emergence from sowing
		F_p	1	73	14	13	91	0	9	12
			2	89	0	11	92	0	8	19
			3	70	0	30	77	8	15	16
			Mean	77	5	18	87	3	11	16
	MEAN			71	4	11	80	1	9	17
	Mixed	Fo	1	62	0	38	83	0	17	19
			2	86	0	14	100	0	0	15
			3	40	40	20	33	33	33	8
			Mean	63	13	24	72	17	17	14
		Fn	1	62	0	38	78	11	11	16
			2	93	0	7	100	0	0	21
			3	48	31	21	13	25	62	11
			Mean	68	10	22	64	12	24	16

Continued..

Treatments: Moisture	Treatments: Placement	Treatments: Fertiliser	Replicate	In-groove seed status (% seeds) on day from sowing: 12 Germinated	12 Viable	12 Dead	20 Germinated	20 Viable	20 Dead	Days to maximum seedling emergence from sowing
		F_N	1	29	7	64	90	0	10	16
			2	87	0	13	88	0	12	14
			3	21	64	15	50	0	50	17
			Mean	46	24	31	76	0	24	16
		Fp	1	13	62	25	80	10	10	18
			2	93	0	7	81	0	19	17
			3	81	19	0	29	14	57	11
			Mean	62	27	11	63	8	29	15
		F_P	1	57	9	34	40	0	60	21
			2	85	0	15	60	10	30	20
			3	11	44	45	33	33	33	17
			Mean	51	18	31	44	14	41	19
	MEAN			53	9	20	60	4	21	16
MEAN				64	8	12	65	4	14	17