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# BARLEY SEEDLING ESTABLISHMENT AND INFILTRATION FROM DIRECT DRILLING IN A WET SOIL

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## ABSTRACT

Barley seeds were direct drilled with a range of drill openers into a soil which subsequently became very wet. In the absence of earthworms, only surface broadcasting of seed produced an acceptable level of seedling establishment (89%). Forty-two percent of seeds sown with a power-till opener which cultivated strips 100mm wide emerged but only about 20 percent of seeds sown with the other openers emerged. In soils where earthworms and residue were present, seeds sown with a winged opener averaged 77% emergence equivalent to surface broadcasting. Power-till and hoe openers also performed reasonably well in these conditions (69% and 62% respectively) but triple disc and punch planter openers failed (31% and 17% emergence respectively).

In soils which contained earthworms, the presence of surface residue increased seedling emergence by about 70% with winged and hoe openers (which separated the seed from the residue), but had little effect on most of the other treatments, except the triple disc opener. With this opener, surface residue appeared to reduce seedling emergence (by an average of 24%) because of toxic contact between seed and decaying residue. High seedling emergence was associated with high levels of earthworm activity, high soil oxygen diffusion rate, high infiltration and root and shoot weights, and low levels of soil bulk density. Agreement between the above criteria was high which suggests that the cumulative and interactive effects of treatments on the micro-environment of the seeds and seedlings was the single most important determinant of seedling establishment in this otherwise sub-optimal habitat.

*Additional Key Words: direct drilling, wet soil, opener design, earthworms, plant residue.*

## INTRODUCTION

Several authors (Baker, 1976; Baker and Desborough, 1983; Choudhary and Baker, 1980, 1981) have defined the requirements of seeds and seedlings direct drilled into dry, untilled soils. Direct drilling machinery technology has now been developed in New Zealand and Australia which is able to meet these requirements. Internationally direct drilling is primarily used in dry soils, and early research work on direct drilling was undertaken on dry soils.

Less research work has been undertaken in wet soils. Ellis *et al.* (1975), Lynch (1977, 1978) and Lynch *et al.* (1980) highlighted the problem of fatty acid production from decaying plant residues and the resulting seedling mortality in the cold saturated soils of the United Kingdom. They reported that applications of substances which neutralised acetic acid and that separation of the seed and plant residue, overcame the problem, but they did not identify differences amongst opener designs in terms of their ability to separate the seed from the plant residues.

This paper summarises a series of experiments in which the micro-environmental requirements of barley seeds (*Hordeum vulgarae*) direct drilled into a Tokomaru silt loam soil which subsequently became very wet were compared. Attempts to define design criteria for the openers of seed drills and the management practices to overcome the problems associated with wet soils and crop residues are discussed.

### Materials and methods

Details of materials and methods and individual experimental results have been reported by Chaudhry (1985), Chaudhry and Baker (1987), Chaudhry *et al.* (1988) and Baker *et al.* (1988). Briefly, five experiments were carried out. Each was a split plot design with three replicates.

Experiment 1 compared seed and seedling responses from slots made by three openers in plots with different amounts of residue. These plots were split for irrigation and no irrigation.

Experiment 2 examined the same opener and residue treatments as experiment 1, but were conducted under irrigation and in the partly controlled atmosphere of a glasshouse. Measurements included seed and seedling responses, earthworm numbers and oxygen diffusion rates.

Experiment 3 was identical to experiment 2 except that the soil was soaked with a rising water table rather than by simulated rainfall, in order to avoid possible raindrop splash effects in the open grooves.

Experiment 4 compared the same opener and residue treatments as experiments 1-3 in the glasshouse, but also compared effects arising from the absence of earthworms with those where natural earthworm numbers were maintained.

Experiment 5 compared six openers under irrigation, each with and without residue, and with and without earthworms in the glasshouse at a slightly lower temperature regime than experiments 2-4.

Barley is reported to be tolerant of wet soils (Letey *et al*, 1962) and is an important crop in the Manawatu. Two main objectives of the experiments were to examine the effect of the drill openers, surface residue, and earthworms on:

(1) Seed and seedling performance.
(2) The bulk density and infiltration characteristic of the soil around the seed and its oxygfen diffusion rate.

Experiments in both the field and the laboratory were used. In the field experiments broad responses to excessive irrigation and the presence of surface residue were determined, while in the laboratory experiments undisturbed soil from the field was collected in large bins (up to 0.5 tonne each) and irrigated in a glasshouse so that the climate around the seed would be controlled

after drilling, and the fate of seedlings monitored. The temperature, moisture content and bulk density of the soil in the groove produced by each opener was also monitored. The seeds in the field and laboratory experiments were drilled at a normal speed (8 km/hr) when the soils were at a normal soil moisture level, since few operators would normally drill seed into an already saturated soil. The soils in the field were then saturated using spray-irrigation. In the laboratory, either a garden soak hose was used to wet the soils in their bins at the rate of 5 mm/hr, or the bins of soil were placed in large water-tight trays and the water table raised to within 150mm of the soil surface. In these ways, soils were soaked for four hours per day for a period of 21 days.

Ambient temperatures in the glasshouse were maintained at 20-25° (night-day) in experiments 2,3 and 4 and 15-20° in experiment 5.

A predominantly ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) pasture was allowed to grow to 200mm in length (approximately 3000 kg DM/ha) and then sprayed with glyphosate (5.6 l/ha) and dicamba (1.5 l/ha) seven days before drilling to create the residue treatment. In the "No-residue" treatments the dead vegetation was cut and removed from appropriate plots just prior to drilling.

In the infiltration experiments rectangular single sided infiltrometers (120 x 200mm x 300mm deep) were pushed into the soil to a depth of 100mm, so that the longitudinal axes were centered on drilled rows.

Populations of resident earthworms were maintained in some experiments, while in others carbaryl (1-naphthyl methyl-carbamate) was applied to kill soil fauna. Preliminary experiments had shown no effect on germination or growth of seedlings.

The drill openers and their resulting soil slots are described as follows:

*Winged opener* - This created a closed groove with an invert T-shape by returning the residue-covered soil over the groove. The seed and residue were physically separated by a distance of 40mm.

*Hoe opener* - This created an uncovered groove with a U shape by sweeping residue to either side of the groove. Seed and residue were separated by a distance of about 50mm.

*Triple disc opener* - This created an uncovered groove with a V shape. A proportion of the residue was pushed into contact with the seed.

*Power-till opener* - This rotary-tilled a 100mm wide strip of soil. Plant residue and soil were mixed together so that the amount of seed-residue contact was reduced. A proportion of earthworms were killed during this process.

*Corer opener* - This made vertical uncovered holes of 11mm diameter in the manner of a "punch-planter" (Lal, pers. comm. 1983). Care was taken to avoid contact between the seed and plant residues.

*Surface broadcasting of seeds in rows* - This was done by hand to help explain the role of oxygen in the soil because surface sown seeds were well supplied with oxygen.

The number of seedlings which emerged was counted. Technically seedlings from the surface broadcast treatment did not "emerge", but the short duration of the experiments (21 days) made it difficult to regard any seedlings as having "established". Visible seedlings from all treatments were therefore listed as "Seedling emergence".

Counts were also made of ungerminated seeds and seeds which had germinated but not emerged from the soil. Cylindrical cores of 120mm diameter and 100mm depth centered on the rows were taken around the slot made by the openers, and the number of whole earthworms present were counted. The oxygen diffusion rate (ODR) and temperature of soil were measured in situ in a 16 point grid pattern to one side of and below the seed (Letey & Stolzy, 1964; Birkle *et al*, 1964). Soil bulk density and moisture content were measured in soil sampled in a similar grid pattern on the other side of the seed.

Measurements were also made of infiltration rates and the weight of roots and shoots of seedlings. The activity of earthworms was assessed by measuring the area covered by worm holes and

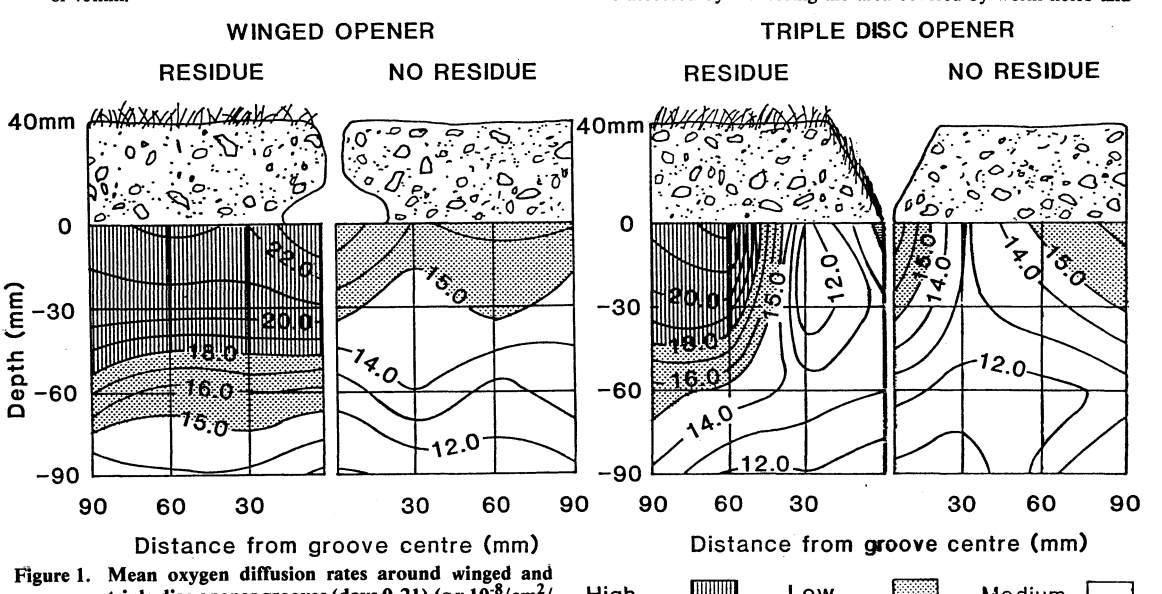


**Figure 1. Mean oxygen diffusion rates around winged and triple disc opener grooves (days 0-21) (g x $10^{-8}$/$cm^2$/min)**

casts in relation to ground surface area, and was expressed as an area index (area of holes or casts / total ground area.)

## RESULTS

Seedling emergence and earthworm populations of the five experiments are summarised in Tables 1, 2 and 3. As experiment 5 tested the most comprehensive range of openers and treatments, the bulk density of the soil from this experiment is shown in Table 4. Figures 1, 2, and 3, show oxygen diffusion rate regimes and Figures 4 and 5 show root and shoot weights from this experiment. Figures 6, 7 and 8 show infiltration rates and totals from experiment 5.

In Tables 1 and 2 there was a strong interaction in the number of seedlings emerging as a result of surface residue and openers, but only in the presence of earthworms (Table 1). Where earthworms were absent (Table 2) the only influence that either sowing method or residue had on the seed micro-environment arose from exaggerated mechanical aeration (Power-till opener) or from removing the seed from the soil altogether and exposing it to atmospheric oxygen and adequate water.

Where earthworms were present (Table 1) winged and hoe openers responded consistently and markedly to the presence of surface residue which was reflected in increased seedling emergence. This appeared to be directly influenced by both the number of earthworms and their activity around the groove (Table 3) both of which favourably influenced oxygen diffusion rate (Figs 1-3) and the bulk density of the soil in the seed zone (Table 4). These effects were not altered when a high water table was used to substitute for regular rainfall, suggesting that raindrops had no measurable effect on the open grooves.

These two openers, however, were the only two which performed best in the presence of surface residue. The triple disc opener did not result in increased seedling emergence in the presence of residue, probably because the decaying grass was pushed down into the groove. Care was taken at sowing to avoid this problem when the corer opener was used but this may not be typical of punch planters. Most designs of true punch planters (which the corer was intended to simulate) have a wedging action not unlike the double discs of a triple disc opener and could be expected to push some residue into the slot.

When seed was surface broadcast it was deliberately placed under the residue on to the bare soil although this is unlikely to occur during normal field operations. Thus the germination of seed sown by this method was not affected by residue even although residue may have had other indirect effects on the micro-environment from shading and the attraction of earthworms. There was sufficient soil water for germination and seedling development due to the frequent irrigation. When the power-till opener was used its short-term lack of response to residue was also not surprising because the residue was chopped and mixed with the soil.

Seedling emergence data were reflected by root and shoot weights (Figures 5 and 6).

In the absence of earthworms all measurements of oxygen diffusion-rate (ODR) of the soil were below the value of $15 \times 10^{-8}$ g/cm$^2$/min which Letey *et al.*, (1962) regarded as the minimum value for barley growth. Even so the ODR regime produced by the power-till opener was consitently more favourable and the bulk density of the soil was consistently lower than all other treatments except surface broadcasting. Because of the low levels of responses neither ODR-iso-data nor bulk density data are presented for the experiments where earthworms were absent.

**Table 1. Effects of direct drilling openers and surface residue on emergence of barley seedlings from a saturated soil with natural levels of earthworms. (% seedling emergence)**

PRESENCE OF EARTHWORMS:

| | Experiments | Residue | Opener types | | | | | | S.E. differences | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Winged | Triple disc | Hoe | Power-till | Corer | Surface broad-casting | openers | interactions |
| (1) | Field Expt. (Irrigation) | No-residue | 47.0 | 38.3 | 41.7 | | | | | |
| | | Residue | 75.0 | 30.0 | 67.7 | | | | 4.3 | 3.3 |
| (2) | Tillage bin (Glasshouse-simulated rain) | No-residue | 43.8 | 26.2 | 32.9 | | | | | |
| | | Residue | 73.3 | 25.2 | 63.8 | | | | 3.2 | 1.1 |
| (3) | Tillage bin (Glasshouse-Temporary high water table) | No-residue | 35.7 | 57.1 | 31.9 | | | | | |
| | | Residue | 73.8 | 27.1 | 60.5 | | | | 5.1 | 5.5 |
| (4) | Pot Expt. (Glasshouse-simulated rain) | No-residue | 53.3 | 63.3 | 66.7 | | | | | |
| | | Residue | 86.7 | 56.7 | 88.3 | | | | 5.8 | 6.9 |
| (5) | Tillage bin (Glasshouse-simulated rain) | No-residue | 48.0 | 24.7 | 40.0 | 62.0 | 14.7 | 86.7 | | |
| | | Residue | 75.3 | 17.3 | 64.7 | 62.7 | 17.3 | 84.0 | 6.2 | 7.2 |

**Table 2. Effects of direct drilling openers and surface residue on emergence of barley seedlings from a saturated soil in the absence of earthworms.**
**(% seedling emergence)**

| | Experiments | Residue | Opener types | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Winged | Triple disc | Hoe | Power-till | Corer | Surface broad-casting | S.E. differences openers / interactions |
| (4) | Pot Expt. (Glasshouse-simulated rain) | No-residue | 63.3 | 53.3 | 60.0 | | | | |
| | | Residue | 50.0 | 40.0 | 56.7 | | | | 15.2 / 9.4 |
| (5) | Tillage bin (Glasshouse-simulated rain) | No-residue | 22.0 | 18.7 | 22.7 | 41.3 | 16.0 | 88.7 | |
| | | Residue | 20.0 | 15.3 | 24.0 | 43.3 | 14.0 | 89.3 | 1.5 / 1.7 |

The ODR data, shown in Figures 1-3 as iso-ODR zones, illustrate the microenvironmental changes which occurred in the presence of earthworms as a result of the use of the openers and the presence or absence of surface residue.

The figures are arbitrarily divided into three zones. Low values are 15 x $10^{-8}$ g/cm$^2$/min and below, medium values are 15-18 x $10^{-8}$ g/cm$^2$/min, and the high values are 18 x $10^{-8}$ g/cm$^2$/min and above. These figures show that when residue was present the winged, corer, hoe and power-till openers produced zones close to the seed where ODR was high. When residue was removed the ODR regime produced by most of the openers contracted so that zones of only medium ODR were close to the seed. With the corer opener, the removal of residue resulted in an almost totally low ODR regime close to the seed. Because of its wide zone of mechanical aeration, the power-till opener maintained a zone of high ODR around the seed even when residue was removed.

Generally the triple disc opener produced seedbeds which were markedly different from those produced by other openers. This opener created a very small zone where ODR was high, even in the presence of plant residues but this zone was separated from the seed by an envelope of low ODR. In the absence of plant residue the ODR regime produced by this opener deteriorated still further. Although there was a very small zone where medium ODR persisted around the seed the envelope of low ODR persisted to the exclusion of any zone of high ODR, and the isolation of even medium ODR.

Table 4 lists the effects of the treatments on the bulk density of the seed around the grooves produced by the openers. The bulk density of the soil was lower around the grooves produced by each opener when residue was present than when the soil was bare, and all openers produced lower bulk densities than the triple disc opener. It is likely that the data for bulk density reflect earthworm activity since earthworms were generally high where the bulk densities of the soils were low.

Where there were no earthworms or residue present there was little difference in the infiltration rates of the soils (Fig.6). The maximum infiltration rate was produced by the winged opener and was a little over 40 mm/hr but this fell rapidly with time and the infiltration measured in the soil disturbed by all openers was negligible after 70 minutes and puddling was evident.

All openers performed well in soils with earthworms but differences between openers were magnified (Fig. 7). When earthworms were present but there was no plant residue the highest infiltration rate was produced by the winged opener

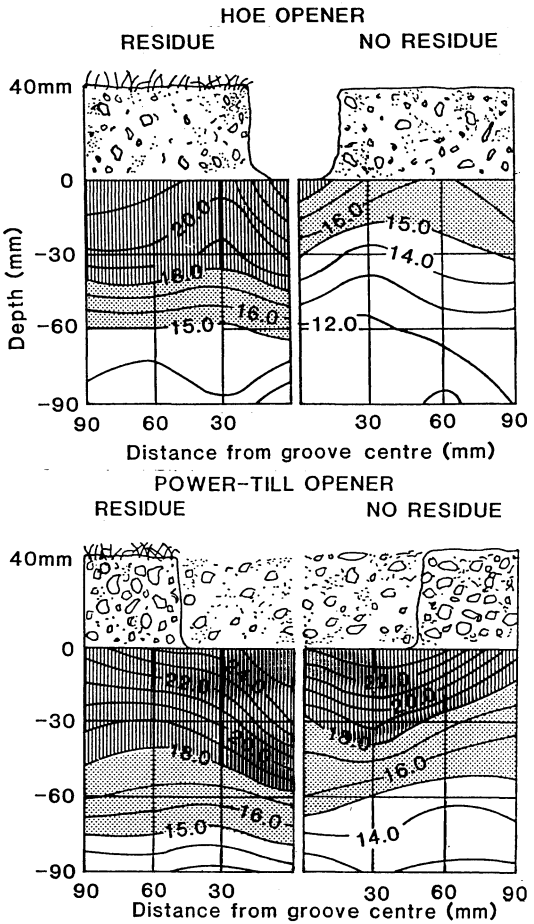


**Figure 2. Mean oxygen diffusion rates around hoe and power till opener grooves (days 0-21) (g x $10^{-8}$/cm$^2$/min)**

throughout the experiment. This reached 200 mm/hr after 10 minutes but settled after 60 minutes to about 120 mm/hr.

The presence of both earthworms and plant residue had little effect on the infiltration rates associated with the winged opener which continued at a high level (Fig. 8). However with most other treatments infiltration rates improved to plateau at about 70-80 mm/hr after 60 minutes. The triple disc opener did not perform well in the presence of residue and the infiltration rate after 60 minutes was reduced to about 40 mm/hr and declined thereafter.

**Table 3. Effects of direct drilling openers and surface residue on earthworm numbers in a saturated untilled soil. (number per soil core)**

| | Experiments | Residue | Opener types | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Winged | Triple disc | Hoe | Power-till | Corer | Surface broad-casting | S.E. openers | differences interactions |
| EARTWORM NUMBERS: | | | | | | | | | | |
| (2) | Tillage bin (Glasshouse-simulated rain) | No-residue | 13.3 | 6.7 | 11.3 | | | | | |
| | | Residue | 27.3 | 8.0 | 26.7 | | | | 2.5 | 1.8 |
| (3) | Tillage bin (Glasshouse-Temporary high water table) | No-residue | 15.0 | 8.7 | 16.3 | | | | | |
| | | Residue | 29.1 | 10.7 | 30.9 | | | | 2.2 | 2.0 |
| (4) | Pot Expt.* (Glasshouse-simulated rain) | No-residue | 19.3 | 16.7 | 14.7 | | | | | |
| | | Residue | 25.3 | 25.7 | 28.3 | | | | 6.1 | 5.3 |
| (5) | Tillage Bin (Glasshouse-simulated rain) | No-residue | 12.7 | 8.0 | 12.7 | 14.3 | 10.0 | 13.7 | | |
| | | Residue | 24.7 | 9.3 | 22.0 | 23.0 | 18.3 | 22.3 | 2.1 | 2.2 |
| AREA INDICES: Earthworm activity (area casts + holes/area soil) | | | | | | | | | | |
| (5) | Tillage Bin (Glasshouse-simulated rain | No-residue | 0.7 | 0.4 | 0.6 | 0.7 | 0.7 | 0.7 | | |
| | | Residue | 0.9 | 0.4 | 0.8 | 0.9 | 0.8 | 0.8 | | |

*Note: The pot experiment had a larger unit soil mass from which earthworm populations were counted than the other experiments.

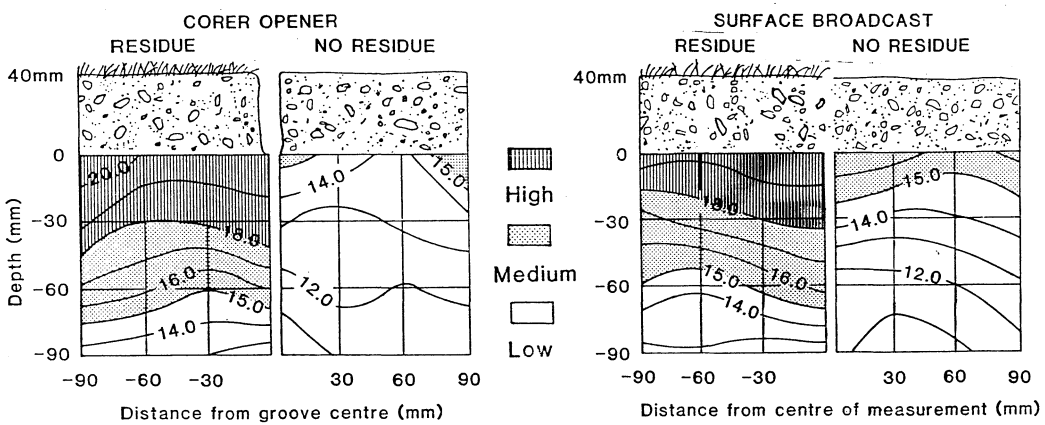


**Figure 3. Mean oxygen diffusion rates around punch planter grooves and the undisturbed soil beneath surface broadcasting (days 0-21)(g x $10^{-8}$/$cm^2$/min)**

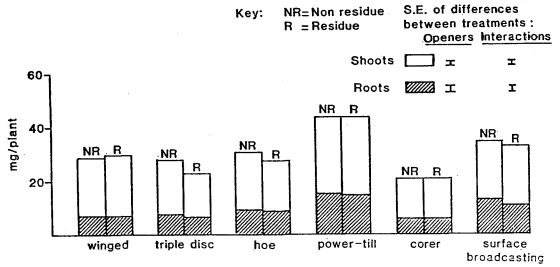


**Figure 4. Effects of seed-sowing techniques and crop residue on root and shoot weights of barley in the absence of earthworms in a wet soil.**

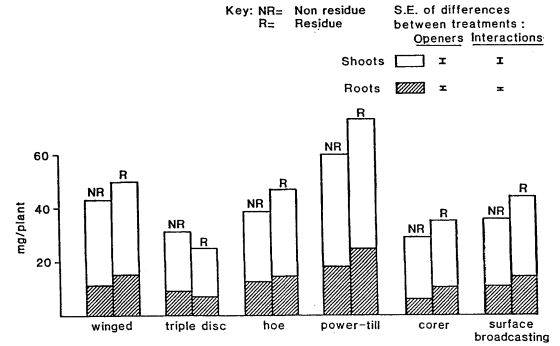


**Figure 5. Effects of seed-sowing techniques and crop residue on root and shoot weights of barley in the presence of earthworms in a wet soil.**

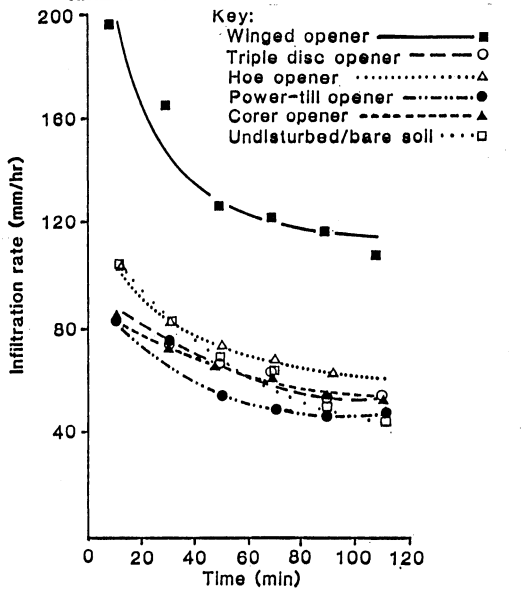


**Figure 7. Effects of direct drilling opener types and undisturbed/bare soil on infiltration rate to 60mm, in the presence of earthworms and absence of crop residue.**

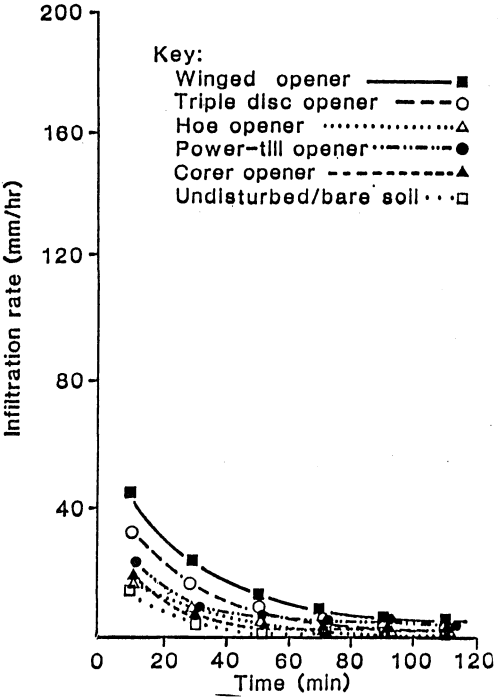


**Figure 6. Effects of direct drilling opener types and undisturbed/bare soil on infiltration rate to 60mm, in the absence of earthworms and crop residue.**

## DISCUSSION

The clearest effect in these experiments was the contrast between the presence and absence of earthworms. In the absence of earthworms and perhaps other soil fauna, there was little effect of the openers or interaction with plant residue. The oxygen regime in the seed zone appeared to have a major influence on seedling performance. Surface broadcasting of the seed and use of the power-till opener ensured maximum oxygen supply to the seed even in the absence of earthworms which contrasted with the other seed sowing methods. This was reflected in the rate of seedling emergence, final plant population and the weight of roots and shoots of established plants.

By contrast, in the presence of earthworms, seed sowing techniques and the presence or absence of crop residue significantly effected all the factors monitored around the seed. Seedling emergence was markedly increased by the presence of earthworms, and to a lesser extent by residue. In the presence of earthworms the winged and hoe openers increased seedling emergence almost three fold and these openers benefitted markedly from crop residue.

In some cases seedling emergence could be considered to be quite acceptable. For example, in the single experiment in which it was included, surface broadcasting resulted in 80% seedling emergence. The winged opener used in the presence of residue and earthworms compared well and produced 77% seedling emergence over five experiments. Power-till and hoe openers in the presence of earthworms and residue were slightly inferior (69% and 63% respectively), but triple disc and corer openers

**Table 4. Effects of seed-sowing techniques and crop residue on soil bulk density in the presence of earthworms in a wet untilled soil.**

| | Seed sowing techniques / Residue | Winged | Triple disc | Hoe | Power-till | Corer | Surface broadcasting | S.E. differences |
|---|---|---|---|---|---|---|---|---|
| Soil bulk density ($g/cm^3$) | No-Residue | 1.20 | 1.27 | 1.21 | 1.22 | 1.23 | 1.23 | Openers = 0.008 |
| | Residue | 1.12 | 1.23 | 1.13 | 1.17 | 1.19 | 1.18 | Overall = 0.007 |

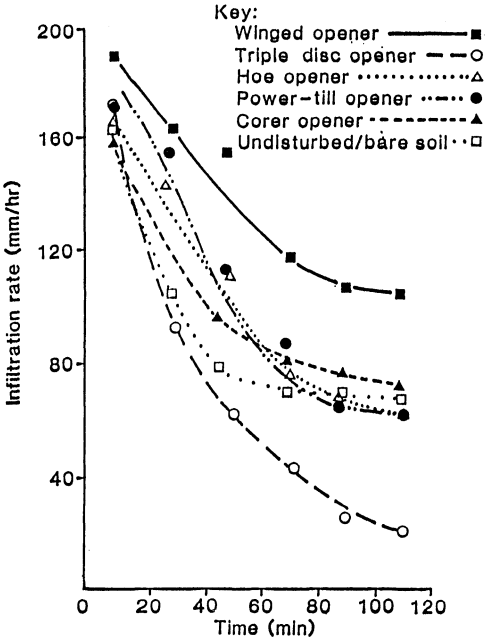


**Figure 8. Effects of direct drilling opener types and undisturbed soil on infiltration rate to 60mm, in the presence of earthworms and crop residue.**

failed to produce acceptable emergence under any conditions.

In the presence of earthworms there was remarkable agreement between most criteria used to reflect the interactions between openers and residue.

Earthworm numbers were closely related to both bulk density and oxygen diffusion rates which were themselves related, and both appeared to have an influence on seedling emergence. It appears that the beneficial effects resulting from the winged opener were indirect and biologically induced while those resulting from the power-till opener (although less pronounced) were more the direct result of mechanical agitation.

The effectiveness of the winged opener under these sub-optimal soil conditions is particularly noteworthy as it had earlier been shown to have a similar effectiveness in very dry soils for different reasons (Baker, 1976, Choudhary and Baker, 1980, 1981, Baker and Desborough, 1984). This indicates a wide tolerance of soil conditions by this opener.

With the triple disc there were interactions between openers and plant residue, but these reduced seedling emergence while with the corer and power-till openers there was no effect. It is probable that the triple disc opener may have increased contact between seed and the residue. This opener was also observed by Mai (1978) to reduce porosity close to the groove which is an observation that was confirmed by the iso-ODR figures in these experiments (Figs 1-3).

The good performance in these experiments of surface broadcasting relied on a regulated daily 4-hour rainfall event of 20 mm for 21 days which ensured germination of exposed seed and survival of seedlings even without root anchorage. Such conditions are most unlikely to be repeated in a field situation.

Although these results examined the effects of the passage of a range of openers, only the winged and triple disc openers could be expected to operate satisfactorily without problems of physical blockage from surface residues. Hoe, power-till and punch planter openers all have varying problems with blockage but are nonetheless used in these conditions with a range of trash handling aids which justified their inclusion.

The infiltrometers measured only infiltration in the groove area and since no water was applied in the inter-groove zone, lateral movement of water below the infiltrometers almost certainly occurred. Nonetheless the tests indicated the extent to which the openers had modified that particular zone of soil in relation to infiltration and showed similar trends to those produced by earthworm activity.

When earthworms and plant residue were present cumulative infiltration during a two hour period was approximately nine times greater when both were absent. The presence of earthworms alone accounted for a seven fold increase in infiltration.

The winged opener showed more rapid, and a greater total infiltration than all other treatments except in the absence of earthworms at depths greater than 140mm. In the presence of earthworms and residue the winged opener recorded twice the cumulative infiltration of any other opener, while the triple disc opener was substantially lower than all other openers. Both of these effects appeared to be largely due to earthworm activity, a finding that is consistent with other reports (Hopp and Slater, 1949).

The failure of the triple disc opener might be explained by the lower porosity (Mai, 1978) and decaying residue which appeared not only to have had a direct mortality effect on seeds, but also to have discouraged earthworm activity.

## CONCLUSIONS

The following conclusions can be drawn:

(1) The influence of openers and residues on seed and seedling performance in a wet direct drilled soil appears to centre on their influence on earthworm activity, together with infiltration capacity of soil water, bulk density and oxygen

diffusion rate in a zone close to the drilled grooves.

(2) When soils containing low populations of earthworms are direct drilled with barley and subsequently become very wet there is likely to be poor seedling emergence and low infiltration rates.

(3) In such conditions the influence of openers and residue on seedling emergence will be negligible unless substantial mechanical aeration takes place such as with a power-till opener.

(4) When such direct drilling takes place in soils with reasonable populations of earthworms, satisfactory levels of seedling emergence and infiltration might be expected to occur if winged openers or power-till openers are used. Hoe openers will also perform satisfactorily provided plant residue is present.

(5) In wet soils, regardless of the presence or absence of earthworms or residue, triple disc or corer (punch planter) openers are likely to result in poor seedling emergence and low infiltration into the groove area.

(6) Broadcasting bare seed onto the surface of the soil is not recommended.

Clearly, by giving attention to the shape of the seed groove created by drill openers, and deliberate positioning of surface residues, it is possible to promote direct drilling (no-tillage) with a substantially lower biological risk in a range of field conditions, than is being achieved by some of the narrow-tolerance technology currently in use.

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