A STUDY OF THE EFFECTS OF GROUND COVER ON OVERWINTERING SLUG POPULATIONS AND THE EFFECT OF COULTER DESIGN ON SLUG INCIDENCE IN DIRECT DRILLING

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ABSTRACT

A two stage study involving the effect of vegetation cover on overwintering slug populations, and the effect of coulter design on slug incidence and damage in a direct drilled cereal was carried out during the 1980/81 growring season.

The first stage of the study showed that ground cover affected slug activity on the soil surface, but only in the most adverse environment did any actual decrease in slug populations occur. Differences occurred in the effectiveness of the trapping techniques depending on the density of the ground cover. Pitfall traps appeared to be more effective in dense ground covers, while brick or shelter traps appeared to be more effective in low density ground covers and especially with bare ground. Rainfall, soil temperature and soil moisture were measured and it appeared that slug numbers recorded in the traps were correlated to different environmental parameters depending on the ground cover. In dense covers the slug number recorded was correlated to temperature, in medium density ground covers the numbers had a slight correlation to soil moisture, and in low density ground covers they were correlated to rainfall.

The second stage of the study involved two dates of drilling, using three coulter types (triple disc, hoe, chisel coulter) and measuring slug numbers occurring in the seed grooves and slug damage to seeds and seedlings. It was found that coulter design had no effect on slug ingression into the seed groove, or on slug damage to the direct drilled crop. There was however a strong correlation between slug numbers in the seed groove and seed and seedling damage ($r=0.78$, $r=0.93$ respectively). Pre drilling conditions affected the number of slugs entering the seed grooves (the denser the vegetation the greater the slug number occurring in the seed groove), and slug damage to the seedlings. Moisture levels also affected the number of slugs entering the seed grooves and seed and seedling damage by slugs. Moister conditions produced the greater number of slugs in the seed grooves and the highest seed and seedling damage.

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1. GENERAL INTRODUCTION

Slugs are an ever present problem in agriculture and horticulture. They damage a wide variety of plants such as wheat, barley, brassicas, root crops, celery, tomatoes and pasture plants. Little quantitative information is available on the status of slugs as pests, but it is clear that they cause considerable damage throughout the temperate regions of the world.

With the development of new sowing techniques that involve little or no cultivation of the soil, slugs are becoming a much greater problem in the agricultural scene than has previously been the case. Patterson et al (1980), Edwards (1975), Anon (1973), Edwards & Lofty (1979), Whiting & Lofty (1967) have all observed increased slug numbers in direct drilled areas and greater plant damage by slugs than in ploughed and/or cultivated areas.

It has been noted that using these non tillage systems allowed slugs to completely destroy a crop before the seeds have germinated or the seedlings have had a chance to emerge and to be exposed to their normal range of pests or to express their potential for growth and production (Baker per comm, Anon 1973, Edwards, 1975). Matthews (1972) states that this "no tillage system of crop production heralds a revolution that is as striking as the shift from horse power in agriculture, ameliorating many deficiencies of cultivation". It is therefore necessary to develop methods to overcome arising pest problems such as slugs before this new method (direct drilling) can become widely accepted.

Relatively little is known of the species of slugs present in New Zealand; Coleman (1970) states that slugs are a natural although rather temporary part of the organic complex of the soil, which they use for shelter and to provide some food and scavenging territory. It is this, along with their aggregated sparse distribution that makes it difficult to carry out field experimental work.

The present study examined the effects of slugs on a direct drilled crop, the effect of coulter design on the slug numbers moving into the seed grooves, and the effect of winter ground cover and irrigation on slug populations.

2. INTRODUCTION AND REVIEW

Farmers for centuries have sought new procedures of crop production and labour saving devices (Kuipers 1970). Over the years the general system of cultivation has remained the same, that is ploughing as a primary deep cultivation technique followed by various secondary cultivations of a shallower nature which may include harrowing, discing, rolling, levelling etc (Phillips & Young 1973). Recent developments in herbicides have allowed the development of other cultivation methods of which direct drilling is one.

2.1 Definition of direct drilling. Many definitions for direct drilling have been offered (Baeumer & Bakermans 1973, Free 1960, Jones et al 1968), all have mentioned the use of herbicides for weed control and reducing the resident vegetation as well as little soil disturbance apart from that needed to introduce the seed/or plant. Baker (1976A) defined direct drilling as the practice where seeds were introduced by mechanical means into an untilled seed bed, the vegetation of which had been reduced to a non competitive stage by harvest, herbicide application, natural mortality or drought. A more full definition of direct drilling was presented by Young (1973) who stated that it was placing the crop seed or crop transplant into the soil, by a device which opened a trench or slot through the soil or previous crop residues only sufficiently wide and deep to receive the seed or transplanted roots, and to provide satisfactory seed or root coverage. Weeds were controlled by herbicides, crop rotation and crop competition.

No tillage, direct drilling, zero tillage are all terms which refer to a similar operation as defined above. In this study the term direct drilling will be used as it has already received wide use in New Zealand literature.

The main points of difference between direct drilling and conventional cultivation therefore are (a) direct drilling leaves the soil relatively undisturbed (Baker 1976A, Jones et al 1968, Free et al 1963), and (b) trash or litter is often left behind on or near the soil surface with direct drilling (Jones et al 1968, Baeumer 1970).

2.2 Advantages and disadvantages of direct drilling.

To direct drilling has been attributed the following advantages in given situations —

(i) It has lessened the problem of soil erosion (Matthews 1972, Schmidt & Koetz 1969, Phillips & Young 1973).

(ii) It has lessened the damage to soil structure (Phillips & Young 1973, Baeumer 1970).

(iii) It has reduced the loss of soil moisture (Baeumer & Bakermans 1973).

(iv) It has reduced water logging (Shear 1968, Baeumer & Bakermans 1973).

(v) It was beneficial to earthworm populations and soil fauna in general. (Pottinger 1979, Edwards 1975).

Of these advantages only (v) is relevant directly to this study. However, the preceding four indirectly affect the soil fauna and will be discussed where appropriate.

Direct drilling has been observed to have the following disadvantages for it is not a perfect ecological and agricultural tillage tool.

(i) Cost of herbicide. (Dr Baker per comm).

(ii) Retention of surface trash leading to reduced effectiveness of chemicals for weed and pest control (Pottinger 1979).

(iii) Lack of cultivation makes it difficult to achieve good pest control (Edwards & Lofty 1978).

(iv) Increased pest problems (Pottinger 1979).

The latter three of these disadvantages are concerned with pests and soil fauna.

2.3 Direct drilling coulters. Direct drilling machines have been described as needing to fulfil some or all of several basic requirements

(a) To be heavy enough and strong enough to plant under adverse soil conditions and cut through crop residues (Phillips & Young 1973).

(b) To provide a narrow band of tillage for receiving the seed and fertilizer (Phillips & Young 1973).

(c) To plant at different depths (Phillips & Young 1973).

(d) To cover the seed in such a way that germination and emergence are encouraged (Baker 1973) and/or that seed/soil contact is maintained under very hard or very wet soil conditions (Phillips & Young 1973, Koronka 1973).

(e) To be able to dispense seed and fertilizer in an acceptable pattern and to be able to be operated at reasonable speeds (Baker 1973).

Research groups around the world have worked on attaining these goals, some have even been contradicted, and machines (albeit often experimental) are now available which can meet most of the requirements. The most important part of any drill is the coulter for this is the soil engaging component. It is this which opens the seed groove and allows the seed and fertiliser to be placed in the soil.

There are a variety of effective direct drilling coulters available commercially and experimentally. Phillips & Young (1973) reported that these included coulter assemblies with chisels, discs, sweeps and rotary strip tillers. The three coulters which are most commonly used in New Zealand for direct drilling are:

(a) Triple disc coulter

(b) Hoe coulter

(c) Chisel coulter (Baker per comm).

(a) Triple disc coulter. Baker (1976A) claimed that the triple disc coulter had become established amongst users of direct drilling as the normal direct drilling coulter. Koronka (1973) stated that the triple disc coulter was closer to his requirements than any other coulter system, as it gave good trash clearance, even wear, seed was deposited in a "V" shaped furrow which ensured positive seed/soil contact without much damage or disturbance to the soil. This coulter consisted of a flat vertical pre disc followed by two flat discs angled towards each other and touching near the bottom (Choudnary 1979). It tended to create the seed groove with a compressive action usually leaving little loose soil in the seed environment (Choudhary 1979, Mai & Baker 1977). Baker (1976b) found that the triple disc coulter left the seed more or less wedged between well defined near vertical slits which substantially exposed them to the atmosphere.

(b) Hoe coulter. The hoe coulter consisted of a flat vertical pre disc followed by a narrow V shaped hoe coulter which gave rise to a "V" or "U" shaped groove with considerable loose soil available due to shattering (Choudhary 1979, Choudhary & Baker 1977). Baker (1976A) found that the hoe coulter tended to produce more complete soil/seed contact because of the greater amount of loose soil around and over the seeds.

(c) Chisel coulter. The term chisel coulter has been used in overseas reports, but in the main this has been a form of modified hoe coulter (Baker per comm). It should not be confused with the New Zealand chisel coulter. This coulter was first reported in its simplest form by Baker (1976A). Subsequently Baker et al (1979) described an improved version of the chisel coulter which was expected to be used largely in cropping. It consisted of a scalloped disc with detachable hinged wings hanging on either side which were inclined at a 5^0 angle above the horizontal. The scalloped disc coulter produced an initial groove in which the two wings travelled (Anon 1980). These wings shattered the soil on either side of the disc but beneath the surface, and, therefore, it left the surface substantially undisturbed (Choudhary 1979, Baker et al 1979). The seed groove of a chisel coulter was described as being roughtly the inverse of the hoe and triple disc coulters in that it was narrow at the top and wider at the bottom (Baker 1976B). Because of the split coulter assembly seed and fertiliser could be placed in the same groove but separated by about 1 cm (Anon 1980). The underground tillage of the chisel coulter created a good seed-bed which encouraged seed germination even under dry soil conditions (Baker 1976B, Baker 1973). Baker (1976A) considered the action of the chisel coulter to be similar to a miniature sub soiler where the area of the sub-surface disturbance was considerably in excess of that at the surface. Mai & Baker (1977) noted that the chisel coulter tended to pulverise the soil as it passed through it. This resulted in the seed groove having more loose soil and soil cover than was the case with the triple disc coulter. The chisel coulter was observed to displace the surface soil zone by lifting and bearing but not inverting it (Mai & Baker 1977).

Figure 1 shows a diagrammatic representation of a typical cross section of the seed grooves formed by the chisel coulter, hoe coulter and triple disc coulter at varying soil moisture levels in a silt loam (Dixon 1972).

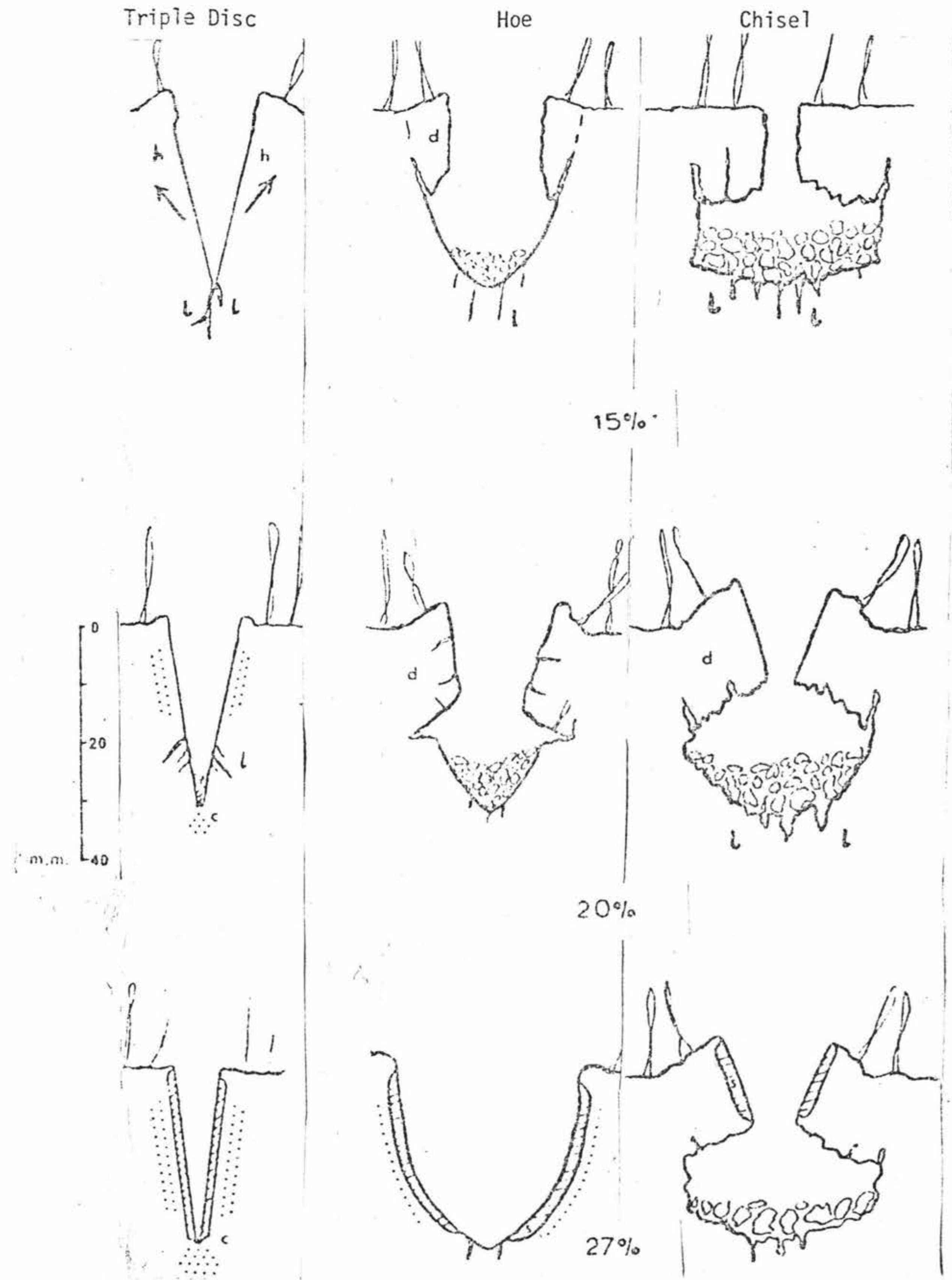


Figure 1 The principal characteristics of direct drilled grooves in a silt loam at moisture contents, 15%, 20% and 27%

2.4 Performance of the three coulters.

(a) Seed cover - Baker (1976b) set up an arbitrary classification of seed cover as follows:-

Class I negligible loose soil cover
Class II complete loose soil cover
Class III intermittent turf or mulch cover
Class IV complete turf or mulch cover.

He found that the triple disc produced a Class I cover, the hoe coulter Class III; and the chisel coulter Class IV. He established strong correlations between the grade of seed cover and seedling emergence from dry soils. Further work has verified these results (Choudhary 1979, Choudhary & Baker 1981 a, b).

(b) Seedling emergence - Choudhary (1979) found that there were differences between the chisel, hoe, and triple disc coulters in terms of the rates of seedling emergence and final counts of emergence in dry soils. In one experiment it was found that the chisel coulter gave a peak emergence of 68.1% compared with 25.5% for the hoe coulter and 2% for the triple disc coulter. In another experiment Choudhary (1979) found that the chisel coulter recorded the highest seedling emergence of 59.3% followed by the hoe coulter of 16.1%, the emergence counts for the triple disc coulter was only 1%. Baker (1976a) found that the chisel coulter may have sustained a substantially higher emergence percentage than both the hoe and triple disc coulters. In another experiment on wheat seed germination Baker (1976a) found that the chisel coulter had significant superiority in terms of seedling emergence.

Soil moisture levels affected the seedling emergence from the three coulters. At low initial soil moisture levels there were significant differences between all three coulters, the chisel coulter gave the highest and the triple disc the lowest seedling emergence. At adequate soil moisture levels it was found that no significant differences occurred between the hoe and chisel coulters, but that the triple disc was still significantly lower (Choudhary 1979). Baker (1976a) reported that both the triple disc and hoe coulter grooves appeared to respond more to sprinkle irrigation that the chisel coulter in terms of seedling emergence. This was related to the more open nature of the triple disc and hoe coulter grooves. Along with the effect of soil moisture on seedling emergence there is the interrelated effect of seed cover. Choudhary (1979) found that when improved seed cover was provided over the triple disc grooves there was some seedling emergence evident. Choudhary & Baker (1981b) confirmed these results and related it to the maintenance of higher moisture potentials at the seed soil interface as had Baker (1976a).

When drilling was carried out in the field it was found that at high soil moisture levels (nearing field capacity) there was generally high seedling emergence and no obvious significant differences between the three coulters, Choudhary (1979). At low soil moisture levels the triple disc coulter was most sensitive and lease effective in seedling emergence, while the chisel coulter showed superiority compared to the triple disc coulter and to a lesser extent the hoe coulter in terms of promoting seedling emergence, Choudhary (1979). Baker (1976b) quantified the moisture effect on seedling emergence when he found that when the presowing soil moisture content was deliberately decreased by 22.3% in the case of the chisel coulter in comparison with the triple disc and hoe coulter a situation developed where plant emergence counts showed no significant differences between the coulters.

(c) In groove soil moisture -

(i) Liquid moisture - the need for moisture during seed imbition, seed germination, and seedling emergence has long been recognised (Choudhary 1979). Choudhary (1979) observed that the triple disc groove had significantly more moisture from day 3 to day 12 after sowing compared to the chisel and hoe coulter grooves. He explained this partly by transpiration from the larger number of emerged plants in the chisel grooves. Also there were more unbroken capillary channels which could be expected to transport moisture to the surface of the triple disc groove, where it would have subsequently evaporated and given rise to a thin layer of dry soil which could then act as a barrier to further moisture diffusion after the seed had germinated. This would also explain the results from Baker (1976a), Choudhary (1979) who found that in the triple disc coulter seeds which germinated but had not emerged seem to have dessicated and died. While in the chisel and hoe coulter the seeds either germinated or did not.

(ii) In groove relative humidity - relative humidity can be important for seed germination, as seeds can in some cases absorb water from the surrounding atmosphere to initiate germination, (Choudhary 1979). Relative humidity has been shown by Choudhary & Baker (1981c) to be perhaps the dominant determinant of seedling emergence in a dry soil. Choudhary (1979) found that the triple disc grooves appeared to have greater moisture stress on the seedling because of the higher initial vapour drying rate which dessicated the germinated seedlings. He observed no significant differences between the three coulters in terms of in groove relative humidity one day after sowing. But by day four after sowing the relative humidity in the triple disc seed grooves was significantly lower compared to the chisel and hoe coulters. These differences were maintained thereafter. Measured on a daily rate of loss basis Choudhary (1979) found that when the triple disc coulter was employed the ingroove relative humidity decreased at a rate of 4.23%/day for the first six days after sowing. This rate was significantly higher than that of the chisel groove (2.34%/day) and the hoe groove (2.75%/day). These humidity differences seemed to be related to the differences in cover over the groove. Choudhary & Baker (1981c) found that relative humidity was moderately correlated with seedling survival (r= 0.75). The chisel coulter left the seed groove well covered by a vegetation mulch and separated from the atmosphere. This accounted for the slower drying rate while the triple disc coulters left a seed groove which was very open to the atmosphere and lost moisture quickly (Choudhary 1979).

2.5 Soil fauna in direct drilling - Wild habitats such as woodlands and grassland have usually supported a diverse flora and fauna. When these were used in agriculture the flora was replaced by a few species of plants as in pasture or by a single species when a crop was sown; this in turn usually caused a decrease in both total numbers and species diversity of animals (Edwards & Lofty 1975a). However the systems of cultivation used today appear to have affected the animal populations differently especially the invertebrate soil fauna (Edwards & Lofty 1975a).

Direct drilling seems to have favoured most soil invertebrates; populations being up to three times larger in direct drilling than in ploughed soil (Edwards & Lofty 1978). These have included not only the beneficial invertebrates in groups such as *Acarina, Collembola, Diploda, Mollusca* and some insects but also pest species such as slugs, wireworms, cutworms and predators, eg, *carabid* and *staphylinid* beetles (Edwards & Lofty 1978). This established that direct drilling favours populations of soil invertebrates from many taxa (Edwards 1975, Edwards & Lofty 1977, 1978). The numbers of most species of invertebrates were found to be greater in soil that had been direct drilled (Edwards & Lofty 1975b). Indirect evidence suggested that direct drilling also changed the microbial activity, as direct drilled areas were observed to have higher rates of decomposition than cultivated areas (Herzog & Bosse 1969). Corbett & Webb (1970) found that the total number of nematodes was sometimes larger with direct drilling than ploughed areas. Wilkinson (1977) found that soil microarthropods were slightly greater in direct drilled plots than ploughed.

(a) Earthworms. Although earthworms form the most obvious group of soil inhaviting animals little information has been forthcoming about the changes in weight and number of earthworms resulting from the use of direct drilling. Baeumer & Bakermans (1973) reported that a West German worker found on average a 12 fold increase in number and a 16 fold increase in weight of earthworms collected on direct drilled areas compared to conventionally cultivated areas. Edwards & Lofty (1975a) used a slit seeding/herbicide treatment (direct drilling) and found that the effect on earthworm populations was variable and depended on the species of worm. *Lumbricus terrestris* for example was found to be much more numerous in the uncultivated plots at the end of the first year of experimentation but thereafter increased greatly in numbers in the ploughed plots, so that over the length of the experiment ploughing greatly favoured this species. Edwards & Lofty (1977) found that the total earthworm populations were greater in direct drilled plots than in the ploughed ones, but not all species were favoured by lack of cultivation. There were between 1.5 - 6.0 times more *Lumbricus terrestris* in direct drilled than in ploughed plots. Other more common species such as *Lumbricus castaneus, Allolobophora longa, A. caliginosa, A. chlorotice, A. rose,* and *Octolasium cyaneum* differed much less in numbers between direct drilled and ploughed plots, overall differences ranged from 1.1 to 2.6 times. Cannell & Finney (1973) reported that total earthworm populations were three times greater after direct drilling for three years than after ploughing or tine cultivation. Edwards & Lofty (1979) found that the average number of all earthworms species was larger in direct drilled fields (range 51.5 - 109.5m^2) than in ploughed fields (range 16.0 - 48.0m^2). Table I taken from Edwards & Lofty (1979) shows the differences in earthworm populations between direct drilled and ploughed fields.

As well as the number of earthworms, their activity seemed to increase as well. Baeumer & Bakermans (1973) claimed that this was what the agronomist was interested in, as it was

TABLE I

Average numbers of earthworms m^2 (mean of seven fields, assessed by formalin method)

(Edwards & Lofty (1979))

	Direct drilled	Ploughed
Lumbricus terrestris	34.4	6.8
Allolobophora longa	11.0	3.1
Allolobophora Chlorotica	25.9	11.3
Allolobophora caliginosa	11.5	10.9
TOTAL	72.8	32.1

earthworm activity which altered the ecological conditions of naturally compacted soils. Graff (1969) measured the rate of casting of three years and found that between 2-4.5kg/D.M./m^2 was deposited on the soil surface in direct drilled areas which was within the range of values normally encountered in old pasture. Graff (1969) also observed a 20-25 fold increase in rate of casting on direct drilled plots compared to ploughed barley stubble. Edwards & Lofty (1979) found that in many soils earthworms were undoubtedly beneficial to the growth of direct drilled cereals as they showed that earthworms caused better germination, more tillering, taller plants and greater yield.

(b) Mites and other arthropods. Edwards & Lofty (1975b) found that although the overall changes in populations were relatively small, slit seeding (direct drilling) favoured most groups of soil arthropods. The principal exceptions were the larger predatory mites, deeper soil dwelling *Collembola* and dipterous larvae. Edwards & Lofty (1977) reported that overall populations of mites and springtails were favoured by direct drilling, although like the earthworms the effect differed with different species. Populations of mites were 1.3 to 3.8 times greater in direct drilled soil than in ploughed whereas numbers of springtails were 1.2 to 3.1 times larger. Van de Bond (1970) found that tillage affected the vertical distribution of the springtail and mite populations. In uncultivated soil almost all the springtails and mite populations occurred in the top 5cm where most of the organic matter was, whereas cultivated soil had the populations more evenly distributed through the soil. Wilkinson (1977) found more microarthropods in direct drilled plots than cultivated ones.

(c) Slugs. Slugs tended to be more numerous in direct drilled areas than in ploughed and cultivated areas (Patterson et al 1980). Edwards (1975) stated that attacks by slugs were much less serious after ploughing. Hunter (1967) suggested that slugs may beocme an increasingly serious pest as cultivations become less necessary to the growing of arable crops. Edwards & Lofty (1979) reported that slug attacks were consistently greater in direct drilled crops. It was reported (Anon 1973) that crops that were direct drilled were often attacked by slugs which tended to congregate in the slits cut into the turf by the direct drilling machine. Whiting & Lofty (1967) observed that on plots planted by direct drilling many *Deroceras reticulatum* were present whereas few were found on ploughed plots. The literature does not seem to contain reports which might suggest preferences by slugs for the different habitats created by different design of direct drill coulters.

2.6 Advantages and disadvantages of an increased soil fauna.

Increased number of soil fauna can be advantageous or disadvantageous depending on whether the pest or non pest portion of the soil fauna was increased. The advantages of direct drilling on the soil fauna and the soil fauna on the crop were cited by Pottinger (1979) as being:

(a) survival of pathogens that control soil invertebrates

(b) better survival of predators and parasites of pests

(c) larger populations of earthworms, mites and springtails for decomposition of organic matter and hence release of nutrients

(d) achieves incorporation of organic matter into the soil, humification, translocation of minerals to the surface, creation of better soil structure, increased pore formation, aeration, root penetration, improved water holding capacity, continued stabilisation of the soil, nutrient ion retention in the soil, mineralisation, modification of soil pH, and increased crop production.

The disadvantages due to the increased soil fauna occurred mainly through a portion of the soil fauna becoming large enough in population numbers to cause an economic loss in the crop. According to

Pottinger (1979) the disadvantages were:

(a) retention of crop and pasture residues ensured better protection of pests

(b) root and seedling pests transferred from residues to the crop

(c) seed grooves provided a haven for pests and an easily available food supply.

2.7 Effects of direct drilling on the soil fauna.

Edwards (1977) noted that the more drastic the type of cultivation and the more operations involved the greater were the effects upon the soil fauna. Hunter (1967), Edwards & Lofty (1975b, 1977) have also reported this trend. Luxton (1967) pointed out that not only was the time of mechanical interference (ie, ploughing) important, but also the kind of mechanical instrument used can affect the soil fauna. The practice of direct drilling provided a very different habitat to that of a ploughed and cultivated soil (Edwards 1975). Soil invertebrates have taken advantage of this habitat by usually increasing their numbers. Whiting & Lofty (1967) suggested that increased soil fauna could be due to increased reproduction in the area as a whole, or in the seed grooves or by migration into the seed grooves from the surrounding area, or by fewer losses due to predation. There is no information in the literature to show whether the populations of soil invertebrates in direct drilled fields increased or were just maintained at the previous population level. A number of changes associated with direct drilling were able to lead to decreased or increased pest attack. These were:

(a) soil compaction and effect on drainage (Edwards 1975). Patterson, Chamen & Richardson (1980) found that there was a trend towards firmer soil with the conventional plough and drill down to a depth of 200mm while direct drilled plots were particularly hard on the surface and down to about 75mm but beneath this the resistance was less. Russell et al (1975) observed that direct drilled soils had greater consolidation and compaction than ploughed soils. The bulk density was often higher and the mechanical strength greater in direct drilled soils (Cannell & Finney 1973). Shear (1968) reported that no tilled soils had improved porosity of the surface soil resulting from aggregation which enhanced infiltration of water and improved aeration. Baeumer & Bakermans (1973) found that the rate at which rainwater moved down the profile was more rapid in direct drilled areas probably because of greater earthworm populations.

(b) lack of cultivation, so no longer controlling the soil pests by mechanical damage (Edwards 1977). Spring cultivations were carried out to control grass grubs *(Costelytra zealandica)* by causing high mortality of the pupal stage, autumn cultivations were also effective (East & Kain 1977). Australian soldier fly *(Inopus rubriceps)* was controlled by 2-6 workings of surface cultivation (Gerard 1977). Hunter (1967) found that cultivations could cause up to a 90% reduction in population numbers of *Deroceras reticulatum*. Crowley (1980) reported that direct drilled grasses were very susceptible to pest damage because pest populations in the original sward were not destroyed. Edwards & Lofty (1978) noted that direct drilling changed most pest problems because there was no mechanical damage to pests and less predation by birds.

(c) provision of hiding places for pests in organic trash (Edwards 1975). Organic matter increased under direct drilling (Phillips & Young 1973). Cannell & Finney (1973) found that where direct drilling was continued for several years the organic matter content near the surface was greater than after ploughing. Edwards & Lofty (1978) reported that accumulation of surface trash could lead to increased pest and disease problems. Rodgers — Lewis (1977), Whiting & Lofty — (1967), Musick (1970) found that direct drilling resulted in increased trash residues which lead to pest attacks such as slugs.

(d) carry over of pests from crop to crop or pasture to crop by trash and weeds (Edwards (1975). Pottinger (1979) reported that in conservation tillage survival and successful transfer of many root and seedling pests was greater, eg. Argentine stem weevil *(Hyperodes bonariensis)*, greasy cutworm *(Agrotis ypsilon)*, Australian soldier fly *(Inopus rubriceps)*.

(e) possibility of earlier sowing dates changing susceptibility to pest attack (Edwards 1975).

(f) possible effects of subsidiary techniques (Edwards 1975). Pottinger (1979) reported that the killing off of existing vegetation with herbicides forced invertebrate pests to feed on the crop. Pottinger (1979) pointed out however that this could be used for control of pests such as Australian soldier fly *(Inopus rubriceps)* where the crop was planted with an insecticide.

(g) provision of shelter and food in seed grooves (Edwards 1975, Pottinger 1979). This involved pests such as slugs (Anon 1973), weevils, cutworms and crickets (Pottinger 1979).

2.8 Slug problem in direct drilling.

Slugs are perhaps the most widely known of all the pests that attack cultivated plants (Anon 1973). They have a very wide host range including such diverse plants as cereals, peas, clover, re-seeded ryegrass, root crops such as carrots, kumara, potatoes, and other vegetables including brassicas, celery, lettuce, pumpkins, silver beet, tomatoes, (Charlton 1978), Anon 1973, Coleman 1970). This wide host range along with their ability to survive extended periods of time without food means slugs are generally widespread and present in most agricultural-horticultural areas (Stephenson & Bardner 1976, Duval 1972).

Slugs are often a problem in conventional cultivation overseas (Anon 1973, Stephenson & Bardner 1976, Runham & Hunter 1970). Since information on slugs in New Zealand is far from complete it is difficult to state whether slugs cause the same problems here. However Charlton (1978) reported that recent studies on legume oversowing showed that slugs are one factor in seedling survival, causing up to 90% mortality in the month following sowing. Blair & Morrison (1949) reported slug problems on cereals grown after old pasture and Coleman (1970) listed slug problems on horticultural crops. In direct drilling it is the damage that slugs do to the sown seed and germinating seedling that is important. It has been stated (Anon 1973) that the most serious losses result from the slugs scraping the germ of the seed below the ground before it has a chance to germinate. This was more common on heavy land when cereals are direct drilled than when conventional cultivation was practiced.

Hunter (1967) looked at the effect of cultivation on slug populations and found that cultivation reduced the number of slugs with more intensive cultivations giving the greatest reductions. He concluded that slugs may become increasingly serious pests as cultivations become less necessary to growing arable crops. Edwards (1977) reported that the more drastic the type of cultivation and the more operations involved the greater the effects upon the soil fauna (including slugs). Luxton (1967) wrote that generally the rule seems to be that a reduction in animal numbers follows each measure taken to cultivate the soil. If conventional cultivation reduces the soil fauna in general and slugs in particular because of soil compaction, degree of mechanical damage to animals, reduction of hiding places and reduced carry over of animals in trash (Edwards & Lofty 1975a) then direct drilling with its minimum soil disturbance, trash cover etc must tend to conserve the soil fauna. Edwards (1977) for example found that a direct drilled rotation of cereals and oil seed rape was extremely favourable to the build-up of slug populations.

Slug problems appear to be much greater in direct drilling than in conventional cultivation. Edwards (1975) reported the numbers of most species of soil invertebrates were greater in soil in which direct drilled crops had been grown and that attacks by slugs and wireworms were much less serious after ploughing. Allen (1975) suggested that one of the reasons for the ICI plant protection produced Mechanical 3 drill not having much success was the slug problem. Gregory & Musick (1976) reported that reduced tillage methods of crop-production have created many pest problems with slugs being the most serious - non insect problem encountered in some areas ie. Ohio and northeastward. Musick (1970) reported that in severely infested Ohio fields in 1969, slugs destroyed up to 60% of the stand in no-tillage corn but less than 5% in conventionally tilled corn. Baeumer & Bakermans (1973) reported that slugs were observed to feed preferentially on zero tilled crops. Patterson, Chamen & Richardson (1980) found that the only major pests occurring in direct drilled plots were slugs. There were no serious slug attacks in the period of assessment but more slugs were trapped in the direct drilled plots than in cultivated ones. Stephenson & Bardner (1976) reported that the slug problem in Britain has been aggravated in recent years by an increased area subjected to direct drilling, for direct drilling leaves surface trash on the surface which can provide cover for slugs, whilst the seed grooves in which seeds are sown provide shelter and enable slugs to feed on the exposed seed. Edwards (unpublished, cited Stephenson & Bardner 1976) compared slug populations of direct drilled and conventionally sown wheat plots on different sites and found that direct drilled plots had a mean of 6.4 times as many as ploughed ones and in one trial had 23 times as many.

Within New Zealand little information is available on the pest status of slugs or their effect on direct drilled crops, but Proude (1970) stated that overseas work indicated that slugs may become a more serious problem in agriculture when cultivations become less necessary to the growing of arable crops, particularly where precision drilling is carried out. Carpenter et al (1978) investigated insect damage to maize *(Zea mays)* seedlings following different methods of tillage. They found that an unidentified species of slug did considerable damage to the first two true leaves in the direct drilled plots but did not destroy any plants. Choudhary (1979) observed that some of the emerged seedlings from his direct drilling experiment were being affected by insects and/or other pests. In the earlier stage of one experiment snail and slug attacks on the emerged seedlings were apparent and considerable damage was visible. This problem had been reported earlier in part by Baker (1976a). Dr Baker (per comm) suggested that slug attacks seem to be greater in direct drilled crops especially when the chisel coulter is used. Pottinger (1979) suggested that slugs may be quite a problem in direct drilling in New Zealand.

2.9 Species of slugs.

The term slug refers to a gastropod mollusc with the shell completely lost or so reduced as to be unable to contain the animal (Barker 1979). In New Zealand there are representatives of two widely differing families of slugs, the introduced slugs from Europe and the native slugs which are found only in the Western Pacific area (Burton 1962). Native and introduced slugs rarely occur together; in general, the native species are inhabitants of forested regions and the introduced slug species occupy modified habitats such as pasture and arable crop land. The two families can easily be separated as the introduced slugs (with the exception of the *Testacellidae*) have no external shell and carry dorsally and anteriorly a saddle shaped mantle (Barker 1979). It is the introduced European slugs which are the pest species in New Zealand. These occur in four genera; *Limax, Agriolimax, Arion* and *Milax* (Martin 1978). Each genus has certain characteristics such as mantle shape, colour, position of pneumostome etc which enables identification and is used in the key of Barker (1979). Barker (1979) revised and clarified nomenclature and provided a key to identification of eleven species of introduced slugs. The most widely distributed pest species in New Zealand are *Arion hortensis, Milax gagates, Deroceras reticulatum* and *Deroceras panormitanum*. Of these the latter two are the most important established pests (Barker 1979, Van der Gulik & Springett 1980). *D. panormitanum* is a common slug being very widespread and can be found in both slightly and greatly modified habitats but never in native forest. It is an established pest causing damage in greenhouses, gardens, horticultural crops and pastures (Barker 1979). *D. reticulatum* is the most common and widespread of New Zealand's introduced slugs occurring in large numbers only in areas greatly modified by human activity. It is an important pest of cultivated plants in greenhouses, domestic gardens, horticultural crops, field crops and pastures (Barker 1979). *D. panormitanum* and *D. reticulatum* are both surface dwelling (Hunter 1967, Stephenson & Bardner 1976, Stephenson 1968) while *Milax* species and *Arion hortensis* are subterranean species (Stephenson 1968, Stephenson & Bardner 1976, Hunter 1967).

2.10 Biology of slugs

(a) Life Cycles. Slugs are hermaphrodite and protandrous. Although mating is usual, self fertilisation can occur (Stephenson & Bardner 1976). Cross fertilisation acts in one direction only, one member acting as a male, the other as female without any obvious clue as to which is which (Coleman 1970). Eggs are laid in clusters in sheltered places, or in the soil, for the eggs are quickly killed by drought or frost unless protected (Anon 1973). The number of eggs per cluster varies from 10-50 depending on the species (Anon 1973, Stephenson & Bardner 1976). Most species lay two or three clusters usually between autumn and the early spring (Stephenson & Bardner 1976). *Deroceras reticulatum* breeds throughout the year except in very dry or very cold weather (Stephenson 1968) and lays most of its eggs in the cooler months (Stephenson & Bardner 1976), or in spring (Carrick 1938). Other species have more restricted breeding seasons; for example *Arion hortensis* breeds in the autumn, *Milax budapestensis* and *Milax sowerbyi* in autumn and early winter (Bett 1960). Egg hatching varied in time from three weeks under warm spring conditions, to where eggs laid in autumn may not hatch until the following spring (Anon 1973). Stephenson & Bardner (1976) reported that the duration of development in the egg stage varies and is largely governed by the ambient temperature. A similar result has been found for New Zealand slugs by Van der Gulik (1980). The young slugs tend to remain near the egg and though they disperse over time there is no evidence of long distance movement (Stephenson

& Bardner 1976). Ferro (1976) stated that the growth of young slugs is slow at first and that they tend to be gregarious feeding in groups. They do not reach full size until about six months of age and probably live for more than a year. However slugs mature sexually before they are full grown (Stephenson 1968). Stephenson (1968) reported that longevity differs from species to species. *Deroceras reticulatum* live 9-13 months completing their life cycle in one year, *Arion hortensis* 7½-12 months (occasionally 20 months) depending on the time of hatching and *Milax budapestensis* 20-24 months (biennial life cycle). Hunter (1968b, 1966, 1969a, Bett (1960), Anon (1973) also observed these lengths of life cycles. Dependent upon the species and the weather there may be one or two generations per year (Stephenson & Bardner 1976). *Deroceras reticulatum* has two generations a year; a spring and an autumn generation (Hunter 1966, 1968b, Anon 1973). *Arion hortensis* one generation per year (Hunter 1966, Anon 1973) and *Milax budapestensis* also has one generation per year (Bett 1960), though if hatching occurs late there will be longer interval between generations of 12-18 months (Runham & Hunter 1970). There is probably considerable variation in the life cycle of slug species between different years, different countries and parts of countries (Hunter 1969b). Little work has been done on the life cycles of introduced slugs in New Zealand. Ferro (1976) suggested that in warm moist localities of New Zealand, slugs can be found all year round, while in colder areas they overwinter in the egg stage. Barker (1980 per comm) suggested that overseas literature would be applicable to New Zealand making allowances for temperature differences, different localities etc.

(b) Temperature, humidity and light relationships. Most terrestrial invertebrates possess some form of protection against adverse environmental conditions usually in the form of a cuticle or shell. Slugs however possess no such protective device and thus their activity is largely dependent on the local microclimate (Crawford-Sidebotham 1972). Slugs thrive in a cool moist environment (Stephenson & Bardner 1976) and are generally active all year round in New Zealand whenever the temperature and moisture conditions are suitable (Ferro 1976). During adverse conditiosn such as very dry or frosty weather slugs stop feeding and move down into the soil or shelter under debris (Anon 1973). It has been stated (Anon 1973) that slugs are most active on still nights when the soil is wet and the atmosphere humid; wind and heavy rain decrease activity. Slugs have been observed to be active at near freezing temperatures that render most other invertebrates comatose (Stephenson & Bardner 1976). Mellanby (1961) found that *Deroceras reticulatum* was particularly well adapted to life at low temperatures, for it was not completely immobilized even at $0^{o}C$ and at $0.8^{o}C$ moves and feeds apparently normally. *Arion hortensis* however seldom moves spontaneously or feeds below $5^{o}C$. Dainton (1954) reported that slugs can survive exposure to one or two degrees of frost, but oviposition and normal development do not occur below $5^{o}C$. Getz (1959) found that *Deroceras laeve* was able to survive very low temperatures. In one of his experiments the slugs were subjected to $-8^{o}C$ for five hours, all were frozen solid at the end of the experiment and all revived upon being thawed out. Thus although slugs are usually most active in more ideal conditions, they are well adapted to remain active at low temperatures (Mellanby 1961). In contrast to these low temperature effects slugs cannot withstand high temperatures. Carrick (1942) observed that *Deroceras reticulatum* survived only one hour at $35^{o}C$. Getz (1959) found that temperatures of 36-$35^{o}C$ killed slugs with a slight difference in tolerance occurring between species. Dainton (1954) reported that temperatures of 30-$32^{o}C$ were lethal to slugs. Slugs have been observed to be active at night and following showers or mist by day, both occasions are when the temperature of the earth is falling (Dainton (1954). Temperature has been reported to stimulate and also to inhibit slug activity. Dainton (1954) looked at the induction of activity by changing temperatures and temperature preferences. She found that a fall in temperature below about $21^{o}C$ stimulates activity and as little as $0.1^{o}C$ fall was enough, though this varied with individuals. Rising temperatures within the range of 20-$30^{o}C$ activated slugs which then moved down the temperature gradient to a cooler place (Dainton 1954). Baker (1973) found that in some cases a fall in temperature was imporant in the initiation of movement from the shelter. Karlin (1961) observed that fluctuating temperatures were the major factor promoting the locomotion activity of slugs. Dainton (1954) showed that slugs preferred temperatures of 17-$18^{o}C$ with another slight preference occurring below $8^{o}C$ though this seemed to be because they were overcome by the low temperature. Getz (1959) found that *Arion circumscriptus* and *Deroceras reticulatum* both prefer temperatures between 18-24^{o}C. *Deroceras laeve* was much less selective, grouping between 14-26^{o}C.

Slug activity has also largely been associated with conditions of high humidity (Dainton 1954). The amount of water vapour in the atmosphere affects feeding activity (Stephenson 1973). Slugs do not feed when the relative humidity of the microhabitat is less than 100% (Runham & Hunter 1970). Carrick (1942) found that *Deroceras reticulatum* did not lay eggs in excessively dry or wet soils and for devleopment the optimum water content of the soil was 70-80% of field capacity. With the use of humidity gradients it can be shown that slugs normally prefer more humid areas, (Runham & Hunter 1970). Lewis (1969à) observed that at the boundary between a dry and a humid zone *Arion ater* executed head movements and then crawled into the damper area. Slugs cannot survive for long periods when the relative humidity of the atmosphere is below 90% (Runham & Hunter 1970). Slugs can lose body water either by evaporation or production of mucus, and this loss is usually made up by absorption of water through the epidermis (Stephenson & Bardner 1976). Dainton (1954) found that locomotion activity is not decreased by small evaporative losses but if larger amounts of water were lost the animal may be immobilized and die. Slug activity was observed to be influenced by the degree of hydration of the body (Howes & Wells 1934, Wells 1944). Runham & Hunter (1970) reported that when *Limax maximus* had its body weight reduced from 9.1 to 6.6g due to excessive mucus production, it could regain its weight by absorbing water from the surrounding saturated atmosphere. Slugs have the ability to survive losses of large amounts of water (Runham & Hunter 1970). Stephenson (1968) wrote that because a large daily loss of water is usual for slugs, they can survive for short periods in dry conditions or at least remain active enough to move to a more favourable habitat. The importance of water in the slug environment has long been noted. Barnes & Weil (1942) found that as long as the soil did not dry out completely, slugs inactivated by a short dry spell would become fully active after only a small amount of rain. If the soil dried out, considerable rain was necessary to activate them. Excess water such as flooding will reduce the slug populations with surface dwelling species being more affected than subterranean species (Stephenson 1976).

Surface crawling normally occurs at night and hence it is a reasonable assumption that changes in light intensity may induce activity (Anon 1973, Lewis 1969a, Karlin 1961). Dainton (1954) postulated that slug activity is stimulated by falling temperatures and inhibited by rising temperatures but is unaffected by light intensity after a period of habitation. Karlin (1961), Getz (1963) however showed that in the field slugs are sensitive to changes in light intensity. Newell (1967) found that the activity of slugs is initiated by an inherent rhythm, when the slugs approach the surface they are deterred from emerging if the eye tentacles encounter bright light; they do not emerge until after a low threshold value is reached usually after sunset. Runham & Hunter (1970) reported that normal activity in *Arion ater* could be maintained with a daytime level of light of 3.580 lux and night level of 5 lux. Nocturnal crawling often finished before sunrise. When slugs are on the surface increased light intensity prior to sunrise increases the rate of crawling and since slugs are photonegative this initiates the crawl "home". (Lewis 1969, Newell 1966, 1967). Duval (1970) observed that slugs move towards dark areas when given a choice of light or dark with a difference occurring between species in the speed in which they react to the light ie, *Deroceras reticulatum* reacted within a minute whereas *Arion hortensis* reacted much slower. Lewis (1969a) found a similar trend in that during the day slugs display negative phototaxis while at night they prefer dim light (positive phototaxis). *Arion ater* was shown by Lewis (1969a) to be very sensitive to small changes in light intensity at night, possibly enabling them to find cover at the end of their active phase. Newell & Newell (1968) have suggested that *Deroceras reticulatum* has an infra red receptor in the accessory retina for while reacting to visible light slugs seem particularly sensitive to infra red. Runham & Hunter (1970) reported on an experiment by Lewis (1967) where slugs were given a choice between normal daylight and one with a 50% reduction in infra red. They preferred the latter.

Temperature greatly affects slugs both in initiation of activity (Dainton 1954, Karlin 1961, Baker 1973) and the length of the life cycle (Runham & Hunter 1970). Humidity affects the duration of activity and may in some cases stimulate it (Baker 1973). Light has a variable influence in some species it regulates activity (Lewis 1969b) while in others it has no effect (Dainton 1954). Endogenous rhythms may also play a part in initiating slug activity for slugs remain under cover during the day-time and are not subjected to the changes in the environment as a whole. They are therefore unable to estimate the time from their surroundings. Thus it is considered that they remain inactive under cover until rather less than 24 hours after the start of the previous active phase. As a result of their internal rhythm they then move and are able to determine if conditions are suitable for activity (Lewis 1969b). All these observations help to illustrate the complexity of the stimuli and responses involved in the initiation of slug activity in the field.

(c) Weather and slug activity. Long dry periods adversely affect both slugs and their eggs (Stephenson & Bardner 1976). Runham & Hunter (1970) reported that slugs do not lay eggs during very dry or very cold weather. In dry weather surface dwelling species such as *Deroceras reticulatum* seek sheltered places such as under stones, clods of earth, surface litter, or in cracks and crebices in the soil (Stephenson & Bardner 1976). In prolonged dry weather mortality may be high amongst those slugs that fail to find moist hiding places (Stephenson & Bardner 1976). Subterranean species such as *Arion hortensis* descend to lower levels in the soil in dry weather with *Milax budapestensis* actually ingesting soil so it can burrow to deeper levels (Stephenson 1968).

The number of slugs active on the soil surface at night is influenced by both wind and rain (Barnes & Weil 1945). On very windy or very rainy nights fewer slugs were active than on calm or rain-free nights (Stephenson 1968). In their night time movements on the soil surface or vegetation, slugs enjoy a moist cool microclimate but changes in the weather can affect this (Stephenson & Bardner 1976). Attempts have been made to correlate the environmental changes with slug activity. Barnes & Weil (1945) found no single weather factor or combination of factors that was associated with changes in slug activity except falling rain and freezing temperatures. White (1959) observed that the numbers of slugs caught during night searching began to decrease as soon as the temperature fell below 4.4^{0}C. Webley (1964) noted that catches of slugs by baits was dependent on activity, which in turn depended on the weather. The number of days for which the baits were left out was the most important factor that affected day to day catches and this together with the average night temperature accounted for 70-80% of the variance. Relative humidity wind speed and rainfall was responsible for some of the variance but had no major effect (Webley 1964). Crawford-Sidebotham (1972) looked at the number of slugs active on the soil surface and four weather parameters - temperature, relative humidity, vapour pressure and vapour pressure deficit. He showed that slug activity is a function of both the temperature and the vapour pressure deficit though this depended on the species.

2.11 Distribution in the soil and movement. The physical characteristics of the soil can affect the behaviour, activity and survival of slugs (Stephenson & Bardner 1976). Stephenson (1975) found that *Deroceras reticulatum* prefers very coarse soils composed of aggregates retained by 10 or 12.5mm sieves. Even newly hatched slugs just emerged from eggs moved to the one composed of larger aggregates. The slugs usually took up positions between the soil aggregates that ensured maximum contact with the soil. Hunter (1966) looked at the vertical distribution of slugs in the soil and found that *Deroceras reticulatum* and *Arion hortensis* descended deeper into the soil in dry or frosty weather. Over the year as a whole these two species had different vertical distributions. In a 30cm deep section of soils the top 8cm contained 82.5% *Deroceras reticulatum*, 61.6% *Arion hortensis* and 49.5% of *Milax budapestensis*. South (1964) found that *Deroceras reticulatum* was found within 2.5cm of the soil surface on grassland while in the arable situation they occurred in the upper 10cm.

South (1965) studied the spatial distribution of slugs and found little evidence of aggregation of slugs in arable land but in the grass plots the distribution of *Deroceras reticulatum* was correlated with the distribution of tufts of cocksfoot. This was probably due to the shelter it provides for both adult, immature slugs, and eggs. He found no strong association with other components of the habitat. Slugs were aggregated in patches 9.0 - 25.8cm across. This distribution seemed to arise from individuals nesting near to one another in sheltered places such as cracks in soil, hoof prints. No positive correlation has been found between the aggregations of slugs and soil pH, soil organic matter content or availability of food plants. Runham & Hunter (1970) reported that aggregation can be measured as the 'coefficient of dispersion' and when this was plotted against time for one study it was seen that slugs were particularly aggregated immediately after breeding seasons. Clearly the resulting hatched young had not yet dispersed. Some aggregation is found throughout the year, presumably mostly due to the uneven distribution of cracks and spaces in the soil (Runham & Hunter 1970). Gould (1961) observed that slugs are most common in heavy soils where the moisture remained at higher levels during the summer, in contrast to the lighter soils which become dry. Dense populations are also commonest where crops such as peas or beans have given shelter during the summer, few slugs are found where such cover does not occur (Runham & Hunter 1970, Anon 1973). Runham & Hunter (1970) reported that species composition of slugs differs in different cropping rotations. *Deroceras reticulatum* is most common where cereals and grass are grown, *Arion hortensis* or *Milax budapestensis* are most common where root crops are grown. The reason for this is that *Deroceras reticulatum* is able to move quickly and further than *Arion* or *Milax* so is better adapted to search for surface shelter and it has a higher reproductive capacity.

South (1965) released slugs from a central point and observed that in the first five days they dispersed fairly evenly; travelling a mean distance of 45.7 - 17.0cm in five days in one experiment and 113.0 - 28.0cm in seven days in another. He also noted that after some initial dispersive movement *Deroceras reticulatum* established a home range. Francois, Riga & Moeris (1965) found that a slug covered a linear distance approximately 9m but because the route was circuitous on the eighth day it was only 4m from the point of release. Stephenson (1968) reported that slugs marked with irradiated wire beneath the vestigial shell, when released in carrot plots adjacent to potatoes travelled long distances until they reached the potatoes then moved little. Verdcourt (1947) looked at the speed of land Mollusca and reported that *Arion hortensis* can move at 0.027cm/sec, so in a 12 hour period this slug could cover

11.6m. Newell (1966) made time lapse photographic records of slug movement and observed that these slugs seemed to show definite tendencies to return to the place from which they had started. Duval (1972) looked at slug movement in late summer and discovered that slugs make circuitous movements with the daytime resting places constantly changing rather than the establishment of any permanent home base. A minority of the population above ground may use the same resting place for several consecutive days. Howitt & Cole (1962) found that slugs were capable of migrating considerable distances within a relatively short time particularly if it rained.

2.12 Size of slug populations. Populations of slugs are difficult to measure as they are in part if not entirely subterranean, aggregated, and farily sparsely distributed (Runham & Hunter 1970). Attempts have been made to assess them however. Gimmingham & Newton (1937) estimated that there were 50,000 slugs per acre in the centre and 70,000 per acre at the edge of a field. Carrick (1942) applied copper sulphate dust at night to infested grass and stubble and obtained counts of slugs ranging between 7.5 to $123.8/m^2$. Thomas (1944) used inverted turves as traps and reached an estimate of $105.5/m^2$. In another experiment using baits encircled alternately with ammonium sulphate, (an effective barrier to the surface movement of slugs), he arrived at an estimate of $148.5/m^2$ *Deroceras reticulatum* in a very severely damaged wheat field. Thomas (1948) treated a plot with metaldehyde and the total kill for three nights was approximately $67.8/m^2$ *Milax budapestensis* and $11.8/m^2$ *Arion hortensis*. Charlton (1978) reported that a moderate population in pasture is $100/m^2$. All of these population estimates depend upon the activity of the slugs and therefore are likely to be underestimates. South (1965) obtained an estimate of 67.8 slugs/m^2 using soil samples and Hunter (1966) obtained 276.7 slugs/m^2.

2.13 Methods for measurement of slug populations. Accurate determinations of slug numbers/unit area is necessary in economic and ecological studies. It is obviously not possible to count the slugs directly, so it is therefore necessary to obtain a sample of slugs that is representative of the population as a whole (Runham & Hunter 1970). Previous studies have used many different methods of assessing the population -

(a) so called traps:

(i) boards, sacking, stones, leaves, inverted squares of turf and inverted boxes (Howitt 1961, Thomas 1944, Hunter 1968a).

(ii) baits incorporating metaldehyde or more recently methiocarb (Barnes & Weil 1942, Thomas 1944).

(b) using seed or plant damage as a measurement of population (Duthoit 1961, Hunter 1968a.

(c) night searching (Barnes & Weil 1944, Hunter 1968a, Bett 1960, Crawford-Sidebotham 1972).

(d) marking-release-recapture (Hunter 1968a, Johnson 1964).

(e) soil sampling (Hunter 1968a, 1967, South 1964).

With the exception of soil sampling all the above methods depend on slug activity which is largely governed by the weather (South 1964). Most workers have appreciated that sampling measures a variable and unknown fraction of the population (South 1964). Hunter (1968a, found that soil sampling is the only method giving accurate estimates of the total numbers, the species composition and the age distribution of slugs in a given area. South (1964) and Hunter (1968a), used two methods for extracting the slugs from the soil -

(A) soil washing - in this method the soil was broken down with a water jet on a bank of sieves (3 mesh, 10 mesh and 30 mesh to the inch). The sieves with their residues were then agitated in a magnesium sulphate solution of at least 1.17 specific gravity. All organic material rose to the surface so that both slugs and eggs could be seen and removed.

Large slugs collected on the 10 mesh sieve and the small slugs and eggs were washed down to the fine mesh (South 1964). The main disadvantages of this method is that many of the very young slugs are destroyed by the water jet and are not recovered (Hunter 1968a, Runham & Hunter 1970) and it is also extremely laborious (South 1964, Hunter 1968a).

(B) soil flooding - a much less laborious method of extracting slugs is to slowly flood the soil with water (South 1964). South (1964) developed this method for his study of *Deroceras reticulatum* on grassland. In this method a soil sample is taken and slowly immersed in water. Water is added at regular intervals until the sample is submerged in 3-4 days. The slugs crawled up the sample to just above the water level and were picked off as they reached the upper edge. Cultivated soils can also be processed in this way but they first have to be placed in bowls to stop crumbling. Only slugs are extracted by this method, eggs are left in the soil. South (1964) used both a hot and cold water method for flooding. The hot water method has the disadvantage that the slugs are killed by the heat and is not usually suitable for samples from arable land.

Hunter (1968a) and South (1964) found that the soil washing method was very efficient for the older stages - 100% for slugs over 12.5mg in weight and 60 - 86% for smaller slugs (Runham & Hunter 1970). South (1964) achieved 94% recovery with eggs and newly hatched slugs. Stephenson (1968) reported that all species of slugs and their eggs can be recovered from soil samples with almost 100% efficiency with a Salt and Hollick soil washing machine. Soil flooding though not removing eggs, still had a high recovery rate, "*Deroceras reticulatum*" 92%, "*Arion hortensis*" 88%, "*Milax budapestensis*" 99% (Hunter 1969). South (1964) found that the cold water process is more efficient than the hot water process with recoveries for the cold water process 99% for *Deroceras reticulatum* and 94% for

Agrolimax fasciates. Runham & Hunter (1970) suggested that 90% of the slugs could be extracted by this method.

Trapping has been shown by South (1964) to be unreliable for collecting ecological data for slugs on grassland. Hunter (1968a) looked at the efficiency of trapping and found that surface dwelling species were more likely to seek shelter under the traps so that it underestimates the subterranean species and more slugs were trapped in damp cloudy weather than when it was sunny and dry.

Night searching is based on the system of catch per unit effort introduced by Barnes & Weil (1944, 1945) where they investigated the activity of slugs by searching at night for 30 minutes and counting the number of ative slugs. Bett (1960) used this method of collecting for life cycle studies. Hunter (1968a) used this method in a comparison with soil sampling and found that a higher proportion of surface dwelling slugs was recorded in night searching, and lighter and larger slugs are more easily seen and recorded. Barnes & Weil (1944) stressed that the number found active on any one night does not necessarily represent a fixed proportion of the total number for the number active on any one night depends on the weather and is not likely to be the same for each species.

2.14 <u>Slug damage.</u> Damage may include the complete loss of seeds, loss of emerging seedlings, and defoliation of standing plants (Anon 1973). Three types of damage are typically recognized:

(i) scraping of the germ of the seed before it has a chance to germinate - resulting in seed hollowing

(ii) eating of the shoots and leaves above ground causing leaf shredding

(iii) damage to bases of stems by eating into the stem, similar damage occurs in below ground parts of root crops and is often confused with wireworm damage.

Little quantitative information is available on the status of slugs as pests of horticultural and agricultural crops (Pottinger 1979), but it is clear that they cause considerable damage throughout the temperate regions of the world (Charlton 1978). Ferro (1976) wrote that damage by slugs can be considerable. Although they can consume 350g of plant material during their life cycle, they will spoil considerably more than they actually eat by secondary fungi and bacterial attack. Slugs can play a role in the transmission of plant diseases such as cabbage leaf spot, parasites of domestic animals, downy mildew of lima beans and possibly potato blight (Runham & Hunter 1970, Wester, Goth & Webb 1964). Lutman (1980) reported that slugs consumed $16.3 g/m^2/yr$ while Yamashita, Jones & Nicholson (1980) found that a *Deroceras* species of slug could be a serious pest in pastures and at peak infestation (470 slugs/m^2) 60% of the leaf area was eaten.

3. MATERIALS AND METHODS

This study was carried out in two stages covering the period July 12 1980 to February 11 1981. All field work was undertaken on Dairy Farm No 4 at Massey University, Palmerston North (latitude 4030').

The first stage of the study involved overwintering populations of slugs and the effects of three different winter ground covers on populations. Specific environmental parameters were measured to see if there was any correlation between these and slug numbers. The parameters were temperature at the soil surface, soil moisture to a depth of 0-15cm, humidity of the overall site and rainfall. This part of the field work was carried out from July 12 1980 to November 30 1980.

The second stage was in the summer from December 31 1980 to February 11 1980. It involved direct drilling a cereal crop (barley) into the winter ground covers which at this stage had two moisture levels imposed on them. Drilling was carried out using three different coulters - triple disc, chisel and hoe coulter assemblies. Environmental parameters within and outside the seed groove were measured. These were humidity, temperature and soil moisture within the seed groove and air temperature, ambient humidity and rainfall outside. Seed counts, seedling emergence and damage to seed and seedlings were recorded together with counts of slugs within the seed grooves.

The study site was a ryegrass white clover pasture which had been established for several years. The soil was Tokomaru silt loam (see Appendix I) with negligible slope and moderate drainage.

3.1 EXPERIMENTAL DESIGN

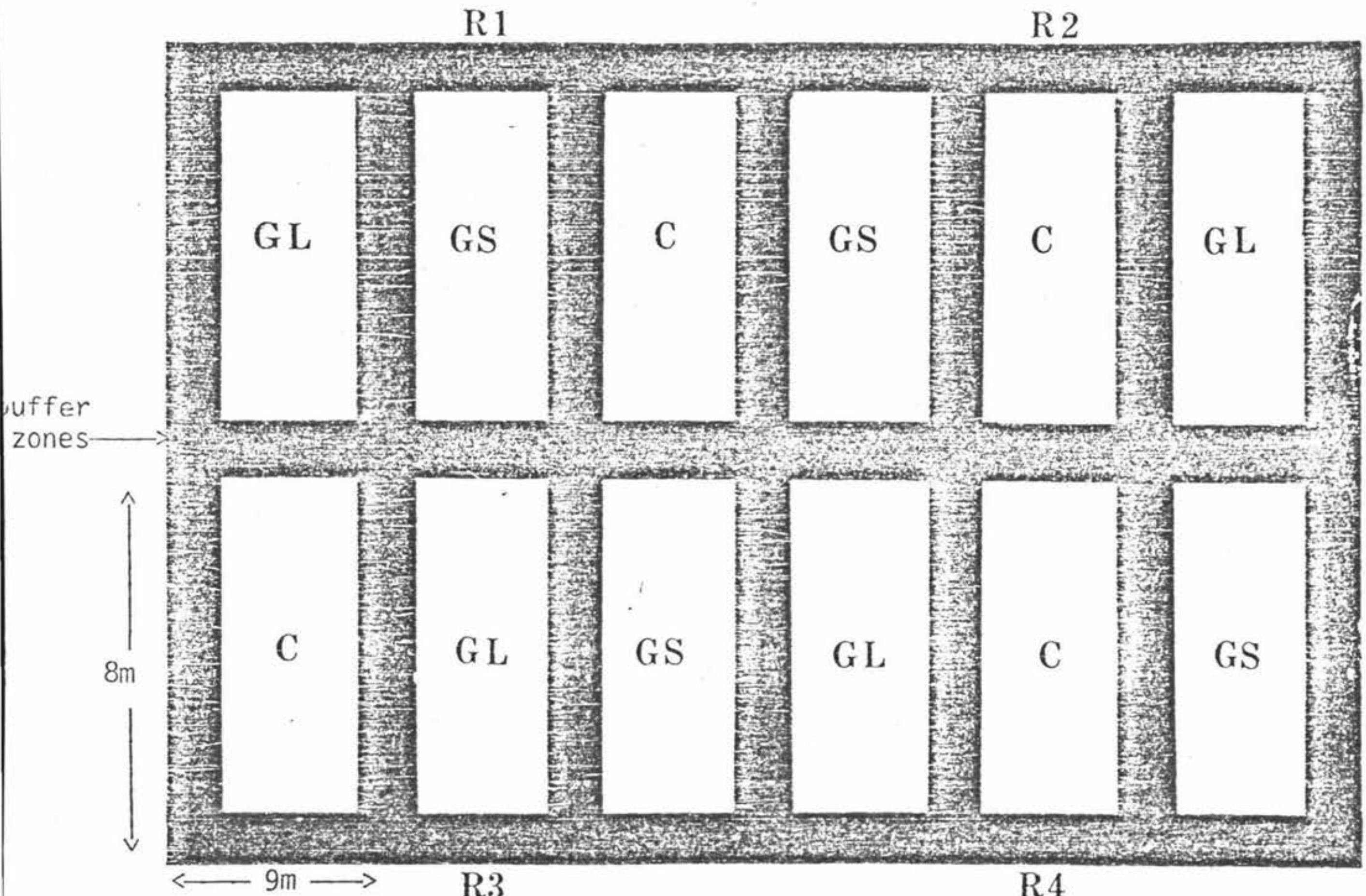
(A) First Stage: Effects of Winter ground cover on over-wintering slug populations. The design was a completely randomized block consisting of four replicates of the three ground covers (main treatments) with a plot size of 9m x 8m ($72m^2$), 12 plots in all. All traps and samples were taken randomly within each plot. Each plot was surrounded by a 2m buffer strip of bare ground and a 2.5cm strip of salt.

(B) Second Stage: Effect of slugs on a direct drilled crop, and effect of three coulters on ingression of slugs into the seed groove under irrigated and non irrigated conditions. The design was a split-split plot design. The main treatments were the ground covers, with the first split being irrigation or non irrigation, and the second split being the three different coulters (72 plots). All traps and samples were taken randomly within each plot or along each coulter row. The plot size was 1½ x 9m in the case of the second split (24 plots) although a 3m x 9m plot was irrigated. The irrigated plots were divided in half so that two separate drillings could be carried out. All plots were surrounded by a 2m buffer strip and a 2.5cm barrier of salt.

3.2 FIRST STAGE: EFFECTS OF WINTER GROUND COVER ON OVERWINTERING SLUG POPULATIONS.

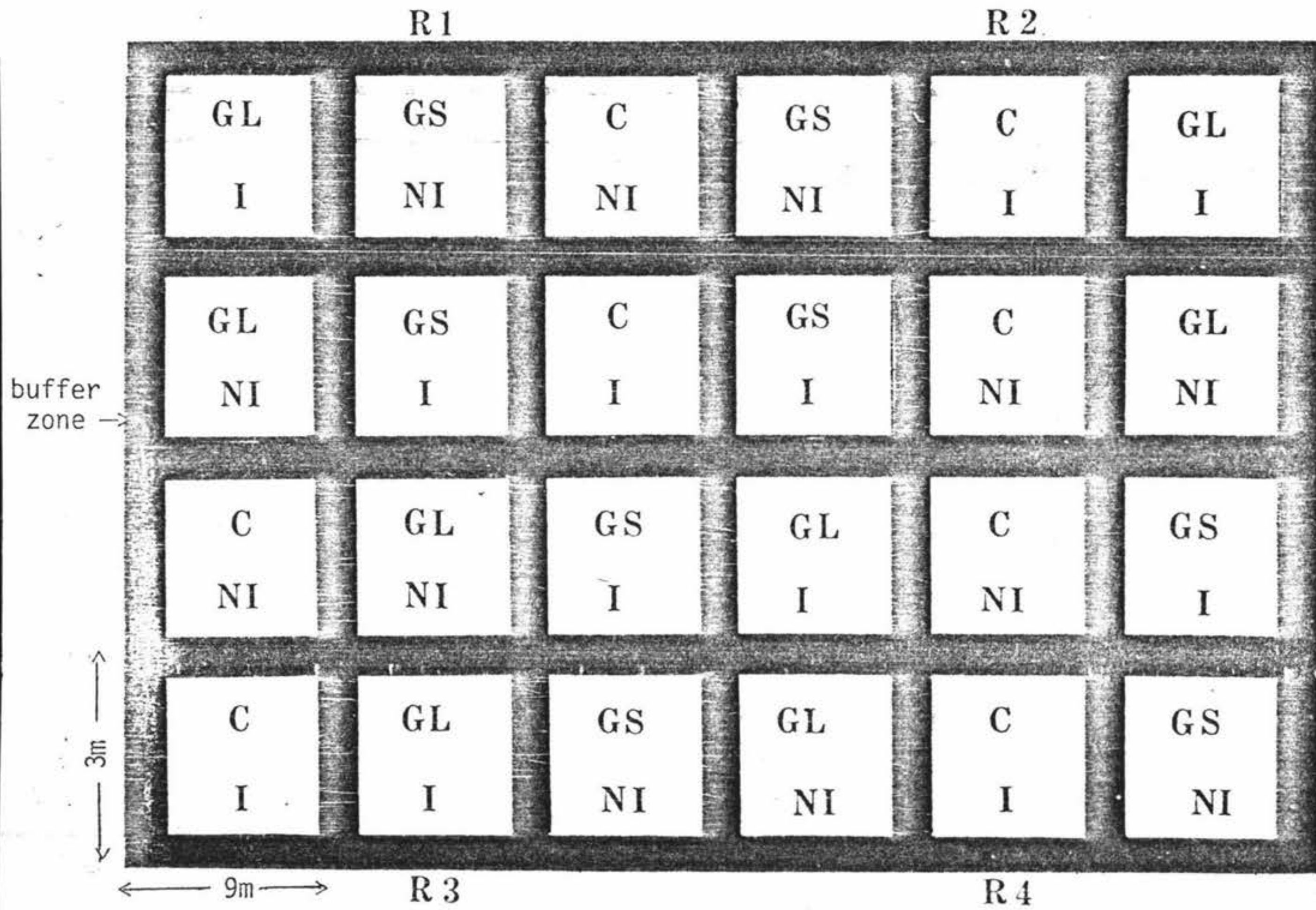
(A) Implementation Ground Cover: The first stage involved the

Figure 2. Experimental layout - first stage.
Main treatments.



Treatments:
GL = Grass long
GS = Grass short R = replicates
C = Chemical

Figure 3. Experimental layout - Second Stage



I = irrigated
NI = non irrigated

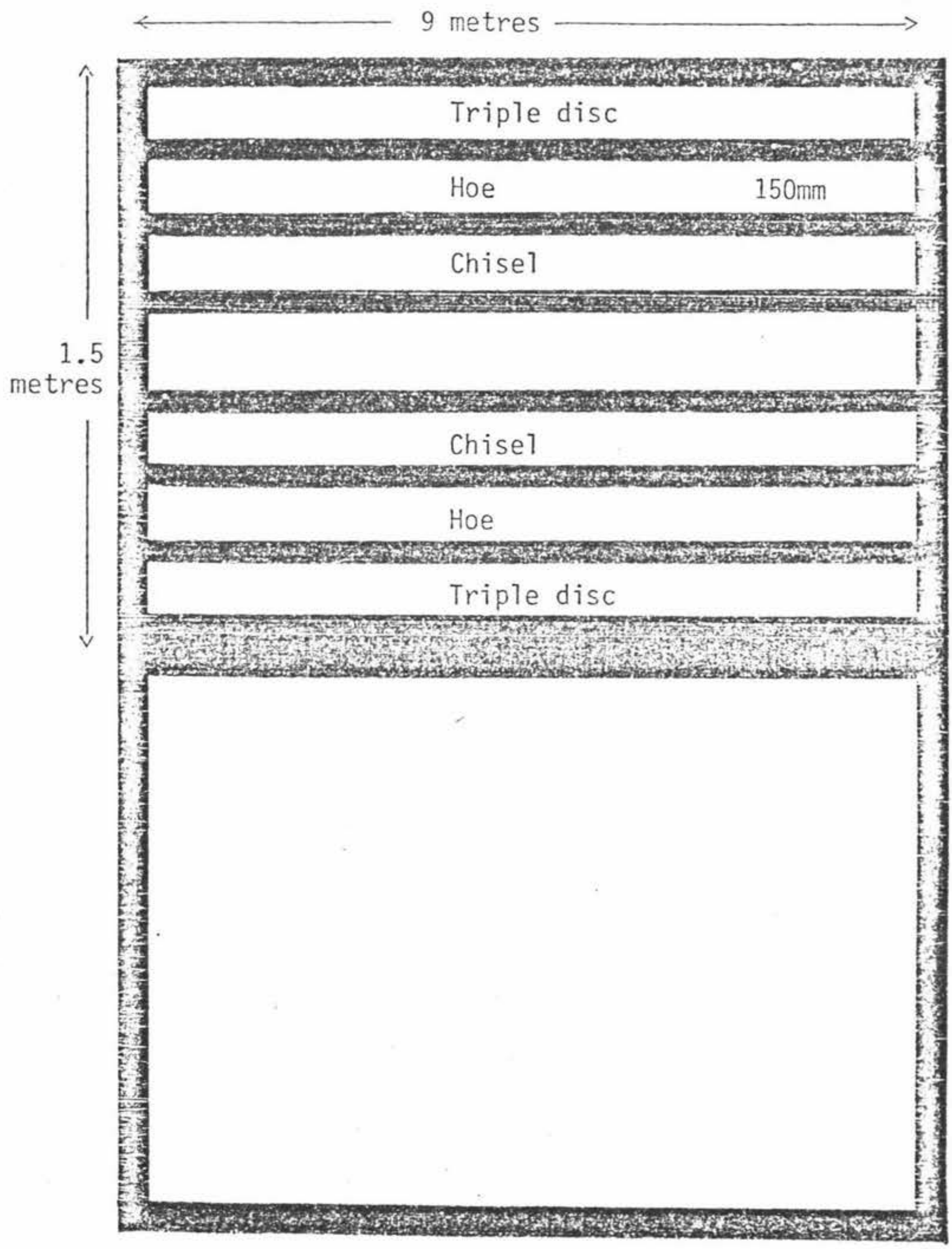


Figure 4. Plan of a plot after drilling

setting up of the three winter ground covers on the experimental area (70m x 26m) which was fenced off from the surrounding pasture. The three winter ground covers (main treatments) were -

(a) unmown pasture - Grass Long (GL)

(b) Short (2.5-10cm) regularly mown pasture - Grass Short (GS)

(c) chemically killed pasture resulting in bare ground - Chemical (C)

These three treatments were used to simulate a range of environments commonly encountered by slugs and ranged from an ideal environment (a) to a very adverse environment (c). One aim of implementing these treatments was to achieve three different slug populations at the time of the drilling (second stage of the study).

(i) Grass Long. At the commencement of the study the site was long (15-20cm) pasture which meant that the long grass treatment was already present. The plots in this treatment were simply marked off and left untouched. As the trial progressed it was necessary to remove large thistles (*"Cirsium arvense"* - Californian thistle, *"Cirsium vulgare"* - Scotch thistle) manually from these plots to facilitate measurements.

(ii) Grass Short. The short pasture plots were mown using a Rotary lawn motor mower whenever the height of pasture reached 8-10cm. In the early stages of the trial this was approximately every 4 weeks. It was mown down to a height of 2.5 - 3cm. This method of timing the mowing by pasture height measurement allowed for differences in pasture growth during the experimental period and enabled a relatively constant height of vegetation to be maintained. All clippings were removed from the plots and placed outside the trial site. In the earlier stages of the trial these discarded clippings were searched for slugs. If slugs were being removed the population would decline unnecessarily and cause the effect of the treatment to be overestimated. At no stage in the hand searching of the clippings were any slugs or parts of the slugs found, though the possibility does exist that they were so damaged as to be unrecognizable. If this did occur it is felt that the number would have been low, as most slugs during the day are sheltering in the soil or at the base of plants (Ferro 1976, South 1965, Yamashita, Jones & Nicholson 1980). These plots were mown six times during the course of the first stage of the experiment.

(ii) Chemical. Bare chemically killed plots were set up by using the herbicide glyphosphate (Roundup*). This herbicide was chosen from a wide range available on the basis of work carried out by Van der Gulik & Springett (1980), who found that glyphosphate at the maximum recommended rate caused no mortality to slugs. Glyphosphate also gives a reasonably broad spectrum kill of vegetation under favourable conditions. The dead vegetation was left on the soil surface. Large amounts were not present as these plots had been mown to 2.5cm before the first spraying. The initial spraying took two weeks to give a complete kill because of low winter temperatures. The dead vegetation on the surface was subsequently present for approximately one month. This would have provided food and shelter for the slugs during this time (Anon 1973). These plots received further herbicidal sprayings as needed for regrowth and germination of weed seeds. In total

* registered trade name

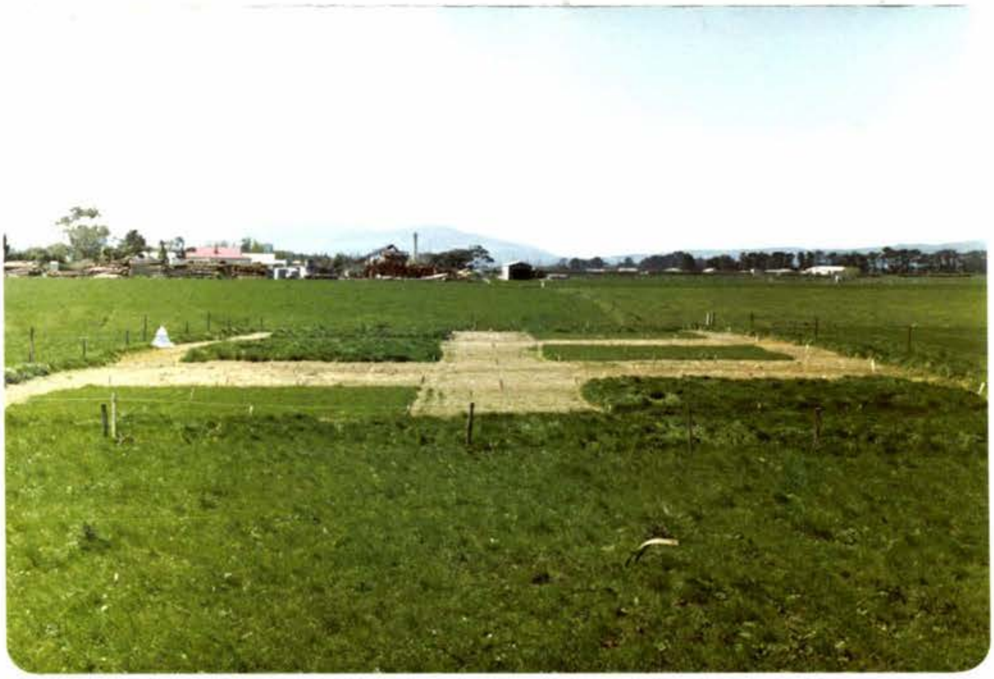


Plate 1(a). Overall view of main treatments (ground covers) September 1980

Plate 1 (b). Close view of Grass Long (GL) treatment October 1980

Plate 1 (c). Close view of Grass Short (GS) treatment
October 1980

four sprayings were carried out. Application was by portable knapsack sprayer (15 litre capacity) at a rate equivalent to 10.4 litres of herbicide formulation per hectare.

(B) Buffer Strips. All plots were bounded by a two metre wide buffer strip of bare ground. These buffer strips were set up one week before the treatments to isolate slug populations within them. This was done to minimise slug movement into or out of treatments, so any change in population would be due to treatment effects. The buffer strips were set up using glyphosphate. Six sprayings at a rate of equivalent to 10.4 litres of herbicide formulation per hectare were made during the course of the experiment. Any dead vegetation was removed by raking and using the mower at it's lowest setting. After three weeks the buffer strips were completely bare and were kept in this state for the length of the experiment.

Whether or not the bare ground (of 2m width) was sufficient to stop slug movement completely was unknown. It appears that slugs do have the ability to travel reasonable distances and possibly could cross such a buffer strip. Since this study was to be run over winter, and the possibility of rain which enhances slug movement (Howitt & Cole 1962) was great it was decided to surround each plot with a 2.5cm wide salt strip.

Common salt ($NaCl$) was chosen because large amounts were readily obtainable and other workers had used it with success (Crowell 1967). Salt was applied twice weekly and also after rainfall so that there was a constant salt barrier. Approximately 33g per metre of salt was applied each time, but this varied depending on the amount present at the time of application. There probably was some residual effect of the salt as it was washed down into the soil, and it may therefore have stopped lateral slug movement within the soil. Subterranean movement was not measured and is felt to be negligible in a compacted soil as occurs in a pasture situation during winter. Salt barriers were used throughout the course of both stages of the study whenever treatments had to be separated to stop slug movement. Four to five weeks after setting up the buffer strips and initially laying down the salt barrier no slug carcasses were found in the buffer strip region, though pitfall traps did continue to record very low numbers (Appendix II). It is not certain whether these were residents of the residual buffer strip slug population or migrants moving from outside the experimental site into the buffer strips. Some dead slugs were noticed on both sides of the salt barrier throughout the study and this can be taken as evidence that few or no slugs passed across it. The numbers of dead slugs were low (0.07/m) and not considered an important factor in changes in slug populations within the treatments.

(C) Irrigation. In the interval between the conclusion of the first stage of the study (30 November 1980) and the commencement of the second stage (31 December 1980) two moisture regimes were imposed.

This involved dividing each of the existing plots (Main treatments - overwintering vegetation covers) in half by placing a two metre wide buffer strip lengthwise giving a plot size now of 3m x 9m (first split in the split-split plot design). Half of these plots were irrigated using soak hoses and half were left to dry out according to the prevailing weather conditions. The two moisture regimes were set up to observe if soil moisture affected the number of slugs moving into the seed grooves. It was possible that high water deficit conditions could exaggerate any differences between the different coulter seed grooves in terms of seedling emergence, and slug damage. It was felt that by presenting extremes of moisture levels any moisture effect would be highlighted. The irrigation set-up involved main feed pipes (1.9cm in diameter) running off the farm trough system which is from town water supply (0.21mPa pressure, 27 litres per minute flow rate). The water was applied to the irrigated areas using a garden soak hose (1.9cm diameter, with perforated holes) nine metres long. By adjusting the number of hoses and the flow rate it was possible to regulate the width of the irrigation area to the three metre plot width. Wind blown water was seen to land 10-15cm into the buffer strip, which made it necessary to watch the salt barriers closely. At no stage did the dry plots receive irrigated water. Twelve plots were irrigated, but only four soak hoses could be run at any one time, and eight plots could be covered in a day, so a 1-2 day irrigation rotation was carried out. Irrigation time was 2½-3 hours, which enabled 5mm of water to be put on, which was sufficient to meet evapotranspiration losses. (Average evapotranspiration losses for December and February are 4.2mm/day Dr Scotter per comm). Moisture levels at the start of irrigation were at field capacity and in the irrigated plots the moisture levels were kept within 8-10mm water deficit of this. The irrigated plots were therefore very moist and care had to be taken that anaerobic conditions were not created. Therefore in some cases irrigation was missed if the soil was sufficiently wet, for the aim was not to maintain a strict soil moisture level but rather a relatively moist environment compared to the dry plots.

3.3 SECOND STAGE: EFFECT OF SLUGS ON A DIRECT DRILLED CROP AND THE EFFECT OF THREE COULTERS ON INGRESSION OF SLUGS INTO THE SEED GROOVE

(A) Preparation of plots: Before drilling could be carried out the vegetation covers had to be killed off. To achieve this glyphosphate was used at the same rate as it was previously applied and three days were allowed for effect. Action of glyphosphate was faster at this time as the average temperature which affects glyphosphate activity (Robertson per comm) was higher. Because of the length of the vegetation in the unmown plots (60cm-1m) these were mown with a sickle bar hand mower which left the plots cut to a height of 2.5 - 3.5cm. This cut residue was too heavy to allow for the passage of the drill so it was raked and removed after searching for slugs by hand. Searching was carried out in the cut residue of two plots. No slugs were found therefore it is assumed that none were removed from the population. It was easy to see slugs sheltering at the base of the tillers.

The short regularly mown plots (GS) had been mown one week before drilling so after spraying the dead vegetation was left on the ground for it was not heavy.

Chemically killed plots (C) also received a herbicide spraying although they did not need it at this stage.

Plate 2. Sub plots after drilling. Foreground shows Grass Short (GS) treatment, next is Chemical (C) treatment and in the distance is Grass Long (GL) treatment.
January 1981

The immediate pre-drilling environment was therefore three differing trash levels -

(A) high trash level (previously long ungrazed plots)

(B) medium trash level (previously short regularly mown plots) and

(C) no trash (previously chemically killed plots).

These equate to commonly encountered situations in the field where (A) is similar to the continuous cropping situation, eg, after maize, (B) is similar to the first drilling of a crop into pasture and (C) is similar to cases where trash has been removed by various procedures, eg, burning, raking, feeding off to livestock, chemical fallow etc. As soon as the plots were set for drilling they were surrounded by salt barriers as now the plots were split in half again to allow for two separate drillings. While one half was prepared for drilling the other was left in the original treatment and slug movement had to be prevented.

(B) Drilling: The second stage of the study consisted of two separate drillings, with each drilling being treated as an individual experiment in terms of statistical analysis and results. The first drilling was carried out on December 31 1980, with measurements being taken from this date until 9 January 1981 (9 days). The second drilling was on 30 January 1981, and measurements were made until 11 February 1981 (12 days). Time of measurement was determined by seedling emergence as measurements were made only up to this point. It is largely before the seedling stage that slug damage occurs in direct drilling situations, and once the plants reach the first leaf stage most seedlings can survive being grazed by slugs. Most damage occurs at the cotyledon and seed stage (Charlton 1978). The longer length of time for measurements in the second drilling was due to slower seed germination and seedling emergence, possibly because of drier conditions. The irrigated plots of the second drilling emerged within the same period as the first drilling.

Because of the two drillings the plot size at this stage was 1½ x 9m, which allowed two passages of the drill per plot, so giving collectively 18m of coulter groove slit per plot. All drilling was carried out by technicians of the Agronomy department using an experimental three coulter drill which had the facility for the coulter positions to be randomized as needed. Drilling was carried out at a speed of 4km per hour. No fertilizer or insecticides were drilled. Each drill row was started on the plot edge to avoid damaging the buffer strips. Therefore there would have been a small lead-in area at the head of each plot where the coulter achieved the correct depth and started to eject seed. The crop drilled was barley, cultivar Hessian, (at a depth of 40mm in 150mm rows) as it can be sown at this time of the year and is readily attacked by slugs both in the seed and emerging seedling stage (Runham & Hunter 1970, Anon 1973, Gair, Jenkins & Lester 1978, Briggs 1978). It was sown at a rate of 165kg/ha.

Three different coulters were used:

(A) Triple disc coulter assembly which was a commercially available assembly consisting of a flat vertical pre disc of 300mm diameter followed by two flat discs (300mm diameter) angled towards each other at approximately 10^{0} and touching near the bottom. This coulter had no positive depth control.

(B) Hoe coulter consisting of a flat vertical pre disc of 300mm diameter followed by a hollow narrow V shaped hoe coulter. The hoe coulter also had no positive depth control.

(C) Chisel coulter which was a newly developed chisel coulter assembly developed at Massey University, consisting of a scalloped disc of 450mm diameter with the wing portions of the chisel coulter separated, and positioned on either side of the disc which they touch at their front edge and are at a slight angle, followed by two press wheels.

Plate 3 (a). Drilling procedure
left = triple disc
centre = chisel
right = hoe

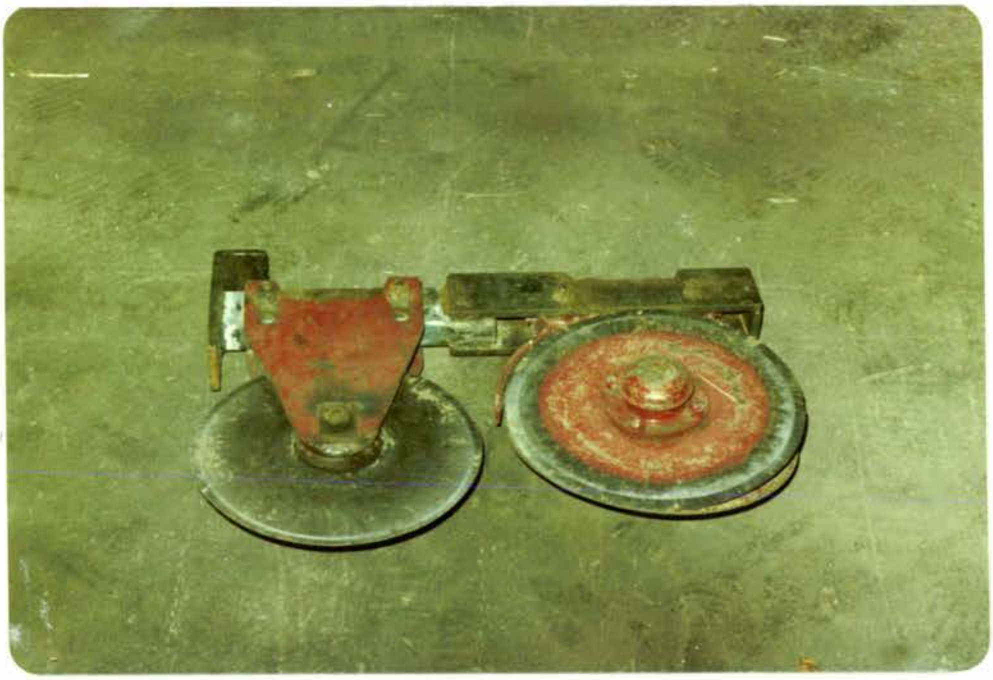


Plate 3 (b). Triple disc coulter

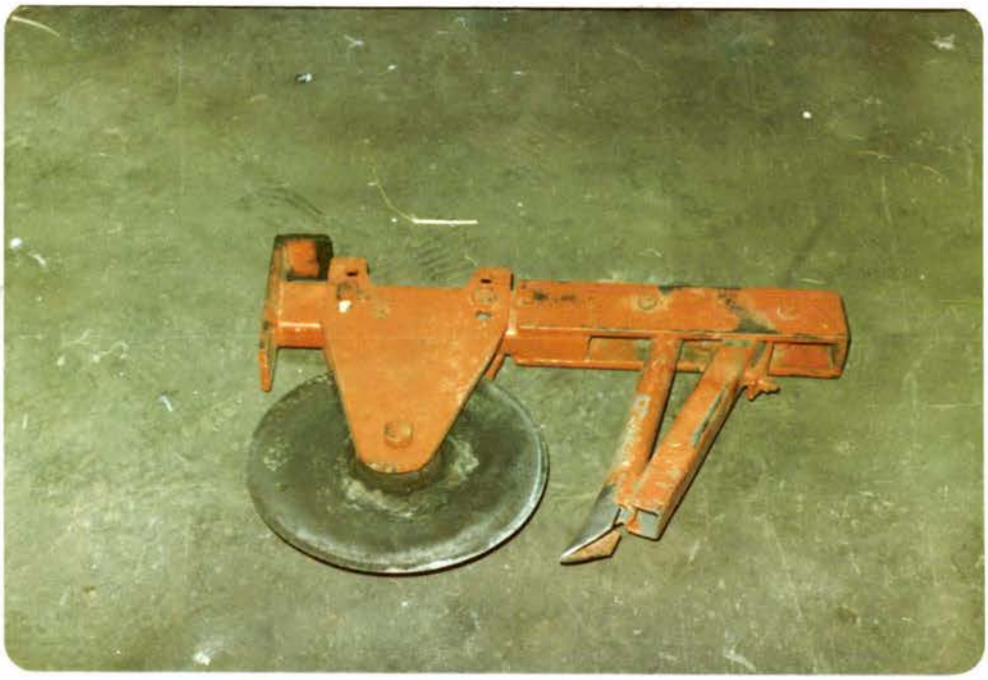


Plate 3 (c). Hoe coulter

Plate 3 (d). Chisel coulter

These three coulter types produce different effects on the surrounding soil and form different shaped seed grooves with different environments therein (see Literature review). The three coulters were chosen because they cover the commonly used ones and the newest one recently coming onto the market, as well as representing the coulters with which the most (chisel coulter) or the least slug damage (triple disc coulter) has been noted.

3.4 ASSESSMENTS

(A) First Stage: Effects of Winter ground cover on overwintering slug populations.

(i) Population estimation techniques. Slug populations were assessed using four different methods:

(A) Pitfall traps
(B) Brick traps
(C) Night searching
(D) Soil sample and flotation technique.

The first three of these techniques depend on slug activity and therefore results depend on conditions of humidity, rainfall, temperature, wind, light etc. It is for this reason that temperature, soil moisture and rainfall were measured on the plots to see if these environmental parameters could be correlated with changes in slug numbers captured by the various sampling techniques. The techniques used range from indirect assessments (A, B) to direct estimates (C, D). As was mentioned in the general introduction, field experiments and advisory work have been hindered by the difficulty in obtaining accurate estimates of slug populations. Slug populations are difficult to estimate since their distribution tends to be aggregated and sparsely distributed with many of the commonest species living underground (Hunter 1966, South 1965, Stephenson 1968).

(a) Direct population estimates.

Night searching: This system is based upon the catch per unit effort introduced by Barnes & Weil, (1944, 1945). The three main disadvantages inherent in the method are:

(a) lighter coloured species tend to be observed in higher proportions than the darker species

(b) surface dwelling species are more likely to be found than subterranean species and

(c) there is a tendency to miss smaller species or the more immature individuals of a particular species.

These criticisms have been discussed by Crawford-Sidebotham (1972), South (1964), Hunter (1968a). Even though this method of population estimation has its shortcomings it was felt that ease of assessment along with its non-destructive nature would make it useful in this study.

Night searching was carried out from 10 o'clock to 12 midnight as this allowed all species of slug time to become active. Stephenson & Bardner (1976) suggested that most slug species are active between 2hr after sunset and 2hr before sunrise. But Barnes & Weil (1945) found that the time of peak activity varies with the species. White (1959) found that slug activity tends to increase up to midnight and fall off gradually till dawn, with *Deroceras reticulatum* becoming less active as the night progresses. *Milax budapestensis* was most active at midnight, and *Arion hortensis* became active late at night. The procedure followed for night searching was that a $0.1m^2$ quadrant was placed randomly on the plots and with the aid of two flashlights the soil surface was searched. In the case of long and short grass plots the vegetation was clipped close to the soil surface using hand shears and the clippings immediately searched on a sheet of white paper. All slugs found were identified in the field. Two quadrats were taken per plot with an average search time of 5 minutes per quadrat. Night searching was carried out once each month from July to November; following the method of Crawford-Sidebotham (1972), who found it was necessary to develop a "hunting image" before commencing a sample. This was done by searching for slugs prior to sampling in order to reduce the number of slugs missed in the early stages of a sampling period.

Soil sampling: Hunter (1967, 1968a), South (1964) used a method of soil sampling and found that soil sampling provides the most accurate estimates of species composition and age distribution of slugs in a particular area. The method does involve however a considerable degree of labour and time.

A modified soil washing technique was used in this study. Soil washing was used in favour of soil flooding as soil flooding was too time consuming and could not handle the large number of samples to be taken. A soil sample of $20cm^3$ was taken and placed in a plastic bag for transport to the laboratory where all samples were processed that day. The sample was first broken down by hand and any grass and obvious organic matter removed at this stage along with any slugs. Once the sample was reduced to a fine to medium tilth it was placed in a bucket with a salt solution (NaCl) of 1.17 specific gravity and thoroughly mixed so that organic matter and slugs floated to the surface. The salt soil solution was decanted into a bank of sieves (6, 12 and 16 mesh to 2.5cm). The soil and salt solution were mixed and decanted 3 times and the sieves separated and individually floated in clean salt solution so that slugs and organic matter floated and were removed. Any slugs seen at any stage of the process were removed. The technique was tested to see how efficient it was by seeding slugs into test samples after they had been marked with neutral red stain. The technique was found to be 90% efficient at both sampling times. Two samples were taken per plot, and the sampling was carried out twice during the study - the first was on 21 August 1980 and the second on 26 November 1980.

(b) Indirect population estimates:

Pitfall traps. Pitfall traps are of little value for the direct estimation of populations or for the comparison of communities (Southward, 1966). The size of the population plays a minor role in determining the numbers trapped. Pitfall traps are influenced by the changes in slug activity due to prevailing weather conditions. Pitfall traps are still useful as a collecting device and may be used to study daily rhythm of activity, seasonal incidence and dispersion of a single species in one type of vegetation (Southward, 1966). In this study pitfall traps were used to gain information on slug incidence over time and the incidence under different treatments.

The pitfall traps consisted of plastic pots of 9.5cm diameter x 9cm deep sunk into the soil so that the mouth was level with the soil surface. Copper sulphate solution of 10% concentration was placed in the traps to a depth of 3 - 4cm. Copper sulphate was used to kill the slugs, as Getz (1959) carried out drowning experiments and observed that drowning time in water was at least four hours. If copper sulphate was not present it was felt that the slugs would be able to escape from the traps before drowning. Copper sulphate also prevents fungal growth and

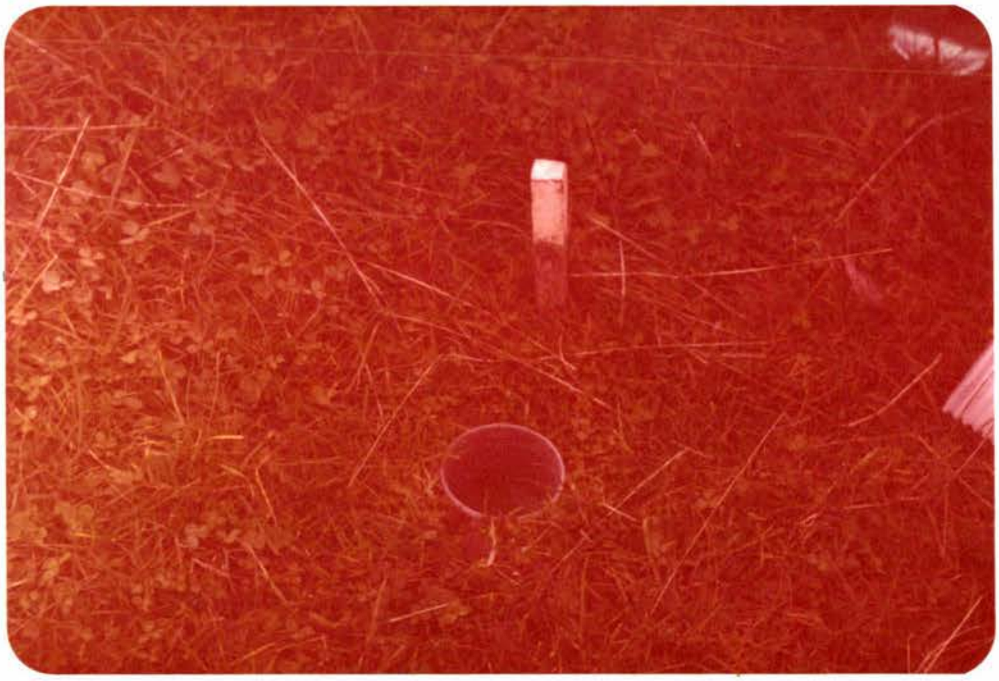


Plate 4 (a). Close up view of a pitfall trap

Plate 4 (b). Close up view of a brick trap general decay of slugs captured as well as preventing birds from eating them. The copper sulphate did however cause a general darkening of the colouration which is one of the characteristics used in identification, so slugs from pitfall traps were only identified to genus. Traps were emptied every seven days and clean copper sulphate solution added. The slugs were identified later in the laboratory using keys from Barker (1979) and Martin (1978). This method of trapping gives an indication of surface activity and numbers active on the surface but not an absolute measurement of total population. It may not give a representative catch of subterranean species, but this could be improved by sinking the traps lower into the soil.

Brick trapping. Slugs may be trapped by placing flat boards or bricks on the soil surface. Getz (1959) used such traps to collect information on the biology and ecology of slugs. This trapping method provides a different estimate from pitfall trapping. Brick trapping relies on the slug's need for shelter and protection and so ideally would work best in situations where other shelter was non existent and conditions had changed from being ideal for slug activity to one where slugs needed to seek shelter. South (1964) has shown that this method is not reliable for collecting ecological data for slugs on grassland. Hunter (1968a) found that surface dwelling species such as *Deroceras reticulatum* were more likely to seek shelter under traps than subterranean species, and more slugs were trapped in damp cloudy weather than when it was sunny and dry.

The bricks used were Winstone Domestic pavers* 220cm^2. Like pitfall traps these were checked every

* registered trade name

seven days and the slugs underneath the bricks were identified and left in the field. The brick traps had the advantage of being a non destructive sampling method. By comparing total slugs removed from plots with population estimates gained from soil sampling it was seen that only 10% of the population was removed by pitfall trapping over the whole study period. Gould (1962) suggested that trapping may not give a representative catch of subterranean species. South (1965) found that when the soil begins to dry out in spring many slugs gather under tiles because the sheltered soil dries out more slowly. When the soil under the tiles eventually dries out however, these slugs are trapped and die from dessication.

(ii) ENVIRONMENTAL MEASUREMENTS.

(a) Temperature. Temperature measurements were made on six plots using a maximum-minimum thermometer placed on the soil surface. The thermometer was placed on the soil surface for it was here that slug activity was taking place, so it was here that any temperature differences would have their effect. Readings were taken every day and averaged for the week.

(b) Soil moisture. At the outset of the experiment it was considered that, because of the nature of the ground covers, a difference would slowly develop between them in terms of soil moisture. Any differences in slug activity that were recorded could be due to soil moisture differences as much as temperature. Since soil moisture over winter does not change greatly samples for soil moisture were taken fortnightly. Two samples per plot were taken to a depth of 15cm. The soil moisture was determined for each 5cm of depth as it was felt that surface dwelling slugs would largely be influenced by soil moisture within a short distance of the soil surface, while subterranean slugs could be affected by deeper soil moisture levels. A soil corer of 2.5cm diameter was used and the holes caused by the corer were refilled with soil so that no artificial shelter was provided for the slugs. Soil moisture was measured gravimetrically - the sample being weighed wet, then dried in an oven at 102°C for 2 days and weighed again dry to give a percentage water content.

(c) Rainfall. Stephenson (1968) reported that on very windy or very rainy nights, fewer slugs were active than on calm or rain free nights. Rodgers-Lewis (1976) found that rainfall encouraged slugs to the surface and even went as far as to suggest that the best practical method of timing treatments is to use rainfall data to indicate when large numbers of slugs are likely to be on the soil surface. From these reports it is apparent that slug activity is in part governed by rainfall, so rainfall data was gathered in this study. Rainfall data was gathered from a Meteorological station, stationed at Massey University, approximately 1.5km from the study site.

(B) Second stage: Effect of slugs on a direct drilled crop and effect of three coulters on ingression of slugs in the seed groove.

This stage of the study was aimed at answering the question of whether there was any difference between three different drill coulters and slug ingression into the seed groove, and whether there were any differences between the coulters in seed and seedling damage caused by slugs. The following measurements were made to answer these questions; slug numbers in the seed grooves and in the plots, temperature within the seed groove, humidity and soil moisture within the seed groove, seed number and damage, and seedling number and damage.

(i) Population estimation.

(a) Slug numbers: The slug populations on the plots ($1\frac{1}{2}$m x 9m) were assessed by night searching on the two nights prior to each drilling. It was no longer practical to take soil samples for the flotation method as sampling on such small plots would destroy too much area. Night searching was non destructive and gave information on the presence or absence of slugs and the approximate number. Also at this stage of the study interest was primarily centered upon the numbers of slugs actually active upon the soil surface under particular microclimatic conditions. It is only the surface active slugs that will move into the seed grooves for shelter. Any tendency to miss younger slugs of a particular species or to underestimate darker species or smaller species will be unimportant as long as the numbers recorded are a fixed proportion of the numbers active on different nights (Crawford-Sidebotham 1972).

Two drillings were carried out, and the time of sampling was changed for the second drilling. The aim in the first drilling was to sample every three days for slugs until seedling emergence which was thought to take about one week. However due to ideal conditions emergence was well under way within four days of drilling. It was decided however that rather than reduce the number of samples, to continue the sampling until the 9 days (3 sampling times) was completed. In the second drilling samples were taken sooner after drilling, for the first drilling had shown that slugs move very rapidly into the seed grooves, and seedling emergence in this case took the expected time.

To choose the most appropriate method of sampling, a preliminary experiment was carried out using two methods which seemed the most practical. These were soil sampling and using baits with attractants. Soil bins were taken from the field. These bins (1.8m long x 660mm wide x 200mm deep) contained undisturbed turf blocks which were drilled on a special support bed using a moving gantry and tool testing apparatus which straddled the bins (Baker 1976a, Choudhary & Baker 1977, Choudhary 1979). A known number of marked slugs were then placed in each coulter groove and left for 24 hours, then the sampling was undertaken. The slugs were marked as in the previous case (for testing soil sampling and flotation technique) by feeding the slugs on jelly agar containing neutral red dye (0.2%) (South 1965, Hunter 1968a, Stephenson 1968). This dye stains the foot and digestive glands a deep pink colour that can be seen through the skin of the foot even in darkly pigmented individuals. The dye was reported to remain visible for up to 3 weeks though in this experiment most slugs lost the colour within 1-1½ weeks. The slugs were kept for two days at 12°C while they were being fed on the agar, with 98-99% being marked in this time. All the species of slugs (4 species) present on the study site were used in this preliminary experiment at approximately the proportions occurring in the field at the time. Soil sampling was carried out using a soil scoop pushed into the soil and in the case of the bin the whole row was sampled. Baits were placed on the soil surface (Metaldehyde baits in the form of a pellet - "Blitzem"*) and slugs were counted every day for four days. The soil sampling was found to be 100% efficient while the baits were only 80% efficient even after 4 days. Soil sampling was then chosen for use in the study as it was efficient at

* registered trade name

Plate 5. Close up view of Vaisala* humidity meter as used in the field, and also thermometers in place to measure in-groove temperature.

* Registered trade name

recovering slugs from the seed groove and also allowed for seed number and damage to be recorded. Baits were less efficient and had the added disadvantages of not measuring seed damage and number and being affected by the weather.

In the field soil samples were not taken with the soil scoop but instead sampling involved taking a 30cm length of coulter row to a depth of 2.5 - 3cm below the bottom of the seed grooves and 2 - 2.5cm on either side of the seed groove with a garden spade. This was found to be easier and less time consuming than taking samples with the soil scoop. The sample was then examined immediately in the field. It was only necessary to count the slugs that had moved into the seed groove. The nature of the seed groove enabled the soil sample to split open very easily along the middle of the seed groove so exposing the inside and any slugs and seeds could then be easily observed.

(ii) Environmental measurements.

(a) Temperature: This was measured by placing mercury thermometers into the seed groove and recording the temperature between 10 a.m. and 12 noon each day.

(b) Humidity: A humidity probe was inserted into the seed groove and left to equilibrate with the air in the groove for 8-10 minutes before the reading was taken. The measurements were made between 10 a.m. and 12 noon each day over the period of the study. Measurements were not made in the irrigated plots as the apparatus does not operate well under very moist conditions and it can be assumed that the humidity was 100% on those plots. Dr Choudhary (per comm) suggested that relative humidity does not drop below 100% until wilting point is reached. A Vaisala*

* registered trade name

humidity meter was used. This indicates relative humidity from 0 - 100%. The sensing element is mounted in a probe which was inserted into the seed groove, and measures the relative humidity by thin film capacitance.

(c) Rainfall. This was measured by using data as in the first stage of the trial from the meteorological station at Massey University. Rainfall measurements during this stage of the experiment were needed so that irrigation water could be applied in amounts equivalent to the water lost by evapotranspiration, and any rainfall had to be taken into account to keep a water budget. Also, as mentioned, rainfall can affect slug activity, and since movement of slugs into the seed grooves depends on surface activity, factors affecting surface activity could affect numbers of slugs in the seed grooves.

(d) Soil moisture: Several methods of measuring soil moisture within the seed grooves have been used in the past (Choudhary & Baker 1977, Choudhary 1979). It has been found that direct sampling using a core sampler is the most reliable method but maybe not the most desirable because it is destructive. A soil corer was used in this study and soil moisture was only measured when soil samples were taken. They were taken from the same length of coulter row that the soil sample was to be taken. This meant that the remaining seed groove was unchanged in its shape by taking soil cores, and hence no effect of taking soil cores was produced. A mini corer 15mm in length and 7.5mm in diameter was used for this purpose. Two samples per seed groove were taken and the soil moisture was determined gravimetrically (sample size 7.5mm x 30mm). The soil moisture of the plot was also taken the day of the drilling to give a starting point, using the larger soil corer used in the previous stage.

(iii) Plant damage assessments.

(a) Seed damage: This was recorded at the same time as slug numbers, the same samples being used for measurements of seed damage and slug numbers. The most serious losses from slugs are at this stage of the crop, and result from scraping of the germ of the cereal below ground level, often completely hollowing out the seed before it has had a chance to germinate. (Anon 1973, Briggs 1978, Gair, Jenkins & Lester 1978).

(b) Seedling damage: Seedling damage assessment was carried out at the one shoot stage (Feekes Scale 1). Slug feeding at this stage is of two types:

(a) eating the young cereal shoots shortly after germination before they have emerged, and

(b) the typical leaf shredding on young leaves.

Seedling damage was assessed by taking a 1m length of row and counting the total number of seedlings and the number damaged either by leaf shredding or grazing below the ground. An estimate of the amount of damage done to each seedling was made by using standard area diagrams which allowed the percentage of the seedling damage to be assessed. The damage ranged from 1% to 10% in individual seedlings. During the seed and seedling damage assessments other pests and damage were looked for and noted, eg, wireworm numbers and damage to seeds, Argentine stem weevil *(Hyperodes bonariensis)* and damage to seedlings.

4. RESULTS

4.1 FIRST STAGE: EFFECT OF WINTER GROUND COVER ON OVERWINTERING SLUG POPULATIONS.

(A) Slug population assessments:

(i) Direct estimates of slug populations.

(a) Night searching: Table 2 shows the results of monthly night searching over the experimental period for each ground cover. The treatment differences only reached significance (P0.05) in the last month (26/11/80), where all differed significantly from each other with GL having the highest number, GS intermediate, and C the lowest. Over the five month period slug numbers recorded declined in all treatments with GL declining by 13.8m^2, GS 40/m^2 and C 43.6/m^2, but only in treatment C were differences between months significant (P0.05).

(b) Soil sampling: Table 3 shows the results for soil sampling for each ground cover. Slug numbers did not decrease over the experimental period in GL and GS treatments but in treatment C a dramatic and significant (P0.05) decline in slug numbers of 50/m^2 occurred.

(ii) Indirect population assessments.

(a) Pitfall trapping: Table 4 shows the mean number of slugs trapped per day over the experimental period in each ground cover. Over the total period the treatments were not significantly

Table 2. Results of night searching for slugs

Mean number of slugs recovered per m^2 of soil surface for each ground cover

Date	Week	Grass long (GL)	Grass short (GS)	Chemical (C)	
13.7.80	0	41.3	56.3	52.5	a
21.8.80	3	25.0	15.0	35.0	b
20.9.80	7	55.0	46.3	31.3	bc
19.10.80	11	43.0	42.5	26.3	c
26.11.80	17	27.5 a	16.3 b	8.9 c	d
$\bar{x}$		38.5	35.3	30.8	

unlike letters in a column or row show a significant difference (P0.05)

Table 3. Results of soil sampling for slugs

Mean number of slugs recovered per m^2 for each ground cover

Date	Grass long (GL)	Grass short (GS)	Chemical (C)
21.8.80	65.8 a	59.5 a	65.8 a
26.11.80	68.8 a	62.5 a	15.6 b
$\bar{x}$	67.3	61	40.7

unlike letters in a column or row show a significant difference (P0.05) different. However, when the results are separated into two periods (weeks 1-7 and weeks 8-17) it was found that over the period (week 8-17) the treatments differed significantly (P0.05) with GL having the highest number, GS intermediate, and C the lowest. The numbers of slugs caught each week were not significantly different in GL but were in GS (P0.05) and C (P0.05 0.01). Overall the trend is for the numbers of slugs caught in the GL treatments to increase with time while a decrease in slug numbers caught occurred in GS and C treatments. In only two weeks was there any significant difference between treatments; week 6 and week 16. At week 6 GL and GS were significantly different from C, and week 16 had C and GS significantly different from GL. Fig 5 shows the slugs trapped per day for each treatment and clearly shows the trends in slug numbers caught in each ground cover as time progressed, particularly during the latter half of the experimental period.

(b) Brick trapping: Table 5 shows the slugs trapped per day over the experimental period for each ground cover. Over the total period the treatments were not significantly different. In week 7 there was a significant difference (P0.05) between treatments with GL giving a significantly higher catch than GS or C. Only the GL treatment had a significant difference occurring between the catches each (P0.05). Fig 6 shows the slugs trapped per day by brick trapping for each ground cover.

(c) Comparison of brick and pitfall traps in each ground cover:

Table 4. Slug numbers recovered in pitfall traps

Mean number of slugs per trap per day

Week		Grass long (GL)	Grass short (GS)		Chemical (C)		
1	10.8.80	0.29	0.43	fgh	HIJ	0.36	hg
2		0.54	0.86	cd	DEF	0.71	edc
3		0.43	0.43	fgh	HIJ	0.36	hg
4		0.61	0.46	fg	BC	0.96	b
5		0.89	0.82	de	A	1.39	a
6		0.5	0.5	f	B	1	b
7		0.82	0.68	e	BCD	0.82	c
8		0.79	0.82	de	DEFG	0.64	e
9		0.79	1.14	a	HIJK	0.32	ihg
10		1.46	1.11	ab	CDE	0.79	dc
11		1.11	0.89	fghi	H	0.43	f
12		1.36	0.5	f	L	0.07	j
13		1.18	1	abc	L	0.07	j
14		1.81	1.04	ab	HI	0.39	g
15		1	0.29	hij	HIJ	0.36	hg
16		1.46	0.21	jk	IJKL	0.21	hi
17	30.11.80	1.11	0.21	jk	HIJKL	0.21	hig
	$\bar{x}$	0.95	0.64			0.54	

unlike letters in a column show a significiant difference

ab = P0.05
AB = P0.01

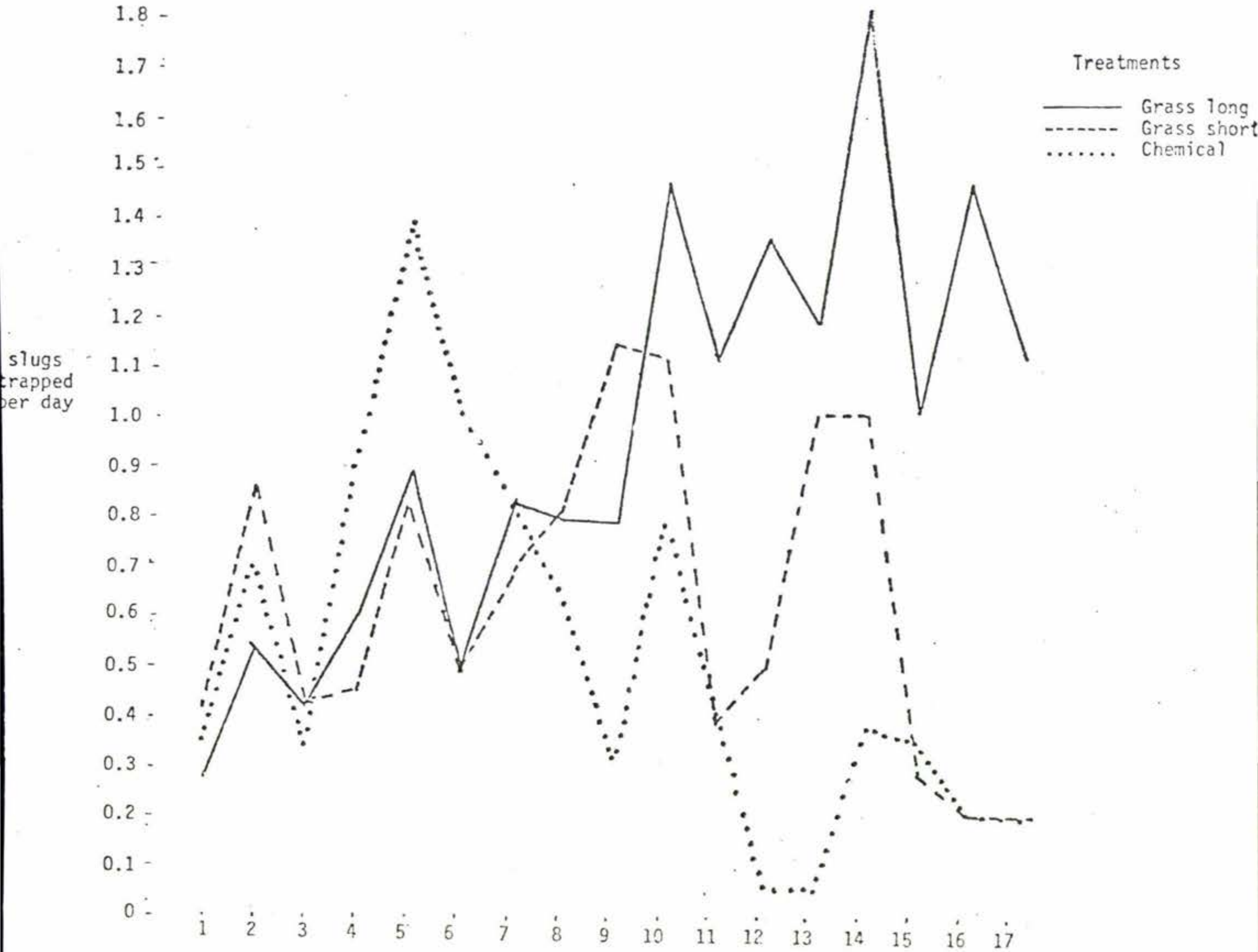


Figure 5. Results of Pitfall trapping. Mean number of slugs trapped per week

Table 5. Slug numbers recovered under brick traps

Mean number of slugs per trap per day

Week		Grass long (GL)		Grass short (GS)	Chemical (C)
1	10.8.80	0.18	jki	0.23	0.12
2		0.13	lm	0.05	0.19
3		0.29	fghijk	0.36	0.23
4		0.05	lm	0.32	0.38
5		0.38	efgh	0.07	0.17
6		0.36	fghi	0.13	0.05
7		0.68	ab	0.23	0.17
8		0.41	defg	0.23	0.3
9		0.63	abc	0.2	0.51
10		0.71	a	0.64	0.05
11		0.54	bcde	1.3	0.07
12		0.32	fghij	0.04	0.02
13		0.41	defg	0.89	1.57
14		0.57	abcd	0.14	0.3
15		0.45	def	0.25	0.55
16		0.5	cde	0.48	1.3
17	30.11.80	0.5	cde	0.23	1.14
	$\bar{x}$	0.42		0.34	0.42

unlike letters in a column show a significant difference (P0.05)

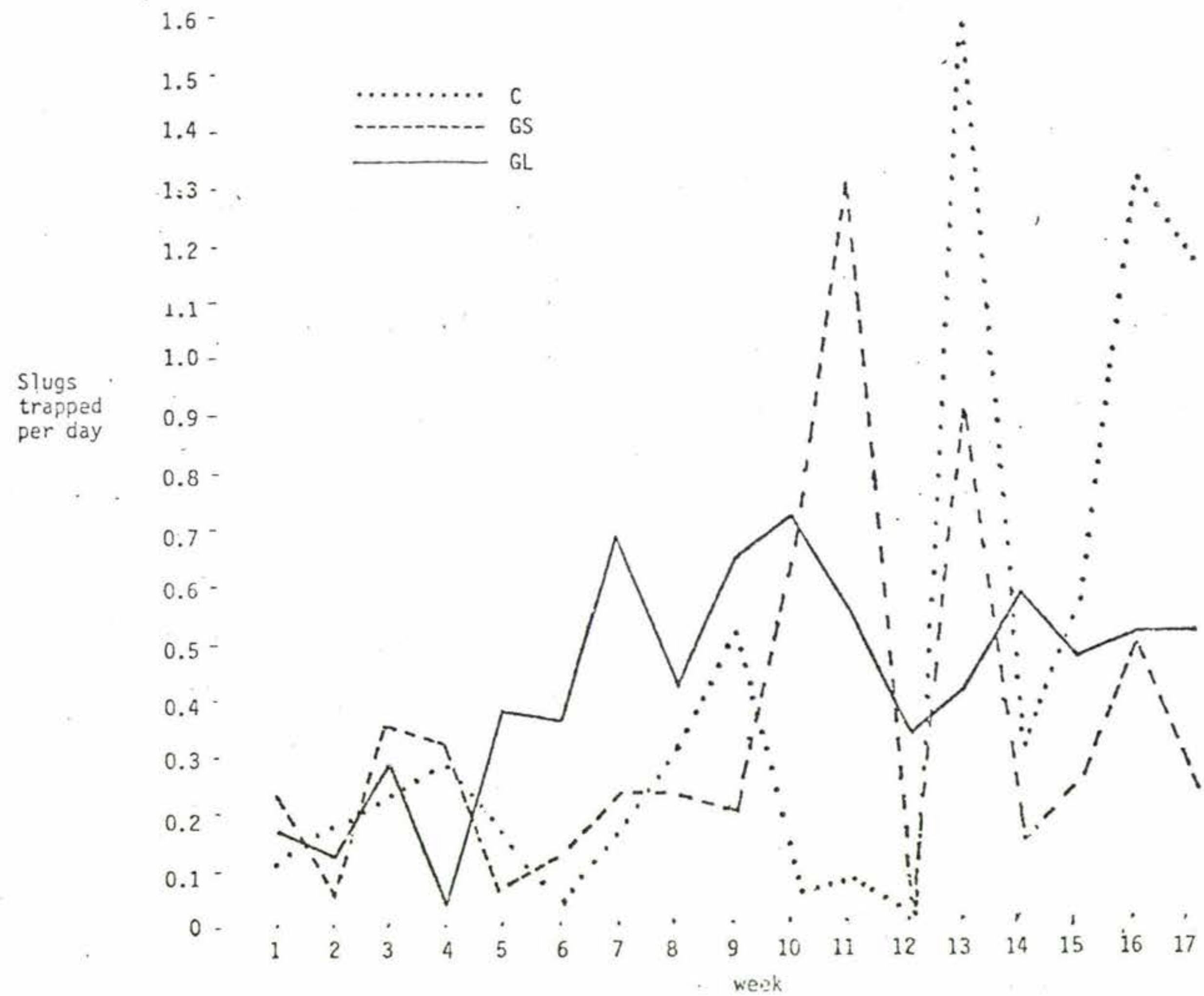


Figure 6. Results of Brick trapping - Mean number of slugs trapped per week

Grass long (GL). Fig 7 shows the slugs trapped per day over the experimental period in brick and pitfall traps. Over the total period there was a significant difference (P0.05, 0.01) between the two trapping methods. Pitfall traps always gave higher catch numbers than the brick traps, but on a week by week basis only in week 8 did a significant difference (P0.05) occur between the trapping methods with pitfall traps recording the highest catch. The overall trend was for an increase in numbers of slugs caught in the pitfall traps over the experimental period while the brick traps showed only a small difference from the first catch to the last.

Grass short (GS). Fig 8 shows the slugs trapped per day over the experimental period in brick and pitfall traps. Over the total experimental period there was a significant difference (P0.05) between the two trapping methods with pitfall traps giving the greatest total catch. It can be noted that up to week 9 pitfall traps were recording consistently higher catches but from week 9-17 brick traps recorded increased numbers and in some weeks (weeks 11, 13, 16, 17) recorded greater numbers than pitfall traps. Only in weeks 2, 5, 6 and 14 was the difference between trapping methods significant (P0.05) with pitfall traps always recording the highest catch.

Chemical (C). Fig 9 shows the slugs trapped per day over the experimental period in brick and pitfall traps. Over the total experimental period there was no significant difference between the two trapping methods though pitfall trapping recorded the highest total catches as in GL and GS. There appeared to be a general trend of decreasing catches in the pitfall traps as time progressed. This is in direct contrast to the brick traps which seem to increase in numbers caught as time progressed. At week 9 brick traps recorded higher numbers than pitfall traps and except for weeks 10, 11, 12, 14 they continued to do so till week 17. This was a similar result to that observed in the GS treatment. The only weeks where the difference (P0.05) between trapping methods was significant were weeks 4, 6, 7 and 10 with pitfall trapping giving the highest catches in all cases.

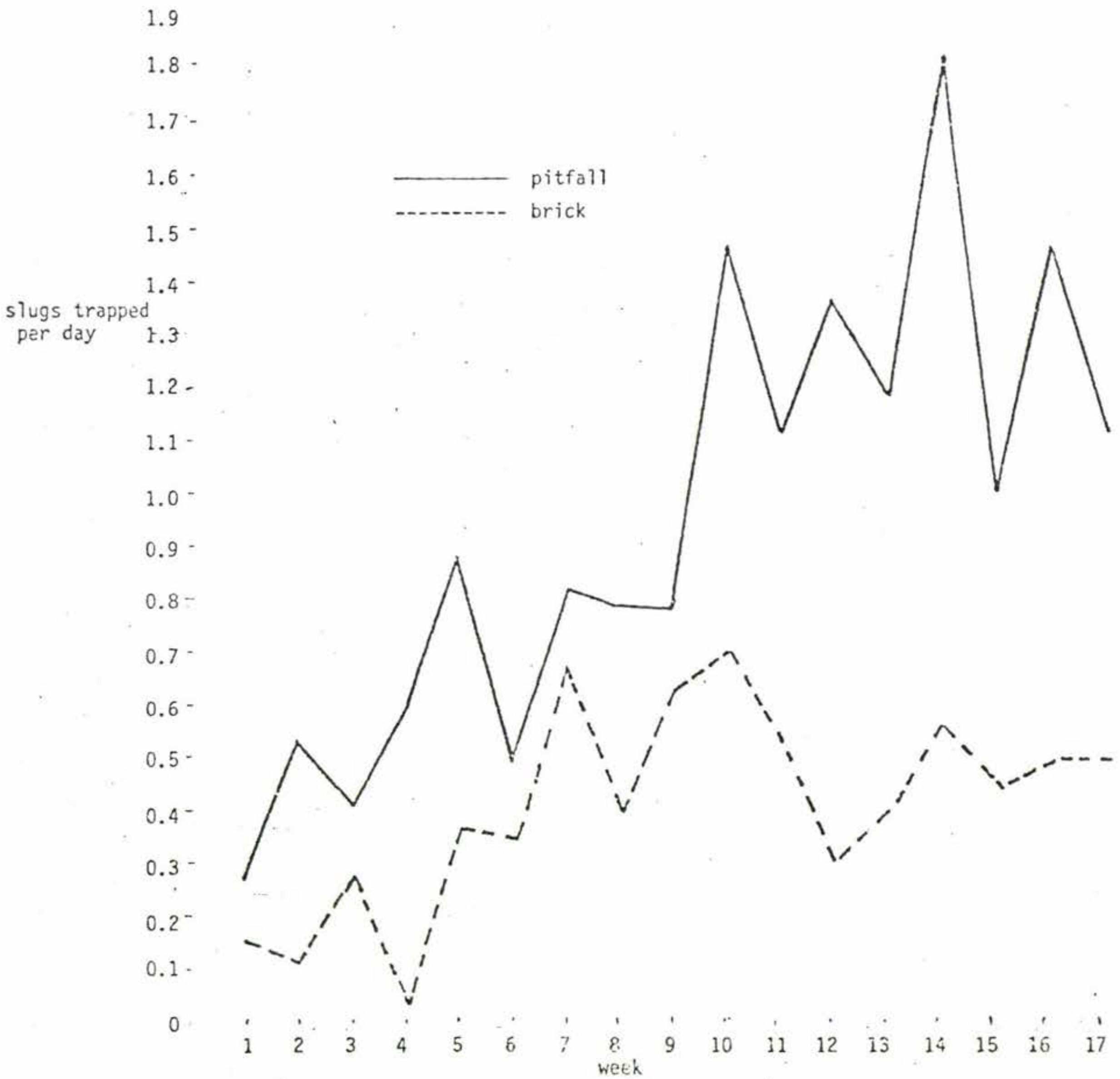


Figure 7. Numbers of slugs caught per week in pitfall and brick traps, GL plots

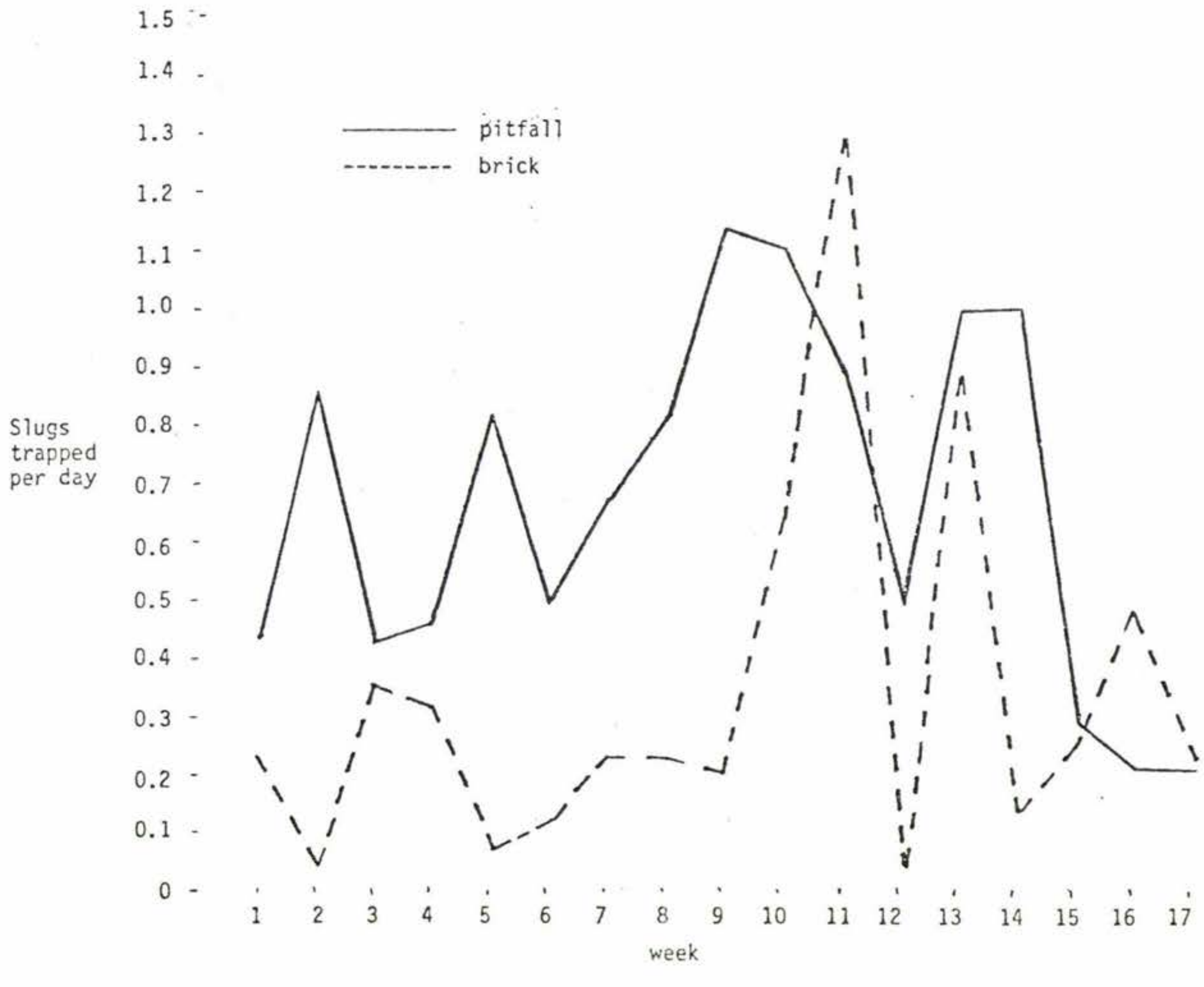


Figure 8. Numbers of slugs caught per week in pitfall and brick traps, GS plots

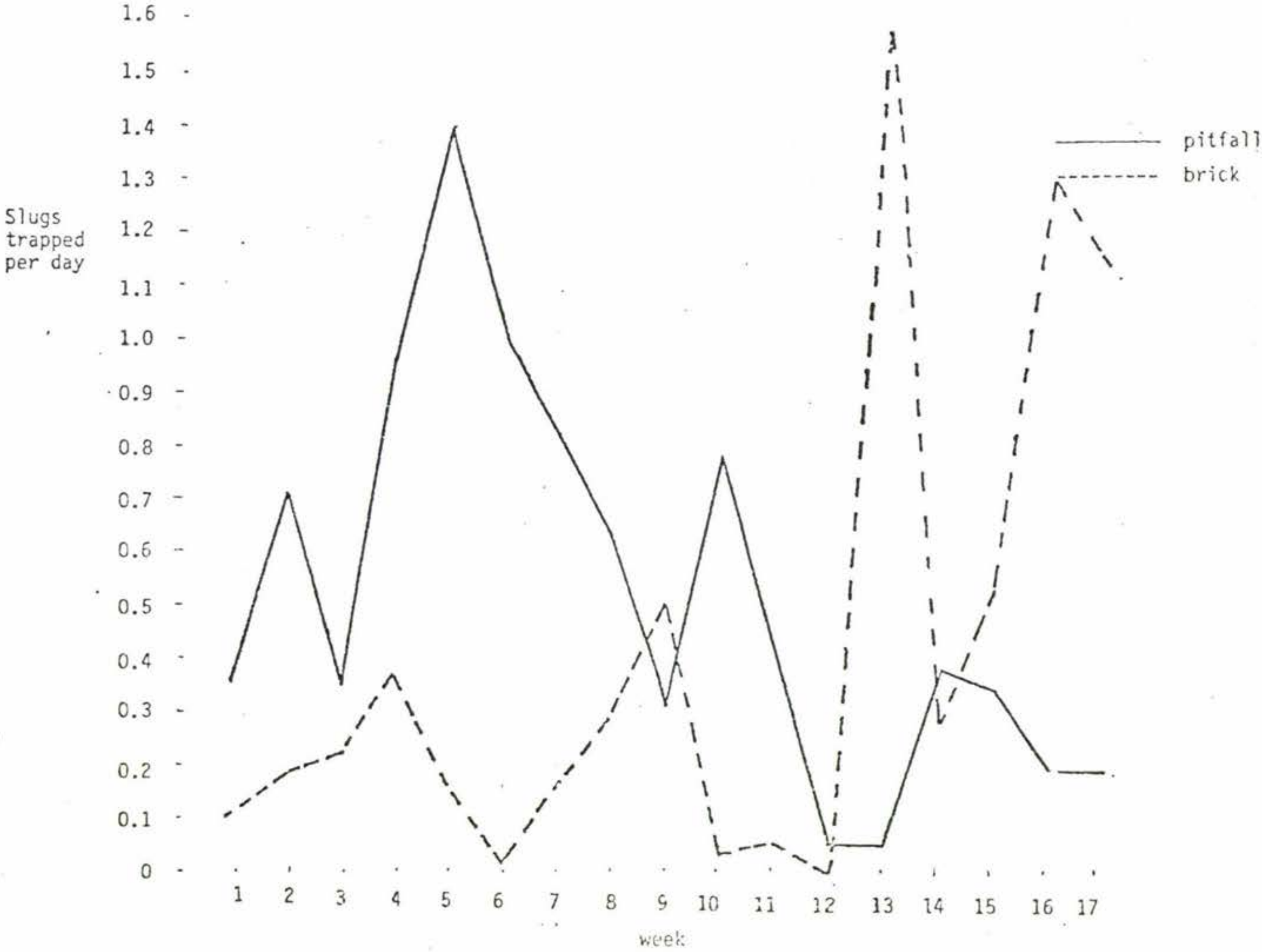


Figure 9. Numbers of slugs caught per week in pitfall and brick traps, C plots

(B) Environmental assessments:

(i) Temperature at the soil surface. Fig 10 shows the average weekly soil surface temperature over the experimental period. Over the total experimental period there was a significant difference (P0.05, 0.01) between the ground covers. GS had the highest average weekly temperature, C intermediate and GL the lowest. The average weekly temperature increased in all treatments over the experimental period with GS always having the higher temperature, C intermediate and GL the lowest. Only in weeks 1, 7 and 13 were the differences between ground covers significant (P0.05). In week 1 GL and GS were significantly different from C, in week 7 GS and C were significantly different from GL and in week 13 C and GS were again significantly different from GL.

(ii) Rainfall. Fig 11 shows the average weekly rainfall recorded over the experimental period. The lowest rainfall was recorded in week 12 - 0.14 mm/week, and the highest rainfall of 10.33 mm/week occurring in week 17. The average weekly rainfall over the experimental period was 3.8 mm.

(iii) Soil moisture. Table 6 shows the soil moistures recorded at a depth of 0-15cm over the experimental period. The mean soil moisture (0-15cm) remained relatively constant in all treatments over the experimental period and in most samples was close to field capacity which for this soil is approximately 40% moisture content. There were no significant differences between the treatments.

The soil moisture within the depth 0-5cm ranged from saturation (50%) to approximately field

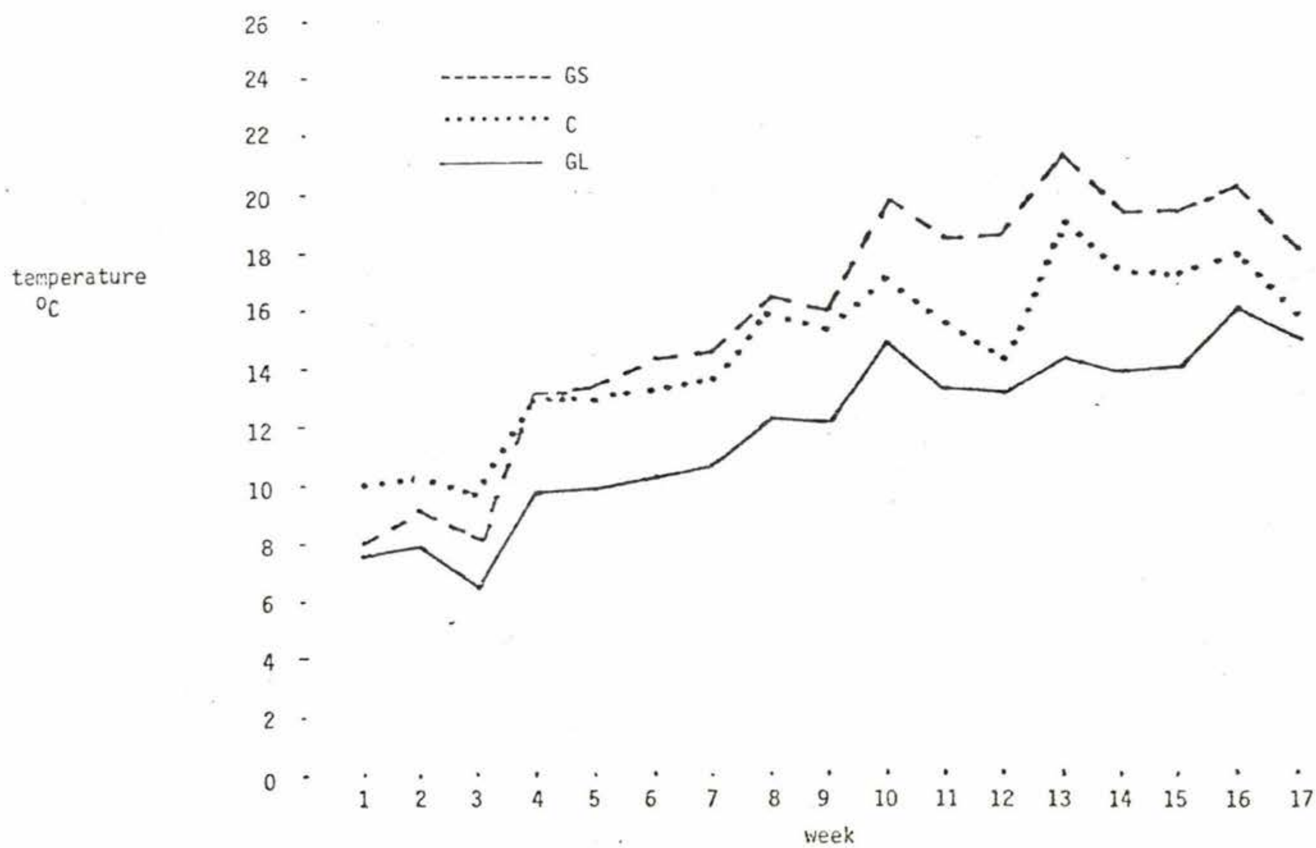


Figure 10. Average weekly temperature at the soil surface.

Figure 11. Mean weekly rainfall

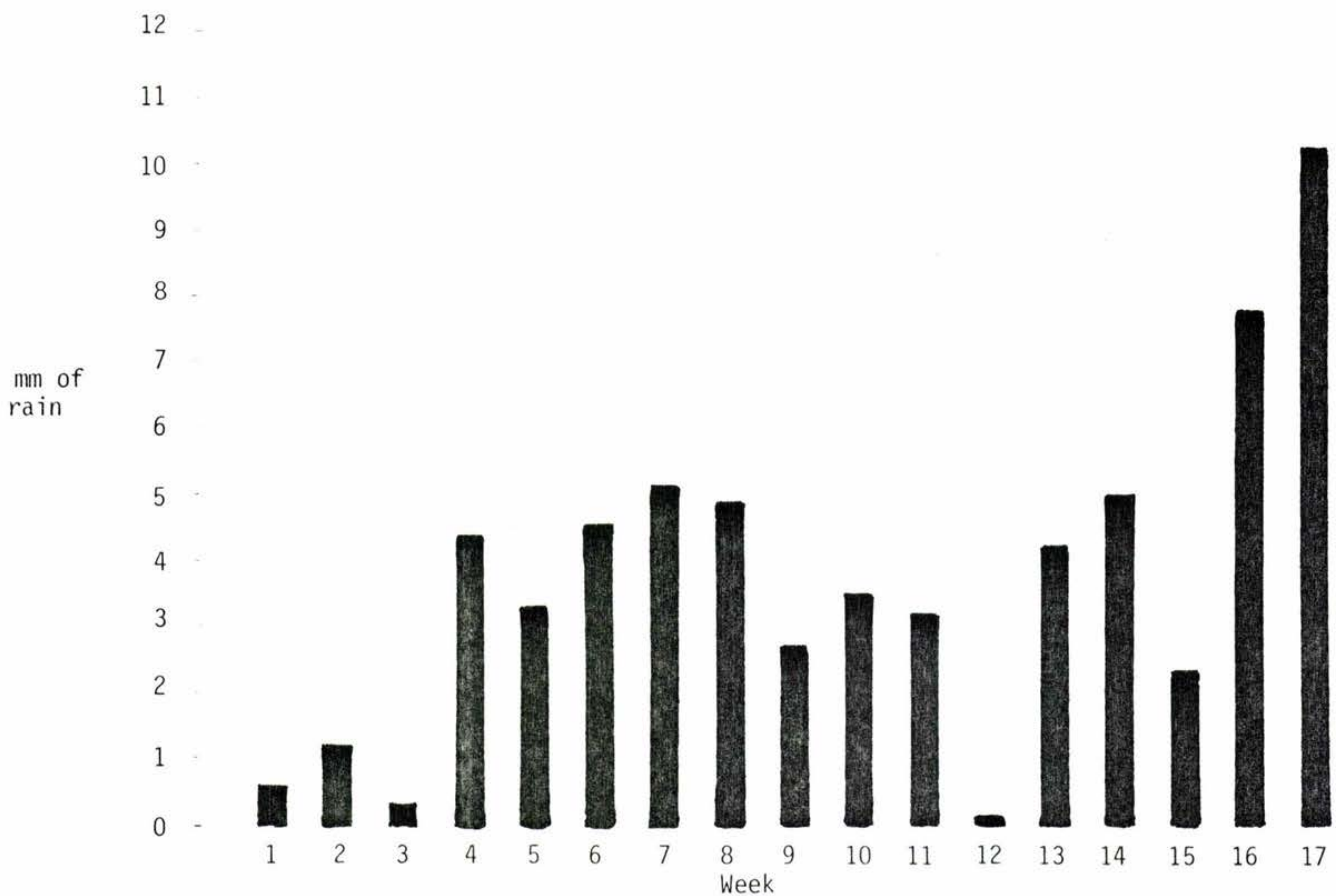


Table 6. Soil moisture at depths from 0 - 15 cm

Date	Week		0 - 5 cm			5 - 10 cm			10 - 15 cm			Mean soil moisture (0 - 15 cm)		
			GL	GS	C	GL	GS	C	GL	GS	C	GL	GS	C
9.8.80	0	1.	AB 53.5 ab	A 55 a	47.1 bc	34.4	35.4	A 34.6 b	30.1	24.4	32.2	39.3	38.6	A 38 bc
23.8.80	1-3	2.	D 45.9 d	D 47.1 d	40 e	37.2	33.4	A 34.8 b	31	29.7	32.2	38	36.7	B 35.7 c
6.9.80	3-5	3.	BC 51.5 bc	BCD 48.7 bc	46.5 bc	37.1	37.6	A 36.5 b	32.6	29	32.3	40.4	38.4	A 38.4 bc
20.9.80	5-7	4.	BC 52.1 bc	B 49.9 b	43.8 d	38	35.5	B 27.6 c	32.6	34.4	33.6	40.9	39.9	B 35 c
5.10.80	7-9	5.	F 42 f	BC 49.6 bc	50.4 a	35.6	37.7	A 40.2 ab	41.3	34	34.5	38.6	40.4	A 41.7 ab
19.10.80	9-11	6.	A 55.3 a	A 54 a	47.9 b	42	36.8	A 44 a	33.6	36.8	36.4	43.6	42.5	A 42.8 a
1.11.80	11-13	7.	DE 45.7 de	F 40.2 f	40 e	34.1	34.6	A 34.8 b	30.6	33.6	34.8	35.8	36.1	A 36.5 c
15.11.80	13-15	8.	GF 40.1 fg	E 42.9 e	33.4 g	32.5	34.2	B 28.6 c	35.4	32.6	33	36	36.6	B 32.7 d
29.11.80	15-17	9.	GF 39.4 g	EF 40.8 f	36 f	35.5	34.9	B 33.1 b	29.4	32.5	33.2	34.8	36.1	B 34.1 c

a, b, c = 5% level of significance

A, B, C = 1% level of significance

unlike letters in a column show significant differences capacity. The mean soil moisture at 0-5cm was significantly different (P0.05) between treatments with C having a significantly lower soil moisture than GS and GL.

At 5-10cm moisture levels ranged from above field capacity to 25% water content. Greater fluctuations in soil moisture were recorded in GL and C than in GS but overall the treatments were not significantly different.

The soil moisture at 10-15cm was largely in the range 29-37% water content and varied little between weeks or treatments.

GL 0-5cm, GS 0-5cm, C 0-5cm 5-10cm and mean soil moisture 0-15cm had significant differences occurring between weeks as shown in Table 6. Significant differences occurred between the ground covers at 0-5cm weeks 1, 3, 4, 7, 8, 9 and at 5-10cm weeks 5, 6 and 8.

(C) Correlations between slug numbers and environmental parameters for each ground cover:

(i) Grass long treatment (GL): Total slug numbers in brick and pitfall traps were found to be strongly correlated (r=0.88) to average weekly temperature at the soil surface but not to rainfall or soil moisture at any depth. When each trapping method was considered separately pitfall trap numbers had a strong correlation to average weekly temperature (r=0.85) but no correlation to rainfall or soil moisture. Brick trapping slug numbers also showed a correlation to average weekly temperature (r=0.64) but again no correlation to rainfall or soil moisture.

(ii) Grass short treatment (GS): Total slug numbers were not correlated to average weekly temperature or rainfall but were correlated to soil moisture at 10-15cm (r=0.75). When each trapping method was considered separately pitfall trapping had no correlation to average weekly temperature, rainfall or soil moisture. Brick traps had no correlation to average weekly temperature or rainfall but a slight correlation to soil moisture at 10-15cm (r=0.66) and total soil moisture (r=0.61).

(iii) Chemical treatment (C): Total slug numbers were not correlated to average weekly temperature or soil moisture but had a moderate correlation to rainfall (r=0.65). When each trapping method was considered separately pitfall traps were not correlated to any environmental parameter, while brick trapping was correlated to rainfall (r=0.65).

(iv) Night searching: Night searching results show no correlation to rainfall temperature or soil moisture. Only in treatment C did a correlation occur between night searching and other slug population assessment methods. Total slug number had a correlation of r=0.62 and pitfall trap of r=0.5 to night searching.

(D) Discussion:

The four methods of slug population assessment used have different degrees of accuracy. The most accurate is soil sampling (Crawford-Sidebotham 1972) as this takes an actual sample of the slug environment and extracts nearly all the slugs contained within it. South (1964) reported a 94% efficiency for newly hatched slugs and 100% for slugs over 12.5mg in weight for this method of assessment. Stephenson (1968) also reported 100% efficiency.

A modified method similar to that of South (1964) was used in this study and efficiencies of 90% were recorded. This was within the expected efficiencies for this method. Soil sampling was employed at the beginning and end of the first stage of the study because it was necessary to ascertain the actual slug populations present in each ground cover. However, because of its destructive nature and the relatively small size of the plots (8m x 9m) it was not possible to carry out soil sampling as often as might have been liked. By sampling at the beginning and end of the first stage of the study it was at least possible to find the overall treatment effect.

Other population assessments were carried out to give some picture of what was happening to the slug populations during the study. Night searching, pitfall trapping and brick trapping are all less accurate than soil sampling for the simple reason that they rely on slug activity on the soil surface, but they do allow for continuous non destructive measurement. Barnes & Weil (1945), Stephenson & Bardner (1976), Webley (1964) and Crawford-Sidebotham (1972) have all reported that slug activity on the soil surface was dependent to a greater or lesser extent on weather conditions. Slug numbers recorded in these three assessment methods are therefore a function of both the population present and the weather conditions.

Night searching assessments were taken monthly due to its non destructive nature and ease of assessment. The efficiency of searching will depend on the skill of the observer and also on the habitat present (Southwood 1966). The sampling area ($0.1m^2$) was therefore cut in all treatments to close cropped vegetation or bare ground so that slugs on the soil surface would be more easily seen, especially in Grass long (GL) and Grass short (GS) treatments. It was also necessary to develop a "hunting image" before commencing a sample as suggested by Crawford-Sidebotham (1972). This was done by spending 5-10 minutes searching for slugs prior to sampling. The night searching as carried out was efficient and no slugs on the soil surface within the sample were missed for when a sample area was rechecked by another observer no additional slugs were ever found. Subterranean slugs are less likely to be recorded than surface dewelling slugs (South 1964, Hunter 1968a). This was accepted as a deficiency in the assessment and population levels from night searching are likely to be underestimations of the total slug population.

Pitfall and brick trapping were both carried out continuously and the traps checked weekly. These two methods differ in the stimulus that leads to the slugs being trapped. Pitfall traps depend on slug activity on the soil surface with the slugs coming in contact with the trap inadvertently. Brick traps on the other hand depend to a greater extent on the need for shelter; the greater the need for shelter the greater the number of slugs trapped. The results from this study tend to confirm this, as the GL treatment would presumably provide the slugs with plenty of adequate shelter so slugs in this case would only end up under the bricks by chance rather than seeking out the shelter. GS and C treatments on the other hand have less shelter and therefore there is presumably more stimulus for the slug to seek shelter and end up under the brick trap, especially in treatment C. Tables 4 and 5 and Figs 7, 8, 9 show the results recorded for brick and pitfall traps in each ground cover. It can be seen that in GL pitfall traps always recorded higher catches than the brick traps, while in GS and C as time progressed more slugs were being recorded in the brick traps than in pitfall traps. This would seem to indicate that in GS and C, shelter, and hence the stimulus needed to be caught in the brick traps, was greater as time progressed. Fig 6 shows that as time progressed (from week 12-17) brick traps were recording more slugs in treatment C than in GS or GL treatments; however this was not significant in any

Species of slugs present on the study site

Plate 6 (a). *Deroceras reticulatum*

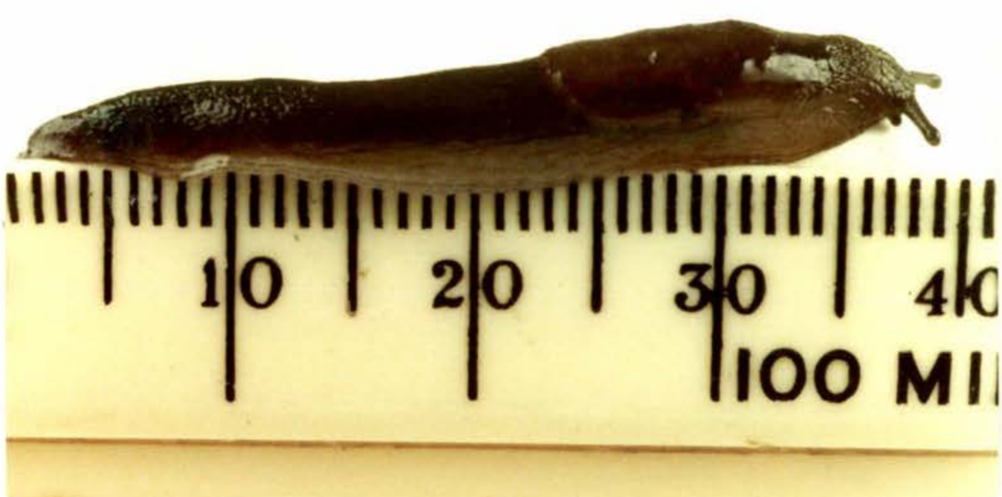


Plate 6 (b). *Milax gatates*

Plate 6 (c). *Deroceras panormitanum*

Plate 6 (d). *Milax sowerbyi*

one week. Further studies would need to be made, but it appears that brick or shelter traps for slug population assessment only work efficiently when the need for shelter is high. Pitfall traps on the other hand depend on slug surface activity, therefore the more conducive the environmental conditions are for activity the more effective is the method. Fig 5 indicated that in conditions where slug activity was possible (GL) the pitfall traps recorded high numbers but where conditions were marginal for activity (GS, C) then pitfall traps recorded lower numbers. Pitfall traps therefore work effectively in ideal slug environments that do not suit brick trapping and conversely brick trapping works best in conditions that do not favour pitfall trapping. This could explain why pitfall traps recorded high numbers of slugs in GL but brick traps recorded low numbers and in treatment C the trend was reversed.

Table 4 shows that there was greater variability in the results from pitfall trapping for GS and C treatments, indicating that these treatments may have had a variable effect on slug activity and hence pitfall trap results. The GL treatment did not have this variability. Table 5 shows that with brick trapping it was the GL treatment that had greater variability in numbers of slugs recorded. This variability in trapping results for the different methods appears to indicate that pitfall trapping operated best in the GL treatment and brick trapping operated best in GS and C treatments.

In New Zealand the four most widely distributed pest species of introduced slug are *Arion hortensis*, *Deroceras panormitanum*, *Deroceras reticulatum*, and *Milax gagates* (Van der Gulik 1980). In this study four species of slug from two genera were identified using the keys from Barker (1979) and Martin (1978). These were in order of most common to least common *Deroceras reticulatum*, *Milax gagates*, *Deroceras panormitanum* and *Milax* *sowerbyi*. Brick trapping recorded a ratio of 1:0.44 0.18:0.1 with a similar result from night searching and soil sampling. Slugs caught in pitfall traps could not be easily identified to species as discolouration and disfiguration occurred due to the copper sulphate and prolonged water immersion. They were however identified as to genus. It was found that *Agriolimax* was the most common genus compared to *Milax* with a ratio of 1:0.13. Brick trapping gave a ratio for the two genera of 1:0.5. It would therefore appear that brick trapping and pitfall trapping differed with respect to genera of slugs trapped. The genus *Milax* includes largely subterranean species of slugs (Anon 1973) though some species may feed above ground and are thus likely to be recorded in brick trapping. *Agriolimax* are surface dwelling species and are recorded at a lower ratio in brick trapping. Brick trapping seems to be more efficient at trapping subterranean species than surface dwelling species. Conversely pitfall traps are more efficient at catching surface dwelling species than subterranean species. Soil sampling gives a ratio for *Agriolimax* and *Milax* of 1:0.5 which is the same as brick trapping. It is likely therefore that pitfall trapping underestimates subterranean slugs. Van der Gulik (1980) found higher numbers of *D. panormitanum* than *D. reticulatum*, with a total ratio of 1.14:1. This study gave lower numbers of *D. panormitanum* than *D. reticulatum*, with a ratio of 0.18:1. This could be due to seasonal or time of year differences, site differences or actual population differences. Slug species composition did not differ between treatments.

In the literature slug populations have been reported as ranging from 7.5/m^2 (Carrick 1942) to 276.7 slugs/m^2 (Hunter 1966). Population densities in this study ranged from an average of 30.8/m^2 (C) to 38.5/m^2 (GL) for night searching and 40.7/m^2 (C) to 67.3/m^2 (GL) for soil sampling. Pitfall and brick trapping results have not been converted to an absolute assessment in this study. Night searching and soil sampling figures are at the low end of the range reported in the literature and were below that reported by Charlton (1978) as a moderate population (100/m^2). Slug numbers recorded by night searching decreased in all treatments over the experimental period with the decline in slug numbers being greater in the environmentally harsher treatments such as treatment C. Soil sampling however shows that only in treatment C was there any actual decrease in slug numbers. Night searching records slug activity on the soil surface so a decrease in numbers recorded by this method could mean a decrease in activity or a decrease in numbers. Therefore it appears that slug activity decreased in all treatments thus giving low night searching numbers, while only treatment C actually decreased slug numbers. The last soil sample was taken in spring (26.11.80) which Ferro (1976) reported as the time when slug eggs hatch. Overseas reports also indicated a spring hatching of some slug species (Hunter 1966, 1968b, Anon 1973). Therefore an increase in slug numbers in GL and GS treatments found by soil sampling is probably a reflection of this spring hatching which may not have occurred in treatment C because of the harsh conditions that had existed for some time. Possibly if the last soil sample had been taken earlier a decrease in slug numbers may have been found in GL and GS treatments.

The GL and GS treatments had little effect on the slug populaitons but treatment C caused a dramatic and significant decrease (P0.05). It therefore appears that reducing the vegetation cover has no appreciable effect on slug populations, unless all the vegetation is removed and bare ground maintained for some length of time. Slug activity was influenced by the treatments. Night searching results (Table 2) show generally low activity in treatment C and GS compared to GL. Similar results were recorded in pitfall trap numbers (Fig 5 Table 4). Since slug activity is dependent on weather and micro environment conditions (Barnes & Weil 1945, Stephenson 1968, Stephenson & Bardner 1976) it seems likely that the treatments altered these conditions. Significant (P0.05 0.01) temperature differences were recorded between the treatments. Crawford-Sidebotham (1972) showed that slug activity was a function of both the temperature and vapour pressure deficit and other workers (Dainton 1954, Baker 1973, Karlin 1961, White 1959) have found that temperature fluctuations can initiate slug activity. Webley (1962) also found that slug activity was related to temperature. In this study however only the GL treatment showed a correlation between slug activity (pitfall traps and brick traps) and temperature. It should also be noted that GL had the lowest average weekly temperature as well as the lowest maximum temperature and highest minimum temperature. Why slug activity in GS and C treatments is not correlated to temperature is unclear, but it is possible that as temperatures increase slug activity does not continue to do so. Dainton (1954) found that slug activity increased as temperature rose within the range 20-30^{o}C whereupon the slugs moved to a cooler place. Once the slugs encountered a cooler place activity ceased so that the chance of coming in contact with traps would be decreased. GL treatments with lower temperatures than GS or C may not have reached the point where temperatures were too high for activity and so slugs could continue to encounter the traps.

Soil moisture during the study period did not fluctuate to any great degree so any moisture effect would have been difficult to detect. The treatments had no effect on total soil moisture but did significantly (P0.05) affect the soil moisture recorded at the 0-5cm depth. The soil moisture at this level could be expected to affect slug activity. Barnes & Weil (1945) showed that slug activity depended ultimately upon there being a film of moisture covering the surfaces over which the slugs moved. Hunter (1966) found that most slugs were in the top 8cm of the soil and South (1964) found most in the top 2.5cm in grassland. No strong correlation was found between slug activity and soil moisture at any depth in any treatments in the present study.

Webley (1964) found that relative humidity, wind-speed and rainfall were responsible for some of the day to day variation in slug activity. Barnes & Weil (1945) found that falling rain was associated with changes in slug activity and Rodgers-Lewis (1976) reported that rainfall encourages slugs to the surface and suggested that rainfall data could be used to predict when large numbers of slugs are likely to be on the soil surface. In this study only the slug activity in treatment C was correlated to rainfall. It is possible that the vegetation covers in GL and GS treatments nullified any effect of rainfall or that conditions in treatment C were adverse enough to prevent slug activity until rainfall arrived.

(E) Conclusions:

The results and conclusions of this study should be interpreted only within the conditions of the experiment and the specific weather-slug combinations that occurred.

(i) Ground covers (treatments) affected slug activity on the soil surface, but only in the most adverse environment (C) did any actual decrease in population occur.

(ii) Ground covers (treatments) affected the temperature at the soil surface and the soil moisture at 0-5cm depth.

(iii) Pitfall traps appeared to be most effective in ideal slug environments (GL).

(iv) Brick or shelter traps appeared to be more effective in adverse slug environments (C).

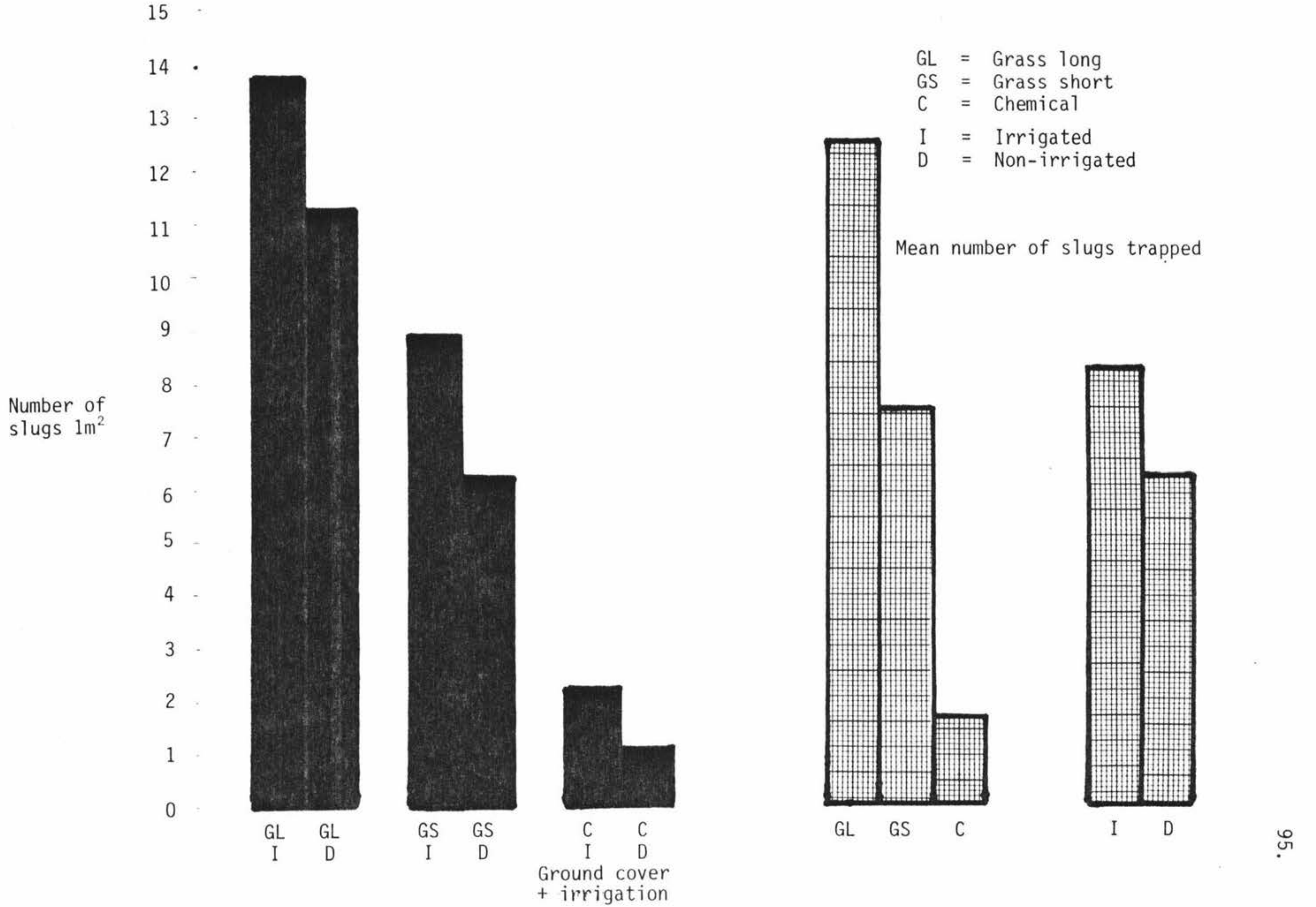
(v) Each ground cover (treatments) appeared to have different environmental parameters affecting number of slugs caught in traps. GL was correlated to temperature, GS had a slight correlation to soil moisture, and C was correlated to rainfall.

4.2 SECOND STAGE: EFFECT OF SLUGS ON A DIRECT DRILLED CROP AND EFFECT OF THREE COULTERS ON INGRESSION OF SLUGS INTO THE SEED GROOVE

(A) Slug populations.

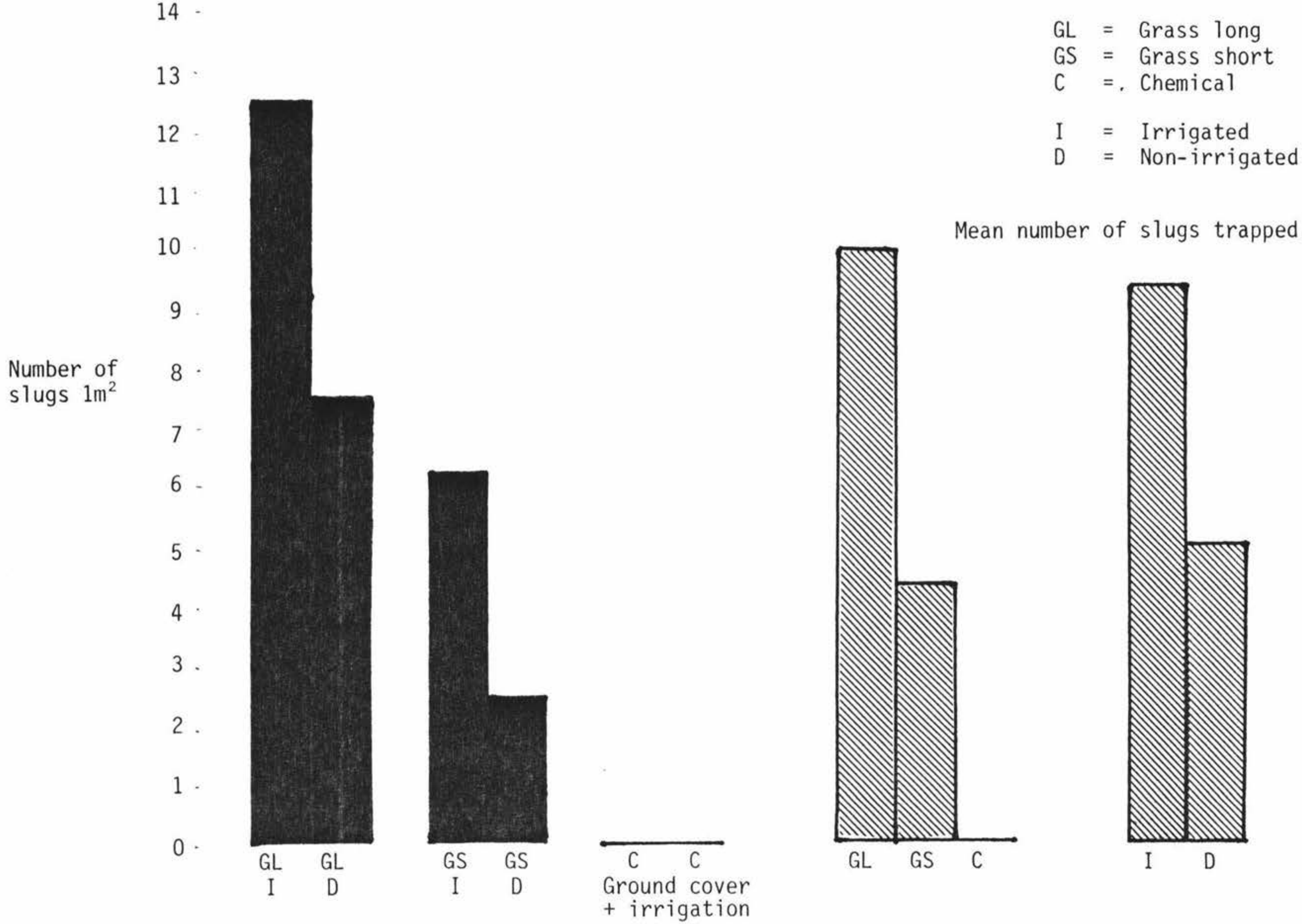
(i) Overall slug population - The first stage of the study showed that four species of slugs were present on the experimental site; *Deroceras reticulatum*, *Milax gagates*, *Deroceras panormitanum*, and *Milax sowerbyi*. Night searching was carried out prior to each drilling to gain some idea of numbers of slugs present. Soil sampling, though more accurate, could not be used due to its destructive nature. Figures 12 and 13 show the total numbers of slugs present at the time of each drilling. There was no difference in terms of species composition between the two drilling dates. The first drilling had higher slug numbers than the second drilling in all treatments. In both drillings the irrigated plots recorded higher slug numbers than the non irrigated plots with significance only occurring in the second drilling (P0.05). The ground covers were significantly different only in the first drilling

Figure 12. Numbers of slugs at time of first drilling.



95.

Figure 13. Numbers of slugs at time of second drilling.



(P0.05, 0.01) with the Grass long (GL) treatment having the highest numbers, Grass short (GS) intermediate and Chemical (C) the lowest numbers. There was a significant interaction between moisture regimes and ground covers in the second drilling (P0.05) and indicates that a different response occurred to moisture level depending on the ground cover.

(ii) Slug numbers in the seed grooves - Table 7 shows the mean number of slugs found per metre length of seed groove. No significant differences occurred between coulter types in either drilling. In the first drilling the ground covers were significantly different (P0.05) with GS recording the greatest slug number, GL intermediate and C the lowest. Ground covers in the second drilling were not significantly different. The difference between irrigated and non irrigated plots was not significant in the first drilling but was in the second (P0.05). Both drillings had greater slug numbers in the irrigated plots compared to the non-irrigated plots. All species of slugs found on the surface of experimental site were found to enter the seed grooves and species composition remained approximately at the same ratio as recorded for the surface population.

(B) Plant damage.

(i) Seed damage - Table 8 shows the percentage of seeds damaged per metre length of seed groove. In both drillings the seed damage was not significantly different between coulters, however both drillings recorded highest damage in the chisel coulter, intermediate in the triple disc coulter and lowest in the hoe coulter. Ground covers were not significantly different in either drilling.

Table 7. Mean numbers of slugs per metre length of seed groove

		First drilling			Second drilling		
	Coulter	Triple disc	Hoe	Chisel	Triple disc	Hoe	Chisel
	Ground Cover						
GL	Irrigated	2.78	2.96	7.4	3.82	1.67	1.63
	Dry	3.98	1.76	3.24	0.21	0.28	0.83
	Overall mean $\bar{x}$ 3.69				Overall mean $\bar{x}$ 1.39		
GS	Irrigated	4.72	7.86	4.99	2.5	3.12	1.11
	Dry	3.61	4.44	5.09	0.35	0.21	0.49
	Overall mean $\bar{x}$ 5.12				Overall mean $\bar{x}$ 1.29		
C	Irrigated	0.19	0.93	0.09	0	0	0
	Dry	0.09	0	0	0	0	0
	Overall mean $\bar{x}$ 0.216				Overall mean $\bar{x}$ 0		

First drilling		Second drilling	
means for main effects		means for main effects	
Irrigation	$\bar{x}$ 3.55	Irrigation	$\bar{x}$ 2.19
Dry	$\bar{x}$ 2.07	Dry	$\bar{x}$ 0.39
coulters		coulters	
Triple disc	$\bar{x}$ 2.56	Triple disc	$\bar{x}$ 1.72
Hoe	$\bar{x}$ 2.99	Hoe	$\bar{x}$ 1.32
Chisel	$\bar{x}$ 3.47	Chisel	$\bar{x}$ 0.99

Both drillings however recorded highest damage difference in the GS treatment, intermediate in GL and lowest in C. The difference between moisture levels was only significant (P0.05, 0.01) in the second drilling, with irrigated plots having the greater damage level. The first drilling recorded a similar but non significant result.

(ii) Seedling damage - Table 9 shows the percentage of seedlings damaged per metre length of seed groove. A damaged seedling was one that showed any visible sign of slug damage. The seedling damage in both drillings was not significantly different between coulter types; in the first drilling the coulters were within 3% of each other and in the second drilling 2% of each other. There was a significant difference between ground covers; in the first drilling GS and GL were significantly greater than C (P0.05, 0.01) and in the second drilling GL was significantly greater than GS and C (P0.05, 0.01). The second drilling had a significant difference (Po.05, 0.01) between moisture levels, irrigated plots giving the greatest damage. The first drilling showed the same result but it was non significant. Damage to individual seedlings ranged from 1 - 10% of the leaf area with most seedlings showing around 5% leaf damage.

(C) Environmental parameters.

(i) Temperature in the seed groove - No significant differences were found with in-groove temperature. The coulters differed in temperature by approximately 0.6^{o}C and the in-groove temperatures were within 1^{o}C of each other for the different ground covers. The in-groove temperature was approxi-

Table 8. Percentage seed damage per metre length of seed groove

	Coulter	First drilling: Triple disc	Hoe	Chisel	Second drilling: Triple disc	Hoe	Chisel
	Ground Cover						
GL	Irrigated	9.69	11.35	13.68	8.15	0	10.7
	Dry	14.66	10.2	13.26	2.5	0.45	2.8
		Overall mean $\bar{x}$ 12.14			Overall mean $\bar{x}$ 4.1		
GS	Irrigated	9.15	18.7	12.99	3.45	12.95	9.65
	Dry	14.81	11.73	7.52	3.8	2.03	4.63
		Overall mean $\bar{x}$ 12.48			Overall mean $\bar{x}$ 6.1		
C	Irrigated	5.16	5.79	6.5	0.173	0.12	1.43
	Dry	7.34	2.31	7.4	0	0.93	0.15
		Overall mean $\bar{x}$ 5.75			Overall mean $\bar{x}$ 0.47		

	First drilling	Second drilling
means for main effects		
Irrigation $\bar{x}$	10.33	5.19
Dry $\bar{x}$	9.91	1.9
coulters		
Triple disc $\bar{x}$	10.14	3.01
Hoe $\bar{x}$	10.01	2.75
Chisel $\bar{x}$	10.23	4.89

Table 9. Percentage seedling damage per metre length of seed groove

		First drilling			Second drilling		
	Coulter	Triple disc	Hoe	Chisel	Triple disc	Hoe	Chisel
	Ground Cover						
GL	Irrigated	51	55	61	34	44	38
	Dry	59	64	60	19	22	22
		Overall mean $\bar{x}$ 58.3			Overall mean $\bar{x}$ 29.8		
GS	Irrigated	70	71	71	23	32	26
	Dry	66	57	56	22	17	23
		Overall mean $\bar{x}$ 65.2			Overall mean $\bar{x}$ 23.8		
C	Irrigated	39	32	25	7	3	3
	Dry	31	26	23	3.1	0.68	0.78
		Overall mean $\bar{x}$ 29.3			Overall mean $\bar{x}$ 2.9		

First drilling			Second drilling		
means for main effects			means for main effects		
Irrigation	$\bar{x}$	52.78	Irrigation	$\bar{x}$	23.33
Dry	$\bar{x}$	49.11	Dry	$\bar{x}$	14.40
coulters			coulters		
Triple disc	$\bar{x}$	52.67	Triple disc	$\bar{x}$	18.02
Hoe	$\bar{x}$	50.83	Hoe	$\bar{x}$	19.78
Chisel	$\bar{x}$	49.33	Chisel	$\bar{x}$	18.80

mately the same as ambient temperature at the soil surface. The triple disc had a slightly higher temperature and the chisel and hoe coulters slightly lower.

(ii) Humidity in the seed groove - Humidity measurements recorded in the first drilling were too low to be taken as actually occurring. This was due to a fault in the equipment used. In the second drilling the equipment was altered in that the probe, when inserted into the seed groove was no longer covered with a gauze sheath thus allowing more direct contact to occur between the probe and the atmosphere in the seed groove. The measurements in the second drilling were within the expected range (from work by Choudhary & Baker 1981c). No significant differences were found between coulters or ground covers. The irrigated plots were not measured as the soil was too moist for the probe, and in-groove humidity would have been almost 100%. The seed grooves were considerably more humid during the day than the ambient air (60 - 80%) but during the night they would have been similar.

(iii) Soil moisture (liquid phase) within the seed groove - The soil moisture at the commencement of the first drilling was 30-32% w/w on the non irrigated plots and 35-36% w/w on the irrigated plots. The second drilling had a lower starting soil moisture of 18-22% w/w on the non irrigated plots and 30-34% w/w on the irrigated plots. The in-groove soil moistures (liquid phase) were not significantly different between coulters in both drillings. Significant differences were found between the ground covers (P0.05) with GL being the highest in-groove soil moisture, C intermediate and GS the lowest. Irrigated plots had a significantly higher in-groove soil moisture than non irrigated plots.

(D) Total pest numbers in the seed groove - This takes into account wireworms, cutworms and slugs. The first drilling had a significant difference between ground covers (P0.05 0.01) with GS having the greatest numbers, GL intermediate and C the lowest. A significant difference (P0.05) also occurred between the ground covers in the second drilling with GL recording the highest number and C the lowest. In both drillings there was a significant difference (P0.05, 0.01) between moisture regimes with irrigated plots having the greater pest numbers. No significant differences occurred between the coulters in either drilling. Total pest numbers were lower in the second drilling. Table 10 shows the mean total pest number recorded per metre length of the seed groove.

(E) Discussion - Coulter design did not appear to affect the number or species composition of slugs found in the seed grooves, as no significant differences were found. It was observed that the model of chisel coulter used in this study, which had press wheels following behind the coulter, caused in some cases a completely closed seed groove which seemed to suggest a difficult entry for slugs. This could account for the low slug numbers in the chisel coulter seed groove and hence lower damage to seeds and seedlings than has previously been reported (Baker 1976b, Baker per comm). Other models of the chisel coulter which do not possess press wheels may well give different results. Further work would have to be done to see if there really was an effect of the press wheels and to what extent. It is possible that by completely closing the seed groove a means of limiting slug damage could be found. Stephenson (1974) found that when the seed of winter wheat was sown

Table 10. Total pest numbers in the seed grooves per metre length of seed groove

	Coulter	First drilling: Triple disc	First drilling: Hoe	First drilling: Chisel	Second drilling: Triple disc	Second drilling: Hoe	Second drilling: Chisel
	Ground Cover						
GL	Irrigated	3.13	3.3	8	4.3	2	2.7
	Dry	4.5	2.3	3.9	0.3	0.7	1.3
		Overall mean	x̄ 4.2			Overall mean	x̄ 1.9
GS	Irrigated	5.3	8.3	5.9	3	3.7	1.7
	Dry	3.8	4.8	5.6	0.7	0.7	1.3
		Overall mean	x̄ 5.6			Overall mean	x̄ 1.85
C	Irrigated	0.6	1.2	0.7	0.3	0.2	0.3
	Dry	0.37	0.5	0.2	0.07	0.1	0.07
		Overall mean	x̄ 0.6			Overall mean	x̄ 0.2

	First drilling		Second drilling	
means for main effects				
Irrigation	x̄	4.07	x̄	2.02
Dry	x̄	2.89	x̄	0.58
coulters				
Triple disc	x̄	2.98	x̄	1.45
Hoe	x̄	3.41	x̄	1.23
Chisel	x̄	4.05	x̄	1.23

in soil having a moisture content of 25% and comprised of aggregates retained by a 6.0mm sieve, it was protected from slugs by applying a pressure of 390kg/m^2 or more to the soil surface after sowing. This pressure covered the seed with finer soil and protected it from slugs. Hunter (1967) looked at the effect of cultivations on slugs and found that soil compaction after ploughing was most effective in reducing slug numbers since slugs cannot find shelter. Baker (1976a) Choudhary & Baker (1981a,b) showed that covering the seed groove should permit improved seedling emergence in dry soils. Therefore research into the effect of seed covering could be advantageous in terms of increasing seedling emergence and reducing slug damage. Similarly differences in seed damage by slugs are non significant though the chisel coulter recorded the highest damage in both drillings. This possibly indicates that although the chisel coulter was not causing any difference in slug ingression into the seed groove, it was either depositing the seed in such a way as to cause increased seed damage by slugs or caused the slugs entering the seed groove to feed more on the seeds. Baker (1976b) suggested that the chisel coulter had greater slug problems due to its apparent ability to protect the seed from drying. No evidence of this was found in this study, as coulter types did not significantly differ in in-groove soil moisture (liquid phase) or humidity and there was no correlation between slug numbers in the seed groove and measured seed groove environmental parameters. Seedling damage was not different between the coulters. This could have been due to a fault in the experimental design as it was possible for slugs to shelter in one coulter seed groove and yet feed on the seedlings of another coulter seed groove so giving a false impression of damage. Further studies would be needed to clarify this situation.

In this study coulter design had no detectable effect on the seed groove micro environment (as measured in this experiment), slug ingression into the seed groove or seed or seedling damage by slugs. However this study was conducted only in one season and under comparatively moist soil conditions. Reports by Baker (1976a), Choudhary (1979), Choudhary & Baker (1981a,b,c) indicated that seed groove micro environment differences were most noticeable under dry soil conditions close to wilting point. The possibility therefore exists that under drier conditions than experienced in this study differences between the coulter types in terms of seed groove micro environment, slug ingression and damage could occur.

Night searching was chosen as the method of assessing slug numbers prior to drilling, due to its relative ease of operation and non destructive nature. Night searching depends on slug activity for its assessment and this is largely governed by the weather conditions (South 1964). By sampling over two successive nights prior to drilling it was hoped that any effect of weather on counts would be lessened. Even so the slug numbers recorded were probably lower than the number actually present and surface active species only could be recorded. But since it is only the surface active slugs that presumably will move into the seed groove and damage the seeds and seedlings this method was appropriate to this stage of the study. The numbers of slugs recorded ranged from 1-13/m^2 in the first drilling and 0-12.5/m^2 in the second drilling which was within the range reported by Carrick (1942) for grass and stubble but were well below that found by South (1964), Hunter (1968a). Because of the size of the plots during this stage of the study (1½ m x 9m) it was not possible to take soil samples to determine slug numbers directly. However one month before the first drilling soil samples were taken and these gave a much higher estimation of populations. It is these figures which have been used to estimate the percentage of the slug population on the plots that moved into the seed grooves. Slug numbers were recorded as decreasing in the time interval between the two drillings but, because of the method of assessing slug numbers (night searching), it is uncertain whether there was an actual decrease in number or whether less slugs were active at the time of sampling. Since the irrigated plots which should have been ideal for slug activity, recorded lower slug numbers it is likely that there was an actual decrease in the population.

The pre-drilling treatment influenced slug numbers present at the time of drilling. Heavier vegetation cover (GL) had a large slug population, medium vegetation (GS) had a medium slug population and no vegetation (C) had few or no slugs present. Therefore at the time of drilling the three ground covers presented three different slug populations. This difference in slug numbers between the ground covers was expected as Anon (1973) reported that slugs tend to build up to epidemic numbers in leafy crops and Hunter (1969) noted that slug damage is particularly prevalent after crops such as peas or clover due to an adequate supply of shelter. This study shows a similar result. It would therefore appear that the greater the shelter presented by vegetation to slugs the higher the population.

The immediate pre-drilling conditions (trash level) affected slug ingression into the seed grooves, the percentage of the population in the seed grooves being 21% in GL, 32.7% in GS and 5.5% in C. Obviously some factor or factors was influencing the number of slugs entering the seed grooves in each ground cover. What factor or factors this was is unclear. It possibly had to do with the effect of trash level on slug activity, need for shelter and food, and the environmental differences between that in the trash and the seed groove.

There was little difference in the temperature between the surface of the soil and the seed groove ($1^{o}C$). However slugs can respond to subtle temperature differences. Dainton (1954) found that as little as $0.1^{o}C$ change in temperature can cause activity and slugs prefer temperatures of $17-18^{o}C$. Getz (1959) found that slugs preferred $18-24^{o}C$. The temperatures found within the seed grooves are in the range reported to be preferred by slugs. The possibility exists that slugs could have used the temperature difference as a stimulus for entering the seed grooves though, because of the small differences in temperatures between ground covers, coulters and ambient temperature, it seems that temperature is not able solely to explain the results. Duval (1970) found that at dawn slugs seek shelter away from light which usually means the discovery of a relatively humid place to shelter. Getz (1963) found that slugs prefer low light intensity and when given a choice of light or dark move towards the dark. Lewis (1969a) found that during the day slugs display negative phototaxis. Therefore differing light intensity could lead to the slugs moving into the seed groove, though no measurements of light intensity were made in this study. Humidity levels were different between the trash and the seed groove (30% higher in the seed groove). Slugs prefer moist, humid conditions (Runham & Hunter 1970). Lewis (1969a) observed that at the boundary between a dry and humid zone *Arion ater* executed head movements and then crawled into the damper area. Humidity differences between the ground covers were not measured but presumably existed. Humidity differences could account for movement into the seed groove but not for differences between ground covers as treatment C had a low percentage of the population entering the seed groove. The differences between ground covers in the percentage of the population entering the seed groove is most likely due to a combination of activity (highest in GL, lowest in C) and environmental differences between trash and seed groove (presumably less difference in GL and most difference in C). Three seed groove environmental differences from ambient conditions have been discussed as possible causes of slug ingression into seed groove. These are not the only differences or possible factors involved in slug ingression into the seed groove but they are the more obvious. It is likely that the cause of slug ingression is a combination of factors which together produce a stimulus that causes ingression. The possibility also exists that ingression is by chance and that the more seed grooves there are the greater the chance of ingression and hence damage to the crop. Further studies are needed in this area to see what distance slugs move to reach the seed grooves and exactly what factor or factors are involved in ingression.

Irrigated plots in both drillings had greater numbers of slugs in the seed grooves than non irrigated plots. This must have been due to greater slug activity or higher slug numbers. At first it appears that the result should have been the opposite as in drier conditions (non irrigated plots) the need for shelter and areas of higher humidity, or lower temperatures would presumably be greater. However this was not the case in this study, and it appears that moister conditions will cause greater slug problems probably because of greater slug activity on the soil surface.

Seed damage by slugs was not significantly different between the coulters so little can be concluded even though the chisel coulter recorded greater damage in both drillings. The chemical treatment (C) in the second drilling was recorded as having no slugs present in the plot or seed grooves yet a low level of damage was recorded. Seed damage by slugs and wireworms is similar and as a low population of wireworms was present in the plots a small percentage of seed damage may be attributed to wireworms.

The possibility also exists that a low slug population was present but was too small to be detected by the sampling methods used. The estimated number of seeds deposited per metre length of seed groove was 53 and the results show that 95-100% of the seeds were accounted for in counts of seeds. The method of sampling was therefore accurate. The very small numbers of unaccounted seeds could have been missed, or the drill may not consistently plant 53 seeds per metre, or the seeds could have been so damaged by slugs as to be overlooked. The trend of seed damage in the ground covers was similar to that for slug number in the seed grooves. There was a moderate correlation between slug numbers in the seed groove and seed damage (r=0.78).

Seedling damage was even more strongly correlated to slug numbers (r=0.93). The low level of seedling damage in treatment C in the second drilling may have been due to cutworms, though the cutworm population was at a low level. Again a low undetected slug population could also have caused the damage. No seedlings were completely destroyed though it was doubtful if those which had been grazed below ground would have continued to grow. Seedling emergence was not significantly different between the coulters in either drilling and was about 60-70% overall.

(F) Summary and Conclusions:

(i) Coulter design had no effect on slug ingression into the seed groove.

(ii) Coulter design had no effect on slug damage to a direct drilled crop.

(iii) Coulter design had no effect on in-groove micro environment. However, it was not possible to measure accurately some aspects of the in-groove micro environment such as humidity. Other workers (Baker 1976a, Choudhary & Baker 1981a,b,c) have shown differences in the micro environments.

(iv) There was no correlation between slug numbers in the seed groove and any "measured" groove micro environmental parameter.

(v) There was a moderate correlation between slug numbers in the seed groove and seed damage.

(vi) There was a strong correlation between slug numbers in the seed groove and seedling damage.

(vii) Pre-drilling conditions affected slug numbers entering the seed groove. The heavier the vegetation (GL) the greater the slug numbers in the seed grooves.

(viii) Pre-drilling conditions can affect slug damage to seedlings.

(ix) Moisture level affects the number of slugs entering the seed groove, seed damage and seedling damage by slugs. Moister conditons have the greater slug number in the seed groove and greater seed and seedling damage.

APPENDIX I: Mechanical properties of "Tokomaru" silt loam soil

(Tran Van Mai 1978)

Horizon	Depth (cm)	Clay	Silt	Sand	B_D g/cm^3	Porosity %	Field capacity g/water 100g of solid soil	Wilting point g/water 100g of solid soil	Available water g (water) 100g of solid soil	Root g/100g of solid soil
Ah,	0-8	23%	68.5%	8-9%	1.07	60	43.2	15.3	27.9	
Ah_1	0-5				1.04	61	40	14	26	1.4
Ah_2	8-20	22%	69%	8.7%						

APPENDIX II.

Numbers of slugs caught in the buffer zones

Week	Slugs per trap per day
1	0.1
2	0.12
3	0.1
4	0.16
5	0.09
6	0.11
7	0.14
8	0.2
9	0.01
10	0.06
11	0.05
12	0.07
13	0.05
14	0.01
15	0
16	0
17	0.01

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