The effect of non-inversion tillage on farmland birds, soil and surface-active invertebrates and surface seeds

Thesis

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The effect of non-inversion tillage on farmland birds, soil and surface-active invertebrates and surface seeds

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ABSTRACT

The effect of non-inversion tillage on farmland birds, soil and surface-active invertebrates and surface seeds

This thesis investigated the effect of non-inversion tillage (NIT) compared to conventional tillage (CT) on farmland birds and their invertebrate and seed food resources. Farmland birds have suffered severe population and range declines over the last few decades. One major reason is the increased intensification of agriculture leading to a decline in the abundance and availability of food over the summer and winter months. Conventional farming systems have traditionally used a mouldboard plough (CT) to invert the soil to prepare the seedbed for crop establishment. Due to economic pressures and increasing interest in environmental and soil protection, approximately 30% of arable crops in the UK are established by NIT methods. Machinery involved in NIT generally involves the use of discs and tines.

Field occupancy by farmland birds was studied on commercial farms over three winters from 2000 to 2003. In addition, the abundance of seeds and earthworms were investigated during the autumn and spring (2001 - 2003) and surface-active arthropods during March and July (2002 - 2003). The study was carried out at fourteen farms in Oxfordshire, Leicestershire and Shropshire. Experimental work examined the effect of two types of NIT and mouldboard ploughing on the movement of weed and crop seeds in the autumn of 2003.

Skylarks, other granivorous passerines and game birds occupied a greater proportion of cereal fields established by non-inversion tillage than conventional mouldboard ploughing.

Tillage was not significant in explaining the variation in the relative abundance of carabid beetles, staphylinid beetles or spiders trapped in March, May or July. A greater relative abundance of beetle larvae were observed in conventionally tilled fields in July in wheat fields preceded by oil seed rape.

Tillage was not significant in explaining the variation in seed or earthworm abundance or weights in the autumn or spring. The cultivation experiment showed few seeds retained at the soil surface after mouldboard ploughing compared to two NIT methods.

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AUTHOR'S DECLARATION

This thesis is the work of, and has been written by, the author. No part of this work has been submitted for any other degree or professional qualification.

Heidi M. Cunningham

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Chapter 1

INTRODUCTION

1.1 Summary

This chapter describes the current state of farmland bird populations in the UK and the known reasons for their declines. The diet of farmland birds changes throughout the year; many species take invertebrates over the breeding season, but seeds are also important for many species throughout the year and especially over the winter months. The types of invertebrates and seeds taken by farmland birds are discussed. The intensification of agriculture is highlighted as one of the main reasons for declines in farmland birds and their food resources. Much is known about the ecology of farmland bird species and their invertebrate and seed food resources in agro-ecosystems. Some studies have compared the effects of intensive agricultural practices or systems with those believed to be less intensive e.g. conventional versus organic systems. A poorly studied area of agro-ecology in the UK and the rest of Europe is the effect of crop establishment methods on wildlife. Non-inversion tillage (NIT) is a method of establishing a crop without using a mouldboard plough (i.e. the conventional method of crop establishment) and is becoming increasingly popular in the UK. Non-inversion tillage generally disturbs the soil to shallower depths than conventional tillage and is therefore expected to have beneficial effects on biodiversity on arable land when compared to mouldboard ploughing. This chapter reviews the current knowledge of the effects of non-inversion tillage on farmland birds and their food resources, particularly soil and surface-active invertebrates and seeds. To assess the mechanisms behind the effects of tillage on seeds, literature on the effects of cultivation on seed movement has been reviewed. The structure, content and hypothesis of the thesis are included at the end of this chapter.

1.2 Farmland birds

1.2.1 Decline of farmland birds

The population and range of many farmland birds have shown substantial declines in the UK over the past few decades (Fuller *et al.* 1995, Gregory *et al.* 2003, Siriwardena *et al.* 1998a, Figure 1.1). Many of these species, including Skylark *Alauda arvensis*, Song Thrush *Turdus philomelos*, Linnet *Carduelis cannabina*, Yellowhammer *Emberiza citrinella* and Grey Partridge *Perdix perdix* are now on the UK Red List of species of conservation concern (Gregory *et al.* 2002). A large body of evidence now links many of these declines to aspects of agricultural intensification (Aebischer *et al.* 2000, Anderson *et al.* 2001, Boatman *et al.* 2002, Chamberlain *et al.* 2000) and, across Europe, the extent of national population decline is correlated with various indices of intensification of agricultural production (Donald *et al.* 2001). These declines are of so much concern in the UK that a wildlife 'indicator' based on the population trends of farmland birds is now used as a 'headline' indicator of the sustainability of UK lifestyles (Gregory *et al.* 2003).

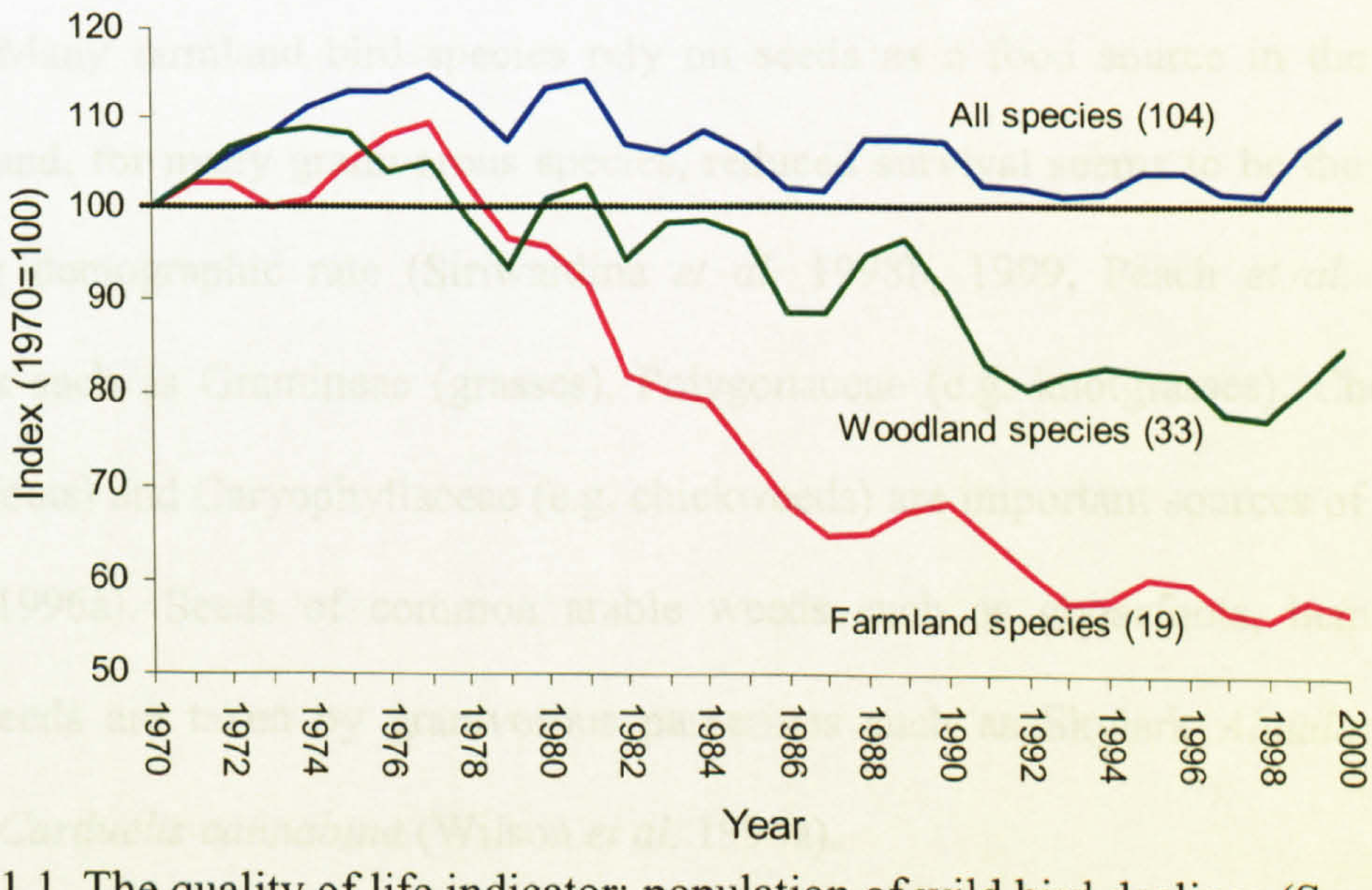

Figure 1.1. The quality of life indicator: population of wild bird declines (Source RSPB, BTO, DEFRA).

1.2.2 Farmland bird diet and the decline of bird food resources

The changes in farming practice have resulted in a loss of summer food, winter food and nesting sites, all of which are potential limiting factors for farmland birds. Losses of arable weeds and seeds have been attributed to modern, more intensive, farming methods (Marshall *et al.* 2003). The switch from spring- to autumn-sown crops, together with the widespread use of autumn-applied residual herbicides, has resulted in the loss of autumn stubbles and a reduction in the number of weeds and seeds present after harvest. More efficient combine harvesters and the requirement for bird-proof grain stores to comply with crop assurance schemes have also reduced the availability of seeds to birds. As a consequence, recent studies have shown that farmland birds aggregate in localised areas with abundant sources of seeds, such as weedy stubbles (Wilson *et al.* 1996a, Robinson & Sutherland 1999, Moorcroft *et al.* 2002), wild bird cover (Stoate *et al.* 2003) and set-aside (Buckingham *et al.* 1999). Stubbles and wild bird cover have been included as options in UK agri-environment schemes, such as the Countryside Stewardship Scheme (England), Rural Stewardship Scheme (Scotland) and the Pilot Entry Level Scheme (England), to encourage uptake on farms in the UK (Bradbury & Allen 2003, Evans *et al.* 2002).

Many farmland bird species rely on seeds as a food source in the autumn and winter and, for many granivorous species, reduced survival seems to be the current most limiting demographic rate (Siriwardina *et al.* 1998b, 1999, Peach *et al.* 1999). Plant families such as Gramineae (grasses), Polygonaceae (e.g. knotgrasses), Chenopodiaceae (goosefoots) and Caryophyllaceae (e.g. chickweeds) are important sources of seed (Wilson *et al.* 1996a). Seeds of common arable weeds such as goosefoots, hemp-nettles and chickweeds are taken by granivorous passerines such as Skylark *Alauda arvensis* and Linnet *Carduelis cannabina* (Wilson *et al.* 1996a).

Invertebrates are an important food source during the breeding season, for both adults and chicks, of many species (Green 1978, Jenny 1990, Wilson *et al.* 1996a, Brickle

& Harper 1999, Donald *et al.* 2001). The main groups of invertebrates that are important for declining bird groups tend to be those invertebrate groups that are the most abundant on agricultural land (Wilson *et al.* 1996a). Sawfly (Hymenoptera: Symphyta) larvae form an important part of the diet of game birds (Potts 1970). Surface-active invertebrates such as carabid beetles and spiders are important for many birds, while soil-dwelling invertebrates, such as earthworms, are important for species such as Lapwing *Vanellus vanellus* and Song Thrush *Turdus philomelos* (Gruar *et al.* 2003, Wilson *et al.* 1996a). There has been a long-term decline in the number of invertebrates associated with arable cropping systems (Aebischer 1991, Benton *et al.* 2002), one major factor being increases in pesticide use (Campbell *et al.* 1997). Indeed, one of the four main aspects of agricultural change that are responsible for the population declines of farmland birds are use of herbicides for weed control (Newton 2004).

1.2.3 Impact of CAP reform on food resources for farmland birds

The Common Agricultural Policy (CAP) has encouraged farmers to intensify production methods by subsidising grain production. Current reforms of the CAP will provide a single farm payment in the future, which will remove the incentive to intensively manage all parts of the farm for agricultural crops. Modulation will mean that financial support is diverted from production subsidies to provide more funds for agri-environment schemes (Kleijn & Sutherland 2003). A possible outcome of the reforms will be that productive arable land in the centre of fields will be managed intensively, with less productive areas and field edges managed for environmental benefit. Therefore, it is important to ascertain the effect on biodiversity of both non-crop management and practices within intensive cropping areas, such as crop establishment methods.

1.3 Non-inversion tillage (NIT)

Non-inversion tillage (NIT) is used to prepare the seedbed for sowing and establishing a crop from the previous year's stubble. Non-inversion tillage can include various types of cultivation equipment that disturb the surface of the soil without inverting it, and incorporate, to varying degrees, the stubble of the previous crop. The percentage of crop residue left on the soil surface has been used as a way of defining non-inversion tillage, i.e. over 30% cover of previous crop residue (Gebhardt *et al.* 1985). The type of equipment can include various combinations of discs, harrows and tines, whereas conventional tillage in the UK would involve mouldboard ploughing (Figure 1.2 and Figure 1.3). Typically, ploughing would involve soil inversion to depths of 20-25 cm, whereas NIT would involve disturbance only, to depths of 10-15 cm. However, some NIT machinery can have optional tines attached that loosen deeper soil horizons. Non-inversion tillage is also known as reduced tillage, no-till, ECOtillage, minimum tillage (min till) and conservation tillage, the latter being a term often used in North America and which can include reduced forms of tillage and direct drilling (Stinner & House 1990). However, it is important to note that no-till is often referred to as direct drilling in the UK. Here, the seed is drilled into the stubble of the previous year's crop with no cultivation taking place.

Approximately 30% of arable land in the UK has been estimated to be established by NIT methods (ECAF 2004), although over half the area of arable land in the UK is suitable for establishing winter cereal crops with NIT (Ball 1989). In comparison Denmark, Italy, Portugal and Ireland have under 10% of their arable land established by NIT; Hungary, Spain, Germany, Belgium, Slovakia and France have between 10-20% and Switzerland has the highest estimate of 40%. This gives a total estimated area of 10,054,000 ha of arable crops established by NIT in Europe (ECAF 2004).

Figure 1.2. A mouldboard plough (Cunningham)

Figure 1.3. Non-inversion tillage equipment: Vaderstad combination drill (Source: Vaderstad)

1.3.1 Advantages and disadvantages of non-inversion tillage

The drive to produce grain at the lowest cost per tonne has encouraged farmers to establish more crops by NIT. The main benefit is the speed of operation, allowing a two- to three-fold increase in the area sown per unit of time. Significant savings in terms of labour, fuel and time can be made with NIT when compared to conventional mouldboard ploughing (Sijtsma 1998, Ball 1989) (Table 1.1) without incurring losses in yield, at least on some soil types (Chaney *et al.* 1985). The retention of vegetative cover and reduced disturbance of the soil with NIT also provides soil and water conservation benefits, including reduced risk of soil erosion. It is therefore likely that NIT will become a more widespread practice in Europe, independent of any need for additional financial incentive for helping biodiversity (e.g. Birkas *et al.* 1989). Given additional potential to enhance soil and water conservation, it may well prove to be a useful tool for countries across the whole of the enlarged European Union, to produce competitively priced crops whilst minimising environmental impact (Donald *et al.* 2002).

Table 1.1. The establishment work rates with non-inversion tillage and conventional ploughing (Adapted from: SMI, 2004)

Operation	Output (ha/hr)	Time taken (min/ha)
Plough	1.2	50
Mono	1.2	50
Discs	3.0	20
Vaderstad Drill	3.2	20
Rolls	6.0	10

Ploughing provides weed control by burial of weeds and seeds, whereas NIT systems rely on the use of herbicides to control weeds that emerge from the post-harvest stubble. One of the most significant problems faced by using NIT methods is the control of grass weeds, such as sterile brome *Anisantha sterilis* and black grass *Alopecurus* *myosuroides* (e.g. Cannell 1985). For all types of weeds except summer annuals, Andersen (1999) observed a greater weed cover in no-tillage systems compared to mouldboard plough-based systems. However, modern and more refined chemical weed control methods can be used to keep this problem to a minimum (Stride & Wright 1997).

Other disadvantages when establishing crops with NIT methods include disease and pest problems. There may be an increased risk of fungal diseases with NIT systems that can have knock-on effects for wildlife, such as staphylinid beetles (Aebischer & Potts 1990). Slugs have been observed in greater abundance in crops established by NIT systems (e.g. Stinner & House 1990). However, the abundance of slugs has been positively correlated with the number and cover of weeds (Andersen 1999, 2003), so if the weeds in a NIT system are managed correctly this potential problem will be reduced.

1.4 Impact of NIT on invertebrate food resources for farmland birds

A relatively large amount of research has been carried out on the diets of farmland birds in the UK. However, research on the effect of NIT has been carried out on only a few of the invertebrate groups that comprise the diet of farmland birds. The most commonly studied groups are ground beetles, spiders and earthworms. It is likely that this is largely due to these invertebrates being the most abundant in an arable context, as well as being relatively easy to sample and identify. These invertebrate groups are important in agroecosystems; earthworms have been shown to improve soil quality, whereas carabid and staphylinid beetles have been shown to be important predators of arable pests such as aphids (Lang 2003). The only other groups that are known to be important in the diet of declining farmland birds and which have been studied with respect to the effects of tillage practices are sawfly (Hymenoptera: Symphyta) larvae; these form an important part of game bird chick diet (Wilson *et al.* 1999). The emergence of adult sawflies from the soil was shown to decline by up to 50% after ploughing (Barker *et al.* 1999).

Many of the studies investigating the effects of tillage on invertebrates have been carried out by comparing conventional tillage to no tillage, where disks or tines create slots and the seed is deposited directly in to the stubble of the previous year's crop. It has been claimed that, as non-inversion or reduced tillage creates a disturbance that is between no tillage and conventional tillage, the resultant effect on invertebrates will be intermediary (Kladivko 2001). This suggestion is supported by the study showing an intermediate response in terms of deep-burrowing earthworm abundance, in plots that had been established by chisel ploughing compared to direct-drilled and mouldboard-ploughed plots (Edwards & Lofty 1982). However, an investigation involving similar tillage equipment found that earthworm abundance was similar in crops established by tine cultivation and ploughing compared to direct drilling (Barnes & Ellis 1979). It has been observed for macro-arthropods, such as beetles and spiders, that larger individuals are more susceptible to increased tillage intensity (Kladivko 2001, Baguette & Hance 1997).

Many factors can influence the presence and the abundance of invertebrates on agricultural land. Although the effects of insecticides and herbicides on invertebrates have been well documented (Aebischer 1990, Campbell *et al.* 1997, Moreby & Southway 1999, Tarrant *et al.* 1997), several studies have identified the need to separate the effects of pesticides from associated tillage practices (e.g. Carcamo *et al.* 1995). It is important to view different crop establishment methods as whole systems from seedbed preparation, drilling and the protection of the crop until harvest. The different tillage methods may themselves have different direct and indirect effects on invertebrates, such as causing mortalities and changing habitats, respectively. They may also lead to the crops being managed in different ways, which may also have implications for the invertebrates and weed populations.

The following studies report various effects of tillage on invertebrate abundance and diversity. Increased abundance of invertebrates as a food source for farmland birds does not necessarily equate to increased availability. Further work is required to ascertain the impact of, for example, surface crop residue on the accessibility of invertebrate and seed food on arable land. However, it is important to appreciate each individual component, such as food abundance and availability, and then how these interact (Butler & Gillings 2004). It should be borne in mind that these studies have been carried out in a variety of crops and in some cases, using a variety of sampling methods (see Table 1.2, Table 1.3, and Table 1.4).

1.4.1 The effect of NIT on carabid beetles.

Ground beetles (Coleoptera: Carabidae) are an important part of the diet of farmland birds (Wilson *et al.* 1996a). There have been very few studies in Europe investigating the effects of reduced or non-inversion tillage on beetles.

Many of the studies examining the effect of cultivation on carabid beetles have been carried out in North America, comparing no-till systems with conventionally ploughed fields (Barney & Pass 1986, Blumberg & Crossley 1983, Brust *et al.* 1985, Clark *et al.* 1993, Tonhasca 1993). Only two studies in North America investigated the effects of NIT; one compared NIT to conventional tillage (Carcamo 1995), the other compared NIT to no-tillage (Clark *et al.* 1993). These North American studies have largely been carried out in maize crops, apart from one investigation in a leguminous crop (Barney & Pass 1986). Studies carried out in Northern Europe have concentrated largely on winter wheat and barley crops, with some inclusion of maize, oats and sugar beet (Andersen 1999, Andersen 2003, Baguette & Hance 1997, Holland & Reynolds 2003).

In terms of overall carabid abundance and, in some instances diversity, conflicting results have been reported (Table 1.2). Some studies have shown no differences between no-tillage and conventional tillage (Barney & Pass 1986, Tonhasca 1993), whilst others observed positive effects of no-tillage (Andersen 1999, Blumberg & Crossley 1983, Brust *et al.* 1985) or conventional tillage (Carcamo 1995, Baguette & Hance 1997). The response to tillage at the species level was mixed in several cases (Carcamo 1995, Clark *et al.* 1993, Tonhasca 1993). Different sizes of carabids appeared to respond in different ways to tillage. Species such as *Pterostichus melanarius*, with a body size ranging from 12-18 mm, were more abundant in conventionally ploughed plots (Baguette & Hance 1997). Smaller beetles, such as *Bembidion* species, were found more in plots with reduced ploughing, for certain crops (Baguette & Hance 1997). This has implications when considering carabid beetles as a food source for farmland birds, as size and temporal activity (i.e. nocturnal/diurnal and spring/autumn breeders) will influence food quality and availability.

Many studies have used pitfall trapping to assess arthropod abundance, but there are limitations with this method (e.g. Clark *et al.* 1993, Tonhasca 1993). Pitfall traps measure activity-density as opposed to true density and numbers of arthropods trapped can be affected by factors such as vegetation density (Thomas *et al.* 1998, Adis 1979). This may explain positive results for conventional compared to no-tillage or non-inversion tillage, as there is likely to be less vegetation or surface trash in conventional crops, which would enable greater movement of arthropods. Additionally, experimental designs and unsuitable sampling methods have been suggested as an explanation of the conflicting results (Holland & Reynolds 2003).

1.4.2 The effect of NIT on rove beetles.

The few studies that have investigated the effects of tillage on rove beetles (Coleoptera: Staphylinidae) have produced mixed results (Table 1.2). When NIT and ploughed arable fields have been compared, NIT fields have been shown to have a greater abundance of staphylinids (Andersen 1999) or no effect of tillage has been observed (Andersen 2003, Holland & Reynolds 2003).

1.4.3 The effect of NIT on spiders.

Spiders (Arachnida: Araneae) are an important food source for declining farmland bird species (Wilson *et al.* 1996a). Very few studies have compared the effects of non-inversion and conventional tillage on spiders. From the studies available, it appears that spider populations can be enhanced by the increased structural complexity provided by the residue from the previous crop (Table 1.3). Indeed, a positive relationship has been observed between the abundance of generalist predators, including spiders, and the ground cover in reduced tillage systems (Clark *et al.* 1993). In contrast, twice as many of the surface-active wolf spiders, *Pardosa milvina*, were observed in conventionally-tilled plots than conservation-tilled plots in the USA (Marshall *et al.* 2000).

1.4.4 The effect of NIT on earthworms

As previously discussed, earthworms (Annelida) are an important food source for several declining farmland birds, such as Song Thrushes *Turdus philomelos* and Lapwings *Vanellus vanellus* (Gruar *et al.* 2003, Wilson *et al.* 1996a). Cultivation, such as mouldboard ploughing, can affect earthworms either directly by causing fatalities or indirectly by changing their habitat or exposing them to predation (Edwards 1977). A higher abundance of earthworms was observed in no-till fields compared to NIT methods (Jordan *et al.* 1997). A number of studies have observed greater earthworm abundance in fields that have been established by direct drill or no-till compared to ploughing, particularly in the upper 10 cm of the soil (Table 1.4, Clapperton 1999, Edwards 1975). Other studies have compared conventional ploughing with NIT methods, many of which have involved the use of a chisel plough (Edwards & Lofty 1982, Nuutinen 1992). The chisel plough can be described as a non-inversion tillage method as it does not invert the soil, although it does disturb the soil to greater depths than other NIT equipment such as disks and tines. Edwards & Lofty (1982) found a greater abundance of earthworms after chisel ploughing than mouldboard ploughing in the UK. Surprisingly, the deeper-burrowing species such as *Lumbricus terrestris* showed the most marked differences between tillage treatments. In Scandinavia, various forms of NIT (referred to as 'ploughless tillage') generally lead to increases of earthworm abundance and biomass, although not all species respond in the same way (Rasmussen 1999). Again, a greater abundance and biomass of earthworms has been recorded in fields established by NIT compared to conventional tillage in the UK, but only after these treatments had been applied for three years (Hutcheon *et al.* 2001). Similar positive effects were seen in a Finnish study, again particularly with *L. terrestris* (Nuutinen 1992). This study also found that soil type affected the responses to tillage. This means that the effects of tillage on farmland bird food resources, such as earthworms, may differ across the UK. The study by Hutcheon *et al.* (2001) showed that differences in earthworm abundance were only observed after three years of the tillage treatments within an integrated farming system. This implies that the benefits of NIT practices for earthworms may take several years to accrue, although increases in abundance were observed after the first and second years in other studies (e.g. Edwards & Lofty 1982).

Table 1.2. European studies investigating the effect of tillage on beetles

Effect of tillage*	Country	Crop	Experimental design	Sampling method	Tillage	Reference
+ Generally more carabids & staphylinids in reduced tillage.	Norway	Spring barley, oats and spring wheat	Plots	Pitfall traps	Reduced tillage (no-tillage or spring harrowing) vs. Ploughing (autumn)	Andersen 1999
Mixed response: Ploughing increase abundance of dominant carabid species. Species richness dependant on crop type. Less abundant species increased abundance in reduced tillage or no till	Belgium	Maize, sugar beet, winter wheat & barley	Plots (40x20m)	Pitfall traps	Ploughing vs. Light ploughing vs. No ploughing	Baguette & Hance 1997
+ Total number of carabids lower in ploughed plots compared to undisturbed plots	UK (England)	Wheat stubble or undersown grass leys	Plots (15x3m; 20x3m)	Emergence traps	Winter ploughing vs. Spring ploughing vs. No ploughing	Holland & Reynolds 2003
Species specific results. + carabids: generally more in reduced tillage staphylinids: no differences	Norway	Spring barley, oats and spring wheat	Plots	Pitfall traps	Reduced tillage (no-tillage or spring harrowing) vs. Ploughing (autumn)	Andersen 2003
Mixed response: species specific responses of carabids and staphylinids to tillage	UK (England)	Winter cereal	Plots (50-30x12m)	Pitfall traps	NIT (Dutzi cultivator or Tine disk cultivator) vs. Plough	Kendall *et al.* 1995
Larval over-wintering populations of carabids are effected by ploughing. Autumn-breeding carabids are more likely to be effected by cultivation.	Ireland	Spring & winter barley, winter barley, beet, grass ley & maize	3 Fields	Pitfall traps	Spring & autumn cultivation	Purvis & Fadl 2002

*Effect of tillage: '+' = a positive effect of reduced tillage or NIT on beetles.

Table 1.3. European studies investigating the effect of tillage on spiders

Effect of tillage	Country	Crop	Experimental design	Sampling method	Tillage	Reference
+ Total number of Spiders lower in ploughed plots compared to undisturbed plots	UK (England)	Wheat stubble or undersown grass leys	Plots (15x3m; 20x3m)	Emergence traps	Winter ploughing vs. Spring ploughing vs. No ploughing	Holland & Reynolds 2003
Autumn ploughing reduced a spider population in one field by 89%	UK (England)	Cereal & grass	Fields	D-vac (suction) & water traps	Ploughing	Thomas & Jepson 1997
Mixed response, but no significant effects	UK (England)	Winter cereal	Plots (50-30x12m)	Pitfall traps	NIT (Dutzi cultivator or Tine disk cultivator) vs. Plough	Kendall *et al.* 1995

*Effect of tillage: '+' = a positive effect of reduced tillage or NIT on spiders.

Table 1.4. European studies investigating the effect of tillage on earthworms

Effect of Tillage*	Country	Crop	Experimental design	Sampling method	Tillage	Reference
+ 2-5 times more *L. terrestris*	UK (England)	Winter wheat	Small plots (6.4x18m)	-	Direct drill and plough No-till vs. Plough	Edwards 1975
+ 17.5 and 37.3 times greater abundance in direct drill	UK (England)	Winter wheat	Small plots (6.4x18m and 33x13.5m) And whole fields	Formalin method	Deep plough, chisel plough and direct drill NIT (chisel plough) vs. Plough	Edwards & Lofty 1982
+ 2.6 times higher in chisel than plough in autumn cultivations	Finland	Spring cereals	Small plots (4x15m)	Formalin method & cast counting	Mouldboard plough NIT (chisel plough) vs. Plough	Nuutinen 1992
+ Abundance & biomass greater NIT than ploughed plots (biomass 36% higher)	UK (England)	Mainly winter cereals, e.g. wheat	25-30 1-ha plots	Formalin method	Dutzi cultivator/ Direct drill/ Vaderstad cultivator and cultivator NIT vs. Plough	Hutcheons *et al.* 2001
+ 6 times greater on NIT plots	Germany	Undersown cereal/ catch crop	6 paired plots (0.5 ha)	Formalin method	Broadshare cultivator and mouldboard plough	El Titi & Ipach 1989
+ Total abundance of worms greater on DD than ploughed. Tine cultivation similar to plough. No significant differences for any species.	UK (England)	Cereals – spring barley and winter wheat	Small plots	Formalin method & Soil cores	Direct drill (i.e. no-till), tine cultivation and Ploughed	Barnes & Ellis 1979
+ Abundance & fresh biomass higher in NIT	Germany	Cereal rotation (green fallow, winter wheat with intercrop, peas, winter rye with intercrop & summer barley)	Small plots (12x100m)	Hand-sorted cores ($25m^2$x30cm) followed by mustard extraction	Ploughing, layer cultivation (deep NIT) and 2-layer (deep NIT & shallow MBP) ploughing	Emmerling 2001

Table 1.4 (cont.) European studies investigating the effect of tillage on earthworms

Effect of Tillage*	Country	Crop	Experimental design	Sampling method	Tillage	Reference
No significant differences in abundance & biomass. But more anaeic species in NIT, and more endogeic species in ploughed.	Switzerland	Spring maize	Small plots (0.75ha divided into four 14m strips)	Hand-sorted cores ($0.1m^3$: 0.5x0.5x0.4m)	Direct drill vs. Rotary plough	Wyss & Gasstetter 1992
Rotary cultivation killed 61-68% of worms	Sweden	Ley pasture (grassland) and Barley after pasture	Small plot (40x14m)	Formalin method	Rotary cultivation vs. Uncultivated pasture	Bostrum 1995
+ 50-100% increases in no-till than ploughed plots	UK (Scotland)	Continuous barley	Small pots (2ha site with 16 plots)	Formalin method	Deep (30cm) and normal (20cm) ploughing, tine cultivation (3 passes of 20cm) and no tillage	Gerard & Hay 1979
+ Abundance 2.82 times greater in direct drill, and biomass is 3.81 times greater	Ireland	Continuous winter wheat – undersown with white clover and a monoculture	Farm-scale field plots	Formalin and electrical extraction methods	Direct-drill vs. Ploughing (NB. Direct-drilled into clover)	Schmidt *et al.* 2001
50% losses of earthworm numbers by cultivation, and increases in populations from arable to permanent fallow	Germany	Abandoned arable land	Whole fields	Formalin method	-	Westwernacher-Dotzler 1992
+ On average, density double and biomass treble in direct drilled plots. E.g. abundance of *L. rubellus* increased 66 times.	Denmark	Cereals – winter wheat, barley, rye, oats and rape.	Plots	Electrical and soil cores	Direct-drilled vs. Ploughed	Andersen 1987

*Effect of tillage: '+' = a positive effect of reduced tillage or NIT on earthworms.

1.5 Impact of NIT on seed food resources for farmland birds

There has been a relatively large amount of research carried out on the effects of different types of tillage on seed banks and weed dynamics. This has implications for farmland birds, as the management and control of weeds is carried out in part by chemical herbicides and the indirect effect of pesticides on birds has been well documented (Campbell *et al.* 1997, Morris *et al.* 2002). Here, the research investigating the effect of tillage on the abundance of seeds on or near the soil surface is discussed, as this will have the most relevance to birds.

Generally, conventional tillage buries seeds to depths greater than 10 cm below the soil surface, regardless of whether they are on the soil surface or buried prior to the cultivation (Marshall & Brain 1999). In contrast, cultivation involving NIT equipment, such as tines and harrows, leave seeds in the upper 5 cm of the soil (Marshall & Brain 1999). As well as having implications for weed emergence, this means that seeds are more available as a food source for short-billed farmland birds (Robinson & Sutherland 1999). Several authors have studied the abundance of seeds at the surface of stubble fields by removing the surface layer of soil from a defined area (Robinson & Sutherland 1999, Moorcroft *et al.* 2002).

1.5.1 Movement of seeds by cultivation

Several studies have investigated the effects of different cultivation methods on the movement of seeds (Colbach *et al.* 2000, Rew & Cussans 1997, Marshall & Brain 1999). As cultivation methods have changed over recent years, research is needed to ascertain how these new methods, with generally less passes over a field, affect the seeds at the soil surface where they are available to birds.

1.6 Birds and NIT

There are many factors that can affect where birds forage over the winter or where they select a nest site in the summer. These include field size and enclosure, field boundary presence and type, and crop type. Some studies have investigated how the crop establishment methods have additionally affected farmland birds. The majority of studies have been carried out in North America, as this is where NIT has been the most widespread and common practice used to establish crops. The studies are largely performed in the summer where the abundance of breeding populations and breeding success has been assessed.

Ground nesting birds have been observed at higher densities in no-till and NIT fields than ploughed fields in North America (Basore *et al.* 1986, Lokemoen & Beiser 1997, Martin & Forsyth 2003). Fields established by NIT also had a greater diversity of birds in the summer, although this was not the case in the autumn, winter or spring (Flickinger & Pendleton 1994). In addition to providing more favourable conditions for nesting, establishing crops using non-inversion tillage systems may enhance food resources for birds. Granivorous passerines such as Yellowhammers *Emberiza citrinella* are dependent on seeds (Wilson *et al.* 1999). In winter, such species may benefit from lack of burial of spilt grain and weed seeds produced in the previous crop. Soil dwelling and surface-active invertebrates such as earthworms, beetles and spiders may potentially benefit from NIT, as the detrimental effects of ploughing on these invertebrates has been well documented (Edwards & Lofty 1982, Ferguson & McPherson 1985, Barker *et al.* 1999). In winter, several bird groups, such as thrushes Turdidae and Lapwings *Vanellus vanellus*, may be able to take advantage of provision of such food resources. A study in Texas (USA) showed that several bird species benefited from minimum tillage in winter, though preferences by individual species were influenced by the impact on that species of enhanced vegetative cover under minimum tillage regimes (Flickinger & Pendleton 1994). The effect of cover on each species depends on how the benefit of cover from predators trades-off against the increased difficulty in finding and accessing food resources in denser swards (Butler & Gillings 2004).

Non-inversion tillage fields may act as an ecological trap, in which birds are attracted to these fields to nest and then the mechanical weeding destroys the nests (Best 1986). However, this type of weed control is not common in Europe, as highlighted by Holland (2004), and is less likely to be a threat to nests. Duebbert & Kantrud (1987) have observed that although the nesting density of dabbling ducks, such as Blue-Winged Teal *Anas discors* and Northern Pintail *Anas acuta,* is quite low on direct-drill winter wheat fields, i.e. 7 per 100 ha, the hatch rate was sufficient to sustain the population.

In Europe, comparatively little work has been carried out to evaluate the effects of NIT on farmland biodiversity (e.g. Kromp 1999, Streit *et al.* 2002). It is important for studies to be undertaken to ascertain the effects of non-inversion tillage in the UK and Europe for several reasons. The most obvious reasons are the different species of birds, insects and plants, but also the different types of crops grown across the USA are not always representative of those grown in the UK and Europe. Due to different climate, soils and crops, the machinery used to establish crops can differ to that found in Europe. For these reasons it is important to carry out research in Europe and the UK, so a true reflection of the impact of tillage practices on birds and their food sources can be determined.

1.7 Research on NIT and farmland birds

Crop establishment by NIT has the potential to increase in area in the UK and elsewhere in Europe, by virtue of its economic and wider environmental benefits. Some evidence suggests that it may also be beneficial to the farmland bird food chain, but more research is needed to determine the generality of this conclusion across different climates, soil types and crops. The ecology of birds and their invertebrate and plant food resources in agro-ecosystems have been well studied. There have been no studies on the effect of crop establishment methods on farmland birds in the UK and very few in Europe. There have been some studies on the effects of crop establishment methods on, for example, earthworms and arthropods (Hutcheon *et al.* 2001, Holland & Reynolds 2003). However, these studies have not compared conventional tillage, i.e. ploughing, with the non-inversion tillage methods that are widely used in commercial situations in the UK at present. Further work is required to assess the impacts of NIT on other groups of fauna and flora that have been identified as important in agro-ecosystems and in the diet of declining farmland bird species.

1.8 Thesis aims and structure

1.8.1 Aims

The aim of this thesis is to quantify the effect of non-inversion tillage, as a method of establishing a cereal crop, on:

- Invertebrate abundance, focusing on earthworms and surface-active arthropods.
- Grain and weed seed abundance at the soil surface.
- The intensity of use of the fields by foraging birds.

1.8.2 Hypothesis

Non-inversion tillage at crop establishment results in improved invertebrate and seed food abundance and greater use by farmland birds.

1.8.3 Structure

This thesis is structured so that each chapter can be read in isolation. The thesis starts with a general introduction providing a review of the literature with a strong reference to the research on the effects NIT, followed by thesis aims and structure. The following chapters examine the effects of non-inversion tillage on: birds in winter (Chapter 2), earthworms (Chapter 3), surface seeds (Chapter 4), and surface-active arthropods (Chapter 5). Chapter 6 examines how cereal and weed seeds are moved by different crop establishment cultivations to enable a greater understanding of the results found in Chapter 4. Each chapter starts with a summary that outlines the main points and concludes with a series of bullet points. Chapter 7 is a discussion of the main findings from each chapter. All references are located towards the end of the thesis to avoid repetition of the key references. Appendices 1-3 contain detailed information about the fields involved in the investigations. Appendix 4 describes the statistics used with a worked example.

Appendices 9-11 presents papers that have been published or are in press from the work carried out in this thesis. Appendix 9 contains Cunningham *et al.* (2005) 'The effect of non-inversion tillage on the field usage of UK farmland birds in winter', Bird Study, 52. Appendix 10 contains Cunningham *et al.* (2004) 'Non-inversion tillage and farmland birds: a review with special reference to the UK and Europe', IBIS, 146, (Suppl. 2), 192-202. This was presented as a platform presentation at the Lowland Farmland Bird Conference, Leicestershire, on 28th March 2004. Appendix 11 contains Cunningham *et al.* (2002) 'The effect of non-inversion tillage on earthworm and arthropod populations as potential food sources for farmland birds', Aspects of Applied Biology, 67. This was presented as a poster presentation at the AAB Farmland Bird Conference in Edinburgh in March 2002.

Chapter 2

THE EFFECT OF NON-INVERSION TILLAGE ON FIELD USAGE BY FARMLAND BIRDS IN WINTER

2.1 Summary

Several guilds of wintering farmland birds showed preferences for cereal fields prepared by non-inversion tillage, rather than ploughing. The aims of this chapter are to compare the effects of cereal crop establishment methods using non-inversion tillage and ploughing on field use by wintering farmland birds. Cereal fields on commercial farms, established by non-inversion tillage or conventional ploughing, were censused for birds over the winter months of 2000 to 2003, using standard whole field count methodologies. Multivariate logistic regression methods were used to assess the difference in bird use between fields with the two crop establishment methods, whilst controlling for the effects of a variety of other variables. In late winter, Skylarks, granivorous passerines and game birds occupied a greater proportion of fields established by non-inversion tillage than conventional tillage. In addition to documented benefits for resource protection such as soil and water conservation, non-inversion tillage methods appear to enhance the suitability of winter cereal fields for foraging birds.

2.2 Introduction

The population and range of many farmland birds have shown substantial declines in the UK over the past few decades (Fuller *et al.* 1995, Siriwardena *et al.* 1998a, Gregory *et al.* 2003). Many of these species, including Skylark *Alauda arvensis*, Song Thrush *Turdus philomelos*, Linnet *Carduelis cannabina*, Yellowhammer *Emberiza citrinella* and Grey Partridge *Perdix perdix*, are now on the UK Red List of species of conservation concern (Gregory *et al.* 2002). A large body of evidence now links many of these declines to aspects of agricultural intensification (Aebischer *et al.* 2000, Anderson *et al.* 2001, Boatman *et al.* 2002, Newton 2004) and, across Europe, the extent of national population decline is correlated with various indices of intensification of agricultural production (Donald *et al.* 2001b). These declines are of so much concern in the UK that a wildlife 'indicator' based on the population trends of farmland birds is now used as a 'headline' indicator of the sustainability of UK lifestyles (Gregory *et al.* 2003).

Many farmland bird species rely on seeds as food in winter and, for many granivorous species, reduced survival seems to be the current most limiting demographic rate (Siriwardina *et al.* 1998b, 1999, Peach *et al.* 1999). Possible reasons for changes in survival include lack of winter seed food, caused by increased pesticide use, improved harvesting efficiency, bird-proofing of food stores, and the loss of winter stubbles with the switch from spring to autumn sowing of cereals. Consequently, granivorous birds show pronounced aggregative responses to stubbles (Wilson *et al.* 1996), set aside (Buckingham *et al.* 1999), game feeders (Brickle & Harper 2000) and game cover crops (Stoate *et al.* 2003). Provision of such habitats is now a key measure in UK agri-environment schemes (Evans *et al.* 2002, Bradbury & Allen 2003), and has delivered population recovery of the English Cirl Bunting *Emberiza cirlus* population (Peach *et al.* 2001).

Against this background, non-inversion tillage (NIT) is potentially another means of enhancing winter food for farmland birds. This is a method of preparing a seedbed to establish a crop from the stubble of the previous crop. NIT is a broad term that encompasses different methods that use a combination of tines, discs and harrows, rather than the conventional mouldboard plough. While the plough inverts the soil to depths of approximately 20-25cm, NIT methods disturb the soil to shallower depths of typically 10-15cm. NIT is also referred to as reduced tillage, no-till, ECOtillage, minimum tillage (min till) and conservation tillage; the latter being a term often used in North America (Stride & Wright 1997).

While a ploughing system relies on burial of weeds and seeds for weed control, NIT systems rely on the use of herbicides to control weeds that emerge from the post-harvest stubble. From an agronomic perspective, the adoption of NIT may lead to a greater susceptibility to grass weeds, although modern and more refined chemical weed control methods can be used to keep this problem to a minimum (Stride & Wright 1997). This method is gaining popularity due primarily to the reduced cost of crop establishment. If implemented successfully, NIT can reduce mineralisation and leaching of soil nitrogen, overall herbicide needs and the risk of soil erosion. Significant savings in terms of labour, fuel and time can be made with NIT when compared to conventional mouldboard ploughing (Sijtsma *et al.* 1998, Ball 1989) without incurring losses in yield, at least on some soil types (Chaney *et al.* 1985). The retention of vegetative cover with NIT also provides soil and water conservation benefits. It is therefore likely that NIT will become a more widespread practice in Europe, independent of any need for additional financial incentive for helping biodiversity (e.g. Birkas *et al.* 1989). Given additional potential to enhance soil and water conservation, it may well prove to be a useful tool for countries about to join the European Union, to produce competitively priced crops whilst minimising environmental impact (Donald *et al.* 2002).

Ground nesting birds have been observed at higher densities in no-till and NIT fields than ploughed fields in North America (Basore *et al.* 1986, Flickinger & Pendleton 1994, Lokemoen & Beiser 1997, Martin & Forsyth 2003). In addition to providing more favourable conditions for nesting, establishing crops using non-inversion tillage systems may enhance food resources for birds. Granivorous passerines such as Yellowhammers *Emberiza citrinella* are dependent on seeds (Wilson *et al.* 1999). In winter, such species may benefit from lack of burial of spilt grain and weed seeds produced in the previous crop. Soil dwelling and surface-active invertebrates such as earthworms, beetles and spiders may potentially benefit from NIT, as the detrimental effects of ploughing on these invertebrates has been well documented (Edwards & Lofty 1982, Ferguson & McPherson 1985, Barker *et al.* 1999). In winter, several bird groups, such as thrushes and Lapwings *Vanellus* vanellus, may be able to take advantage of provision of such food resources. A study in Texas showed that several bird species benefited from minimum tillage in winter, though preferences by individual species were influenced by the impact on that species of enhanced vegetative cover under minimum tillage regimes (Flickinger & Pendleton 1994). The effect of cover on each species depends on how the benefit of cover from predators trades-off against the increased difficulty in finding and accessing food resources in denser swards.

In Europe, comparatively little work has been carried out to evaluate the effects of NIT on farmland biodiversity (e.g. Kromp 1999, Streit *et al.* 2002).

2.2.1 Aim of this chapter

The aim of this chapter is to investigate the field usage of birds on winter wheat and barley fields established by non-inversion tillage and conventional ploughing.

2.3 Methods

2.3.1 Study area

Winter wheat and barley fields established by either NIT or conventional tillage (CT) were censused for birds on commercial farms in Oxfordshire, Leicestershire and Shropshire, UK. Censuses took place once a month between October and March, in three consecutive cropping years from 2000 to 2003. The latter two counties were censused in all three years, but Oxfordshire was only censused in winter 2000/1, due to logistical constraints. In each year of the study between seven and nine farms were visited. Cereals were followed in the crop rotation (i.e. only winter wheat and barley fields were surveyed), so the same fields were not censused in all years. In all, 121 different fields were censused at least once. Previous crop types included winter wheat, winter barley, oilseed rape, peas, beans, maize, carrots, grass, oats, and set aside (Table 2.1). Certain previous crop types were only represented in one county, such as barley and carrots in Shropshire, where as oilseed rape and set aside were represented in all three counties (Figure 2.1). Field area refers to the area of crop within the field, excluding field boundaries and margins, and ranged from 1.63 to 22.27 hectares. Detailed information on the fields used in this investigation can be found in appendices 1-3.

Table 2.1. Variables used in the analyses of variation in field occupancy.

Variable	Type	Factor levels	n[a]	(NIT, CT)
Field area	Continuous variable			
Tillage	2-Level fixed factor	Non-inversion tillage	63	
		Conventional tillage	58	
Crop type	2-Level fixed factor	Winter wheat	105	(59,46)
		Winter barley	16	(4,12)
Year	3-Level fixed factor	2000/1	20	(10,10)
		2001/2	53	(29,24)
		2002/3	48	(24,24)
Previous crop	5-Level fixed factor	Cereal (Winter wheat, Winter barley, Maize, Oats)	43	(17, 26)
		Oil seed rape	24	(13, 11)
		Set aside	28	(17, 11)
		Legumes & Carrots (Peas, Beans, Carrots)	20	(14, 6)
		Grass	6	(2, 4)
Farm	9-Level random effect			

[a] n = Number of fields relating to a given factor.

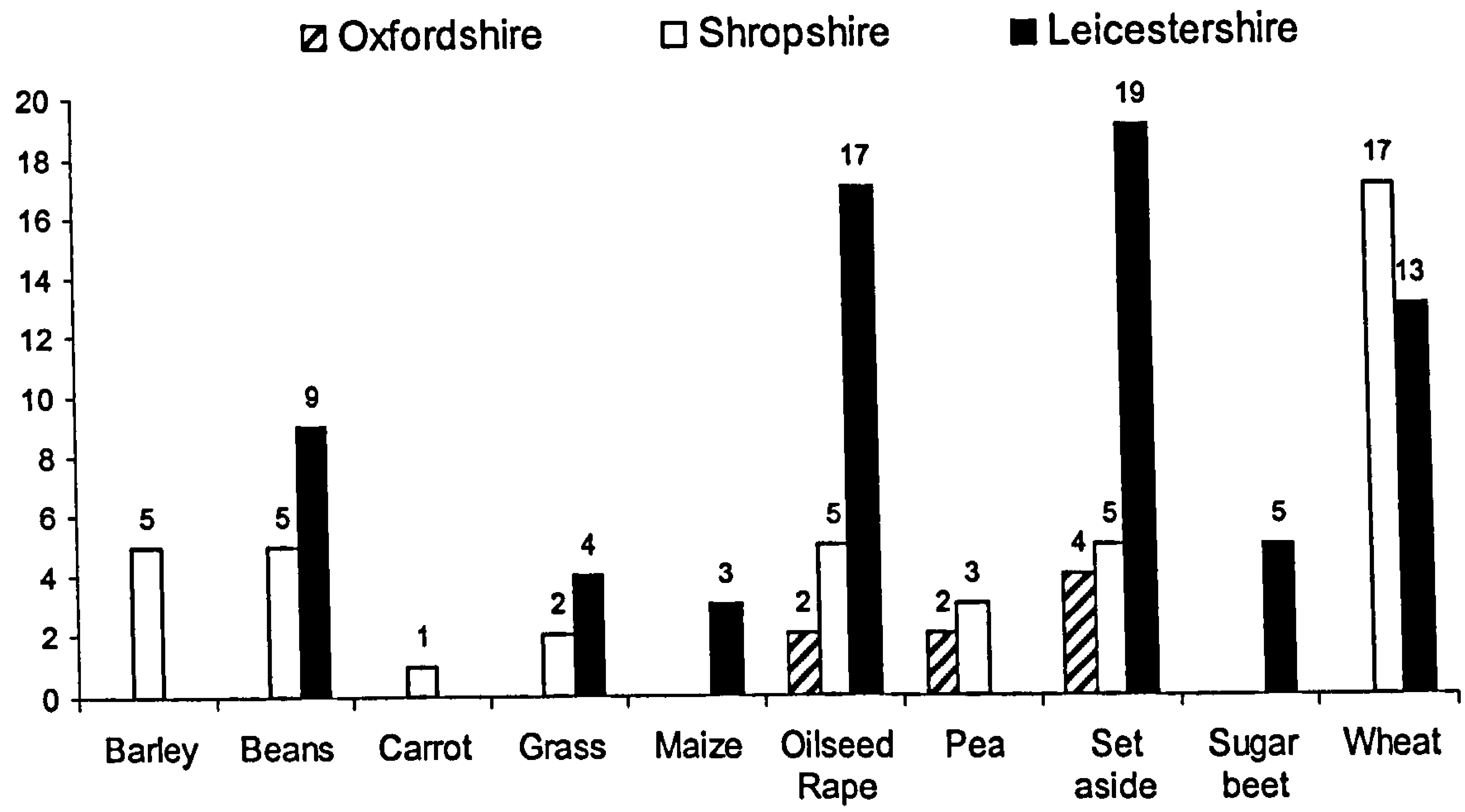

Figure 2.1. Summary of previous crop types in each county.

2.3.2 Survey method

Birds were censused using binoculars by walking the cropped area of fields using straight line transects 50m apart, in order to flush all the birds present (Perkins *et al.* 2000). All birds flushed were identified to species and counted. Birds simply seen flying over fields were not counted. Double counting of birds was minimised by the observer taking into account birds that were flushed to other fields or to other parts of the field being censused. In practise most birds that left the observation field simply moved to the neighbouring field, so it was relatively easy to account for them when counting that field. However, a small amount of double counting is probably inherent in the data. Despite this small drawback, we considered this a better method than counting from the field edge, without flushing, which in our experience can fail to detect many birds. To ensure that birds travelling to and from their night roosts were not counted, censuses were not performed in the hour after sunrise and the hour before sunset. Approximately half the bird surveys were carried out in the morning (47%) and half in the afternoon (52%). The surveys were fairly evenly distributed between the mornings and afternoons for the non-inversion tillage fields (29% AM, 26% PM) and the conventional tillage fields (18% AM, 26% PM). Censuses were not performed on days with strong wind or heavy rain, as this may have affected bird behaviour (Bibby *et al.* 1992).

2.3.3 Statistical analysis

The bird counts were grouped into eight response variables; species richness, Skylarks, game birds, insectivores, granivorous passerines, corvids and pigeons. Composition of the groups is given in Table 2.2. Although they could fit into the granivorous passerines grouping, Skylarks were considered separately because of their ability (not shared with other granivorous passerines) to eat growing shoots of crops (Green 1978).

Table 2.2. Bird groups used in analyses.

Group	Bird species included in group
Skylarks	Skylarks (*Alauda arvensis*)
Game birds	Grey Partridge (*Perdix perdix*), Red-legged Partridge (*Alectoris rufa*), Pheasant (*Phasianus colchicus*).
Insectivores	Blackbird (*Turdus merula*), Fieldfare (*Turdus pilaris*), Lapwing (*Vanellus vanellus*), Meadow Pipit (*Anthus pratensis*), Mistle Thrush (*Turdus viscivorus*), Pied Wagtail (*Motacilla alba*), Redwing (*Turdus iliacus*), Robin (*Erithacus rubecula*), Starling (*Sturnus vulgaris*).
Granivorous passerines	Chaffinch (*Fringilla coelebs*), Goldfinch (*Carduelis carduelis*), Greenfinch (*Carduelis chloris*), Linnet (*Carduelis cannabina*), Yellowhammer (*Emberiza citrinella*).
Corvids	Carrion Crow (*Corvus corone*), Rook (*Corvus frugilegus*), Magpies (*Pica pica*), Jays (*Garrulus glandarius*).
Pigeons	*Columba* species.

The bird counts were collated for two periods over the winter for each year; these were the early (October to December) and late (January to March) winter periods. Splitting the data into these two periods allowed any differences between CT and NIT to be assessed at different stages of crop development, at periods sooner and later after crops were established by the two tillage methods and after depletion or replenishment of food resources may have occurred.

Analyses were performed using generalised linear mixed models (Genstat 4.2 5th Eds. L.A.T. 2000). Field usage was analysed, with presence or absence of each guild in each field at any point during the time period as a response variable, using general logistic regression. Analysis of field occupancy, rather than counts, helps to eliminate potential problems of non-independence of individuals within a flock. A binomial error and logit link function were specified, controlling for over-dispersion.

The effect of tillage (a two-level fixed factor) on field occupancy was tested whilst controlling for significant effects of the following factors: year (a three-level fixed factor), crop type (a two-level fixed factor), previous crop type (a five-level fixed factor), and farm identity (random effect). Minimum Adequate Models were reached by step-down model simplification. The natural log of field size was defined as an offset to control for the probability of encountering birds more often by chance in bigger fields. Due to problems with lack of convergence of the multivariate model, the late winter game bird analysis was run as a univarate test (i.e. the model was run with tillage as the only explanatory variable). Significance testing was achieved by calculating the Wald statistic, and comparing this with the χ^2-distribution ($\alpha = 0.05$). The significance of the tillage factor was tested using $\alpha = 0.05$, whereas the other factors in the model were retained if significant at $\alpha = 0.10$. Further explanation, along with a worked example, of the statistics used in this chapter can be found in Appendix 4.

The total number of each bird group observed in the early and late winter periods, for both non-inversion and conventional tillage fields and in each of the three years can be found in Appendix 5.

2.4 Results

In the early winter period, no differences in field occupancy were observed between NIT and CT, for any of the guilds (Table 2.3, Figure 2.2). In the late winter period, game birds Skylarks and granivorous passerines all occupied a greater proportion of fields established by non-inversion tillage (Table 2.3, Figure 2.3).

Table 2.3. General logistic regression analysis (GLMM) of field occupancy in the early Winter Period (Pre 31st December) and in the late Winter Period (Post 31st December).

	Early Winter Period			Late Winter Period		
Response variable:	Wald statistic	d.f.	P (χ^2)	Wald statistic	d.f.	P (χ^2)
Skylarks	2.59	1	0.107	6.64	1	**0.010**
Game birds	0.16	1	0.685	7.91	1	**0.005**
Insectivores	0.10	1	0.753	0.00	1	0.974
Granivorous Passerines	1.01	1	0.315	4.14	1	**0.042**
Corvids	0.04	1	0.849	0.00	1	0.976
Pigeons	1.52	1	0.218	1.22	1	0.269

Bold = Significantly greater occupancy by birds of NIT fields than CT fields.

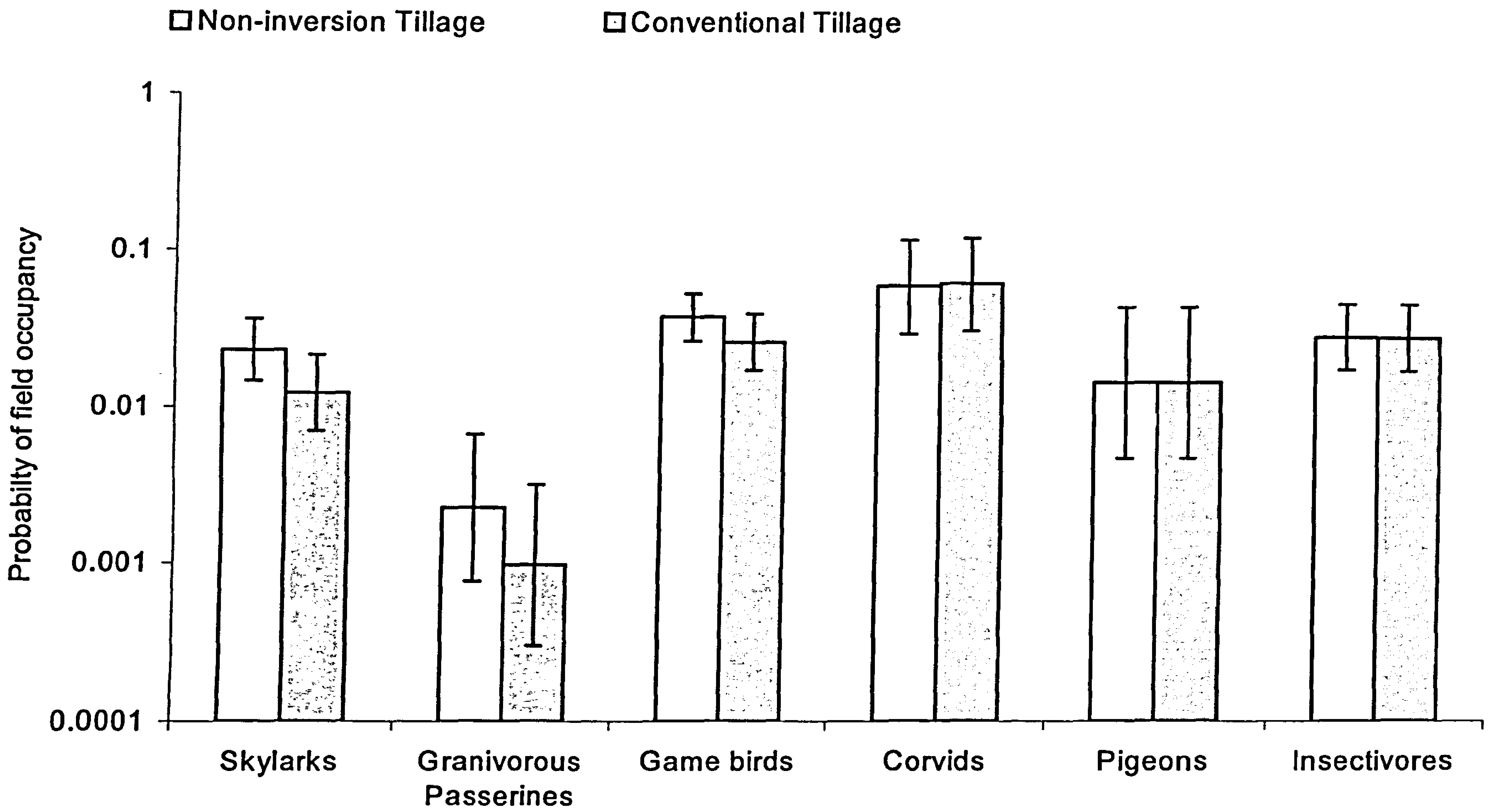

Figure 2.2. Back-transformed probability of occupancy of fields established by non-inversion tillage and conventional tillage in the **early** winter period (October to December). * $P < 0.05$, ** $P < 0.01$. Error bars indicate upper and lower 95% confidence limits.

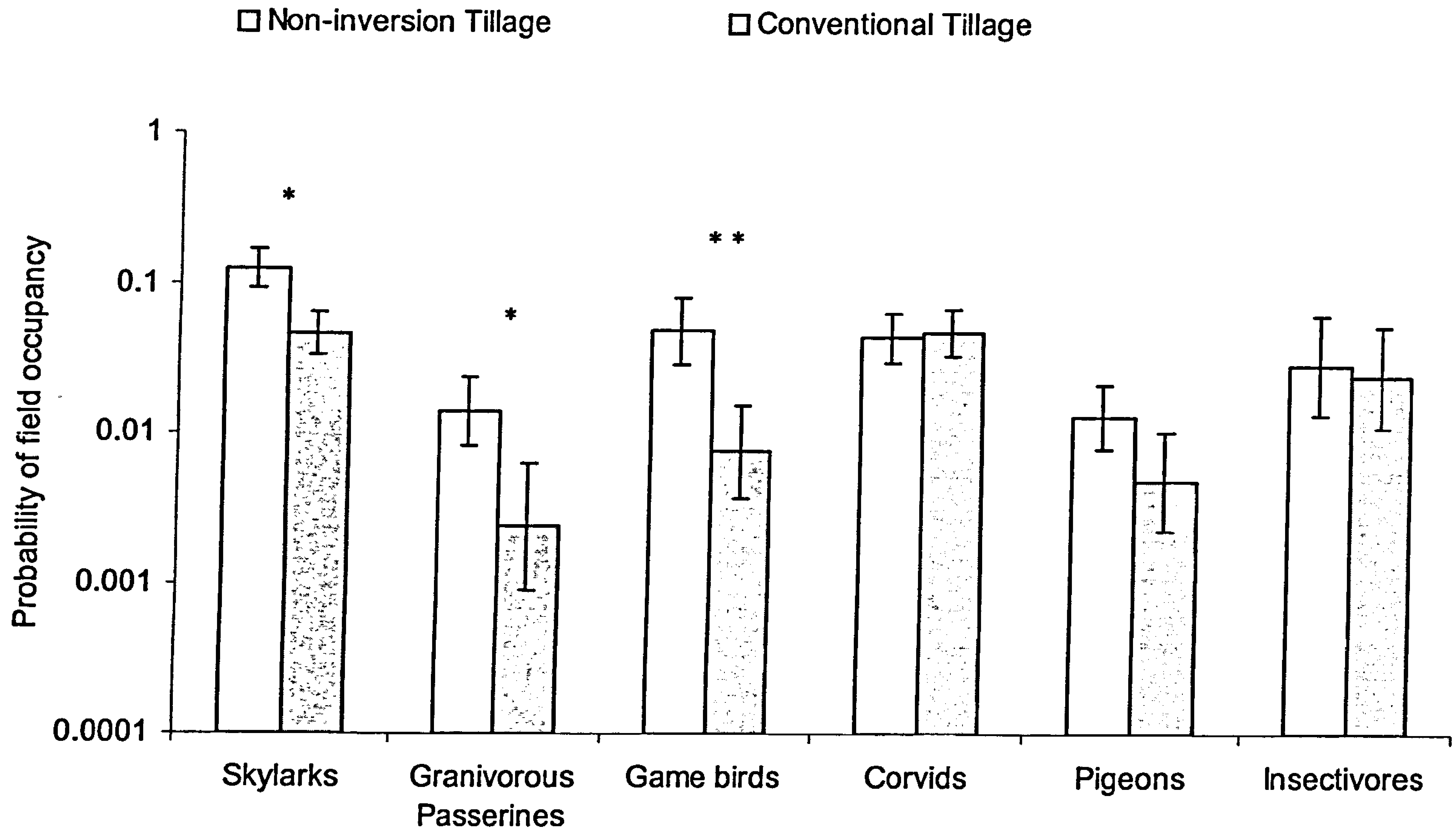

Figure 2.3. Back-transformed probability of occupancy of fields established by non-inversion tillage and conventional tillage in the **late** winter period (January to March). * $P < 0.05$, ** $P < 0.01$. Error bars indicate upper and lower 95% confidence limits.

2.5 Discussion

This study shows several instances of positive responses to NIT, by a range of granivorous birds in late winter. Seeds are an important part of the diet of all these bird taxa in winter (Green 1978, Wilson *et al.* 1999), so these results suggest that NIT may increase the availability of weed seeds for granivorous birds. Seed availability will be determined partly by seed abundance and partly by access to seeds, which itself is largely determined by sward structure (e.g. Perkins *et al.* 2000; Moorcroft *et al.* 2002). It would be interesting to quantify seed abundance at the soil surface in NIT systems, as the lack of ploughing and greater herbicide use may leave more seed available at, or nearer, the surface. However, given that the surface of a NIT field is more complex, because of retained stubble trash, than a ploughed field, it is perhaps likely that access will be more impaired on a NIT field. A study has shown significantly increased intake rates and lower search time for seeds by birds on a bare earth substrate compared with a short grass sward (Whittingham & Markland 2002).

The effects of tillage on field occupancy were much stronger in the late winter period (i.e. from January to March). This suggests that, as food resources become scarcer over the winter, fields established by NIT may retain or encourage a greater abundance of bird food, or at least not become depleted to below thresholds where foraging becomes unproductive. It is possible that, because seedling emergence is strongly related to burial depth (Grundy *et al.* 1996), seedlings may re-establish more quickly on NIT fields, and so replenish seed resources.

As NIT generally disturbs the soil to a more shallow depth than CT, mortality rates of invertebrates may be lower and therefore populations on NIT fields may recover more quickly. Greater amounts of crop residue at the surface may also provide a more suitable microclimate for invertebrates to inhabit and over-winter nearer the soil surface on NIT fields than CT fields. However, insectivorous birds showed no response to NIT. This may be because, due to paucity of data, data for an eclectic group of species was lumped, including species such as Lapwings, Robin *Erithacus rubecula* and Mistle Thrush *Turdus viscivorus*. These birds have a wide range of feeding strategies (some picking at the surface and others probing) and some prefer the field edge and some the field centre. Therefore, their food availability may be affected by tillage in different ways. Alternatively, the types of invertebrates in the diets of these birds may reach such a low level of abundance or availability in winter in this habitat, compared to others, that tillage effects on insectivorous birds are trivial and undetectable. However, it is perhaps surprising that no responses were detectable across groups such as plovers and thrushes, given the strong prediction of enhanced earthworm (e.g. Edwards & Lofty 1982, Clapperton *et al.* 1997, Kladivko *et al.* 1997) and soil-surface arthropod populations (e.g. Stinner & House 1990, Carcamo 1995, Kromp 1999), under NIT regimes.

There are signs that CAP reform will enable agricultural systems in the UK and across Europe to move from intensive crop production towards more sustainable agriculture. In addition to sustaining biodiversity, establishing crops by non-inversion tillage has been shown to have many other resource protection benefits, such as soil conservation, water conservation and carbon sequestration (Triplett & van Doren 1977). Indeed, NIT was developed primarily to solve many issues regarding arable soil degradation, including erosion and the loss of soil structure. This study shows that NIT also seems to have a positive impact on biodiversity, in terms of winter birds, in the UK. This corroborates studies outside Europe, such as the USA and Canada (e.g. Flickinger & Pendleton 1994, Martin & Forsyth 2003). It is therefore encouraging that reduced tillage options have been included, currently primarily for resource protection reasons, in the new pilot Entry-Level agri-environment scheme in England. While wheat and barley cereal crops have been the main focus of this study, it would be important to discover whether these differences are seen across other crops, such as oilseed rape. Further studies should also investigate specifically the effect of different tillage regimes on abundance of, and access to, weed seeds and invertebrates, to identify the mechanisms behind these bird responses.

2.6 Summary

- No differences were seen in field occupancy by birds between NIT and CT fields in the early winter period.
- A greater proportion of NIT fields compared to CT fields were occupied by skylarks, granivorous passerines and game birds in the late winter period.
- It is suggested that the differences observed in field occupancy in the late winter period is due to a greater abundance or availability of food.

Chapter 3

THE EFFECT OF NON-INVERSION TILLAGE ON EARTHWORM POPULATIONS AS POTENTIAL FOOD SOURCES FOR FARMLAND BIRDS

3.1 Summary

Forty wheat fields were surveyed for earthworms over two consecutive cropping years, with twenty fields surveyed per year. Half of the fields were established by non-inversion tillage (NIT) and the other by conventional tillage (CT). Earthworms were surveyed by hand sorting soil cores that had been taken at three distances into the fields – 1 and 8 metres from the crop edge and in the middle of the field. Earthworms were surveyed in the autumn and spring each year. Logistic regression (GLMM) was used to assess the difference in earthworm numbers and weights between NIT and CT field whilst accounting for field variables such as previous crop type and field size. Field identity was defined as a random factor. Earthworm number was defined as having a Poisson distribution with a log link function whereas weight had a normal distribution with an identity link function. Tillage did not explain the variation for either earthworm numbers or weights sampled in autumn or spring. The factor that explained the variation in earthworm numbers and weights in autumn was previous crop type. In spring, factors that explained the variation in earthworm numbers were previous crop type, field size and trap position, whereas the variation in earthworm weights were explained by previous crop type.

3.2 Introduction

3.2.1 Earthworm in agro-ecosystems

Earthworms (Lumbricidae) are an important food source for several farmland bird species, such as Song Thrush *Turdus philomelos* and Lapwing *Vanellus vanellus* (Gruar *et al.* 2003, Wilson *et al.* 1996a). They have an important functional role in many temperate ecosystems as they are decomposers of the crop residue in arable fields (e.g. Tebrugge & During 1999). The factors that effect earthworms have been broadly categorised by Curry (1998) as abiotic factors (i.e. climate, soil, vegetation and litter supply, and management) and biotic interactions (i.e. competition, predation, parasitism and disease, and food relations) (Figure 3.1).

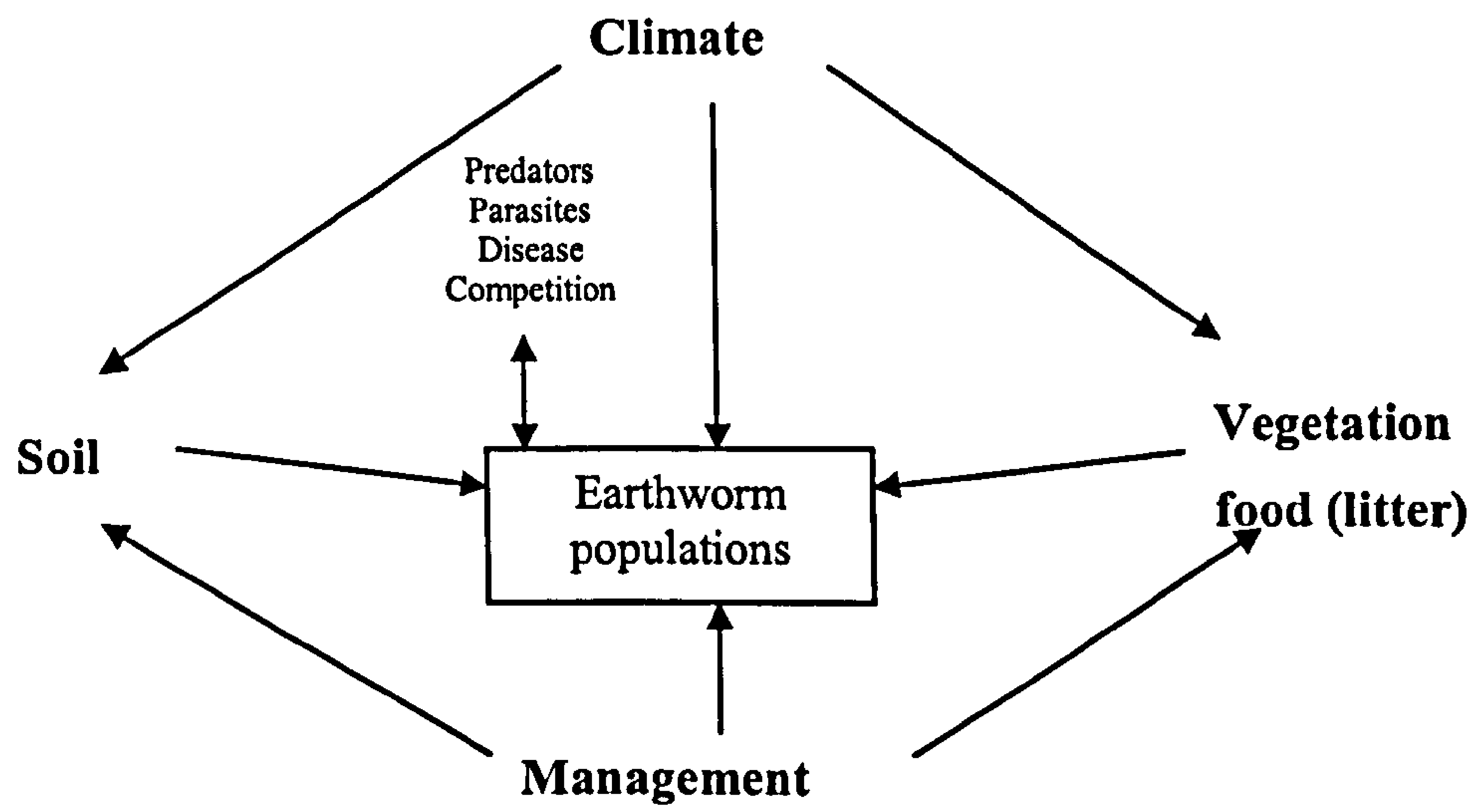

Figure 3.1. Schematic diagram of factors affecting earthworm populations (Re-drawn from Curry 1998).

Earthworm populations can be limited by the availability of food and their most important food source is surface organic matter (Curry 1998). Therefore in agro-ecosystems, the source of the litter will be from dead weed plants and the stubble or crop residue left from the previous years' crops. Greater amounts of organic matter, in the form of crop residues, left on or near the soil surface due to management practises have been shown to have positive effects on earthworm abundance (e.g. Tebrugge & During 1999, Karlen *et al.* 1994). However, organic matter produced by different plants will vary in terms of texture and chemical composition, altering the quality of the organic matter as a food source.

In agro-ecosystems, earthworms can influence the productivity of the land. The presence of earthworms is known to have positive effects on the structure and fertility of soil (Edwards 1975) and as a result, the growth of crop yields. The presence of earthworms has been shown to have positive effects on the emergence and establishment of cereals, in addition to plant height and root biomass (Chaudhry *et al.* 1987, Edwards & Lofty 1978). This may be due to the lower oxygen diffusion rates, higher soil moisture content and soil bulk density that were observed where earthworms were absent (Chaudhry *et al.* 1987). The negative relationship between earthworm biomass and soil bulk density has been confirmed by Binet *et al.* (1997). Soil bulk density is directly related to soil porosity (MAFF 1982), which may affect the growth of plant roots and abiotic factors such as soil moisture and temperature.

Earthworm densities. A range of earthworm densities, from 0 – 1600 m^{-2}, have been observed in agro-ecosystems (Table 3.1). In a review of approximately 125 sites on cultivated fields, Paoletti (1999) found an average earthworm density of 80 m^{-2}, fresh biomass of 35g m^{-2}, and between 1-10 species. The range of densities observed in different studies depends not only on the land use and management, but also on the sampling method, sampling scale and taxonomic expertise (Paoletti 1999). Many studies investigating the distribution of earthworms and the effects of agricultural practices have found a wide range of densities and biomasses of earthworms (Table 3.1).

Table 3.1. Densities and biomass of earthworms reported in studies in arable fields

Density (m^{-2})	Biomass ($g\ m^{-2}$)	Sampling method	Sampling depth (cm)	Reference:
100-1600	10-500	Soil cores	0-10	Clapperton 1999
0-400	0-100	Soil cores	10-25	Marinissen 1992
30-182	-	Soil cores	30	Buckerfield & Wiseman 1997
32-70	-	Soil cores & Formalin	6	Schen 1992
60-110	32-43	Various	-	Paoletti 1999
50-450	19-95	Soil cores	25	Lagerlof *et al.* 2002
3-130	-	Soil cores	5-30	Clapperton *et al.* 1997
211-1097	62-266	Electrical Octet	-	Schmidt *et al.* 2003
194-548	36-137	Formalin & Octet	-	Schmidt et al. 2001

Horizontal distribution. The horizontal distribution of earthworms in a field has been shown to be influenced by the distance from a field boundary. From soil cores taken to 25 cm depth, a greater abundance and wet biomass of earthworms was observed as the distance from the field boundary increased in an arable field (Lagerlof *et al.* 2002) (Table 3.2).

Table 3.2. Approximate mean earthworm densities and biomass gm^{-2} at distances from field boundary (Lagerlof *et al.* 2002)

		Boundary	3 m	9 m	27 m
Density (m^{-2})	May	75	50	100	135
	September	55	195	355	450
Biomass (gm^{-2})	May	38	23	31	48
	September	19	36	83	95

Vertical distribution. The vertical distribution of earthworms has been investigated by several authors. Clapperton (1999) found the greatest number of earthworms was seen between 5 and 15 cm depth compared to depths of up to 30 cm. The mean number of earthworms m^{-2} seen at 0-5 cm, 5-15 cm, 15-25 cm, 25-30 cm were 80, 130, 15, and 3 respectively (Clapperton *et al.* 1997). In an investigation using soil cores taken to depths of

25 cm, the majority of juvenile and adult earthworms were often found in the top 10 cm, although this differed between species and time of year (Marinissen 1992).

Temporal distribution. Annual differences have been seen in earthworm populations and this is believed to be due, in part, to the effects rainfall. Greater numbers of earthworms in arable fields have been recorded in wetter years (Marinissen 1992). Barnes & Ellis (1979) also found soil moisture affected earthworm populations with changes in rainfall causing populations to fluctuate from one year to the next. Throughout the year earthworm populations vary, largely due to the limiting factors of soil moisture and temperature. Higher abundance of earthworm populations has been seen in the autumn compared to the spring (Lagerlof *et al.* 2002).

Other factors that effect earthworm populations are the soil type, with higher densities observed in 'lighter' sandy-loams than 'heavier' clays (Buckerfield & Wiseman 1997, Lagerlof *et al.* 2002). This may be due to more suitable moisture content, organic matter and soil pH (Lagerlof *et al.* 2002).

3.2.2 Aims of this chapter

The aim of this chapter is to compare the relative abundance and biomass of earthworms in commercial cereal fields, which have been established by either non-inversion tillage or conventional tillage, in the autumn and spring.

3.3 Materials and Methods

3.3.1 Study sites

Forty winter wheat fields were selected over two cropping years at seven commercial farms in Leicestershire and Shropshire. Twenty fields were surveyed in 2001/2 and twenty in 2002/3. Half of the fields had been established by non-inversion tillage and half by ploughing. These fields were surveyed for earthworms in the autumn (October/ November) and spring (March) in the cropping years 2001/2 and 2002/3. Detailed information about the fields used in this investigation can be found in appendices 2 and 3.

3.3.2 Earthworm sampling technique

Earthworms were sampled by taking nine 10 cm diameter by 10 cm deep cores, which were hand-sorted to extract the earthworms. The earthworms from each core were counted and then killed in Industrial Methylated Spirit to void the contents of their stomachs and placed on filter paper to dry the surface layer of their bodies and then weighed (Gerard & Hay 1979).

This method was chosen as it would enable earthworms in the top 10 cm of the soil to be sampled during the daylight hours. It was assumed that these earthworms were potentially the most available as a food resource for birds. As well as being the most appropriate method, sampling earthworms using soil cores was considered to be the most practical and therefore enabled surveys to be carried out on a larger number of fields than other methods. Hand-sorting soil cores to survey earthworms have been widely used in previous studies investigating the effects of tillage (Andersen 1987, Schmidt 2001, Wyss & Gasstetter 1992, Emmerling 2001). Other methods that have been used to survey earthworms include chemical extraction using mustard or formalin solutions on a defined area (e.g. Hutcheon *et al.* 2001, Gunn 1992, Nuutinen 1992, Raw 1959, Schmidt 2001) or using electrical methods such as Thielemans Octet method (Andersen 1987, Schmidt *et al.* 2001). However, there are health and safety implications and risks to the scientist and the environment with the use of formalin so it is becoming less popular. As non-inversion tillage is believed to lead to changes in soil structure, soil coring was chosen as the most suitable method with the least bias between tillage treatments.

3.3.3 Experimental design

A stratified sampling design was used to survey the earthworms. This design consisted of three transects running from the field edge to the middle of the field. On each transect there were three sampling points at increasing distances from the crop edge; they were at one and eight metres from the crop edge and in the middle of the field (Figure 2.2). One soil core was taken at each sampling point with a total of nine cores taken in each field. Transects into the field were positioned approximately halfway along the length of one of the field boundaries. The transects were placed five metres apart.

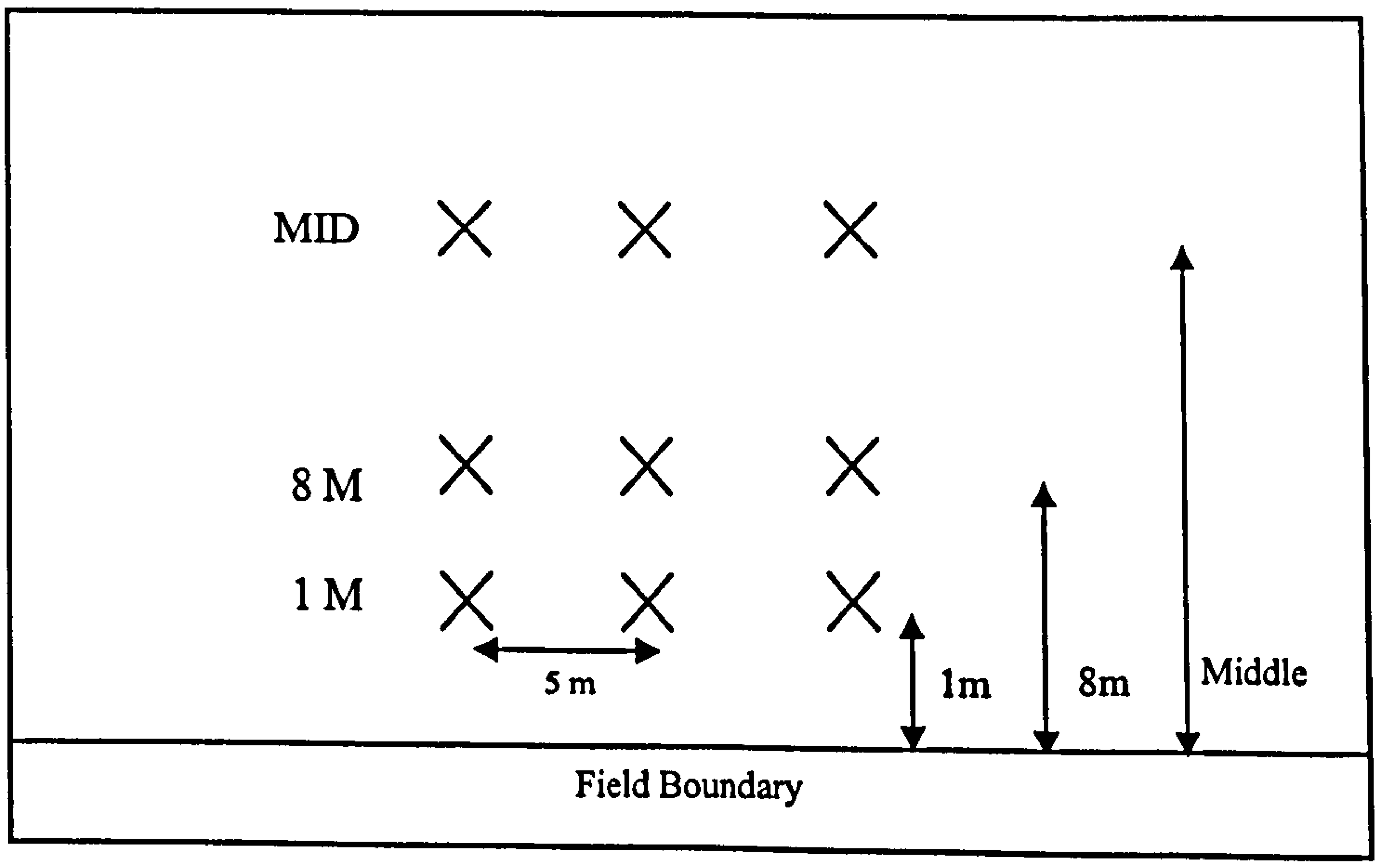

Figure 2.2. Diagram of sampling points for earthworm soil cores.

This design allowed earthworms to be sampled at three distances into the field where different bird species may be foraging. A combination of food availability and predation avoidance, potentially linked to the distance away from cover, is likely to influence where birds forage in fields (e.g. Schneider, 1984; Lima & Dill, 1990). The earthworm numbers and weights were converted into numbers and weight (grams) per meter squared by dividing by a conversion factor of 0.007854. The conversion factor was derived by calculating the area of the soil core: $\pi r^2 = (\pi 0.05^2) = 0.007854$.

3.3.4 Statistical Analysis

To determine if there was a correlation between earthworm numbers and weights, regression analysis was performed for both of the two sampling periods i.e. autumn and spring in the two cropping years.

The mean number and weight per three cores of earthworms for each of the three distances into the field were used. The effect of tillage (a two-level fixed factor) on earthworm numbers per m^3 and biomass grams per m^3 was tested whilst controlling for the following factors, where they were significant: year (a two-level fixed factor), previous crop type (a nine-level fixed factor), and field identity (see table 1). Field identity was included as a random factor, as the sample positions were nested within fields (a twenty-level factor). Field size was included as a covariate. This was achieved by fitting a generalised linear mixed model, procedure GLMM (Genstat 4.2 5^{th} Eds. L.A.T. 2000). For earthworm numbers and weight, a Poisson variance function allowing for over-dispersion and a log link function were used.

Table 3.3. Variables used in the analyses of variation in earthworm abundance and biomass

Variable	Type	Factor levels	n^a	(NIT, CT)
Field area	Continuous variable		See Table 3.4	
Tillage	2-Level fixed factor	Non-inversion tillage	20	(10,10)
		Conventional tillage	20	(10,10)
Year	2-Level fixed factor	2001/2		
		2002/3		
Previous crop	9-Level fixed factor	Winter wheat	3	(2,1)
		Winter barley	1	(0,1)
		Oil seed rape	13	(5,8)
		Set aside	9	(4,5)
		Peas	2	(0,2)
		Beans	6	(6,0)
		Maize	2	(2,0)
		Grass	4	(3,1)
Distance in to the field	3-Level fixed factor	1m from crop edge	20	(10,10)
		8m from crop edge	20	(10,10)
		Middle of field	20	(10,10)
Field	40-Level random factor	2001/2 – twenty fields	20	(10,10)
		2002/3 – twenty fields	20	(10,10)

[a] n = Number of fields relating to a given factor

Table 3.4. Field size information (hectares)

Year	Field Area	n	NIT		CT	
Year 1	Min	10	3.86		3.30	
	Max	10	22.27		16.36	
	Mean	10	8.16	(±1.79)	6.65	(±1.42)
Year 2	Min	10	3.86		3.32	
	Max	10	13.87		8.84	
	Mean	10	7.688	(±0.94)	5.86	(±0.61)

For each response variable, a step-up model simplification procedure was used, with the most significant factor retained until either all the factors remaining in the model were significant. Significance testing was achieved by calculating the Wald statistic, and comparing this with the χ^2-distribution ($\alpha = 0.05$). Further explanation along with a worked example of the statistics used in this chapter can be found in Appendix 4.

The total number and weight of earthworms per metre squared recorded in the spring and autumn periods, for both non-inversion and conventional tillage fields at each distance into the fields, in both years can be found in Appendix 6.

3.4 Results

3.4.1 Regression analysis: earthworm numbers and weights

There was a significant positive relationship between earthworm weights and numbers from soil cores in both the autumn and spring (Figure 3.3 and Figure 3.4). Although in autumn the relationship appeared to be stronger than in spring, with r^2 values of 0.5932 and 0.4463 respectively.

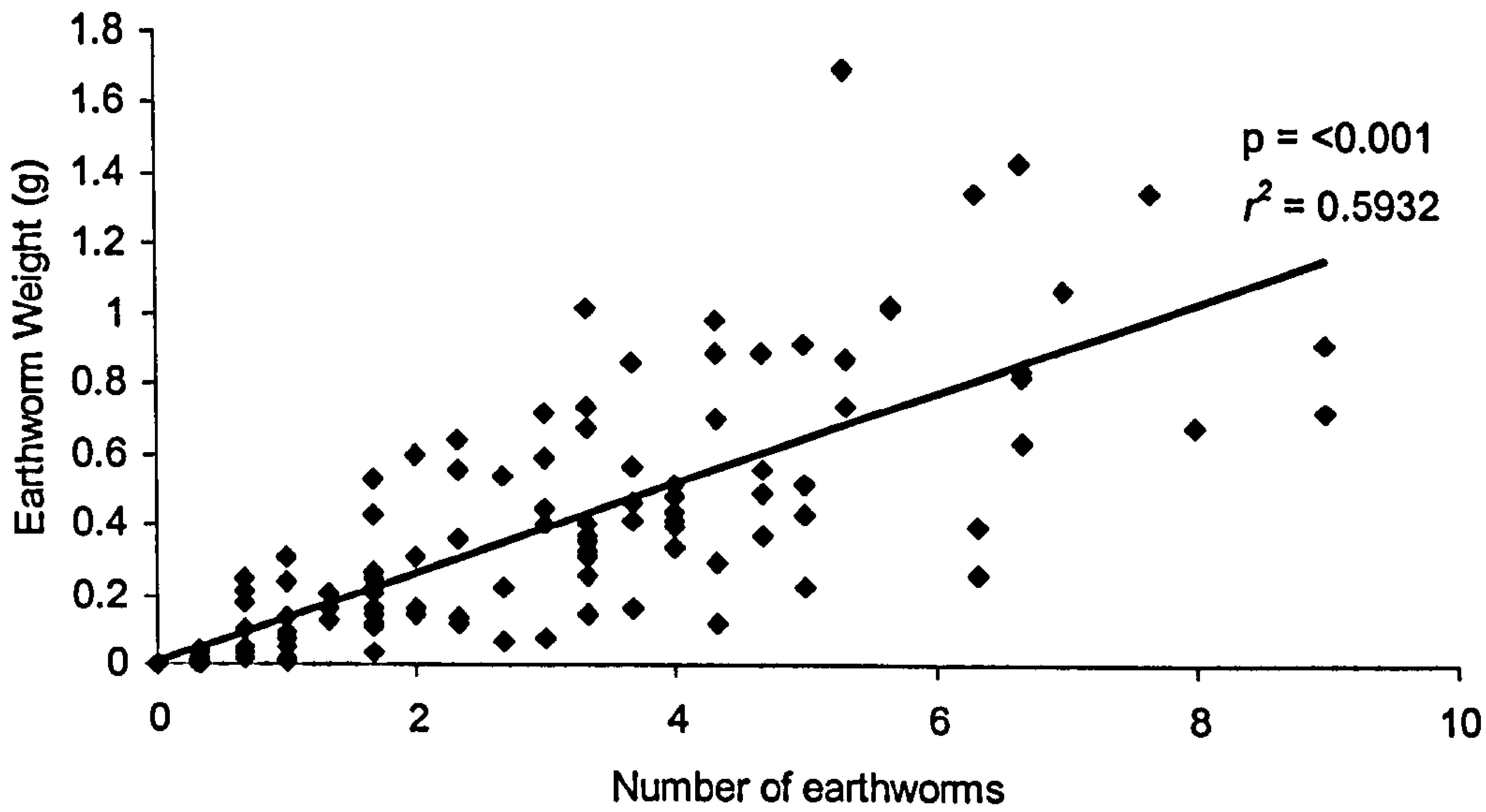

Figure 3.3. The relationship between numbers and weights of earthworms in autumn.

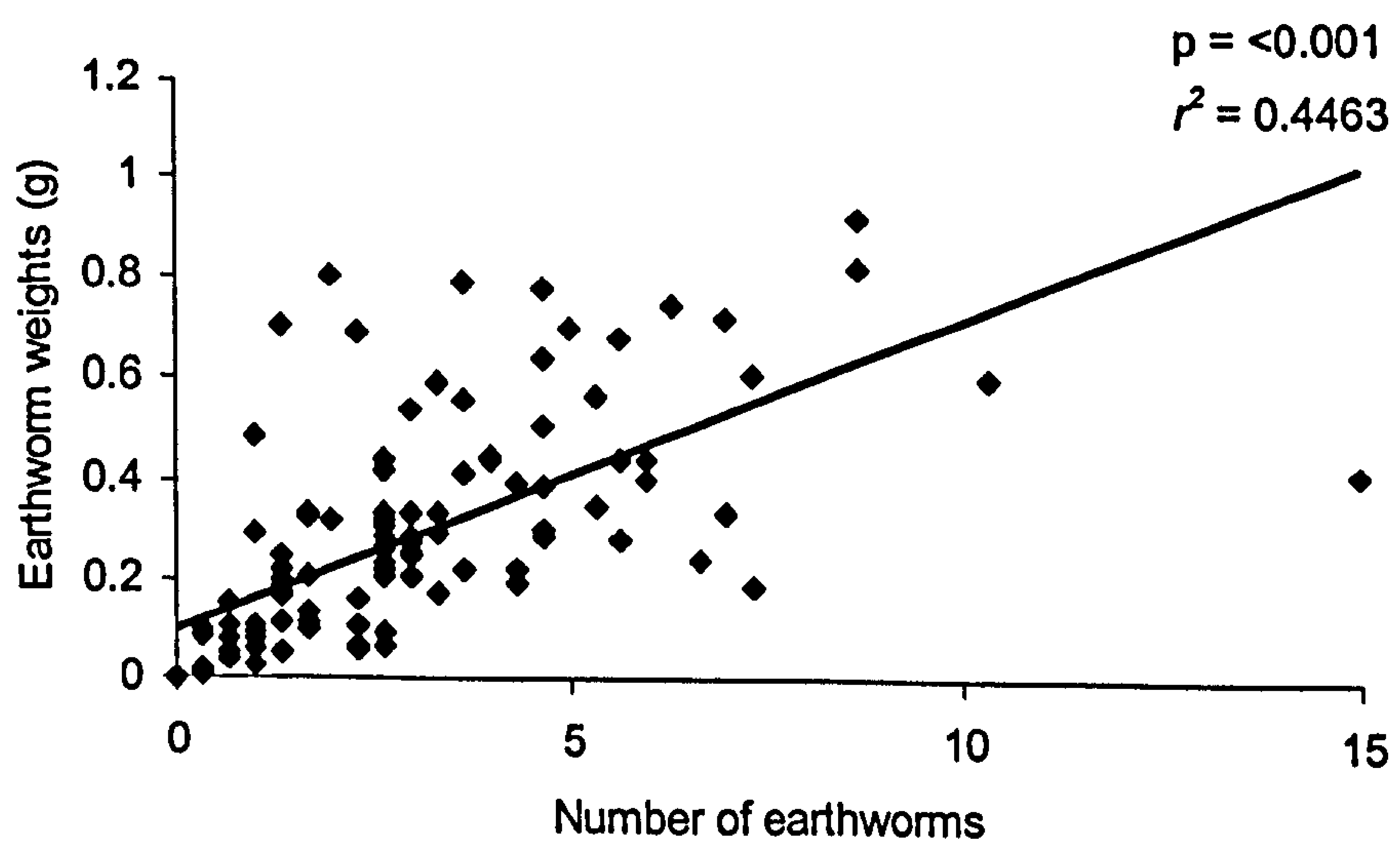

Figure 3.4. The relationship between numbers and weights of earthworms in spring.

3.4.2 Results

Tillage was not significant in explaining the variation in either the numbers or weights of earthworms in the autumn or spring (Table 3.5). Previous crop type was significant in explaining the variation for numbers and weights of earthworms in the autumn and spring (Figure 3.5 and Figure 3.6); for example, there are fewer earthworms per m^2 where the preceding crop was peas than most of the other previous crop types such as oil seed rape or beans. From these figures it can be seen that the relative abundance and weight of earthworms is similar within each sampling period. Generally the weights appear to be higher in autumn than spring and to a lesser extent this is the case for earthworm numbers. The variation in earthworm numbers sampled in spring was also explained by field size and core position i.e. distance from crop edge. There are a significantly greater number of earthworms in the middle of the fields than at 1 or 8 m from the crop edge in spring (Figure 3.7). The smaller fields had a greater number of earthworms in the spring (Figure 3.8).

Table 3.5. General log-linear regression analysis (GLMM) of relative earthworm biomass and numbers in autumn

Sampling period	Variable	Significant Term:	Wald statistic	d.f.	Wald d.f.	P (χ^2)
Autumn	Number	Previous crop	17.46	7	2.49	0.015
	Weight	Previous crop	16.17	7	2.31	0.024
Spring	Number	Previous crop	18.92	7	2.7	0.008
		Field size (ln)	6.23	1	6.23	0.013
		Core position	7.57	2	3.79	0.023
	Weight	Previous crop	23.8	7	3.4	0.001

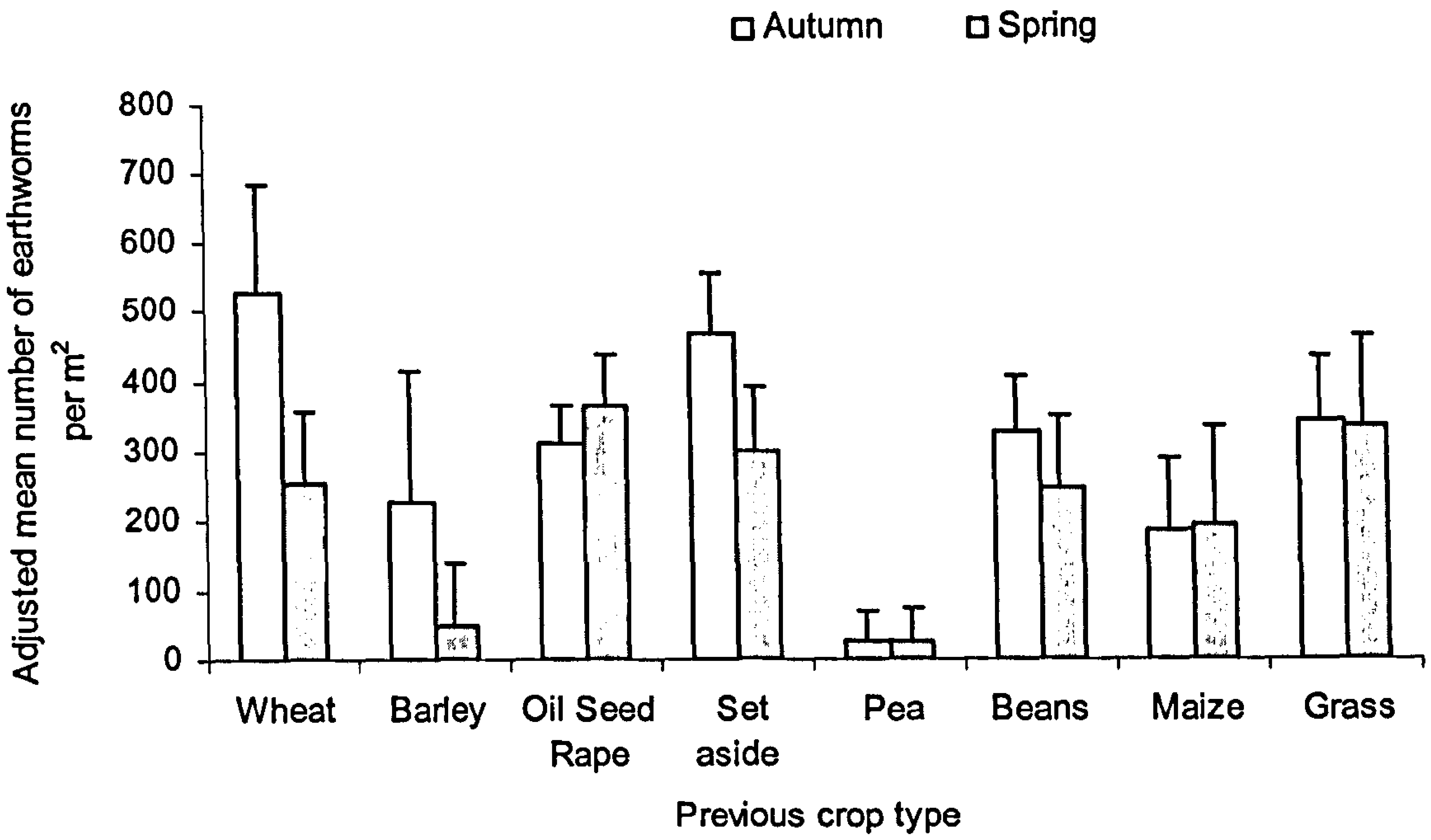

Figure 3.5. Adjusted mean number (+SE) of earthworms per m^2 in each of the previous crop types in autumn and spring

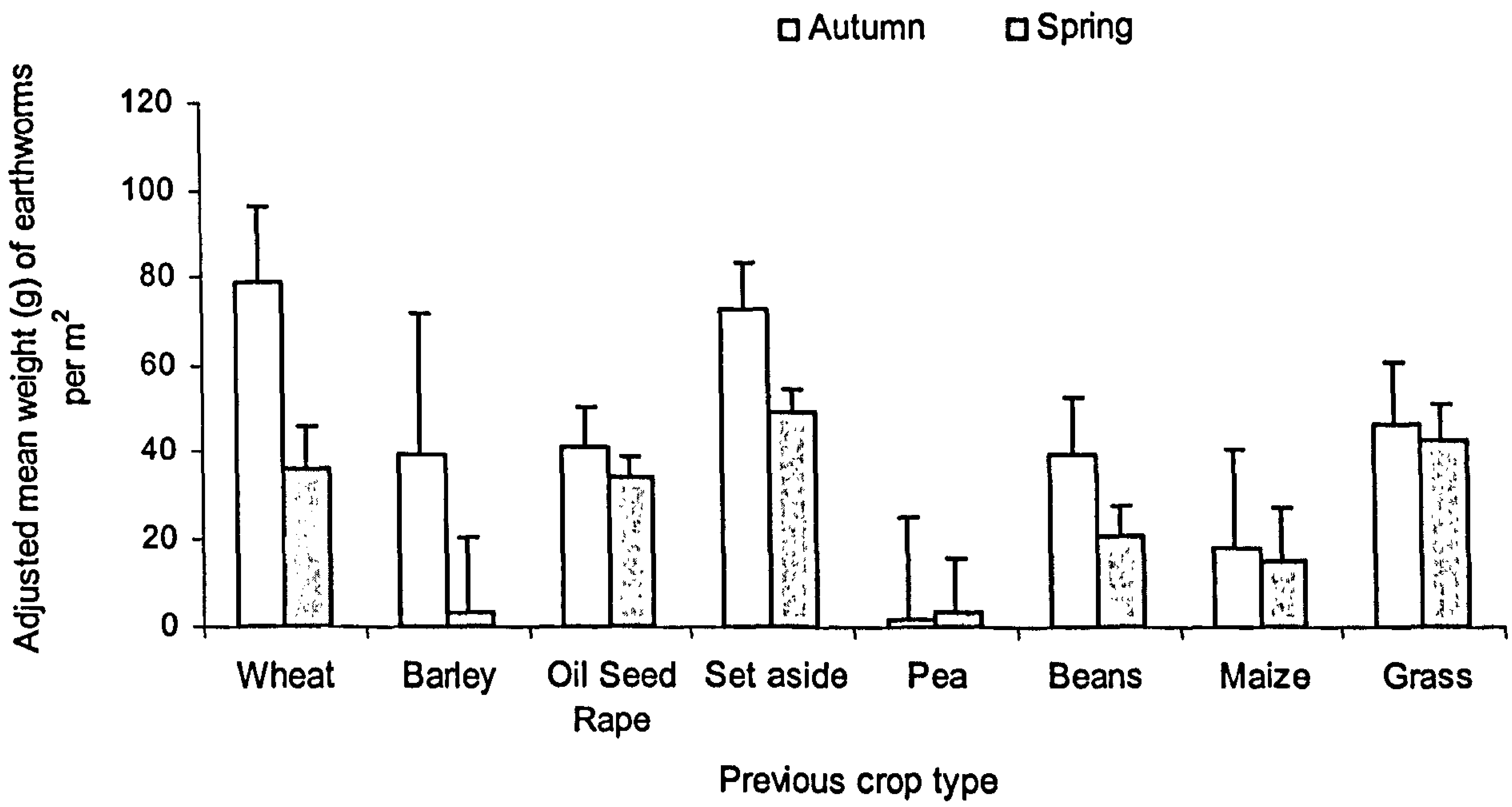

Figure 3.6. Adjusted mean weights (+SE) of earthworms (gm^{-2}) in each of the previous crop types in autumn and spring

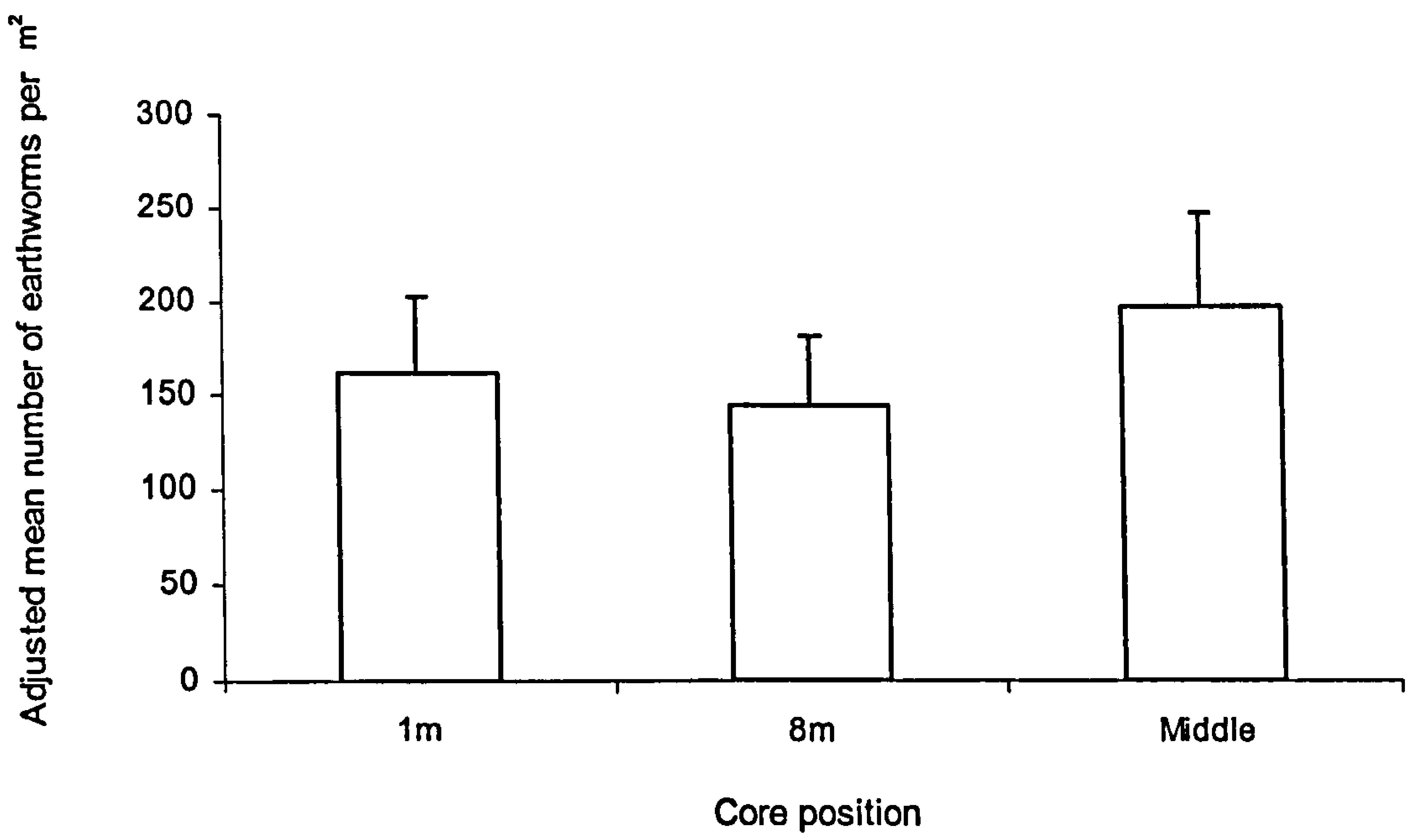

Figure 3.7. Adjusted mean number (+SE) of earthworms at each of the core positions (i.e. meters from crop edge) in spring

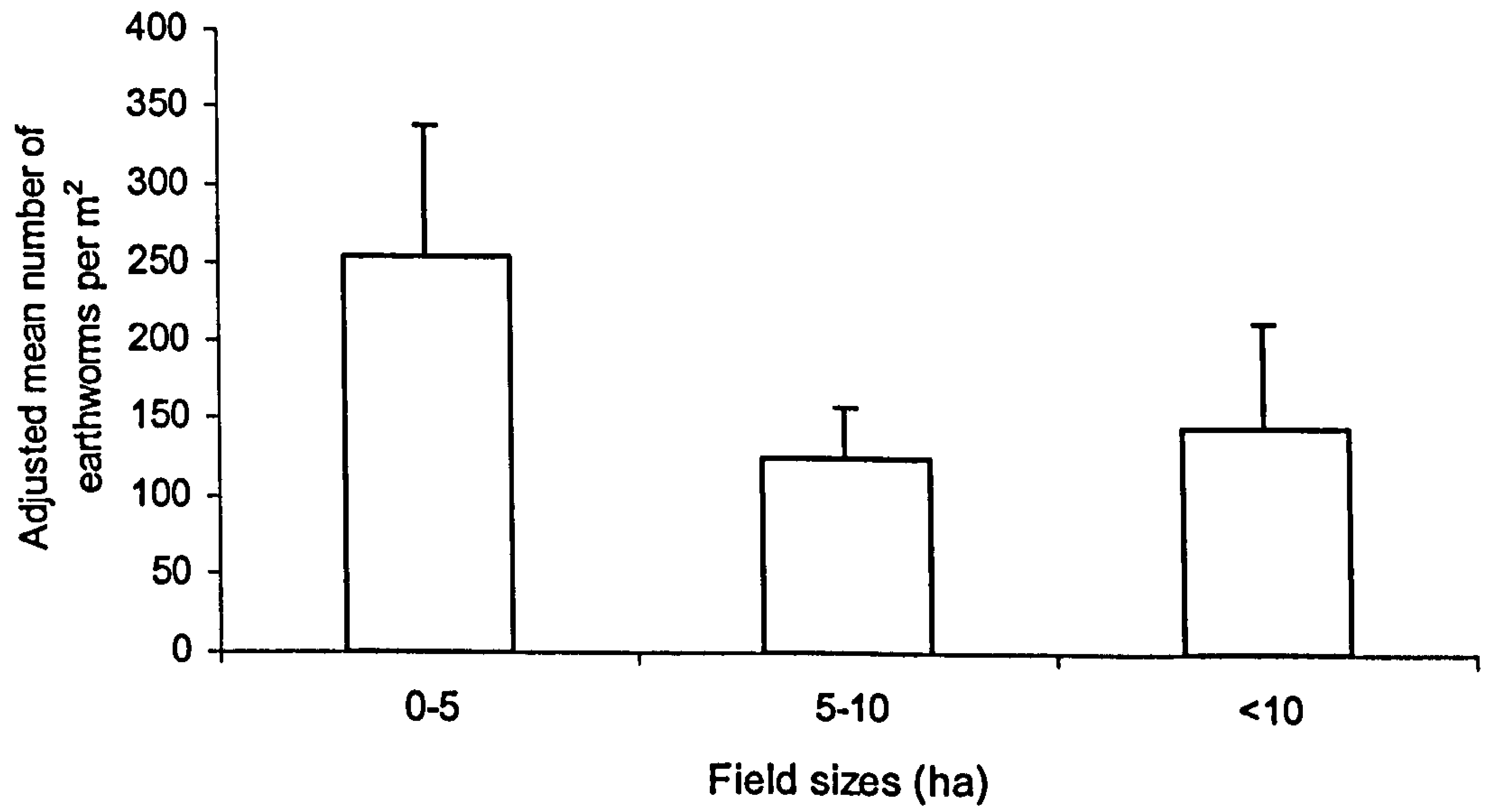

Figure 3.8. Adjusted mean number (+SE) of earthworms at each of three different size classes of fields in spring

3.5 Discussion

In this study crop establishment by non-inversion tillage and ploughing did not affect earthworm numbers or biomass. Other studies have shown differences in the abundance and biomass of earthworm in arable fields established using different tillage methods. However, many of these studies have compared arable fields established by ploughing and no-till or direct drilling (e.g. Andersen 1987, Clapperton 1999, Edwards 1975). In these studies no-till or direct drilling has been found to support greater abundance and biomass of earthworms. This implies that the effects of non-inversion tillage on earthworms are more closely related to those of ploughing than no-till practices. This concurs with Barnes & Ellis (1979) who showed tine cultivations had a similar negative effect on earthworms compared to ploughing, relative to no-till.

The fields in this survey may not have been cultivated using non-inversion tillage regimes long enough to affect the earthworm populations. Other studies have shown that where NIT has been used as part of an integrated farming system, where agrochemical inputs were reduced, increases in earthworm populations occur only after three years of applying the treatments (Hutcheon *et al.* 2001).

The densities of earthworms found in the soil cores were comparable to other studies. A review by Paoletti (1999) found a mean earthworm density of 80 m^{-2} in cultivated fields. In this investigation, for example, 250 m^{-2} earthworms was observed in fields under 5 ha. There was generally a greater abundance and biomass of earthworms in the autumn than in the spring which has previously been observed (Lagerlof *et al.* 2002).

A higher abundance of earthworms was seen in the middle of the field compared to the crop edge (i.e. at 1 m and 8 m from the crop edge). This has also been seen in a study by Lagerlof *et al.* (2002) where earthworm densities in September increased from 195, 355 to 450 at 3 m, 9 m, and 127 m from the boundary.

Previous crop affected the abundance and biomass of earthworms in both autumn and spring. Caution must be given to the interpretation of this factor as the investigation was designed so that the tillage treatments would be sufficiently replicated. The other terms in the model were included to account for the potential effect they have on earthworms without replicating sufficiently for each level i.e. each previous crop type. This means that although previous crop type is significant, some levels within this factor are only represented by a few fields. The following previous crop types: winter wheat, winter barley, pea, maize and grass are only represented by 3, 1, 2, 2 and 4 fields respectively. The three types of previous crop that are represented by over 5 fields (i.e. 6-13 fields) are oilseed rape, set aside and beans and these are discussed here. In the autumn, there were a greater density and biomass of earthworms in crops grown after set aside than oilseed rape or beans. This was also seen for the biomass in spring. This may be due to lower inputs and disturbance of set aside field compared to fields growing crops. Also there may have been a greater amount of plant material on the surface which may have lead to increased soil moisture retention and food abundance. There was little difference in terms of earthworm abundance between these three previous crop types in spring. This may be due to the effects of the present crop (i.e. wheat) becoming increasingly important.

The number and size of samples taken were chosen for biological, statistical and logistical reasons. The soil core size (10 cm diameter by 10 cm deep) was chosen to survey earthworms in the top soil layer, the foraging depth for birds. Nine cores were taken per field, so the total surface area sampled per field was 0.31 m^2. This is a relatively small area compared to even the smallest field in this investigation which measured 3.3 hectares. Soil cores were taken at distances from the crop edge, as differences in earthworm abundance from the edge to the centre of fields have been observed (Lagerlof *et al.* 2002). This stratified design was also implemented to take into account bird species foraging at different distances from field boundaries. However, due to the logistical constraints on the volume of soil sampled for earthworms, it may have been advisable to either take a) fewer larger soil cores or b) a greater number of soil cores, of the size taken in this investigation, on a smaller number of fields. Ten fields of each tillage treatment were considered to be the maximum that could be surveyed, whilst still allowing sufficient replication. An alternative approach would have been to use a split-field or small plot design. Both of these experimental designs would have accounted for the effects of field conditions and history, such as previous crop and soil type, which may have influenced earthworm populations. The disadvantages of these designs are that they both require intervention (i.e. applying treatments) and therefore have financial implications. These designs are also inappropriate for carrying out bird surveys and this would have meant locating additional fields on more farms which is a time consuming process.

Other methods of sampling earthworms were considered inappropriate or impractical. These considerations are illustrated by the impractical formalin or mustard method where a large volume of water must be transported on to the site. Methods that can be affected by the soil type and structure, such as the mustard and electrical (Octet) methods, were considered to be inappropriate to assess differences between tillage treatments. This is because tillage treatments are known to have an impact on soil structure and therefore influence the conductivity of electricity in the Octet method and infiltration of the mustard water.

3.6 Summary

- Tillage was not significant in explaining the numbers or weights of earthworms in either the autumn or spring.
- The main factor that explained the variation in earthworm numbers and weights in autumn and spring was previous crop.
- Fields where the previous crop type was set aside generally had a greater abundance and biomass of earthworms compared to fields where the previous crop was oilseed rape or beans.

Chapter 4

THE EFFECT OF NON-INVERSION TILLAGE ON SURFACE SEEDS AS POTENTIAL FOOD SOURCES FOR FARMLAND BIRDS

4.1 Summary

Forty different wheat fields were surveyed for seeds over two cropping seasons, with twenty fields surveyed per year. Half of the fields were established by non-inversion tillage (NIT) and the other by conventional tillage (CT). Surface seeds were surveyed using surface soil scrapes that were taken at three distances into the fields – 1 and 8 metres from the crop edge and in the middle of the field. Logistic regression (GLMM) was used to assess the difference in seed numbers between NIT and CT field whilst accounting for field variables such as previous crop type and field size. The response variables were the most commonly occurring species and families that are known to be important in the diet of farmland birds. The ten response variables tested were Knotgrass *Polygonium arviculare*, Chickweed *Stellaria media*, Forget-me-not *Mytosis arvensis*, Pansy *Viola spp.*, Gramineae, Broad-leaved weeds, Polygonaceae, Chenopodiaceae, the total number of seeds and species. Tillage was not significant in explaining the variation for any of the response variables in either autumn or spring. Only the explanatory variables year and distance from crop edge were significant in explaining the variation for some of the response variables.

4.2 Introduction

4.2.1 Farmland birds and seeds

Seeds are eaten by most farmland bird species especially over the winter months when other food resources are scarcer. Seeds that are widespread in the diet of granivorous farmland birds are those belonging to the families Gramineae, Polygonaceae, Chenopodiaceae, Caryophyllaceae, Asteraceae, Brassicaceae, Fabaceae (Wilson *et al.* 1999). Within these families, as well as cultivated cereal grains, the weed seeds in the highest proportion of farmland bird diet were those from the genera Polygonum e.g. persicarias and knotgrasses, Stellaria e.g. chickweeds, and Chenopodium e.g. fat-hen (Wilson *et al.* 1999).

Table 4.1. Important families of seeds taken by common farmland birds (Information compiled from Wilson *et al.* 1996).

Bird	Seed families
Skylark (*Alauda arvensis*)	Bistorts (Polygonaceae), goosefoots (Chenopodiaceae), amaranths (Amaranthus), Hemp-nettles (Labiatae)
Red-legged and Grey Partridge (*Alectoris rufa* and *Perdix perdix*)	Bistorts (Polygonaceae), corn spurrey and chickweeds (Caryophyllaceae), cereal grain and wild grass (Gramineae), cornflowers (Compositae), oraches (Chenopodiaceae), dead and hemp-nettles (Labiatae) and gromwells (Boraginaceae)
Pheasant (*Phasianus colchicus*)	Cereal grain (Gramineae), sorrels & bistorts (Polygonaceae), goosefoots (Chenopodiaceae), chickweeds (Caryophyllaceae)
Yellowhammer (*Emberiza citronella*)	Cereal grain and wild grasses (Gramineae), composites (Compositae), bistorts, docks and sorrels (Polygonaceae), chickweeds (Caryophyllaceae)
Linnet (*Carduelis cannabina*)	Bistorts and docks (Polygonaceae), chickweeds and mouse-ears (Caryophyllaceae), brassicas (Brassicaceae) and a variety of composites (Compositae)
House sparrow (*Passer domesticus*)	Bistorts (Polygonaceae), purslanes (Portulacaceae), mouse-ears (Caryophyllaceae), cranesbills (Geraniaceae), meadow and finger-grass and cereals (Gramineae)
Tree sparrow (*Passer montanus*)	Bistorts (Polygonaceae), goosefoots (Chenopodiaceae), amaranths (Amaranthus), chickweeds and mouse-ears (Caryophyllaceae), forget-me-nots (Boraginaceae), cereal grain and wild grass (Gramineae)

4.2.2 Sampling seeds in agro-ecosystems

Most of the assessments of seeds in agro-ecosystems to date have been carried out to assess weed seed banks (e.g. Jones *et al.* 1999). The methods used in these studies have involved taking cores of varying depths and did not separate the seeds on the immediate soil surface. Two studies that have investigated seeds in the section of the seed bank available to birds in arable fields, i.e. seeds at the soil surface (Moorcroft *et al.* 2002, Robinson & Sutherland 1999). Both of these studies sampled at the beginning (October or November) and end of winter (March). Moorcroft *et al.* (2002) took ten soil cores diagonally across twenty-seven stubble fields; the cores were 15 cm diameter by 3 mm deep. Robinson & Sutherland (1999) intensively sampled four fields by bulking five 7 cm diameter by 6 mm deep cores giving an area of 0.019 m^2 per sample and these were taken from an evenly spaced grid across the fields. The soil samples in both studies were wet sieved through sieves of decreasing mesh size (1 mm, 500 μm, 63 μm). The top sieve, 1mm, caught crop residue, stones and larger seeds such as black bindweed. The middle sieve, 500 μm, caught most of the seeds taken by the granivorous farmland birds. The bottom sieve, 63 μm, was used to trap the soil and was found to contain only poppy seeds that are relatively unimportant in the diet of farmland birds and are underestimated by hand-sorting so were excluded in both studies.

In this study, these methodologies were adapted to investigate the effect of tillage on seeds at different distances from the crop edge as different farmland bird species feed in different parts of the field; this is partly dependant on their behaviour for escaping from predators (Lima & Dill 1990) and food abundance. Skylarks *Alauda arvensis* have been observed to feed in the centres of fields, whereas Yellowhammers *Emberiza citronella* have been shown to prefer feeding near hedgerows (Robinson & Sutherland 1999).

4.2.3 Weed seeds in agro-ecosystems and NIT

Seed densities have been observed to be distributed differently in fields that have been cultivated and stubble fields. Seed densities on the soil surface were shown to decline from distance away from the field boundary, whereas no decline was observed in stubble fields (Robinson & Sutherland 1999). This may be important when considering the effects of tillage, as non-inversion tillage may be considered to represent a habitat more like a stubble field than a ploughed field. Few studies have investigated seeds at the surface of the soil that are potentially available to birds, and none have investigated the effect of tillage of the abundance of these seeds.

Seed densities at the surface of stubble fields have been shown to vary between stubble crop types with intensive wheat stubble always supporting significantly less seeds than intensive barley and undersown organic wheat stubbles; mean seed densities m^{-2} observed in October were 434.1 (± 25.9), 647.0 (± 44.1), 614.6 (± 44.1) in intensive wheat, intensive barley and undersown organic wheat stubbles respectively (Moorcroft *et al.* 2002). Depletion of the total number of seeds over the winter, i.e. between October and March, was observed in this study with losses ranging from 11.21% to 34.64%, depending on the stubble type. Similar depletion of surface seeds were observed between November and March by Robinson & Sutherland (1999), where the mean percentage losses ranged from 2.2% in winter cereals to 38% in non-undersown stubbles. Moorcroft *et al.* (2002) found that there was little variation in the number of seed species was seen between stubble types and between the beginning and end of winter, with the mean number of seed species m^{-2} ranging from 2.8 (± 0.249) to 3.86 (± 0.595). Robinson & Sutherland (1999) found similarly low numbers of seed species m^{-2} in stubbles, i.e. approximately 2-3 species m^{-2}, and in winter cereals the number of species found was 1.82 (± 0.20) and 1.53 (± 0.15) in November and March respectively.

Wilson & Aebischer (1995) found that the number of arable weed seedlings for several species decreased with increasing distance from crop edge. Whereas the reverse trend was found for knotgrass *Polygonum aviculare* and field pansy *Viola arvensis* in spring sown crops and for field pansy in autumn sown crops. In spring sown barley similar patterns were seen for seed from the seed bank obtained by taking soil cores of 7 cm diameter by 20 cm deep and the seeds were allowed to germinate and counted. The species that were observed to decrease with increasing distance from crop edge included the seedlings of forget-me-not and dead nettles *Lamium spp*, and the seeds orache *Atriplex patula* and fat-hen *Chenopodium album*. The same decline was observed for the total number of seeds and mean number of species for both seedlings and seeds. However, some species did not have linear responses to the increasing distance from the crop edge. Knotgrass germinated from the seed bank samples had the greatest abundance at 0 and 32 m and the least at 2 m and 128 m from the crop edge; although seedling numbers were observed to increase steadily with distance from crop edge (Wilson & Aebischer 1995). Other species, including stinging nettle and creeping thistle, of seedlings were observed to decline dramatically at 4 m from the crop edge. As this investigation used seeds from below the soil surface and seedlings, this may not be completely representative of the seeds that are present on the soil surface and therefore available to farmland birds. However, it has given an indication that some species decline with distance from crop edge, other increase and some are evenly distributed. Seeds at the surface of cereal fields have been recorded at higher densities at the edges of fields; whilst within stubble fields no relationship with distance from crop edge was detected (Robinson & Sutherland 1999).

Some studies have investigated the effect of different tillage regimes on the abundance of weeds. Torressen & Skuterud (2002) found that without the use of chemicals to control the weeds, increases in weeds were seen in reduced tillage plots compared to ploughed plots. In this study 'reduced' tillage referred to no-tillage and various combinations of spring and autumn harrowing. When chisel ploughing and no-tillage were compared with mouldboard ploughing by Mas & Verdu (2003), no differences were observed in the total weed biomass. Although a greater biomass of oats *Avena spp.* and sowthistle species *Sonchus spp.* were seen under minimum tillage (chisel plough) and no tillage respectively. These studies cannot be directly correlated with the seeds available as a food source for farmland birds as the data are taken from germinated seeds or seeds below the soil surface.

The availability of seeds on different substrates has been assessed by Whittingham & Markland (2002). They found that the surface area required for scanning for seeds increased with vegetation structure. This may be significant when considering the availability of seed on CT and NIT fields. It may mean that the residue left from the previous year's crop may obstruct the search area.

4.2.4 Aims of this chapter

The aim of this chapter is to compare the relative abundance of weed seeds at the surface of commercial cereal fields, which have been established by either non-inversion tillage or conventional tillage, in the autumn and spring i.e. at the beginning and end of the winter when they are an important food source for farmland birds.

4.3 Materials and Methods

4.3.1 Study sites

Forty fields, twenty winter wheat fields established by non-inversion tillage (NIT) and twenty established by ploughing (CT) were selected at seven commercial farms in Leicestershire and Shropshire. Ten NIT and ten CT fields were surveyed in 2001/2, and ten different NIT and CT fields were surveyed in 2002/3. These fields were surveyed for seeds in the autumn (October/ November) and spring (March) in the cropping years 2001/2 and 2002/3. Detailed information on the fields used in this investigation can be found in appendices 2 and 3.

4.3.2 Experimental design and sampling strategy

A stratified sampling design was used to survey the seeds. This design consisted of three transects running from the field edge to the middle of the field. Transects into the field were positioned approximately halfway along the length of one of the field boundaries (Figure 4.1). On each transect there were three sampling points at increasing distances from the crop edge; samples were taken at one and eight metres from the crop edge, and in the middle of the field. The transects were placed five metres apart. One sample was taken at each sampling point, leading to a total of nine samples per field. At each sampling point one surface soil sample was taken; a 25 cm^2 quadrat was laid on the ground and the soil within this area was removed to a depth of approximately 1 cm deep using a builders trowel.

This design allows seeds to be sampled at various distances into the field where different bird species may be foraging. A combination of food availability and predation avoidance, potentially linked to the distance away from cover, is likely to influence where birds forage in fields (e.g. Schneider, 1984; Lima & Dill, 1990).

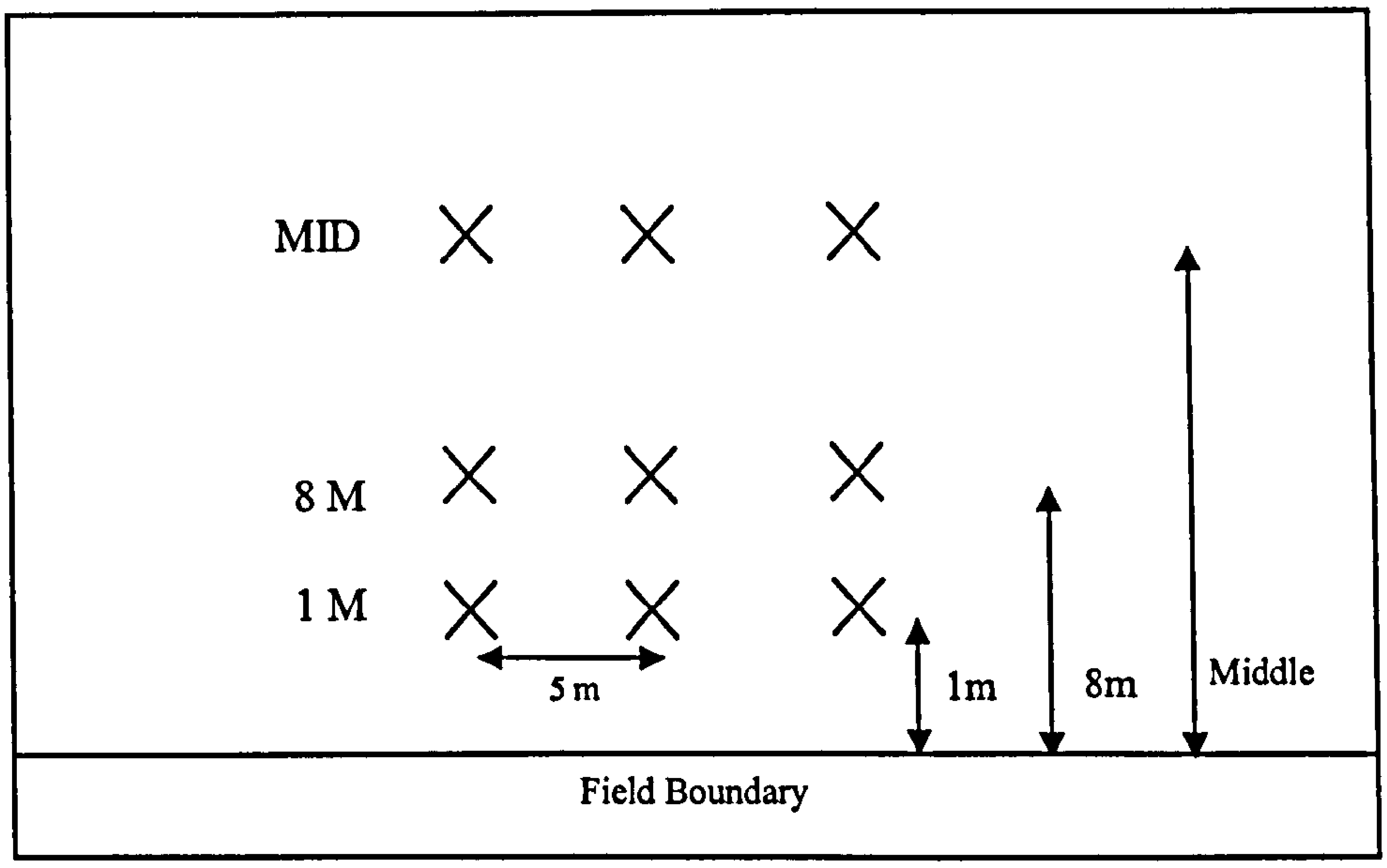

Figure 4.1. Diagram of sampling points for seed soil samples.

All of the soil samples were placed in labelled and sealable plastic bags and stored in a cold store room at approximately 4^0C to prevent the seeds from germinating, before processing and identification could occur. To extract the seeds from the soil, the soil samples were wet sieved through sieves of decreasing mesh size (1 mm, 500 μm), as described by Moorcroft *et al.* (2002) and Robinson & Sutherland (1999). The top sieve (1 mm) caught crop residue, stones and larger seeds such as black bindweed. The bottom sieve (500 μm) caught seeds of sizes that are commonly taken by granivorous farmland birds, such as *Stellaria media* (chickweed). Unlike the other two studies where this system of seed extraction was used a smaller sieve of 63 μm mesh size was not required to trap the soil, as a specially designed soil-trapping sink was available. In the previous studies the smallest mesh sized sieve was found to contain only poppy seeds that are relatively unimportant in the diet of farmland birds and are underestimated by hand sorting. After the soil had been washed from the seed and plant material, the contents of each sieve were separately placed in beakers of saturated calcium chloride solution to assist the seeds to float. The floating seeds and organic matter were removed and placed in petri dishes where the seeds were extracted by hand. However, it was observed that not all the seeds floated, so the layer of seeds and debris that had sunk to the bottom of the beaker were also hand sorted. The seeds collected from each sieve were placed on filter paper in petri dishes to dry to avoid germination and decay. The dry seeds were then placed in labelled plastic tubes and kept in cool and dark storage. The seeds were identified to species using a seed collection and several seed identification guides (NIAB 1986, Holm-Nielsen 1998, Hanf 1983).

4.3.3 Statistical Analysis

The total numbers of seeds in each of the three sampling points per distances into the field were used (i.e. number of seeds per 0.1875m^2). The numbers of seeds were converted to seeds per meter squared. The effect of tillage (a two-level fixed factor) on seed numbers was tested whilst controlling for the following factors, where they were significant: year (a two-level fixed factor), previous crop type (an eight-level fixed factor), and field identity (see Table 4.2). Field identity was included as a random factor, as the samples taken at different distances into a field were nested within fields. The natural log of field size was included as a covariate.

Table 4.2. Variables used in the analyses of variation in seed abundance

Variable	Type	Factor levels	n^a	(NIT, CT)
Field area	Continuous variable		See Table 4.3	
Tillage	2-Level fixed factor	Non-inversion tillage	20	(10,10)
		Conventional tillage	20	(10,10)
Year	2-Level fixed factor	2001/2		
		2002/3		
Previous crop	9-Level fixed factor	Winter wheat	3	(2,1)
		Winter barley	1	(0,1)
		Oil seed rape	13	(5,8)
		Set aside	9	(4,5)
		Peas	2	(0,2)
		Beans	6	(6,0)
		Maize	2	(2,0)
		Grass	4	(3,1)
Distance in to the field	3-Level fixed factor	1 m from crop edge	20	(10,10)
		8 m from crop edge	20	(10,10)
		Middle of field	20	(10,10)
Field	40-Level random factor	2001/2 – twenty fields	20	(10,10)
		2002/3 – twenty fields	20	(10,10)

[a] n = Number of fields relating to a given factor

Table 4.3. Field size information (hectares)

Year	Field Area	n	NIT		CT	
Year 1	Min	10	3.86		3.30	
	Max	10	22.27		16.36	
	Mean	10	8.16	(±1.79)	6.65	(±1.42)
Year 2	Min	10	3.86		3.32	
	Max	10	13.87		8.84	
	Mean	10	7.688	(±0.94)	5.86	(±0.61)

This was achieved by fitting a generalised linear mixed model, procedure GLMM (Genstat 4.2 5th Eds. L.A.T. 2000). A Poisson variance function allowing for over-dispersion and a log link function were used.

For each response variable, a step-up model simplification procedure was used, with the most significant factor retained until all the factors remaining in the model were significant. Significance testing was achieved by calculating the Wald statistic, and comparing this with the χ^2-distribution ($\alpha = 0.05$). Further explanation along with a worked example of the statistics used in this chapter can be found in Appendix 4.

The total number of seeds per metre squared recorded in the spring and autumn periods, for both non-inversion and conventional tillage fields and at each distance into the fields, in both years can be found in Appendix 7.

4.4 Results

4.4.1 Total numbers of seeds in autumn and spring

The most common seeds were Polygonaceae and Chenopodiaceae in both autumn and spring (Figure 4.2, Figure 4.3, Figure 4.4 and Figure 4.5). Mean number of seeds per field were 310 m^{-2} in autumn and 290 m^{-2} in spring. Fifty-four seed species from twenty different non-crop arable plants families were identified, with nine different unidentified grass species (Table 4.4).

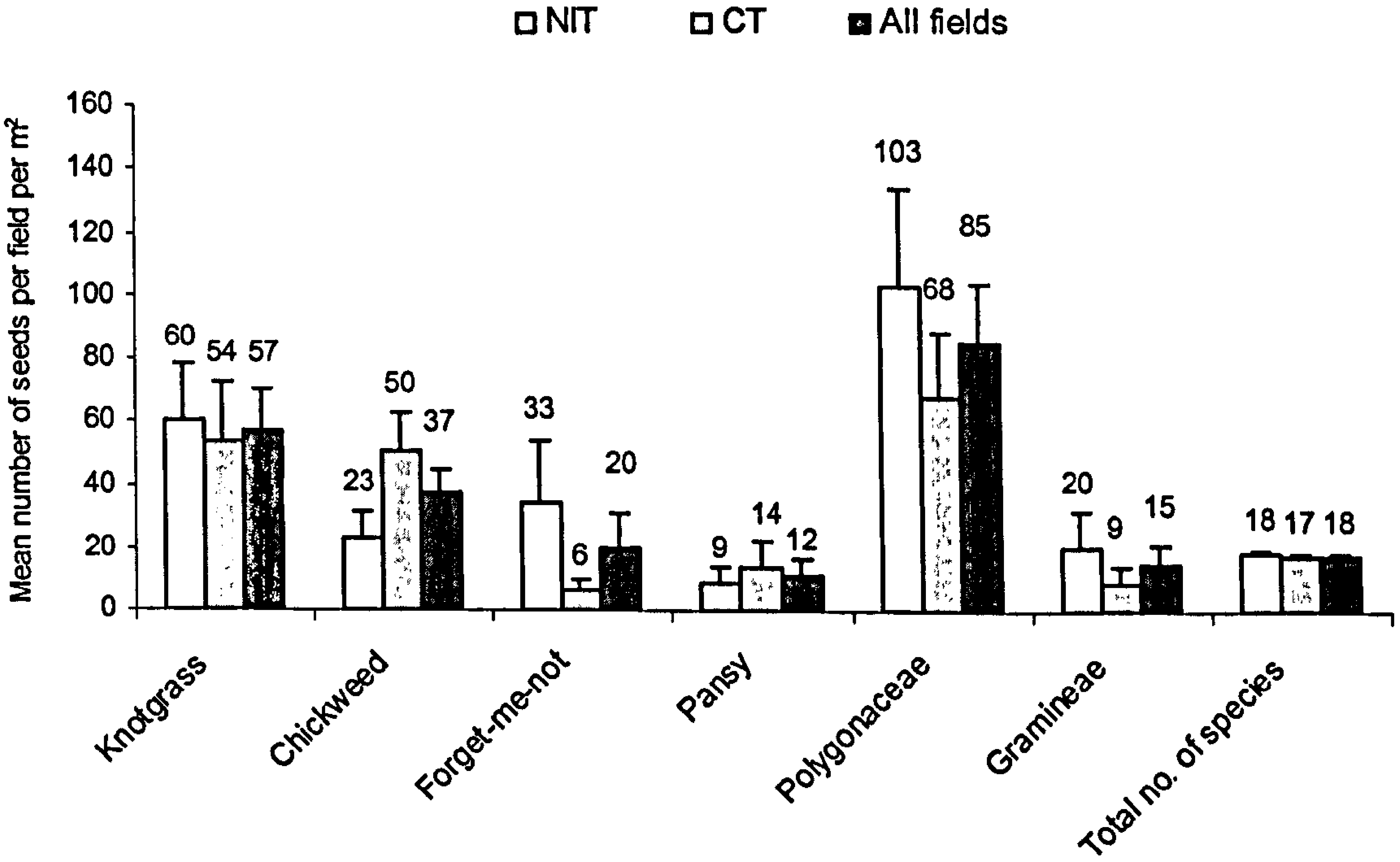

Figure 4.2. Mean number (+SE) of each species/ group found per m^2 per field in autumn. NIT = Non-inversion tillage, CT = Conventional tillage

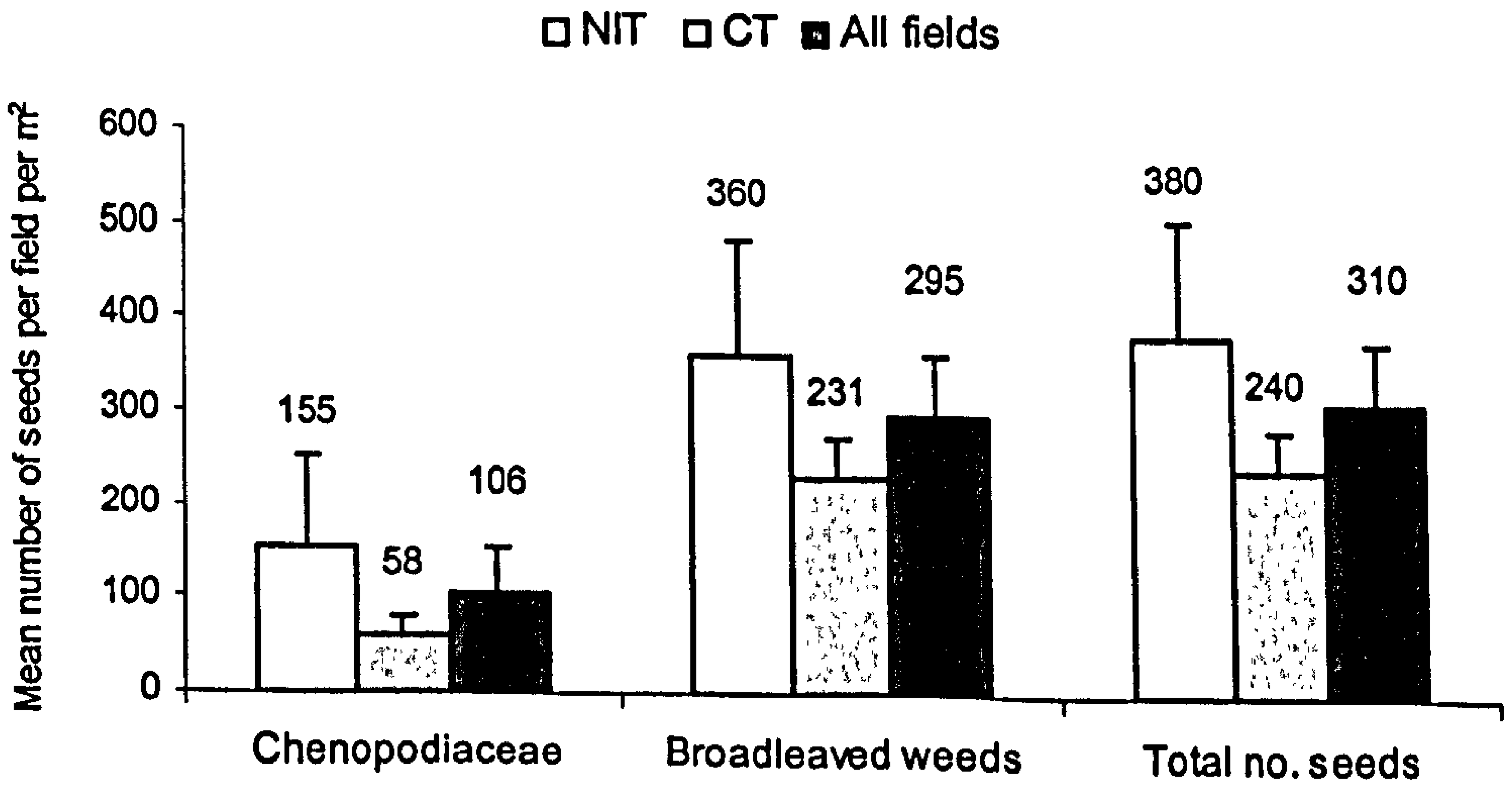

Figure 4.3. Mean number (+SE) of each species/ group found per m^2 per field in autumn. NIT = Non-inversion tillage, CT = Conventional tillage

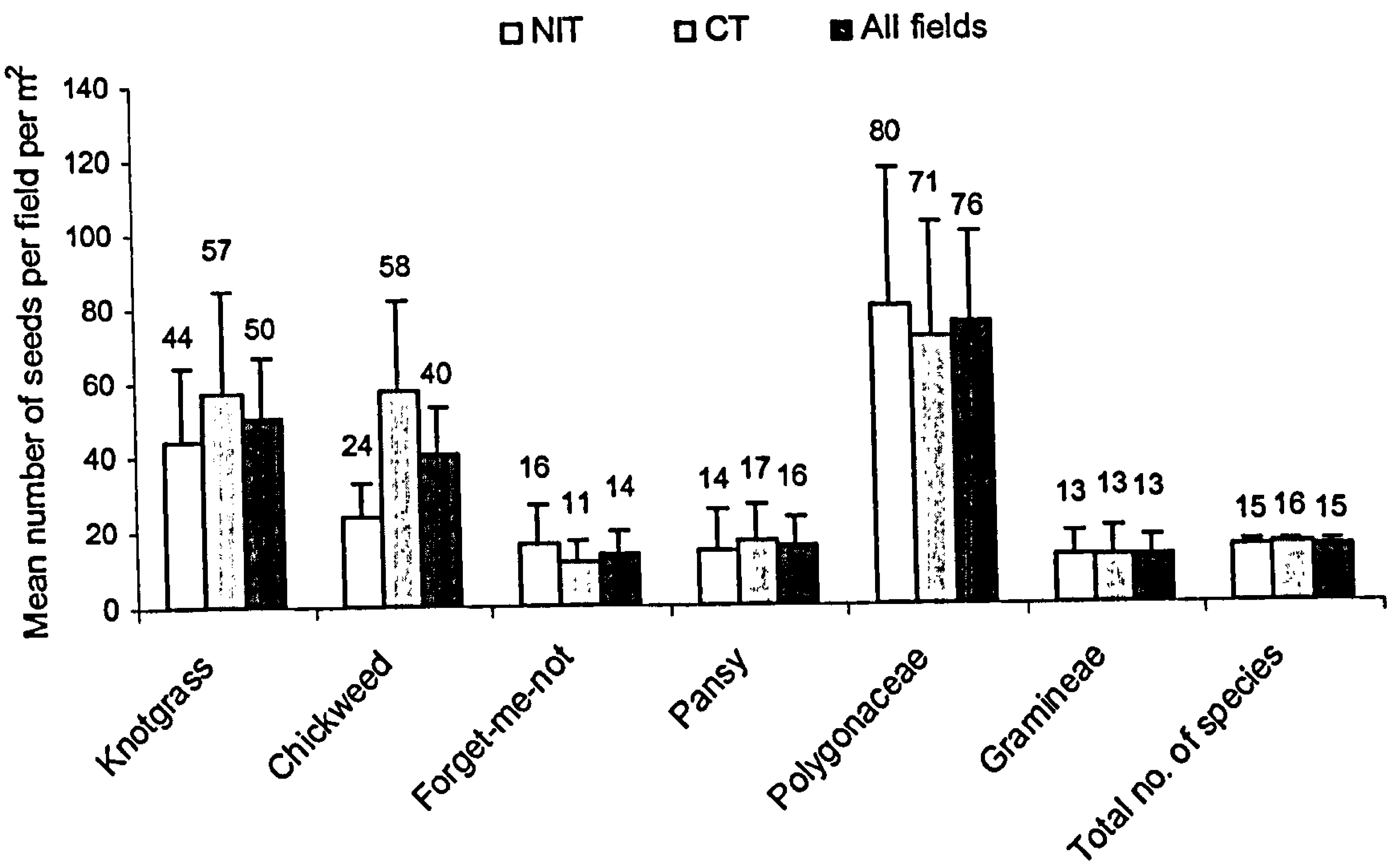

Figure 4.4. Mean number (+SE) of each species/ group found per m^2 per field in spring. NIT = Non-inversion tillage, CT = Conventional tillage

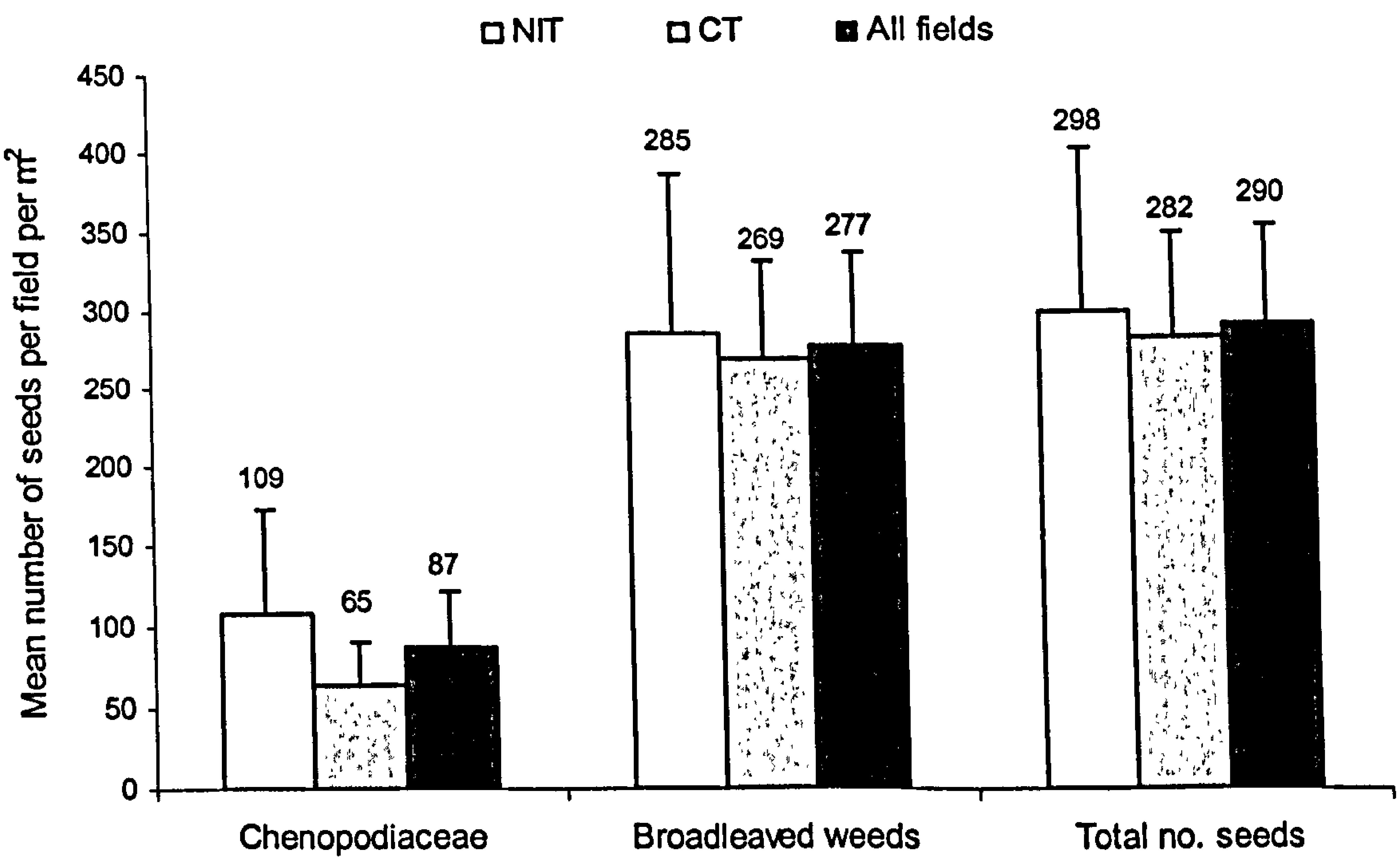

Figure 4.5. Mean number (+SE) of each species/ group found per m^2 per field in spring. NIT = Non-inversion tillage, CT = Conventional tillage

Table 4.4. Seed species list

Family	*Species*	Common name
Boraginaceae	*Mytosis arvensis*	Forget-me-not
Brassicaceae	*Raphanus raphanistrum*	Wild Raddish
	Thlaspi arvense / Cardamine pratensis	Field penny cress/ Cuckoo flower
	Brassica spp	Brassica spp
Caprifoliaceae	*Sambucus nigra*	Elder
Caryophyllaceae	*Silene spp*	Campion spp
	Spergula arvensis	Corn spurrey
	Stellaria media	Chickweed
Chenopodiaceae	*Atriplex patula*	Common Orache
	Chenopodium album	Fat hen
Compositae	*Arctium spp*	Burdock
	Cirsium arvense	Creeping thistle
	Cirsium vulgare	Spear thistle
	Crepis capillaris	Smooth hawksbeard
	Lapsana cummunis	Nipplewort
	Matricaria indorum	Scentless mayweed
	Matricaria matricariodes	Pineapple weed
	Matricaria spp	Scented mayweed
	Senecio vulgaris	Groundsel
	Sonchus asper	Prickly sowthistle
	Taraxacum officinale	Dandelion
Euphorbiaceae	*Euphorbia helioscopia*	Sun spurge
Geraniaceae	*Geranium dissectum*	Cut-leaved cranes bill
Gramineae	9 grass species	Grass
Labiatae	*Galeopsis tetrahit*	Common hempnettle
	Lamium spp.	Dead nettle
	Stachys sylvatica	Hedge woundwort
Onagraceae	*Epilobium spp*	Willowherb
Polygonaceae	*Polygonium arviculare*	Knotgrass
	Polygonium convolvulus	Black bindweed
	Polygonium hydropiper	Water peper
	Polygonium lapathifolium	Pale persicaria
	Polygonium persicaria	Redshank
	Rumex acetosella	Sheeps sorrel
	Rumex obtusifolius/ crispus	Broad-leaved/ Curled Dock
Primulaceae	*Anagallis arvensis*	Scarlet pimpernel
Ranunculaceae	*Ranunculus*	Buttercup
Rosaceae	*Aphanes arvensis*	Parsley piert
	Rubus fructocsus agg.	Blackberry
Scrophulariaceae	*Veronica spp*	Ivy leaved speedwell
Solanaceae	*Solanum spp*	Bittersweet/ Black nightshade
Umbelliferae	*Aethusa cynapium*	Fools Parsley
	Anthriscus sylvestris	Cow parsley
	Heracleum sphondylium	Hogweed
Urticaceae	*Urtica dioia*	Stinging nettle
	Urtica urens	Small nettle
Violaceae	*Viola arvensis*	Field Pansy

4.4.2 Seed loss over winter

The mean seed density in autumn were 379.5 m^{-2} in NIT fields and 240.1 m^{-2} in CT fields with an overall mean for all fields in both years of 309.8 m^{-2}. The mean number of seed species per field was approximately 18 species m^{-2} in autumn and 15 species m^{-2} in spring and was similar for both tillage treatments (Table 4.5). The overall percentage change for all fields was -6.46%, although NIT fields lost-21.3% whereas CT fields gained 17.4% in total numbers of species. There was a great amount of variation in the percentage change of the total number of seeds between fields (Figure 4.6 and Figure 4.7).

Table 4.5. Densities of weed seeds (m^{-2}) and number of species

	NIT	CT	All fields
Autumn			
Number of fields	20	20	40
Seed density m^{-2}	379.5 (± 123.1)	240.1 (± 41.8)	309.8 (± 65.2)
Seed species m^{-2}	18.04 (± 1.259)	17.33 (± 1.023)	17.67 (± 0.802)
Spring			
Number of fields	20	19	39
Seed density m^{-2}	298.4 (±102.6)	281.9 (± 64.5)	290.4 (+/- 60.5)
Seed species m^{-2}	15.20 (± 1.507)	15.53 (± 1.230)	15.36 (± 0.953)
Overall % change	-21.3702	17.40941	-6.2621

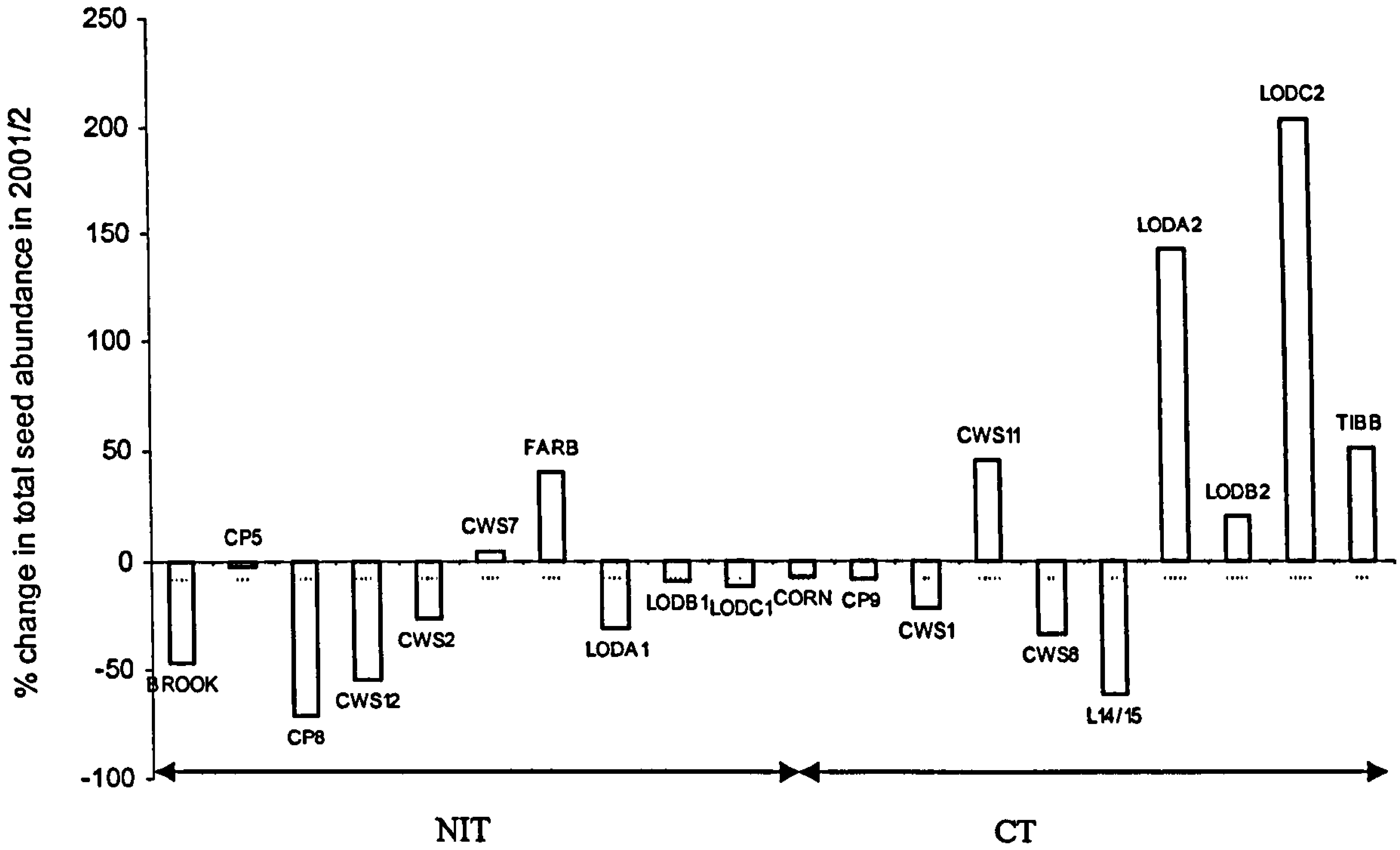

Figure 4.6. Percentage change in seed abundance over the winter within each field in 2001/2. First ten fields are NIT and the rest are CT.

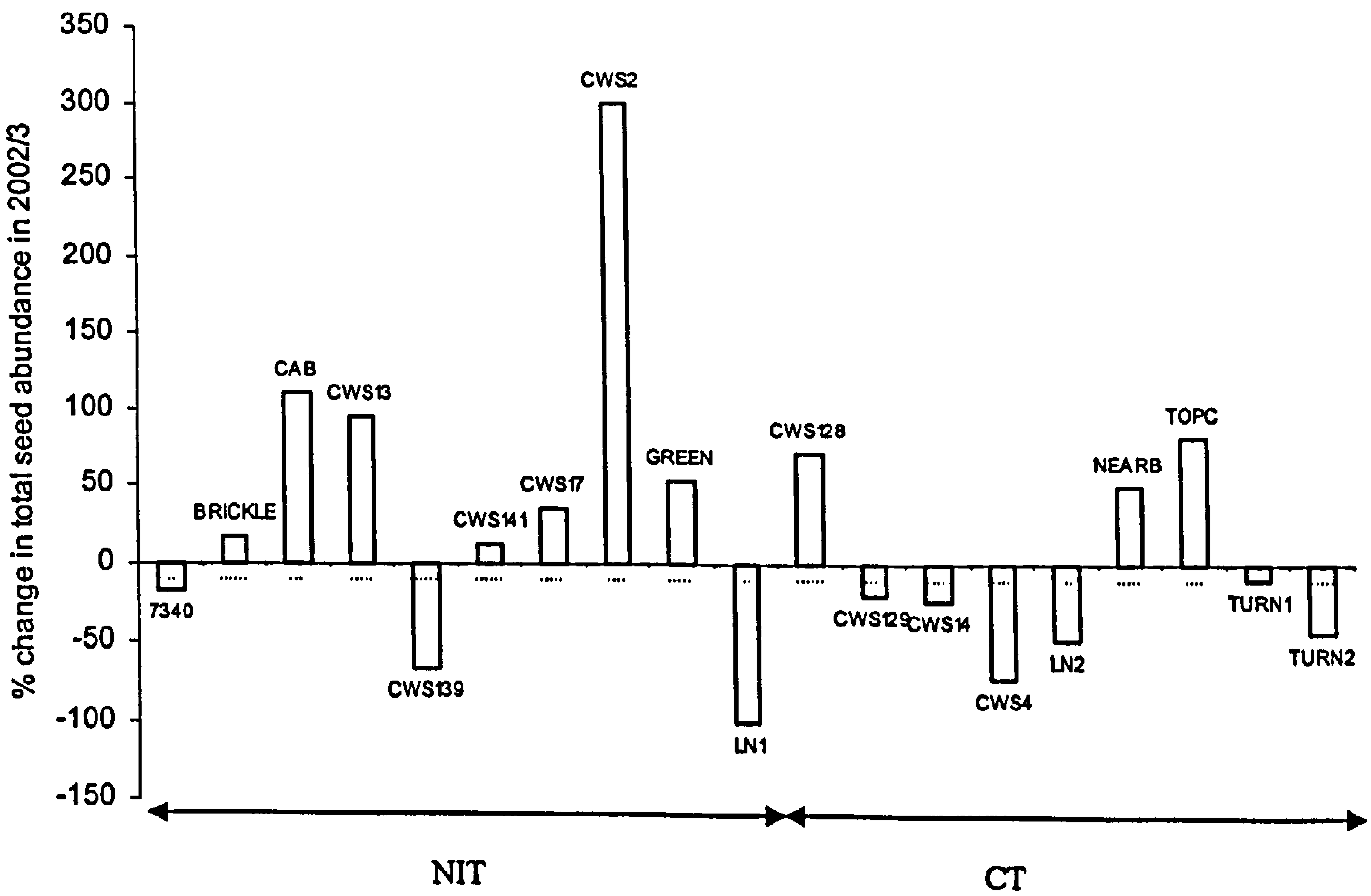

Figure 4.7. Percentage change in seed abundance over the winter within each field in 2002/3. First ten fields are NIT and the rest are CT.

4.4.3 Autumn results

Tillage was not significant in explaining the variation in any of the seed species or groups in autumn. The two factors that explained variation were year and distance from the crop edge (Table 4.6). For Knotgrass, Pansy, Broad-leaved weeds and Chenopodiaceae there were a greater number of seeds at the middle of the field compared to 1 m and 8 m from the crop edge (Figure 4.8 and Figure 4.9). Whereas for Gramineae, a relatively greater number of seeds were observed at 1 m compared to 8 m and in the middle of the field (Figure 4.8). For the response variables Knotgrass, Gramineae, Polygonaceae and total number of seeds and total number of species, year was significant in explaining the variation. There were always a significantly greater number of seeds in year 1, 2001, than in year 2, 2002 (Figure 4.10). An interaction between year and distance was observed for the total number of seeds (Table 4.6). In year 1, 2001, the mean number of seeds increased from the crop edge to the middle of the field and the reverse occurs in year 2, 2002 (Figure 4.11). No factors significantly explained the variation in the relative abundance of chickweed (Table 4.6).

Table 4.6. General log-linear regression analysis (GLMM) of relative seed abundance in the autumn

Seed species / Family	Term:	Wald statistic	d.f.	Wald d.f.	P (χ^2)
Knotgrass	Distance	6.53	2	3.26	0.038
	Year	5.42	1	5.42	0.020
Chickweed	No significant factors				
Forget-me-not	Distance	36.22	2	18.11	<0.001
Pansy	Distance	39.4	2	19.7	<0.001
Gramineae	Distance	25.22	2	12.61	<0.001
	Year	8.8	1	8.8	0.003
Broadleaved weeds	Distance	9.62	2	4.81	0.008
Polygonaceae	Year	5.39	1	5.39	0.020
Chenopodiaceae	Distance	37.19	2	18.59	<0.001
Total number of seeds	Distance	10.06	2	5.03	0.007
	Year	4.06	1	4.06	0.044
	Distance*Year	9.94	2	4.97	0.007
Total number of seed species	Distance	37.58	2	18.79	<0.001
	Year	6.03	1	6.03	0.014

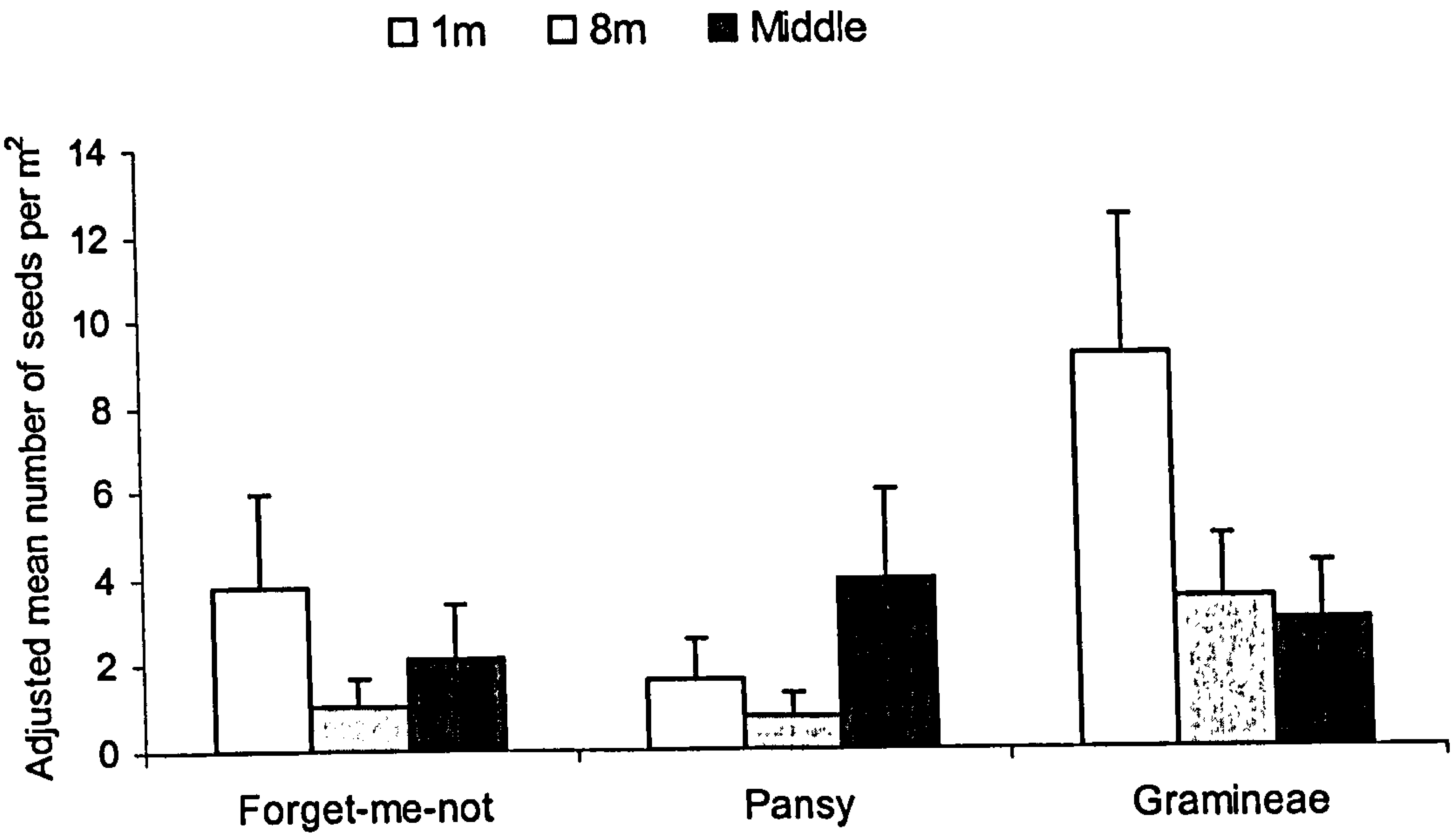

Figure 4.8. Adjusted mean (+SE) number of seeds per m^2 at each distance in autumn (under 10 seeds per m^2)

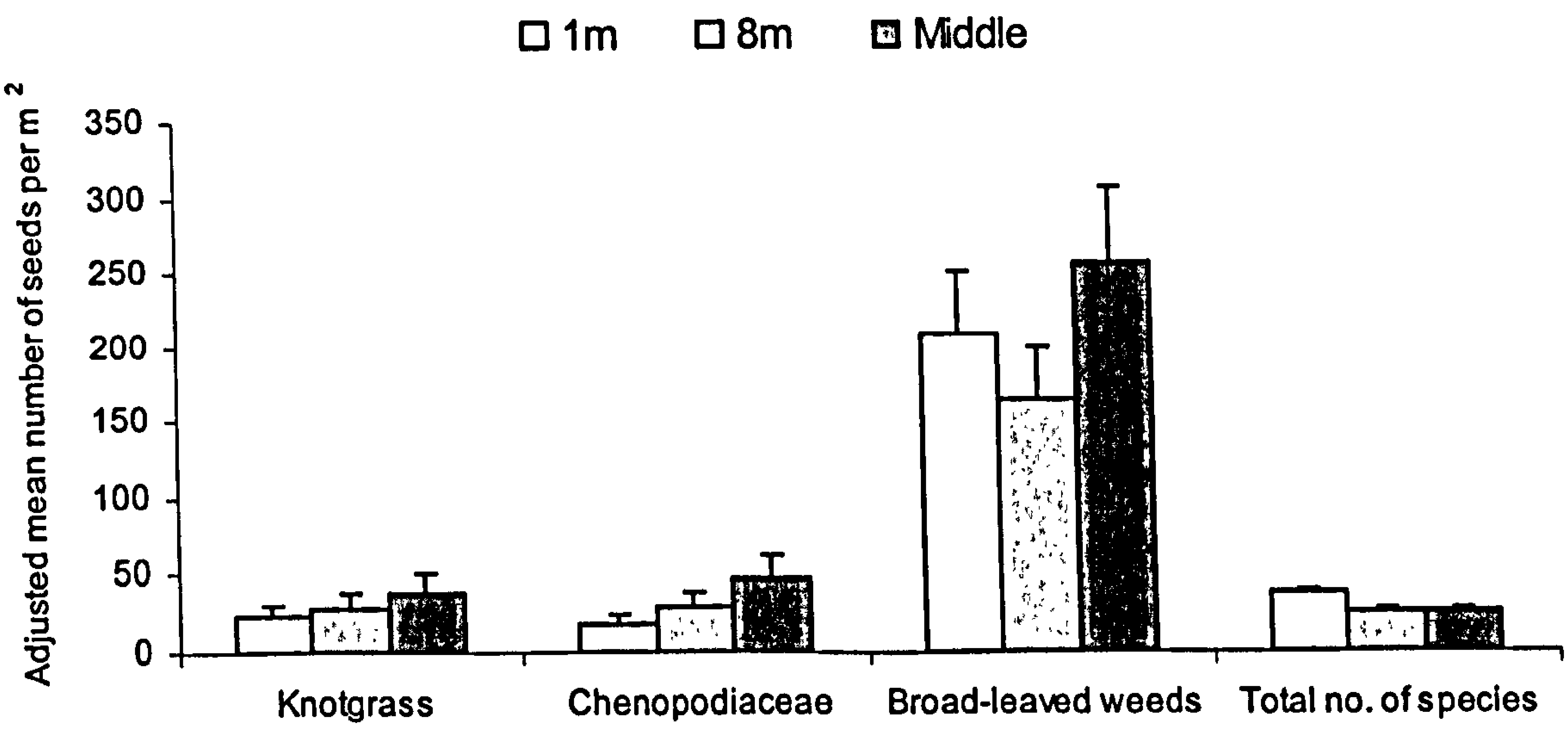

Figure 4.9. Adjusted mean (+SE) number of seeds per m^2 at each distance in autumn (over 10 seeds per m^2)

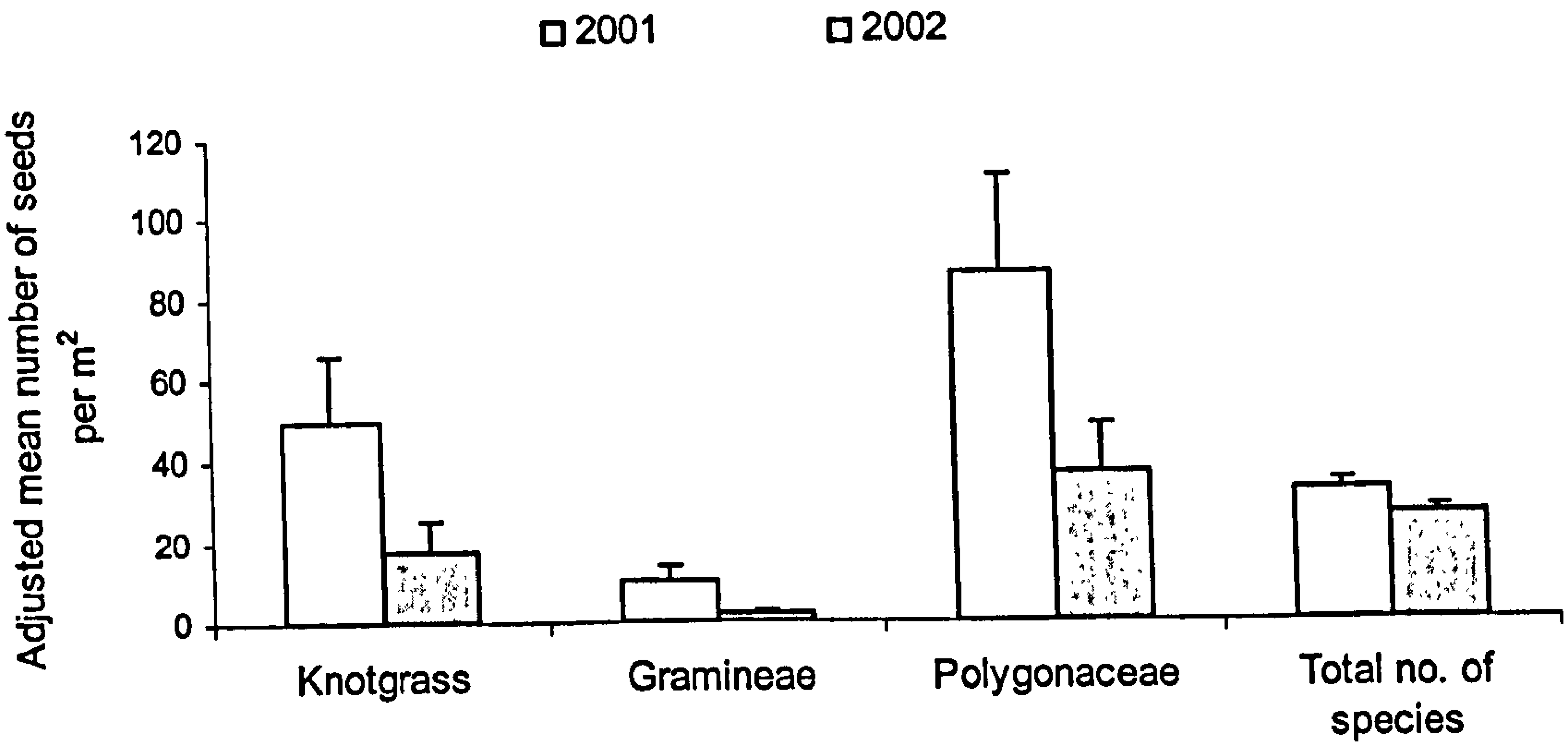

Figure 4.10. Adjusted mean (+SE) number of seeds per m^2 in each year in autumn

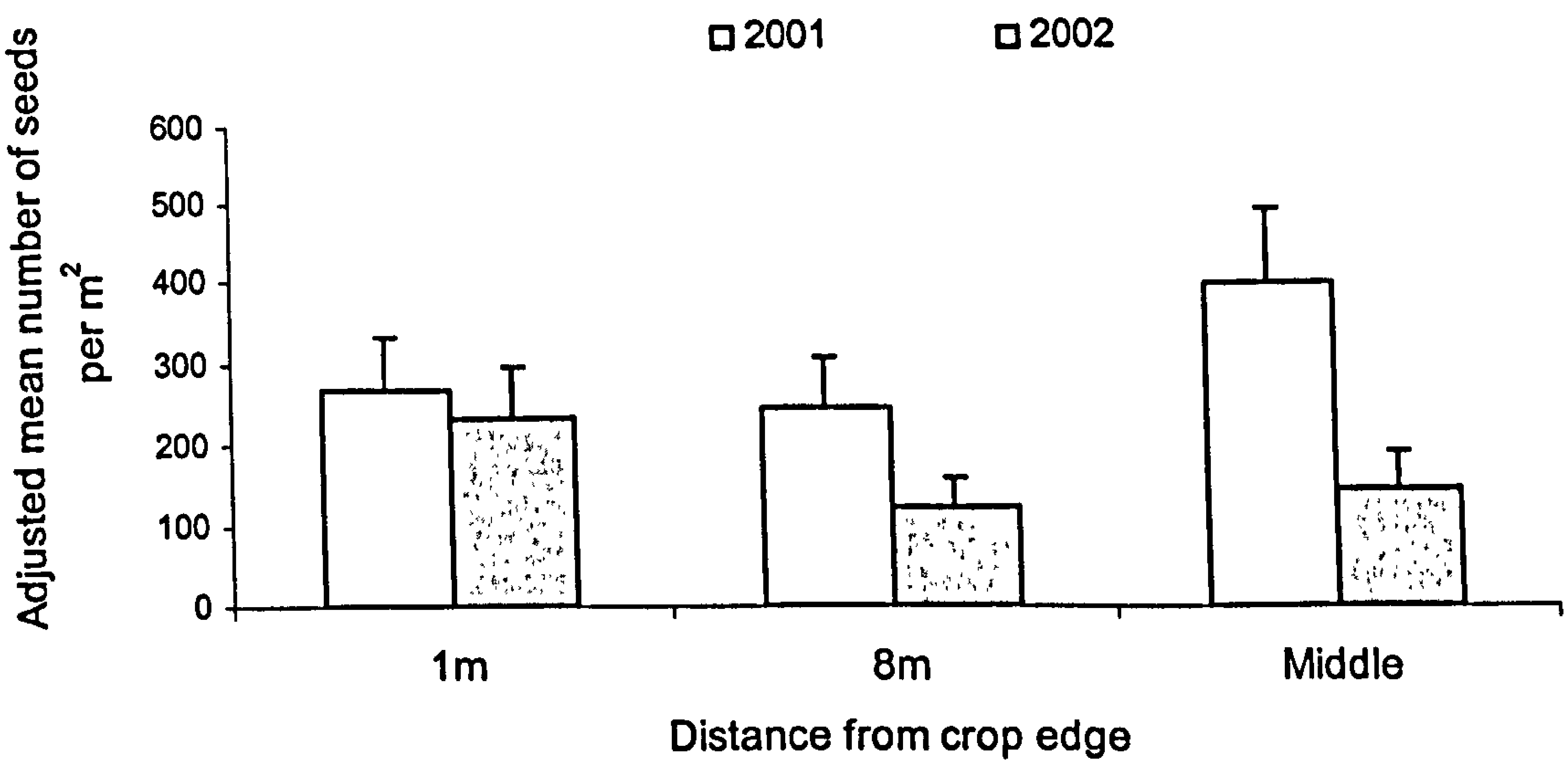

Figure 4.11. Adjusted mean (+SE) number of seeds at each distance in each year in autumn

4.4.4 Spring results

Tillage was not significant in explaining the variation in any of the seed species or groups in spring. The two factors that explained variation were year and distance from the crop edge (Table 4.7). For the response variables Knotgrass, broad-leaved weeds, Polygonaceae and total number of seeds and total number of species, year was significant in explaining the variation in spring (Table 4.7). For Chickweed, Forget-me-not, Pansy and Chenopodiaceae there were a greater number of seeds at the middle of the field compared to 1 m and 8 m from the crop edge (Figure 4.12 and Figure 4.13). Whereas, for Gramineae and total number of seed species, a relatively greater number of seeds were observed closer to the crop edge at 1 m compared to 8 m and the middle of the field (Figure 4.12 and Figure 4.13). This indicates that the number of Gramineae is having an influential impact on the pattern of the overall total number of species. There were always a significantly greater number of seeds in year 1, 2001, than in year 2, 2002 (Figure 4.14).

Table 4.7. General log-linear regression analysis (GLMM) of relative seed abundance in the spring

Seed species / Family	Term:	Wald statistic	d.f.	Wald d.f.	P (χ^2)
Knotgrass	Year	8.79	1	8.79	0.003
Chickweed	Distance	12.65	2	6.33	0.002
Forget-me-not	Distance	18.11	2	9.05	<0.001
Pansy	Distance	34.23	2	17.12	<0.001
Gramineae	Distance	20.9	2	10.45	<0.001
Broadleaved weeds	Year	4.47	1	4.47	0.034
Polygonaceae	Year	10.33	1	10.33	0.001
Chenopodiaceae	Distance	8.57	2	4.29	0.014
Total number of seeds	Year	4.87	1	4.87	0.027
Total number of seed species	Distance	12.97	2	6.48	0.002
	Year	8.93	1	8.93	0.003

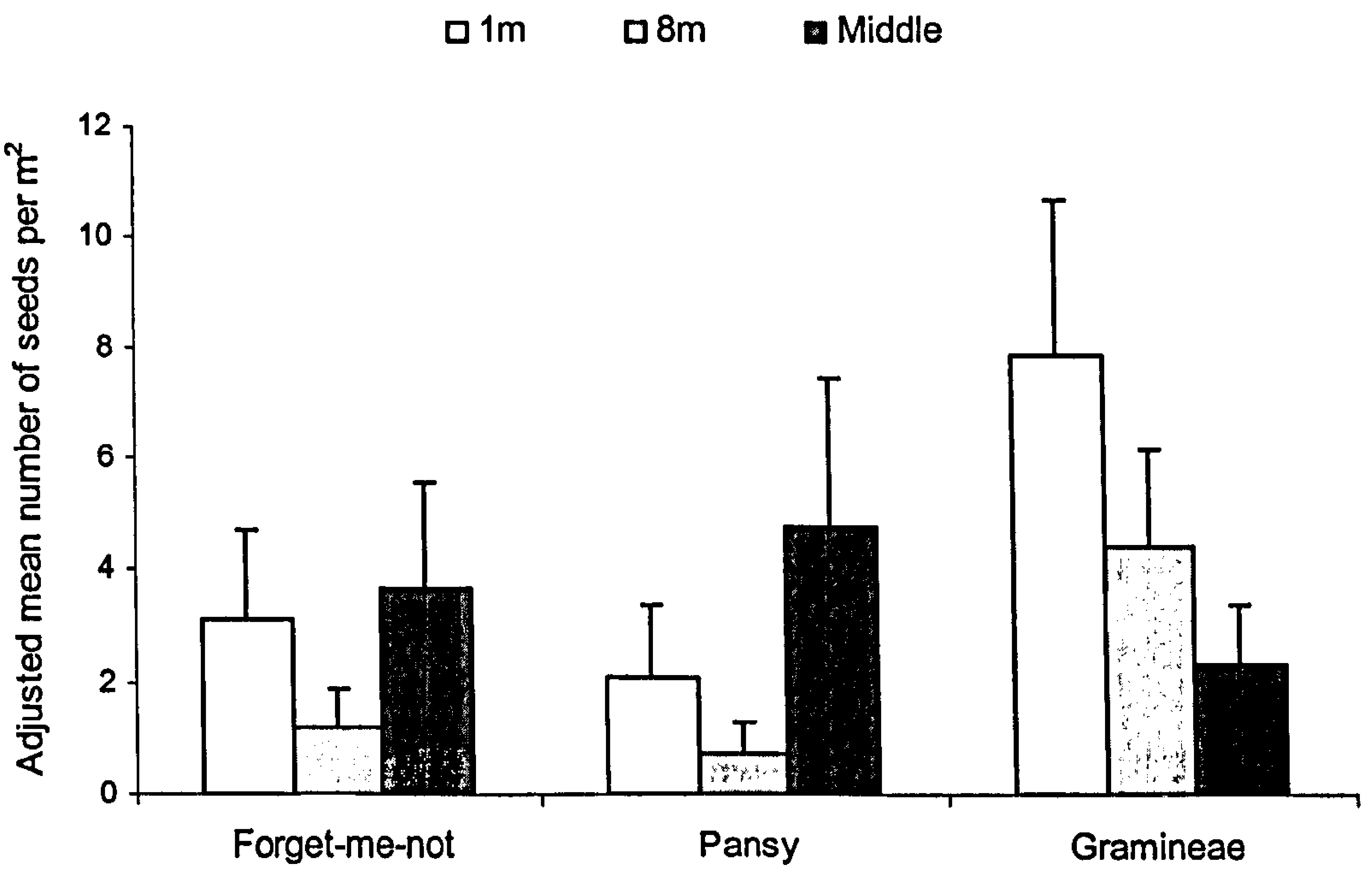

Figure 4.12. Adjusted mean (+SE) number of seeds per m^2 at each distance in spring (under 10 seeds per m^2)

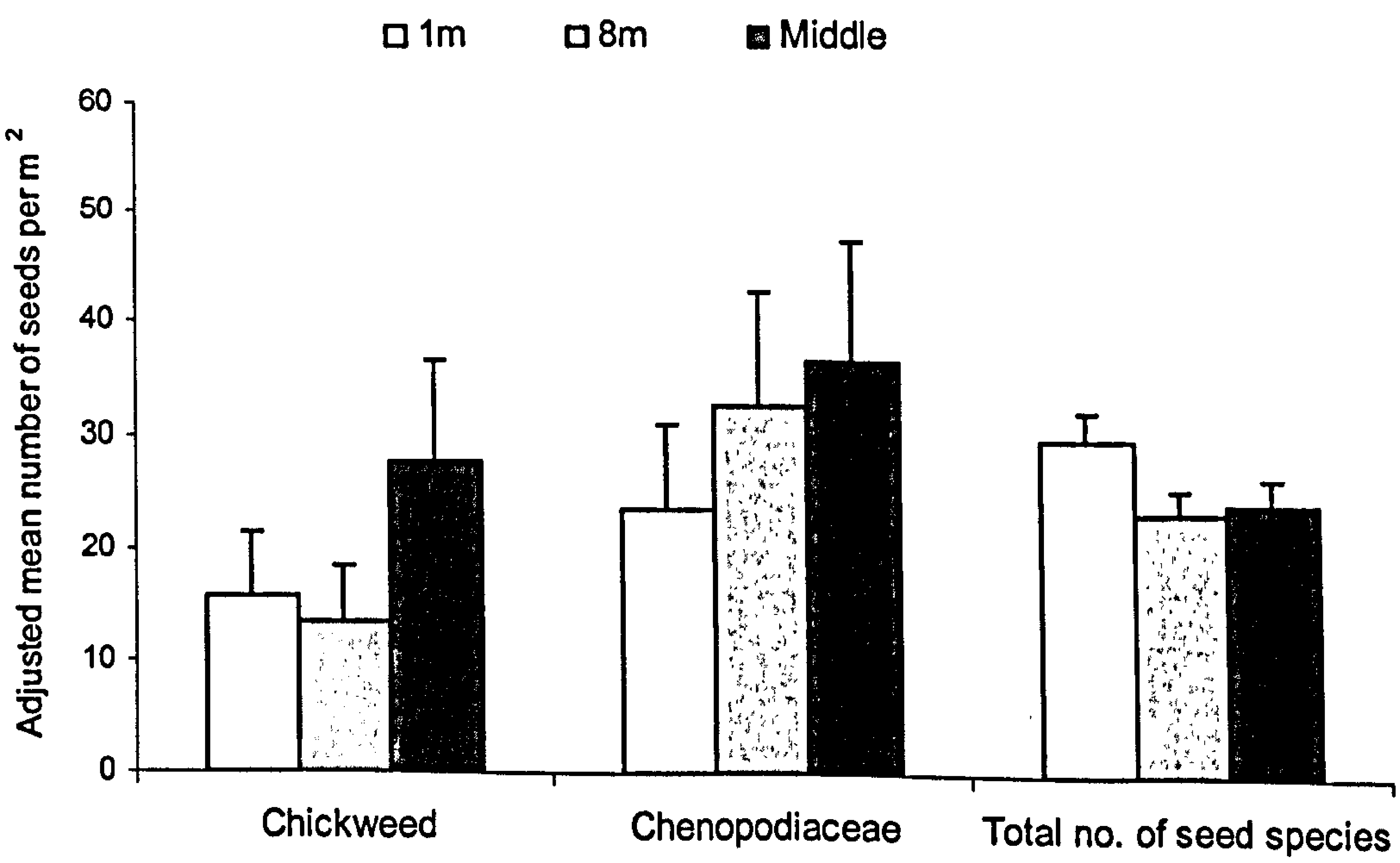

Figure 4.13. Adjusted mean (+SE) number of seeds per m^2 at each distance in spring (over 10 seeds per m^2)

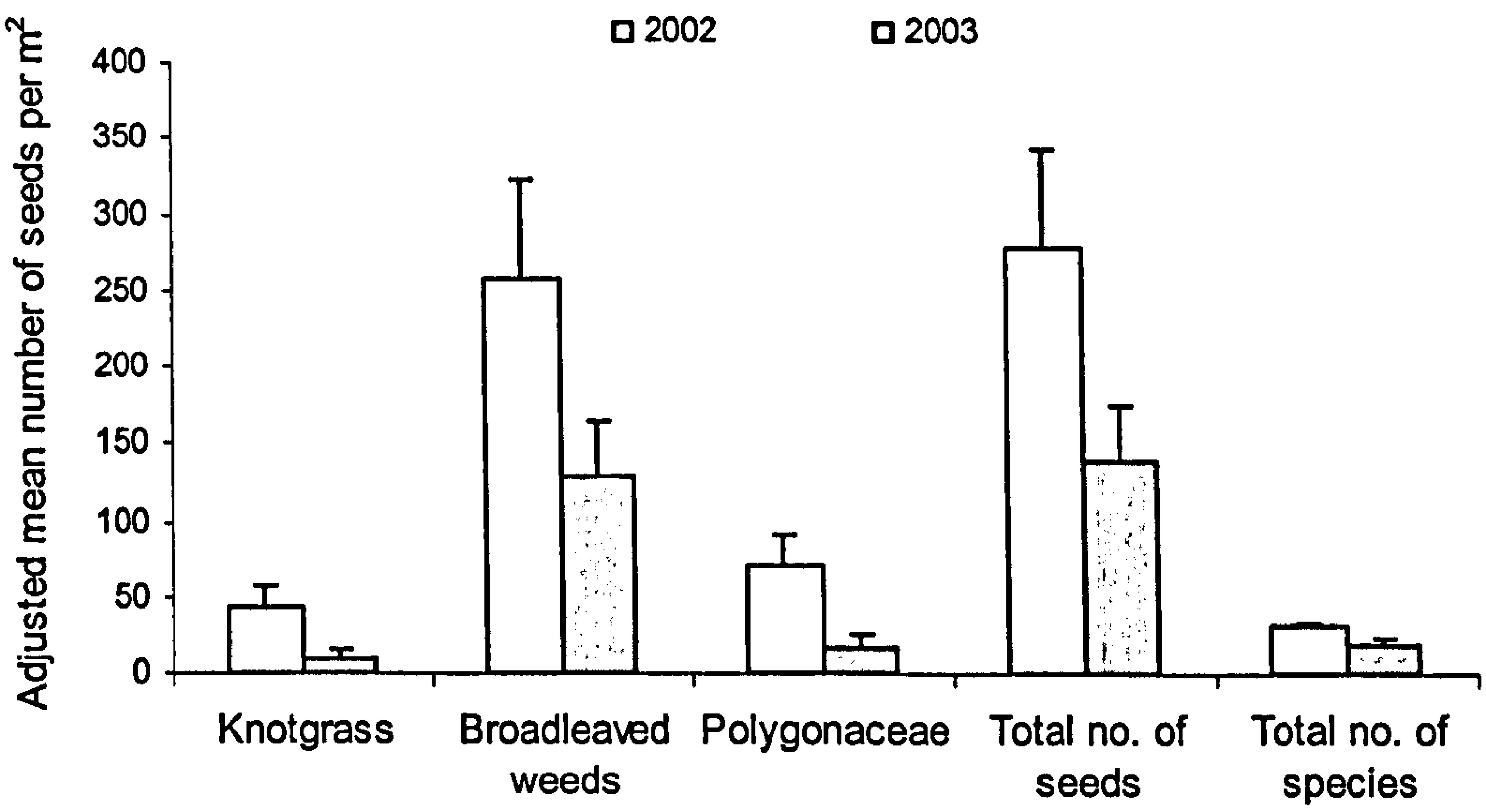

Figure 4.14. Adjusted mean (+SE) number of seeds per m^2 in each year in spring

4.4.5 Summary of autumn and spring results

Table 4.8. Summary of all the MAMs in both sampling periods for each seed species and group.

	Seed species / Family	Sampling period Autumn	Spring
Species	Knotgrass	Distance + Year	Year
	Chickweed	No significant factors	Distance
	Forget-me-not	Distance	Distance
	Pansy	Distance	Distance
Family/ Groups	Gramineae	Distance + Year	Distance
	Broadleaved weeds	Distance	Year
	Polygonaceae	Year	Year
	Chenopodiaceae	Distance	Distance
	Total number of seeds	Distance + Year + Year* Distance	Year
	Total number of seed species	Distance + Year	Distance + Year

Table 4.9. Summary of distance results

	Seed species / Family	Sampling period Autumn	Spring
Species	Knotgrass	Distance (1m< 8m <Mid)	
	Chickweed		Distance (8m≤ 1m <Mid)
	Forget-me-not	Distance (8m ≤ Mid <1m)	Distance (8m< 1m ≤Mid)
	Pansy	Distance (8m ≤ 1m <Mid)	Distance (8m≤ 1m <Mid)
Family/ Groups	Gramineae	Distance (Mid ≤ 8m <1m)	Distance (Mid< 8m <1m)
	Broadleaved weeds	Distance (8m ≤ 1m <Mid)	
	Polygonaceae		
	Chenopodiaceae	Distance (1m < 8m <Mid)	Distance (1m< 8m ≤Mid)
	Total number of seeds	Distance (8m < Mid ≤1m)	
	Total number of seed species	Distance (8m ≤ Mid <1m)	Distance (8m≤ Mid <1m)

Table 4.10. Summary of year results

	Seed species / Family	Sampling period Autumn	Spring
Species	Knotgrass	Year (2 < 1)	Year (2 < 1)
	Chickweed		
	Forget-me-not		
	Pansy		
Family/ Groups	Gramineae	Year (2 < 1)	
	Broadleaved weeds		Year (2 < 1)
	Polygonaceae	Year (2 < 1)	Year (2 < 1)
	Chenopodiaceae		
	Total number of seeds	Year (2 < 1) + Year* Distance	Year (2 < 1)
	Total number of seed species	Year (2 < 1)	Year (2 < 1)

4.5 Discussion

The lack of differences between tillage treatments in terms of the numbers of seeds at the soil surface may be due to several factors. Tillage alone may change the distribution of seeds within the soil and therefore affect the abundance and composition of seeds that germinate. However, NIT and CT systems can differ with respect to the herbicide regime used to control weeds. In NIT systems the weed seeds are encouraged to germinate and a post-emergence herbicide is used to control the weed seedlings. This is a contact herbicide that is applied before the crop emerges. Therefore the amount of weed seeds retained at the soil surface and available to birds may be greatly diminished. Several of the fields had only been established by NIT in the year sampling took place and effects of tillage treatments on weed seeds at the soil surface may be seen only after several years. Between field differences in terms of the residual seed bank (i.e. the seeds already present within the soil matrix) may have had a greater influence on the seeds at the soil surface compared to the effects of the tillage treatments. One way to address this problem is to take samples before and after cultivations and/or take deep cores at the time of sampling to compare or control for between field differences. Another experimental design could have been used to control for these differences such as a split-field or small plot design. However, financial and logistical constraints (as outlined in the earthworm chapter discussion) prevented the implementation of these designs. A small plot design would allow the components of the tillage system to be tested, i.e. the effects of cultivation versus agrochemical. Increases in earthworm abundance have been observed in other farming systems, similar to NIT, only after three years of application, therefore it would be interesting to assess the effect of NIT in the longer term. In the UK, NIT has become a more popular method due to its reduced crop establishment costs. Not all growers completely convert to NIT establishment techniques throughout their farm on all crops. NIT is often used together with a mouldboard plough within certain rotations or to establish certain crops. The decision making process of choosing a crop establishment method can also be influenced by factors such as weather, soil type, grass weed abundance and machinery availability. Therefore, it is important to investigate both the short and long term effects of tillage regimes on the abundance of weed seeds on the soil surface.

In this study the mean number of seed species found was 18 m^{-2} in autumn and 15 m^{-2} in spring. This is much greater than previous studies that have found only a mean seed species of 2-3 m^{-2} (Robinson & Sutherland 1999, Moorcroft *et al.* 2002). However, these two studies used a different experimental design from this investigation. A greater number of seed species may have been observed in this study because two thirds of the samples (six out of nine samples per field) were taken within 8 m of the crop edge. Whereas Robinson & Sutherland (1999) and Moorcroft *et al.* (2002) both took a similar number of samples as this study, but at distances along a transect across each field. Therefore a relatively fewer samples were taken at the field edges in these two studies and, in arable fields, it has been found that there is a greater abundance and species richness of seeds at the crop edge compared to the middle of fields (Marshall 1989, Wilson & Aebischer 1995).

The overall loss of seeds over the winter period was a decline of 6%. This is greater than the 2% decline found in winter cereals and less than the 22% decline observed in wheat stubbles (Robinson & Sutherland 1999, Moorcroft *et al.* 2002). The decline of 21% in seed abundance seen in NIT fields was similar to the 22% decline seen in wheat fields by Robinson & Sutherland (1999). Whereas in CT fields, an increase in seeds of 17% was observed, although this seems to be largely explained by the large increases in seed numbers in 2001 to 2002 in two fields, LOD A2 and LOD C2 (Figure 4.6).

The results presented here contrast with other studies that have found differences in weed abundance in different tillage regimes (e.g. Torressen & Skuterud 2002, Mas & Verdu 2003). However, these studies examined seeds below the soil surface whereas this thesis examined seeds at the soil surface. The deep soil cores and vegetation surveys used in these investigations are likely to over- and under-estimate seeds at the soil surface respectively.

Distance from the crop edge ('distance') was the factor that most commonly explained the variation in seed numbers. In fact, out of the ten response variables used in the analysis in this study Polygonaceae was the only seed group or species where distance did not explain the variation. The abundance of seed groups or species at each distance in to the field did not change from autumn to spring. This can be seen for Pansy, Gramineae, Chenopodiaceae and the total number of species. Where distance was significant in autumn and spring, the patterns of abundance are the same. There were more Forget-me-not, Gramineae and seed species at 1 m from the crop edge compared with 8 m and in the middle of the field, whereas Pansy was observed at higher densities in the middle of the field. This concurs with Wilson & Aebischer (1999) who found similar distributions of seedlings of Forget-me-not and Pansy.

For many of the groups or species, there were often more seeds in the autumn and spring of the first year of the investigation (2001/2) than the second (2002/3). The significant interaction between year and distance showed that there were a greater abundance of seeds in the middle of the field in 2001/2 whereas the reverse was seen in 2002/3. This may be an indication that distributions, in terms of the total number of weed seeds, change annually. In addition to the movement of seeds by cultivations, changing distributions of seeds between years may be a reflection of fluctuating seed predator populations, such as carabid beetles, mammals and birds. Different animals may forage in different parts of the fields, and therefore in certain years, seeds in different areas of the fields may be exposed to different levels of predation.

4.6 Summary

- Tillage did not explain the variation in seed numbers or species.
- Distance from the crop edge and year were the factors that explained the variation in seed numbers.
- There were a greater number of seeds and species in 2001/2 than 2002/3.

Chapter 5

THE EFFECT OF NON-INVERSION TILLAGE ON SURFACE ACTIVE ARTHROPOD POPULATIONS AS POTENTIAL FOOD SOURCES FOR FARMLAND BIRDS

5.1 Summary

Forty different wheat fields were surveyed for arthropods over two cropping seasons, with twenty fields surveyed per year. Half of the fields were established by non-inversion tillage (NIT) and the other by conventional tillage (CT). Arthropods were surveyed by setting four pitfall traps at three distances into the fields (i.e. trap position) – 1 and 14 metres from the crop edge and in the middle of the field. Traps were set for one week in March, May and July in 2002 and 2003.

Logistic regression was used to assess the difference in arthropod numbers between NIT and CT fields whilst accounting for field variables such as previous crop type and field size. Surface-active arthropods were analysed in four response variables: carabid beetles (Coleoptera: Carabidae), staphylinid beetles (Coleoptera: Staphylinidae), beetle larvae (Coleoptera) and spiders (Arachnidae: Araneae).

Tillage did not explain the variation in any of the arthropod groups sampled in any of the three months. Factors that explained the variation in arthropod numbers were the trap position and previous crop type.

As previous crop type was a significant factor in explaining the variation of arthropod abundance, the data were re-analysed using two sub-sets, so there was only one type of previous crop and this factor could be removed from the model. The two sub-sets used were where the previous crop type was oilseed rape and the other was set aside. Generally the minimum adequate models were the same as those using the full data set, except lacking previous crop type where it was previously significant. However, when oilseed rape was the only previous crop type there were a significantly greater number of beetle larvae in CT compared to NIT fields in July.

5.2 Introduction

5.2.1 Farmland birds and arthropods

Many farmland birds use arable fields in two main ways: as nesting and foraging sites. In the breeding season, over the spring and summer months, the birds use arable fields as foraging sites to find food not only for themselves but also for their chicks. Although many of the declining farmland bird species are granivorous, over the breeding season invertebrates are an important food source for chicks and adults. Many of the declining bird species on arable land are ground feeding species, such as Yellowhammer *Emberiza citrinella*, Skylark *Alauda arvensis* and Grey Partridge *Perdix perdix*. Therefore, epigeal or surface-active arthropods form an important part of their diet. Surface-active arthropods commonly found in cereal fields are beetles, adults and larvae, and spiders. The two families of beetles most often observed inhabiting cereal fields are ground (Coleoptera: Carabidae) and rove (Coleptera: Staphylinidae) beetles, and several families of spiders including wolf (Lycosidae) and money (Linyphiidae) spiders. Carabid and staphylinid beetles and spiders are important in the diet of adult farmland birds and their chicks, over the breeding season for some species and throughout the year for others (Table 5.1, Wilson *et al.* 1996). Body size may be important when considering arthropods as a food source for farmland bird and several authors have shown small sized carabids (e.g. *Trechus quadristriatus* and Bembidion species) are important in Grey and Red-legged Partridge *Alectoris rufa* and Pheasant *Phasianus colchicus* chick food (Green 1984, Hill 1985, Potts & Aebischer 1991).

Table 5.1. Farmland birds that carabid and staphylinid beetles and spiders form an important part of their diet (Compiled from information in Wilson *et al.* 1996).

Bird species	Beetles		Spider	Adults (A) /Chicks (C)	Breeding season (B) / All year (Y)
	Carabid	Staphylinid			
Skylark (*Alauda arvensis*)	*		*	A, C	B
Partridge (*Perdix perdix* and *Alectoris rufa*)	*	*	*	A, C	B, Y
Pheasant (*Phasianus colchicus*)	* (&l)	* (l)	*	A, C	B, Y
Lapwing (*Vanellus vanellus*)	*		*	A	A
Meadow pipit (*Anthus pratensis*)		*		A	
Blackbird (*Turdus merula*)	* (l)	* (l)	*	A, C	B
Song Thrush (*Turdus philomelos*)	* (l)	* (l)	*	A, C	B
Mistle Thrush (*Turdus viscivorus*)	* (l)	* (l)		A, C	B
Chaffinch (*Fringilla coelebs*)			*	A, B	B
Yellowhammer (*Emberiza citrinella*)		*	*	A, C	B
Cirl bunting (*Emberiza cirlus*)		*		C	B
Linnet, Greenfinch, Goldfinch (*Carduelis cannabina* and *Carduelis chloris* and *Carduelis carduelis*)			*	C	B

* = arthropod important in the diet, (l) = larvae only, (&l) = adults and larvae.

Carabid beetles occur more frequently in the diets of chicks on cereal fields compared to other arable habitats, such as grass or set aside (Donald, 1999). Spiders were found to be the most commonly occurring invertebrates in Skylark chick diet (Donald, 1999). This may indicate that when Skylarks nest on cereal fields, the field therefore becomes a foraging ground for their chicks, and carabids, and potentially spiders, become an increasingly important food source in their diet. Spiders have been observed to be present and important in the diet of a greater proportion of the declining farmland bird species compared with non-declining species (Wilson *et al.* 1999). This signifies that although spiders were taken by fewer bird species than several other groups, they are important when addressing the declines of farmland birds. It has been recognised that Arachnida and Coleoptera are two of the seven orders of invertebrate that make up almost all of the diet of declining farmland birds (Wilson *et al.* 1999).

5.2.2 Surface active arthropods in arable ecosystems

The majority of spiders inhabiting crops in Europe are from the family Linyphiidae and other common families include Lycosidae, Araneidae, Tetragnathidae, and Theridiidae (Nyffeler & Sunderland 2003). A significant proportion of spiders inhabiting crops are known to be ground-dwelling species (Nyffeler & Sunderland 2003). Carabid beetles and their larvae can be an important part of farmland bird diet, but they can also play an important role in agro-ecosystems as predators of crop pests such as aphids (Jorgensen & Toft 1997), and by controlling weeds by predating seeds (Hartke *et al.* 1998).

Arthropods in farmland have shown long-term population declines (Aebischer 1991). It has been suggested that these declines can be linked to the intensification of agriculture (Benton *et al.* 2002). Agricultural practices that are known to have detrimental effects on beneficial arthropods include insecticides and herbicides (e.g. Basedow 1991), crop rotations and establishment methods such as ploughing (e.g. Holland & Reynolds 2003).

The effects of agrochemicals on target and non-target arthropods have been well documented. Autumn insecticide application has been shown to decrease the density of linyphiid spiders in cereal fields by two to three fold compared with unsprayed fields; these lower spider densities were observed in the sprayed cereal fields until the early summer (Thomas & Jepson 1997). The effects of pesticides on staphylinid beetles can have detrimental effects on their activity and abundance in the long and short term depending on the chemical (Bohac 1999). Abundance and species richness of carabid beetles and spiders, and species diversity of spiders has been observed to be greater in cropped headlands where spraying is restricted (Hassall *et al.* 1992).

Agro-ecosystems are highly disturbed habitats with largely temporary crops surrounded by non-crop habitats such as hedgerows and ditches. Many arthropods inhabit the cropped areas despite high disturbance within them. However, disturbance can affect the type of arthropods inhabiting crop areas. It has been reported for arthropods, including carabid beetles, body size decreases with increased agricultural intensification or management (Blake *et al.* 1994, Buchs *et al.* 1997, Burel *et al.* 2004).

Crop type has been shown to have a significant effect on carabid beetles (e.g. Hance & Gregoire-Wibo 1987, Kromp 1999). It has been suggested one of the main reasons that crop type has such a significant effect on carabids is the varying effects of crops on microclimatic conditions, such as soil temperature and relative humidity, on and around the soil surface (Hance 2002). When assessing the impacts of different agricultural practices on arthropods such as carabids, these differences can be accounted for by sampling within the same crop type.

Crop rotation, largely the impact of the previous year's crop, can have an impact on arthropods in several ways. The previous year's crop can affect arthropods by potentially leaving the soil surface exposed for varying lengths of time. This has been observed for carabids, where detrimental effects on carabid communities were observed in maize crops preceded by wheat compared with continuous maize cropping, as the former led to a greater period of time the soil surface was exposed (Lövei 1984). There are also the associated effects of different husbandry techniques such as crop establishment and harvesting methods as well as weed and insect pest control strategies (Hance 2002). Several studies have observed the effects of previous crop or crop rotations on arthropod populations. Different crop rotations have been shown to change the population size of money spiders (Halley *et al.* 1996). Higher carabid densities have been seen in monocultures of wheat compared to those where the previous crop was sunflower, maize and beet which was believed to be due to pesticide use (Sekulic *et al.* 1987).

Arthropods can have different spatial distributions within fields. Factors that effect their spatial distribution within fields can include vegetation cover, prey distribution and abundance, and dispersal ability from over-wintering sites. Different families of spiders have been observed to have different distributions within agricultural fields. Greater numbers of wolf spiders (Lycosidae) have been observed at the edge of fields compared to the middle, whereas money spiders (Linyphiid) are believed to be more homogenously distributed within fields (Holland *et al.* 1999). These differences between families are because wolf spiders are associated with weed cover (Holland *et al.* 1999) and money spiders aggregated around their prey (Harwood *et al.* 2001). In arable fields, spatial distributions of arthropods, such as beetles and spiders, are known to be affected by factors including microclimate and prey availability (Bryan & Wratten 1984, Honek 1988).

Spiders and beetles in agro-ecosystems have a range of diets specific to families or species, or behavioural groups. Spiders are strictly carnivorous with the web-weavers (such as Linyphiidae) taking insects almost exclusively, and hunters (such as Lycosidae) taking other spiders as well as insects (Nyffeler 1999). Although, some species of spiders from several families have been observed to take slugs (Nyffeler & Symondson 2001), as have the carabid beetles *Pterostichus melanarius* species (Symondson *et al.* 2002). Carabid beetles have been classified by Thiele (1977) in to three feeding guilds: polyphagous predators, oligophagous predators and phytophagous carabids. These guilds have been defined in more detail by Totf & Bilde (2002) as:

- Generalist carnivores (e.g. Carabus, Abax and large Pterostichus) take a wide range of invertebrates.
- Generalist insectivores (e.g. smaller carabids such as *Agonum dorsale*, Trechus and Bembidion species) take a wide range of insects.
- Mollusc specialists (e.g. Carabus and Pterostichus) take slugs and snails.
- Caterpillar specialists (e.g. Calosoma).
- Granivores (e.g. Harpalus and Amara) take a range of arable weed seeds.

Due to disturbance and dependant on prey abundance the groups that are commonly found in cereal fields are likely to be the generalist insectivores and granivores.

Other factors that have been shown to affect arthropods in arable ecosystems are field size, soil type and climate. Field size up to 4 km^2 does not appear to affect population densities of money spiders due to their large dispersal abilities (Halley *et al.* 1996). Carabid assemblages appear to be affected by field size and soil type, defined by percentage sand content (Irmler 2003). Arthropod populations can change from one year to the next. This has been seen in carabid assemblages that are highly variable from year to year and this is believed to be highly correlated with weather conditions (Irmler 2003).

5.2.3 Sampling arthropods in cereal fields

One of the most commonly used methods for sampling surface-active arthropods, such as beetles and spiders, in cereal fields is pitfall trapping (Hawthorne, 1995, Purvis & Fadl, 2002, Baguette & Hance, 1997, Nyffeler & Sunderland 2003). This method has been critiqued by several authors (e.g. Lang, 2000). The numbers of arthropods caught in pitfalls are related to their activity, which is influenced by behaviour and vegetation structure as well as density, and therefore results should be referred to as activity density as opposed to absolute density (Thomas *et al.* 1998). Various other sampling methods have been used in cereal fields to trap arthropods and these include suction sampling (e.g. using a D-vac), sweep netting and fenced pitfall trapping. Several authors have compared these methods and evaluated their comparative biases. Methods that trap arthropods in a defined area, such as fenced pitfall traps and D-vac suction sampling can be used to ascertain arthropod density. However, there are disadvantages with using these methods to assess surface active arthropods compared to using pitfall traps. Suction sampling tends to underestimate or miss animals in cracks in the soil or hiding under stones, such as small beetles and beetle larvae (Samu & Sarospataki 1995). This method has also been identified as inappropriate for sampling carabid and staphylinid beetles and wolf spiders (Lycosidae) as it underestimates them due to their size and weight (Mommertz *et al.* 1996). Despite the limitations of unfenced pitfall traps (i.e. they cannot be used to measure absolute density), their benefits in terms of cost and ease of use has been identified. It is believed that when compared to other sampling methods, unfenced pitfall traps may be more representative of 'encounter rates with prey specimens' (Mommertz *et al.* 1996). Pitfall traps can be used as a relative method to compare between similar habitats within the same time; and the traps themselves should have a circular aperture of at least 6 cm in diameter and the traps should be spaced at least 2 m apart (Adis 1979).

5.2.4 Surface active arthropods and NIT

As previously discussed in chapter one, much of the research on the effects of tillage on arthropods has been carried out in North America (e.g. Barney & Pass 1986, Tonhasca 1993). Whereas there is relatively little research published in Europe (Andersen 1999, Baguette & Hance, 1997, Holland & Reynolds 2003). Conflicting results have been found in terms of the effect of tillage on the abundance of arthropods.

5.2.5 Aims of this chapter

The aim of this chapter is to compare the relative abundance of surface-active arthropods in commercial cereal fields, which have been established by either non-inversion tillage or conventional tillage, over the summer breeding season for birds.

5.3 Materials and Methods

5.3.1 Study sites

Forty different wheat fields established by either non-inversion tillage or by ploughing were selected at seven commercial farms in Leicestershire and Shropshire; six farms in year one (2002) and four farms in year two (2003). Twenty fields were surveyed in year one and twenty fields in year two. These fields were surveyed for arthropods over the summer (March, May and July). The tillage history of the fields was not recorded as the majority of farms do not keep records of crop establishment methods. It is likely that the majority of non-inversion tillage (NIT) fields had been ploughed within the previous year or two, with the exception of six fields in Leicester (three NIT and three CT) which had not been ploughed for over five years. The previous crop in each field was recorded. Fields where the previous crop was potatoes or sugar beet were avoided as the establishment and harvesting methods cause a high level of disturbance to the soil and it was felt that this may mask any potential effects of non-inversion tillage and ploughing. The previous crops recorded were winter wheat, winter barley, oilseed rape, peas, beans, maize, grass, and set aside (Table 5.2). The fields ranged in size from 3.86 ha to 22.27 ha (Table 5.3). More detailed information on the fields used in this investigation is presented in appendices 2 and 3.

5.3.2 Experimental design

A stratified sampling design was used to survey the arthropods. This design consisted of four transects running from the field edge to the middle of the field. On each transect there were three sampling points where pitfall traps were set, at increasing distances from the crop edge; they were at 1 m and 14 m from the crop edge, and in the middle of the field. Transects into the field were positioned approximately halfway along the length of one of the field boundaries and were spaced at ten meter intervals. Epigeal arthropods were surveyed by setting four pitfall traps at each sampling zone, totalling 12 traps per field (Figure 5.1).

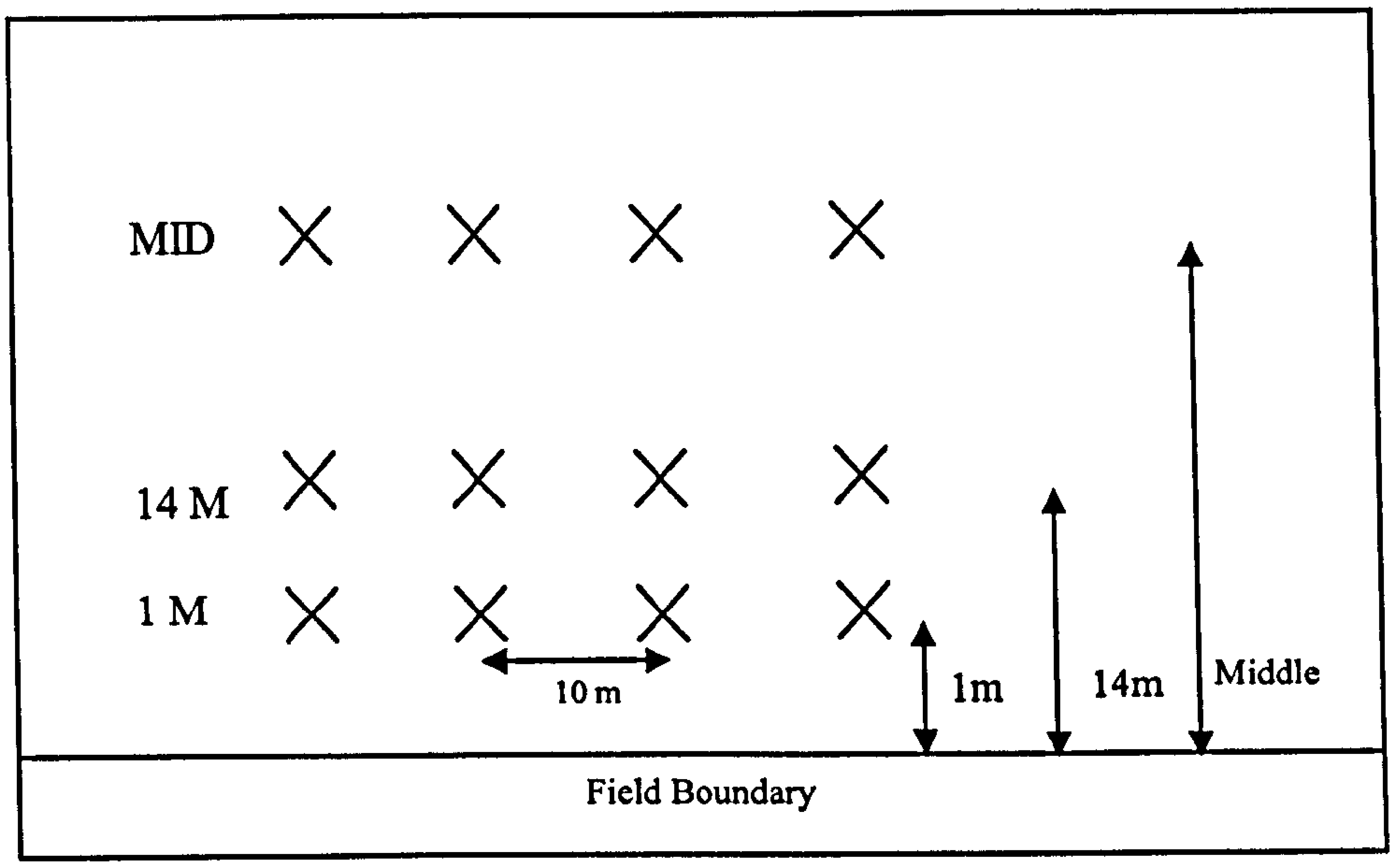

Figure 5.1. Diagram of sampling points for pitfall traps.

This design allows arthropods to be sampled at various distances into the field where different bird species may be foraging. A combination of food availability and predation avoidance, potentially linked to the distance away from cover, is likely to influence where birds forage in fields (e.g. Schneider, 1984; Lima & Dill, 1990).

5.3.3 Pitfall trapping and sampling processing

Epigeal arthropods were surveyed using pitfall traps. The traps were non-brittle polythene beakers (to avoid cracking) with 7 cm inside diameter and 10 cm tall. The beakers were placed in the ground so that the lip of the beaker was flush with the soil surface. The traps were set with 2-3cm of anti-freeze (ethylene glycol) and a few drops of washing up liquid to break the surface tension. To avoid the traps flooding with rain water plastic saucers (16.5 cm diameter) were suspended above each trap using wire. The traps were collected after one week and the samples were secured with snap-on lids. After collection, the samples were placed in a cold store in temperatures below 4^0C until they could be processed. Samples were individually washed using a fine mesh sieve (mesh size 1 mm); the spiders and beetles were counted and preserved in 70% industrial methylated spirits (IMS). The two most commonly occurring beetle families, ground (Coleoptera; Carabidae) and rove (Coleoptera; Staphylinidae) beetles were counted separately, as were beetle larvae. The spiders and the two beetle families (Carabids and Staphylinids) were identified and counted as these have been shown to be important part of the diet of some declining farmland bird species, such the Yellowhammer and Skylark (Wilson *et al.* 1996). Traps were set in March, May and July in 2002 and 2003.

5.3.4 Statistical Analysis

The mean number of arthropods caught in the four traps at each of the three distances (trap positions) into the field was used as the response variable. The arthropods were analysed using four response variables; abundance of carabid beetles, staphylinid beetles, beetle larvae and spiders. Data from each of the three trapping periods, March, May and June were analysed separately.

Logistic regression (procedure GLMM) was used to test for the effect of tillage (a two-level fixed factor) on relative abundance of each arthropod group. This was carried out whilst controlling for the following factors, where they were significant: year (a two-level fixed factor), previous crop type (an eight-level fixed factor), and trap position (a three-level fixed factor) (see Table 5.2). Field identity was included as a random factor as the traps were nested within fields. The natural log of field size was included as a covariate.

Table 5.2. Variables used in the analyses of variation in arthropod abundance

Variable	Type	Factor levels	n[a]	(NIT, CT)
Field area	Continuous variable		See Table 5.3	
Tillage	2-Level fixed factor	Non-inversion tillage	20 (10,10)	
		Conventional tillage	20 (10,10)	
Year	2-Level fixed factor	2002		
		2003		
Previous crop	8-Level fixed factor	Winter wheat	3	(2,1)
		Winter barley	1	(0,1)
		Oilseed rape	12	(4,8)
		Set aside	9	(4,5)
		Peas	2	(0,2)
		Beans	6	(6,0)
		Maize	2	(2,0)
		Grass	5	(2,3)
Trap position	3-Level fixed factor	1 m from crop edge		
		14 m from crop edge		
		Middle of field		
Field	40-Level random factor	2003 – twenty fields	20	(10,10)
		2004 – twenty fields	20	(10,10)

[a] n = Number of fields relating to a given factor

Table 5.3. Field size information (hectares)

Year	Field Area	n	NIT		CT	
Year 1	Min	10	3.86		3.30	
	Max	10	22.27		16.36	
	Mean	10	8.16	(±1.79)	6.65	(±1.42)
Year 2	Min	10	3.86		3.32	
	Max	10	13.87		8.84	
	Mean	10	7.688	(±0.94)	5.86	(±0.61)

Analysis was achieved by fitting a generalised linear mixed model, procedure GLMM (Genstat 4.2 5th Eds. L.A.T. 2000). For each arthropod group, a Poisson error structure, controlling for over-dispersion, and a log link function were specified. Two-way interactions of the factors were also included in the model where possible. The full model used was: Previous Crop + Year + Trap position + Tillage + fieldsize_ln + fieldsize_ln*Trap position + Previous Crop*Trap position + Previous Crop*Year + Previous Crop*Tillage + Year*Trap position + Year*Tillage + Tillage*Trap position.

For each response variable, a step up procedure was used, with the most significant factor retained in the model until all the factors remaining in the model were significant, i.e. until the minimum adequate model (MAM) remained (see Appendix 4 for a worked example). Significance testing was achieved by calculating the Wald statistic, and comparing this with the χ^2-distribution ($\alpha = 0.05$).

Once the MAM was achieved, graphical representations of the means and standard errors of the significant terms were used to identify any outliers that may be unduly influencing the results. An outlier was identified as a level of a factor (e.g. previous crop) where the abundance of arthropods was dramatically greater or less than that of the other factor levels. The outlier was removed from the data set when it was represented by only one field as the differences may have been due the field. For example, where previous crop was found to be a significant factor in explaining the number of Carabid beetles, the previous crop of barley was observed to have three fold the number of Carabid beetles, but was represented by only one field, it was considered an outlier and removed. These fields were removed from the data and the models were then re-run. Caution must be used in interpreting the results of the significant terms left in the MAM other than Tillage. This is because fields were selected for sampling with respect to the tillage treatment and therefore the other factors, such as previous crop type, may not be replicated sufficiently in the model. Further explanation of along with a worked example of the statistics used in this chapter can be found in Appendix 4.

The total number of each arthropod group (Carabid and Staphylinid beetles, beetle larvae and spiders) recorded in July, for both non-inversion and conventional tillage fields and at each distance into the fields, in both years can be found in Appendix 8.

Previous crop type was one of the most common factors in explaining the variation in arthropod abundance. To assess the effect of tillage without the impact of previous crop, two sub-samples of the data were re-analysed where there was only one type of previous crop so that this could be removed from the model. The two sub-samples chosen were the fields that had the two most common previous crop types; these were oilseed rape and set aside.

The results section is divided into four main parts. The results for each type of arthropod are displayed in the following order: carabid beetles, staphylinid beetles, beetle larvae and spiders. For each of the response variables the analysis with the full data set is shown followed by the results from analysis of the data from the fields with only oilseed rape and then set aside as a previous crop. Within each of these sections, where a sub-set of the data has been analysed, graphic representations are only presented where tillage is significant. At the end of the results section, two tables display a summary of all the results from all the analyses. The first table lists the results by arthropod group and the second table lists results by month.

Beetle lengths. The total frequency of carabid beetles in six different size classes was identified for each trap position. The overall mean proportion of carabid beetles per size class was calculated for each trap position and for both of the tillage treatments.

5.4 Results

5.4.1 Carabid beetles

5.4.1.1 Carabid beetles – full data set

Tillage did not explain the variation in carabid numbers in March, May and July (Table 5.4). The mean number of carabid beetles in March was lower in the middle of the field than at 1m or 14m from the crop edge (Figure 5.2). In May, previous crop type was found to explain the variation in carabid beetle numbers, even after an outlier, the one field that had barley as a previous crop, was removed (Figure 5.3). There were a greater number of carabid beetles in wheat fields sown after oilseed rape and beans compared with set aside and grass. The year and the interaction between the previous crop and trap position had a significant affect on carabid abundance (Table 5.1, Figure 5.2).

Table 5.4. General log-linear regression analysis (GLMM) of relative carabid abundance

Month	Term:	Wald statistic	d.f.	Wald d.f.	P (χ^2)
March	Trap position	19.56	2	9.78	<0.001
May	Previous Crop	15.58	6	2.6	0.016
July	Year	11.47	1	11.47	<0.001
	Previous Crop. Trap position	41.78	12	3.48	<0.001

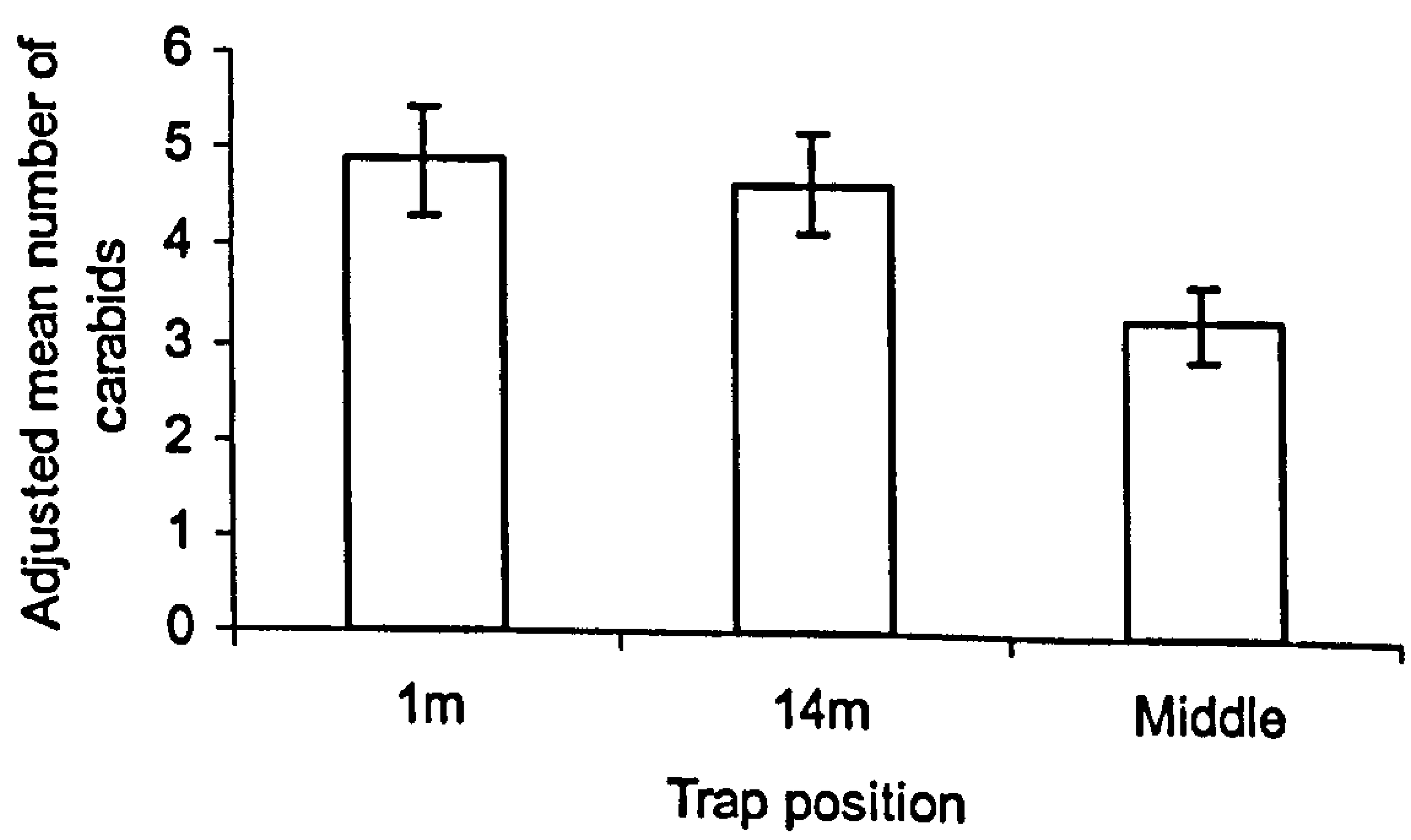

Figure 5.2. Adjusted mean number of carabid beetles at each trap position in March.

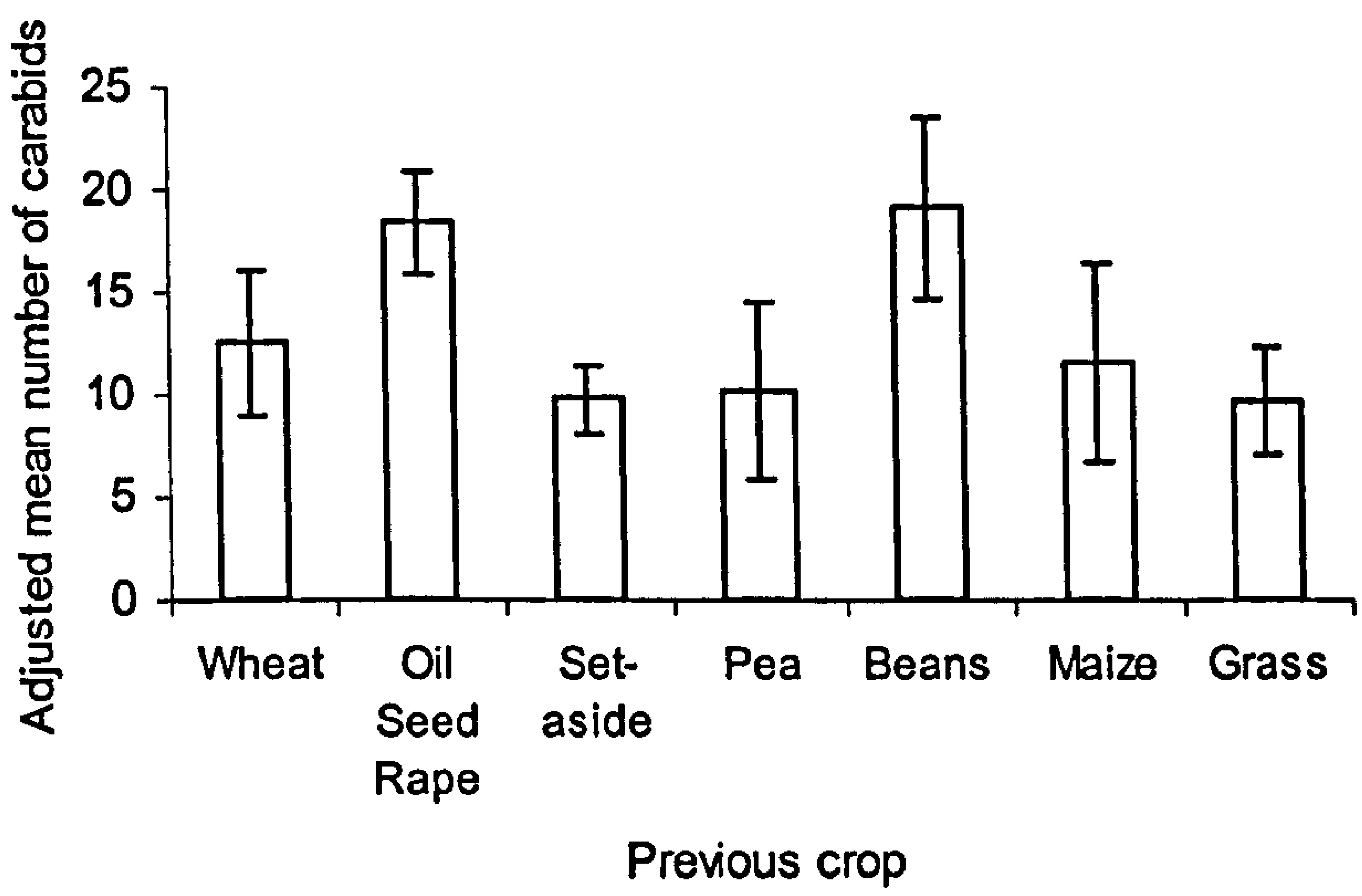

Figure 5.3. Adjusted mean number of carabid beetles in each of the previous crop types in May.

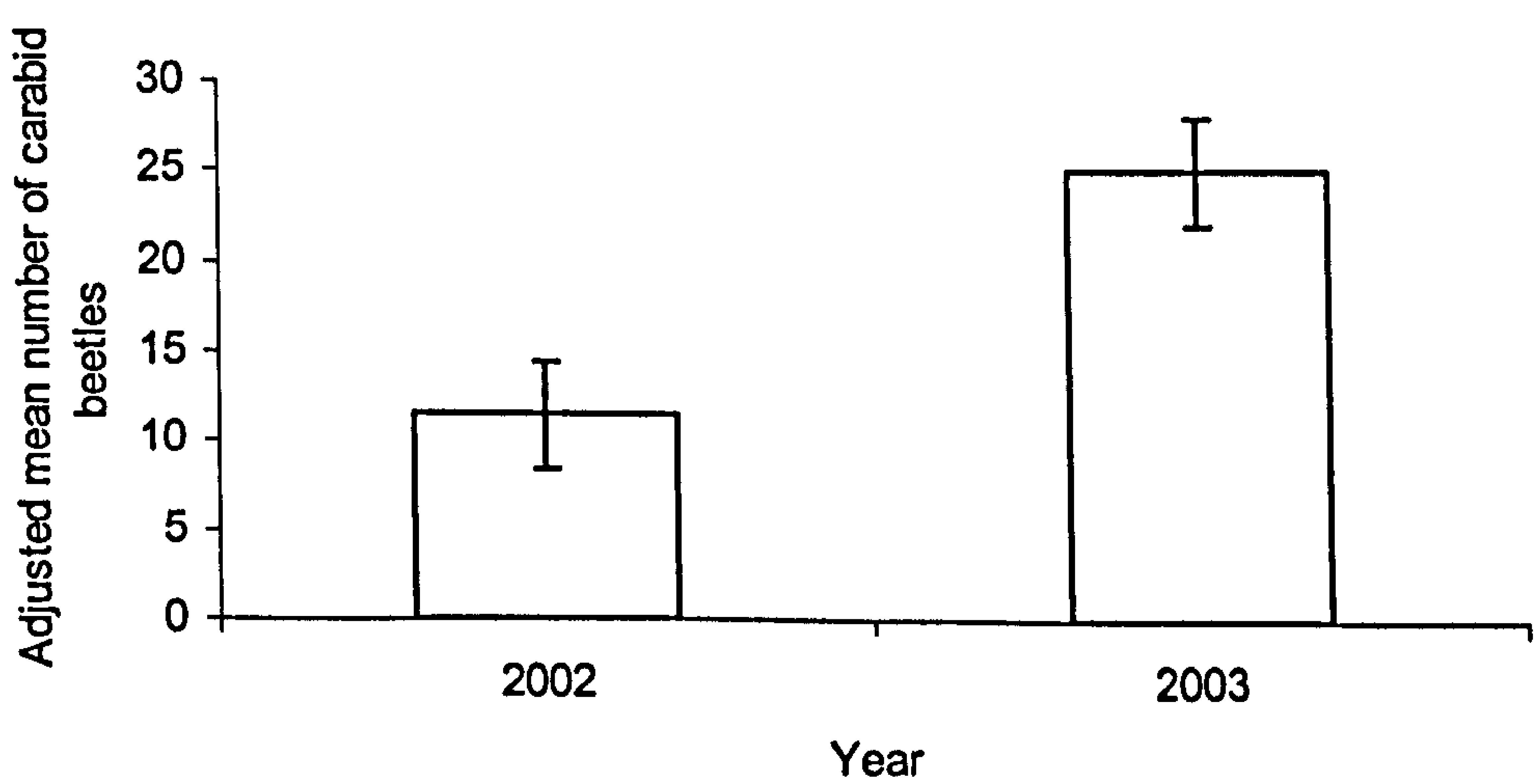

Figure 5.4. Adjusted mean number of carabid beetles per year in July.

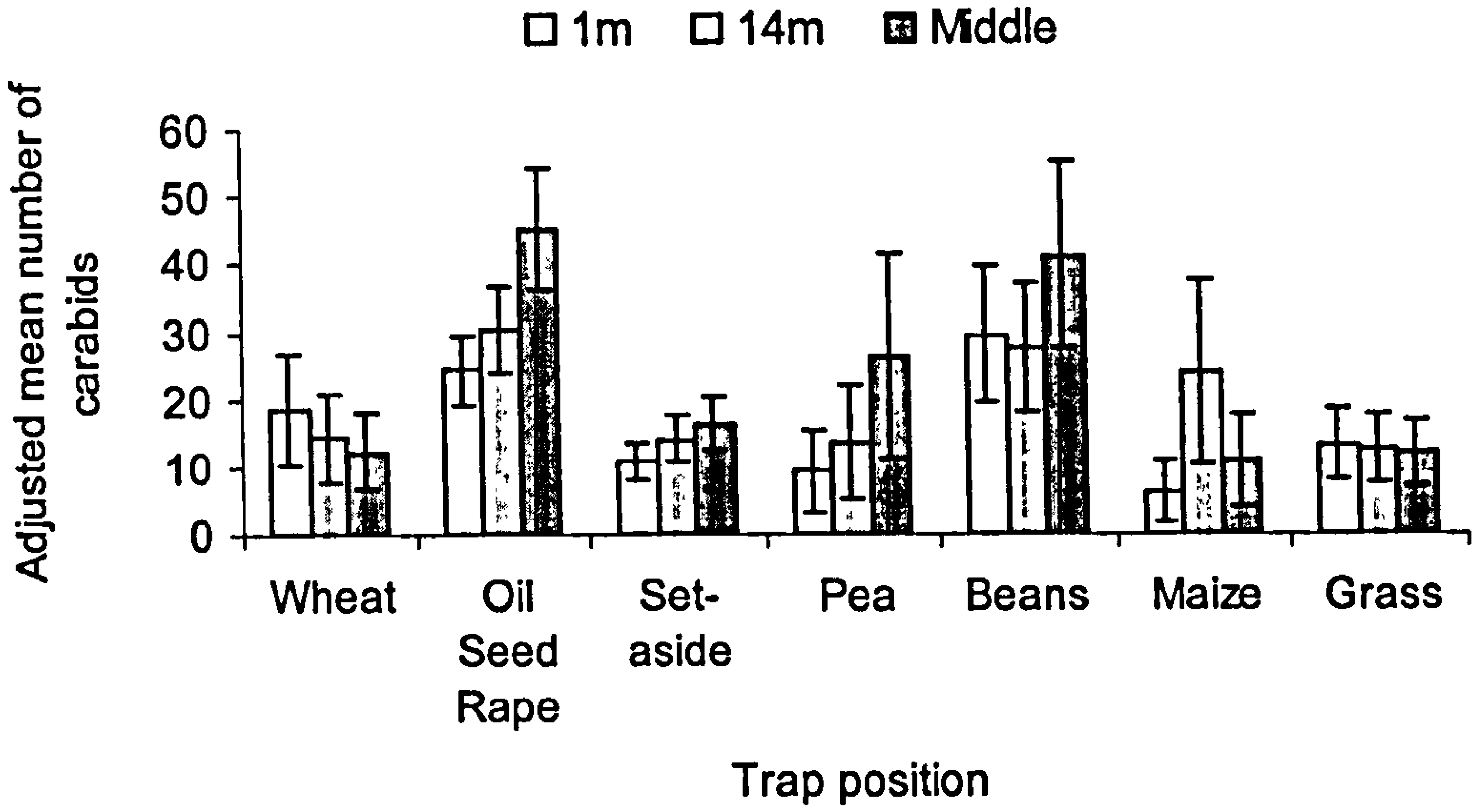

Figure 5.5. Adjusted mean number (+/-SE) of carabid beetles per trap position for each of the previous crop types in July.

5.4.1.2 Carabids – data set with previous crop of oilseed rape and set aside

Tillage did not significantly explain the variation in carabid numbers for either of the reduced data sets (Table 5.5). The only factors found to be significant in explaining the variation in carabid abundance, where oilseed rape and set aside are the only previous crops, are trap position and year (Table 5.5).

Table 5.5. General log-linear regression analysis (GLMM) of relative carabid abundance with the fields where previous crop was oilseed rape and set aside

Previous crop	Month	Term:	Wald statistic	d.f.	Wald d.f.	P (χ^2)
Oilseed rape	March	Trap position	12.03	2	6.01	0.002
	May	No significant factors				
	July	Trap position	43.22	2	21.61	<0.001
Set aside	March	Trap position	10.19	2	5.09	0.006
	May	No significant factors				
	July	Trap position	14.56	2	7.28	<0.001
		Year	4.78	1	4.78	0.029

5.4.2 Staphylinid Beetles

5.4.2.1 Staphylinid Beetles – full data set

Tillage did not explain the variation in staphylinid numbers in March, May and July (Table 5.6). A greater abundance of staphylinid beetles was observed at 1m from the crop edge than at 14 m and the middle of the field in March, whereas the reverse was observed in May (Table 5.6 and Figure 5.6). The abundance of staphylinid beetles was affected by the type of previous crop in July (Table 5.6, Figure 5.7).

Table 5.6. General log-linear regression analysis (GLMM) of relative staphylinid abundance

Month	Term:	Wald statistic	d.f.	Wald d.f.	P (χ^2)
March	Trap position	63.44	2	31.72	<0.001
May	Trap position	20.24	2	10.12	<0.001
July	Previous Crop	26.4	7	3.77	<0.001

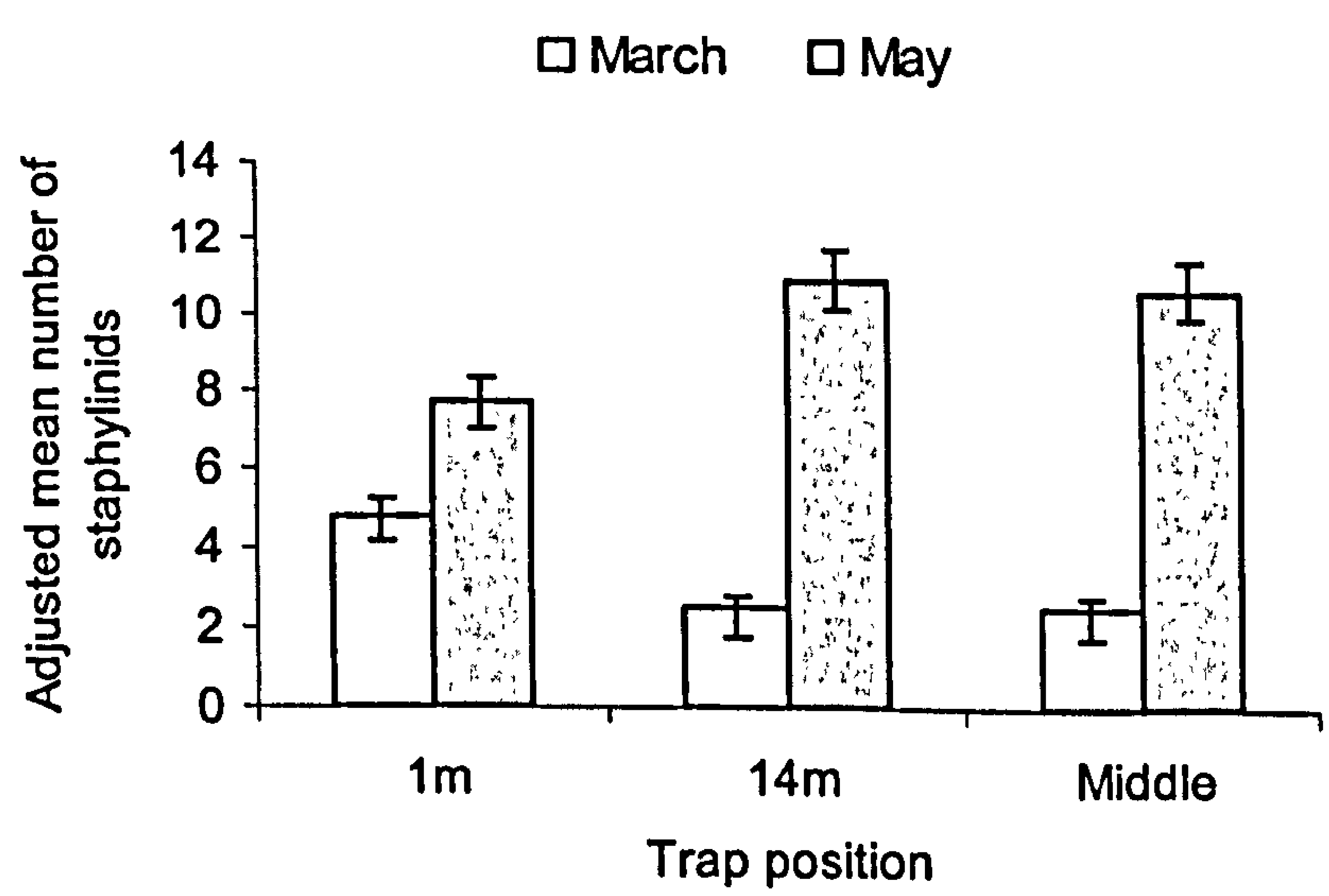

Figure 5.6. Mean number of staphylinid beetles at each trap position in March and May.

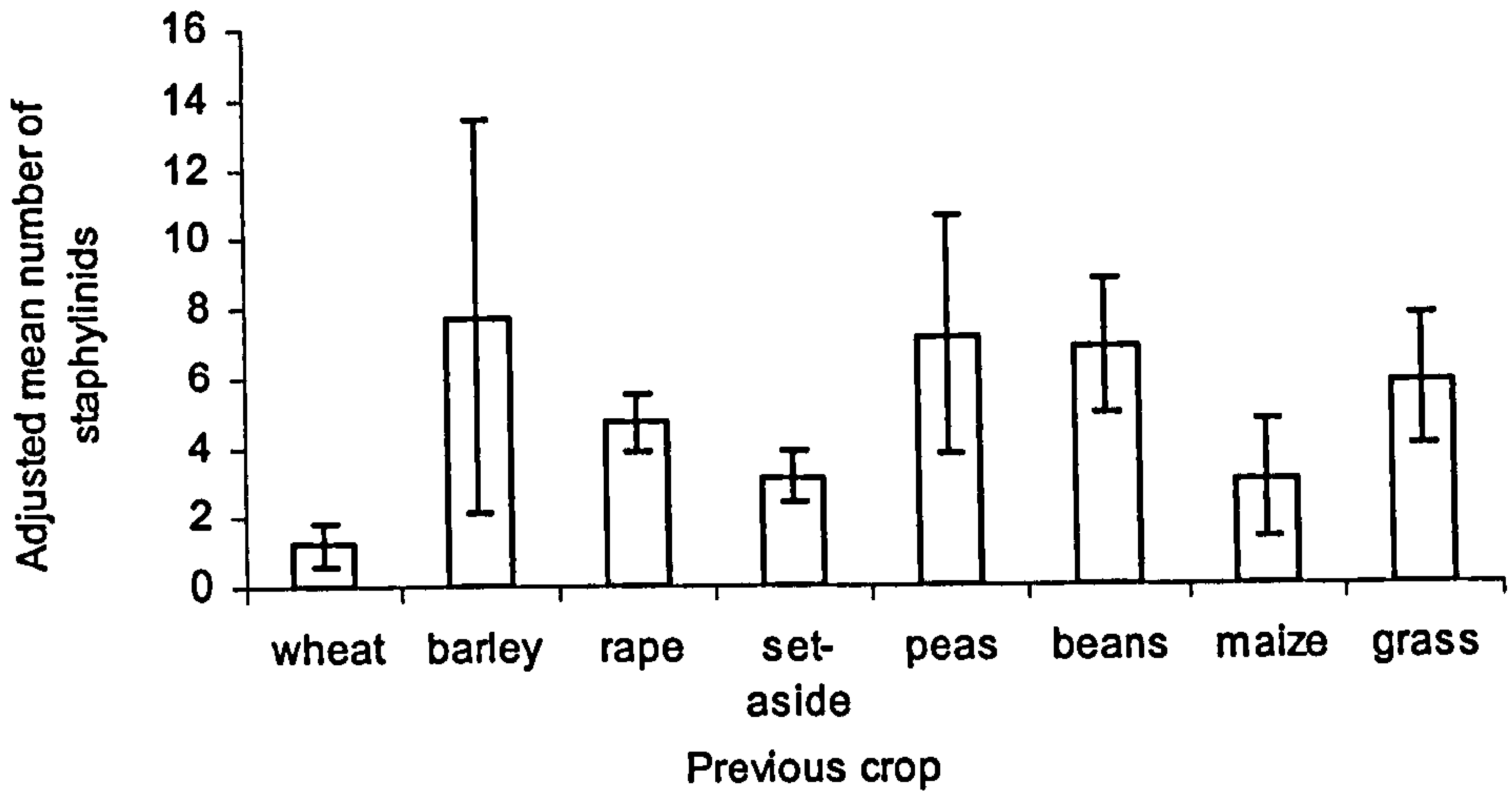

Figure 5.7. Adjusted mean number of staphylinid beetles in each of the previous crop types in July.

5.4.2.2 Staphylinids – data set with previous crop of oilseed rape and set aside

Tillage did not explain the variation in staphylinid numbers in March, May and July when the previous crop was only oilseed rape or when it was only set aside (Table 5.7). Analysis with the sub-set of data where oilseed rape was the only previous crop type showed trap position was significant in explaining the variation in staphylinid numbers in March and May (Table 5.7). Trap position was the only factor that explained significantly the variation in Staphylinid numbers in March where analysis was carried out on the sub-set of data where set aside was the only previous crop type (Table 5.7).

Table 5.7. General log-linear regression analysis (GLMM) of relative staphylinid abundance with the fields where previous crop was oilseed rape and set aside

Previous crop	Month	Term:	Wald statistic	d.f.	Wald d.f.	P (χ^2)
Oilseed rape	March	Trap position	27.31	2	13.66	<0.001
	May	Trap position	8.93	2	4.46	0.012
	July	No significant effects				
Set aside	March	Trap position	16.05	2	8.03	<0.001
	May	No significant effects				
	July	No significant effects				

5.4.3 Beetle larvae

5.4.3.1 Beetle larvae – full data set

Tillage did not explain the variation in beetle larvae numbers in March, May and July (Table 5.8). A greater number of beetle larvae were trapped in 2002 than 2003 in July (Table 5.8, Figure 5.8).

Table 5.8. General log-linear regression analysis (GLMM) of relative beetle larvae abundance with the full data set.

Month	Term:	Wald statistic	d.f.	Wald d.f.	P (χ^2)
March	No Significant factors				
May	No Significant factors				
July	Year	59.13	1	59.13	<0.001

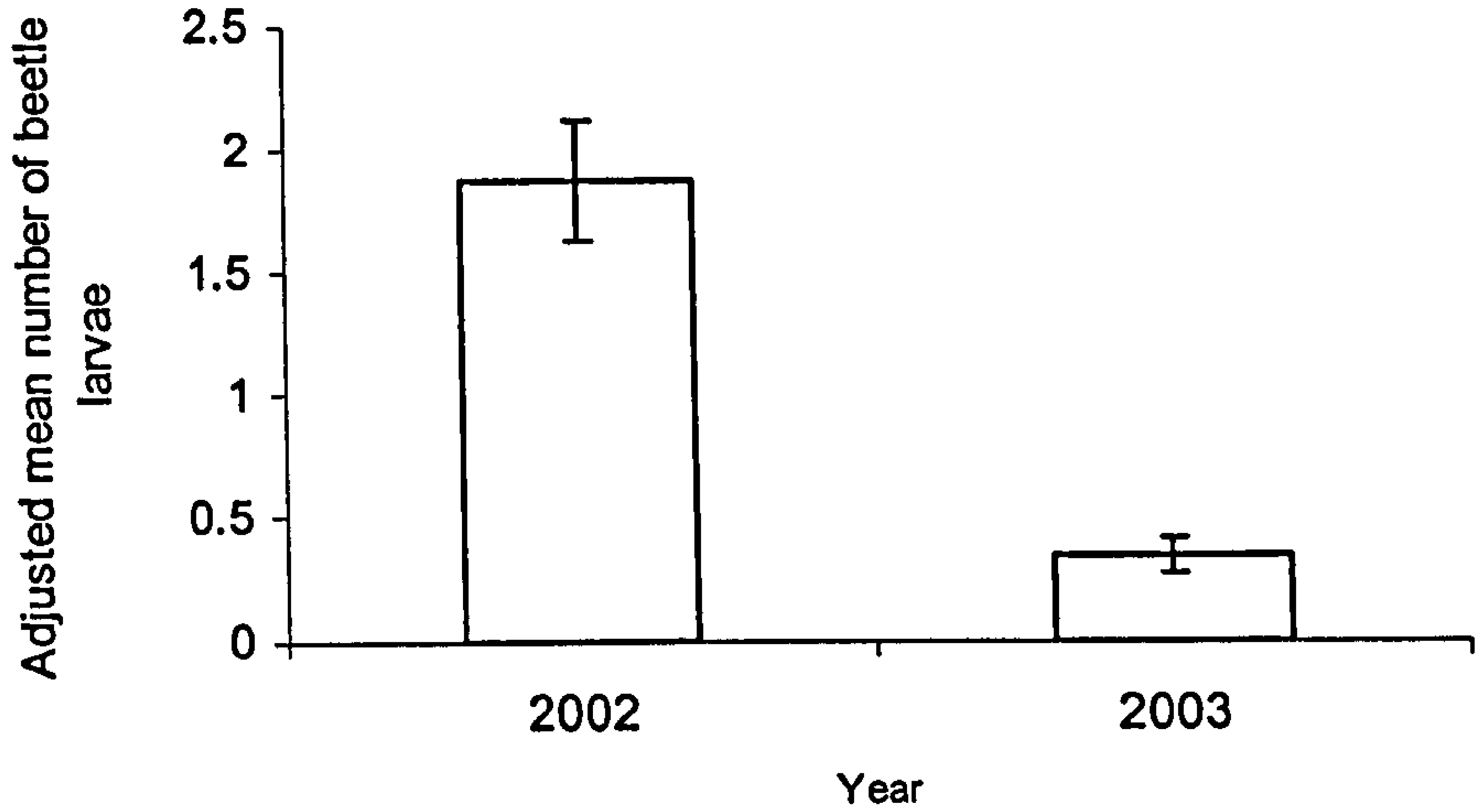

Figure 5.8. Adjusted mean number (± SE) of beetle larvae per year in July.

5.4.3.2 Beetle larvae – data set with previous crop of oilseed rape and set aside

Analysis with the sub-set of data where oilseed rape was the only previous crop type showed tillage was significant in explaining the variation in beetle larvae numbers in July, along with year and trap position (Table 5.9). A greater number of beetle larvae were observed in fields established by conventional tillage than non-inversion tillage (Table 5.9 and Figure 5.9). Tillage was not a significant factor in explaining the variation in the numbers of beetle larvae in March or May. For the sub-set of data where set aside was the only previous crop type tillage was not a significant factor in explaining the variation in the numbers of beetle larvae in March, May or July (Table 5.9).

Table 5.9. General log-linear regression analysis (GLMM) of relative beetle larvae abundance where previous crop was oilseed rape and set aside

Previous crop	Month	Term:	Wald statistic	d.f.	Wald d.f.	P (χ^2)
Oilseed rape	March	No significant factors				
	May	Year	6.81	1	6.81	0.009
		Field size*Year	3.95	1	3.95	0.047
	July	Year	8.57	1	8.57	0.003
		Tillage	7.13	1	7.13	0.008
		Trap position	8.74	2	4.37	0.013
Set aside	March	No significant factors				
	May	Trap position	6.29	2	3.15	0.043
	July	Year	11.9	1	11.9	<0.001

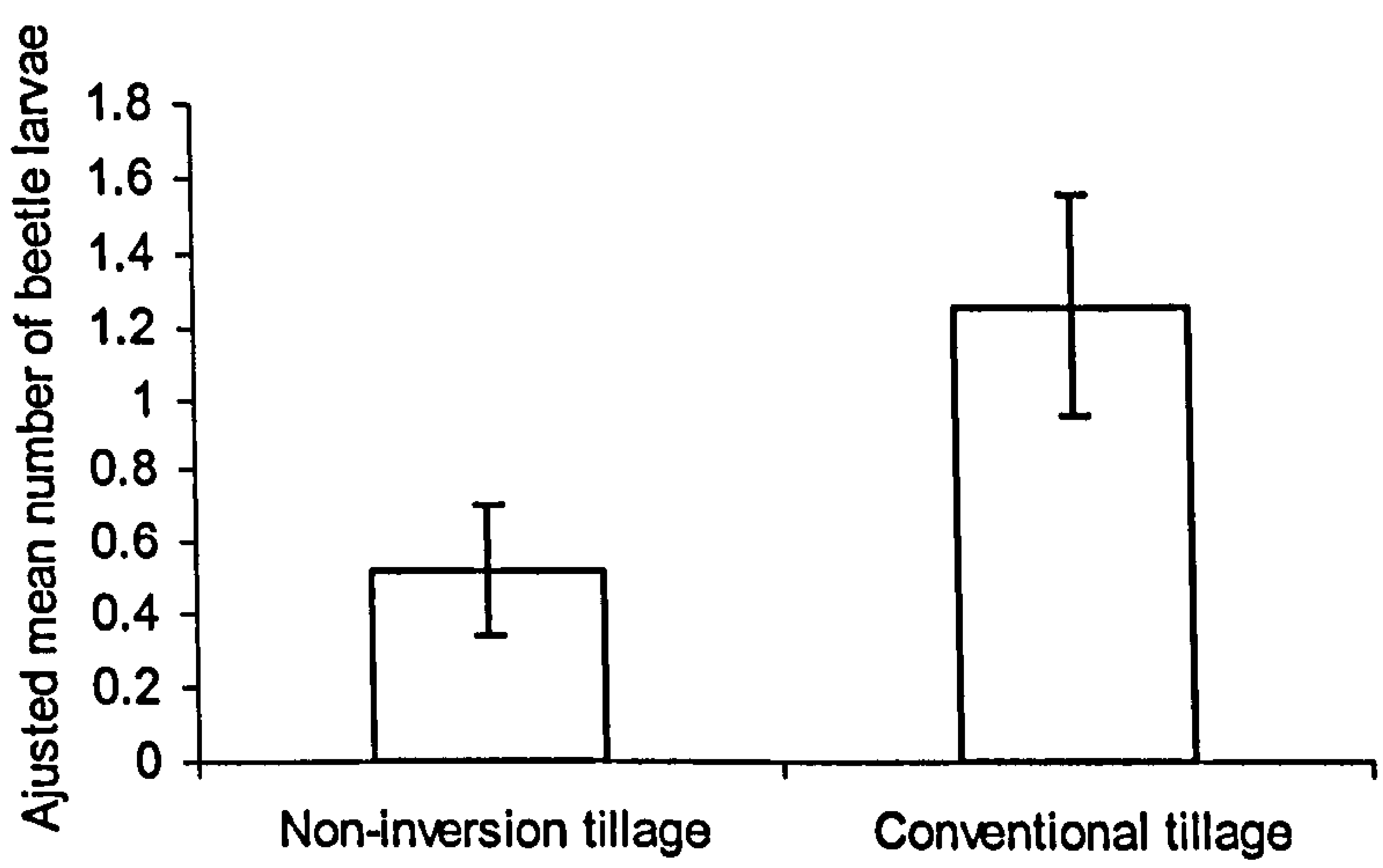

Figure 5.9. Adjusted mean number of beetle larvae in fields where the previous crop was oilseed rape in July.

5.4.4 Spiders

5.4.4.1 Spiders – full data set

Tillage was not significant in explaining the variation in the numbers of spiders in March, May or July (Table 5.10). The number of spiders was affected by the year and trap position in July (Table 5.10). There were significantly more spiders in 2003 than 2002 in March and the reverse was the case in July (Figure 5.10). The previous crop affected the abundance of spiders in March with a significantly lower abundance of spiders observed in wheat after maize than most other crop types. Whereas in fields where the previous crop was grass, a significantly higher abundance of spiders was seen compared to most other previous crops (Figure 5.11). The numbers of spiders increased from the crop edge to the middle of the field in July (Figure 5.12).

Table 5.10. General log-linear regression analysis (GLMM) of relative spider abundance

Month	Term:	Wald statistic	d.f.	Wald d.f.	$P(\chi^2)$
March	Year	12.29	1	12.29	<0.001
	Previous Crop	25.3	7	3.61	<0.001
May	No Significant factors				
July	Year	43.1	1	43.11	<0.001
	Trap position	46.2	2	23.12	<0.001

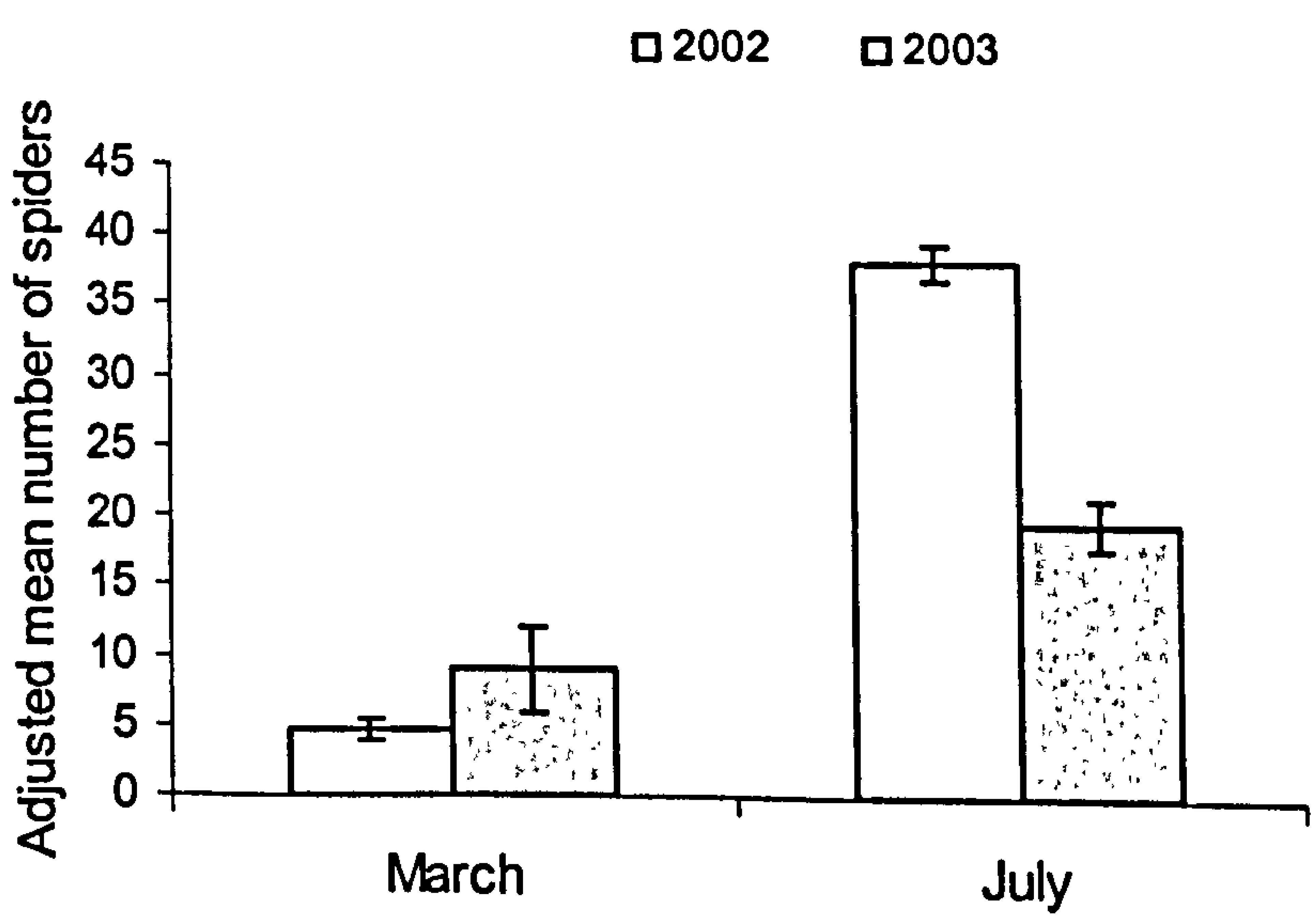

Figure 5.10. Adjusted mean number of spiders in each year in March and July.

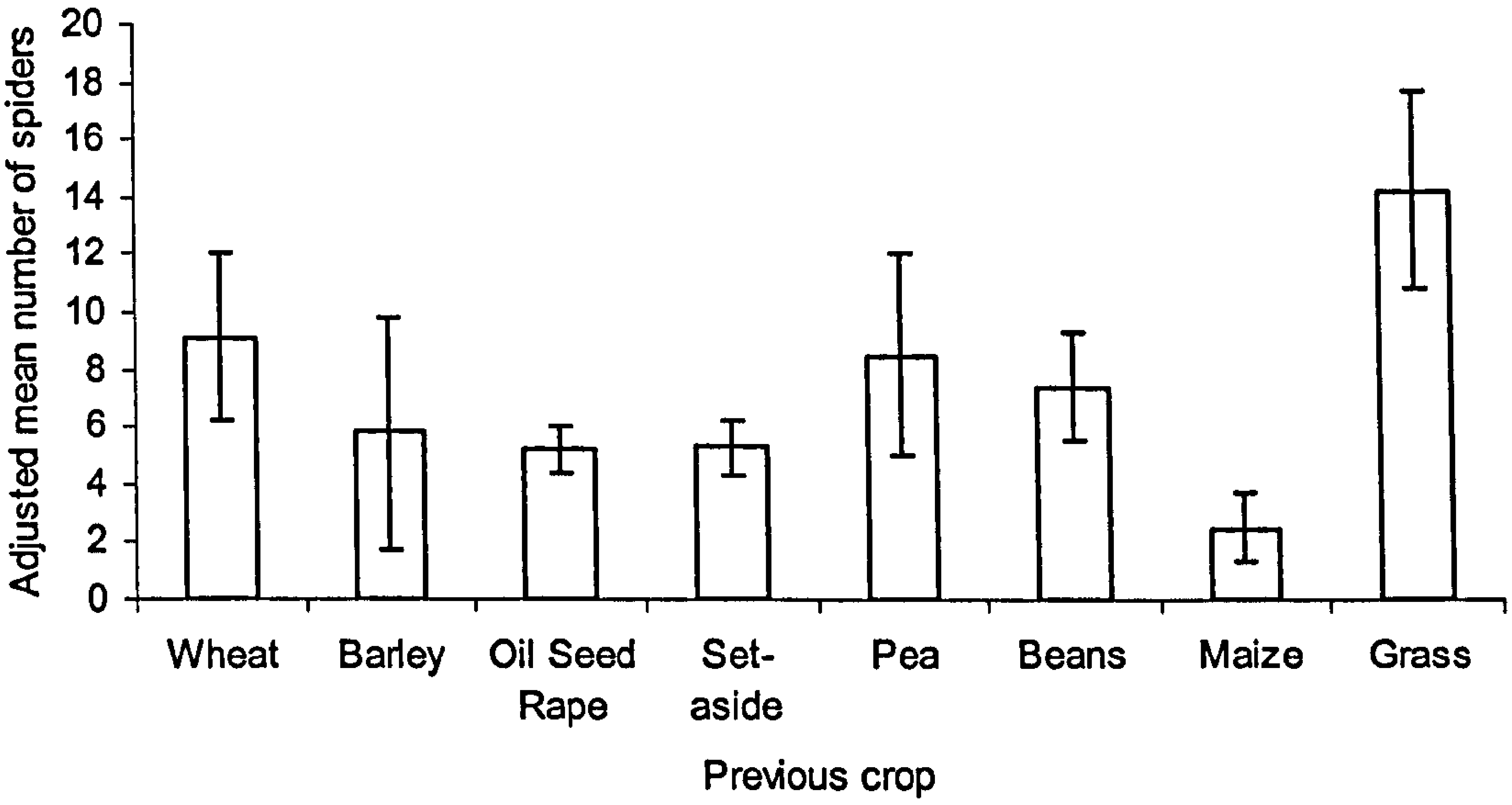

Figure 5.11. Adjusted mean number of spiders in each previous crop in March.

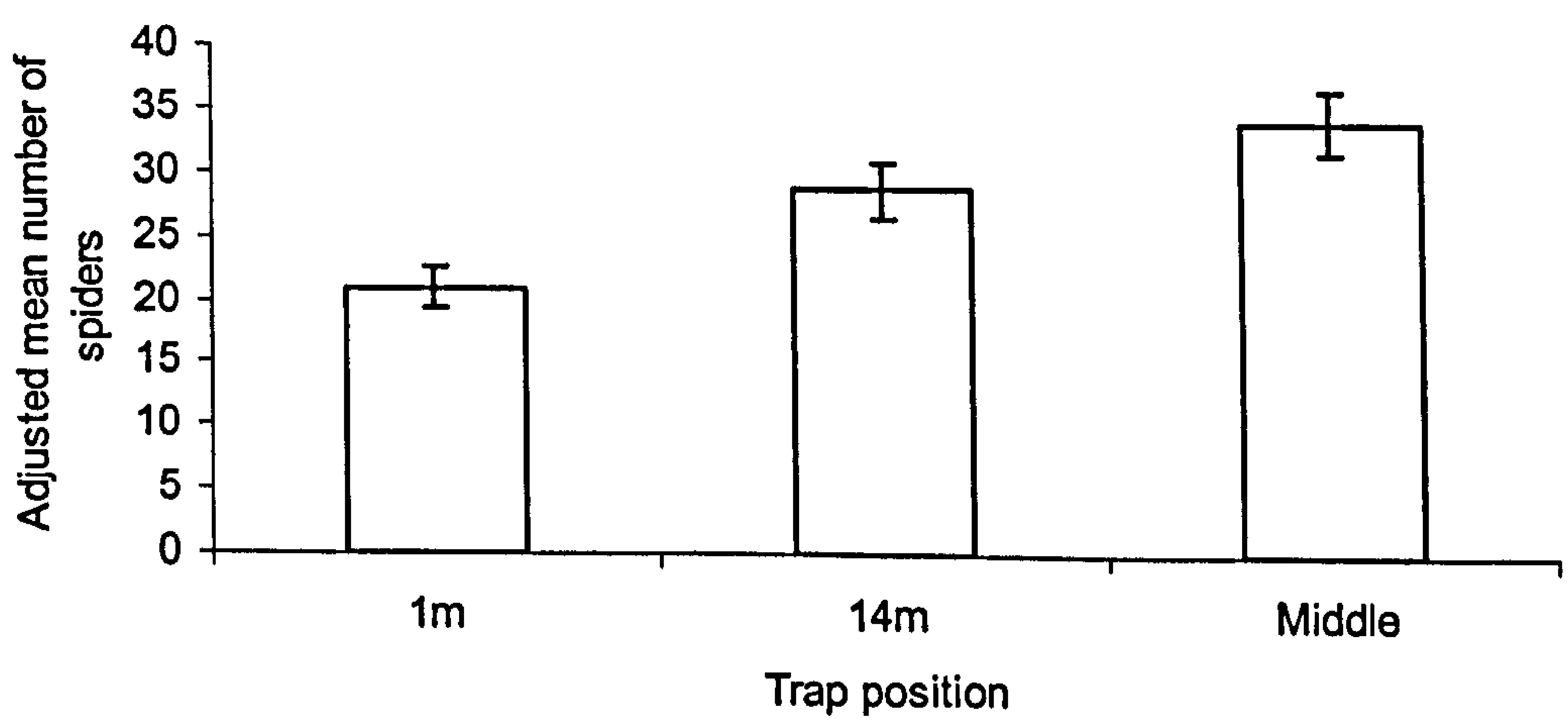

Figure 5.12. Adjusted mean number of spiders per trap position in July.

5.4.4.2 Spiders – data set with previous crop of oilseed rape and set aside

For both previous crop types, year is the only significant term that explained the variation in spider abundance in July; tillage was not significant (Table 5.11). There were no significant factors in March. Trap position and field size accounted for the variation in spider abundance in July.

Table 5.11. General log-linear regression analysis (GLMM) of relative beetle larvae abundance where previous crop was oilseed rape and set aside

Previous crop	Month	Term:	Wald statistic	d.f.	Wald d.f.	P (χ^2)
Oilseed rape	March	Year	10.05	1	10.05	0.002
	May	No significant factors				
	July	Field size (ln)	9.07	1	9.07	0.003
		Trap position	10.26	2	5.13	0.006
Set aside	March	Year	7.24	1	7.24	0.007
	May	No significant factors				
	July	Trap position	22.02	2	11.01	<0.001

5.4.5 Results summary

The minimum adequate models (MAMs) have been summarised in the table below. The first table lists the results by arthropod group (Table 5.12) and the second by month (Table 5.13).

Table 5.12. Summary of all the MAMs for each of the arthropod groups in each month and for each of the analyses.

		Data set*		
Arthropod	Month	Full	OSR	SAS
Carabid	March	Trap position	Trap position	Trap position
	May	Previous Crop	-	-
	July	Year + Previous Crop*Trap position	Trap position	Trap position + Year
Staphylinid	March	Trap position	Trap position	Trap position
	May	Trap position	Trap position	-
	July	Previous Crop	-	-
Beetle larvae	March	-	-	-
	May	-	Year + Field size*Year	Trap position
	July	Year	Year + Trap position + Tillage	Year
Spiders	March	Year + Previous Crop	Year	Year
	May	-	-	-
	July	Year + Trap position	Field size + Trap position	Trap position

*Full = full data set; OSR = only fields with oilseed rape as the previous crop; SAS = only fields with set aside as the previous crop. - = no significant factors found

Table 5.13. Summary of all the MAMs in each month for each arthropod group and for each of the analyses.

		Data set*		
Month	Arthropod	Full	OSR	SAS
March	Beetle larvae	-	-	-
	Carabid	Trap position	Trap position	Trap position
	Spiders	Year + Previous Crop	Year	Year
	Staphylinid	Trap position	Trap position	Trap position
May	Beetle larvae	-	Year + Field size*Year	Trap position
	Carabid	Previous Crop	-	-
	Spiders	-	-	-
	Staphylinid	Trap position	Trap position	-
July	Beetle larvae	Year	Year + Trap position + Tillage	Year
	Carabid	Year + Previous Crop*Trap position	Trap position	Trap position + Year
	Spiders	Year + Trap position	Field size + Trap position	Trap position
	Staphylinid	Previous Crop	-	-

*Full = full data set; OSR = only fields with oilseed rape as the previous crop; SAS = only fields with set aside as the previous crop. - = no significant factors found

5.4.6 Carabid body lengths

Approximately 70% of carabid beetles were less than 5 mm for all trap positions and for both types of tillage (Figure 5.13 and Figure 5.14). The second greatest mean percentage, approximately 10-20%, of carabid beetles were between 5 and 7 mm in length, and the third greatest percentage, approximately 5-15%, were between 10 and 12 mm.

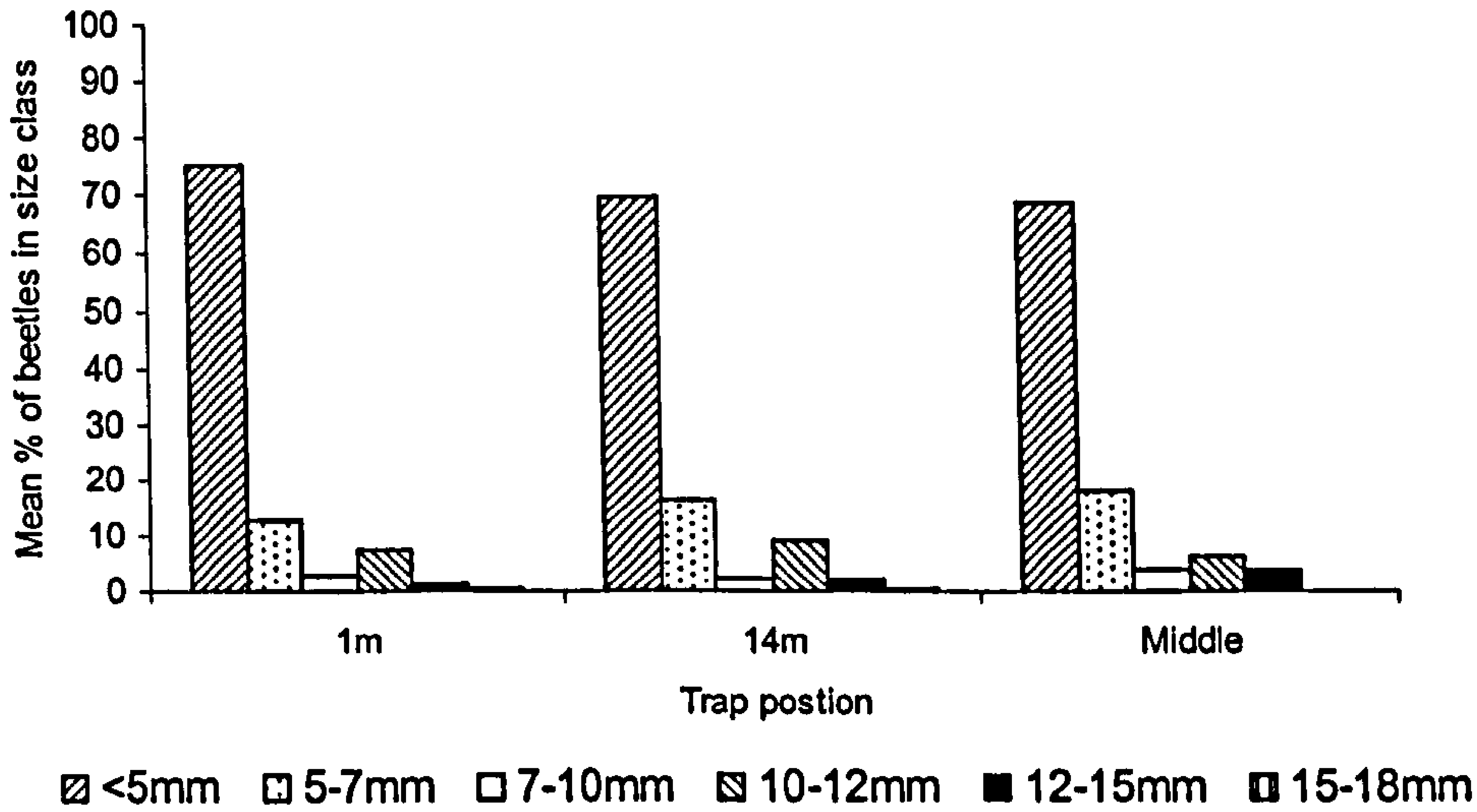

Figure 5.13. Mean proportion of carabid beetles in each size class at each trap position in fields established by non-inversion tillage in March.

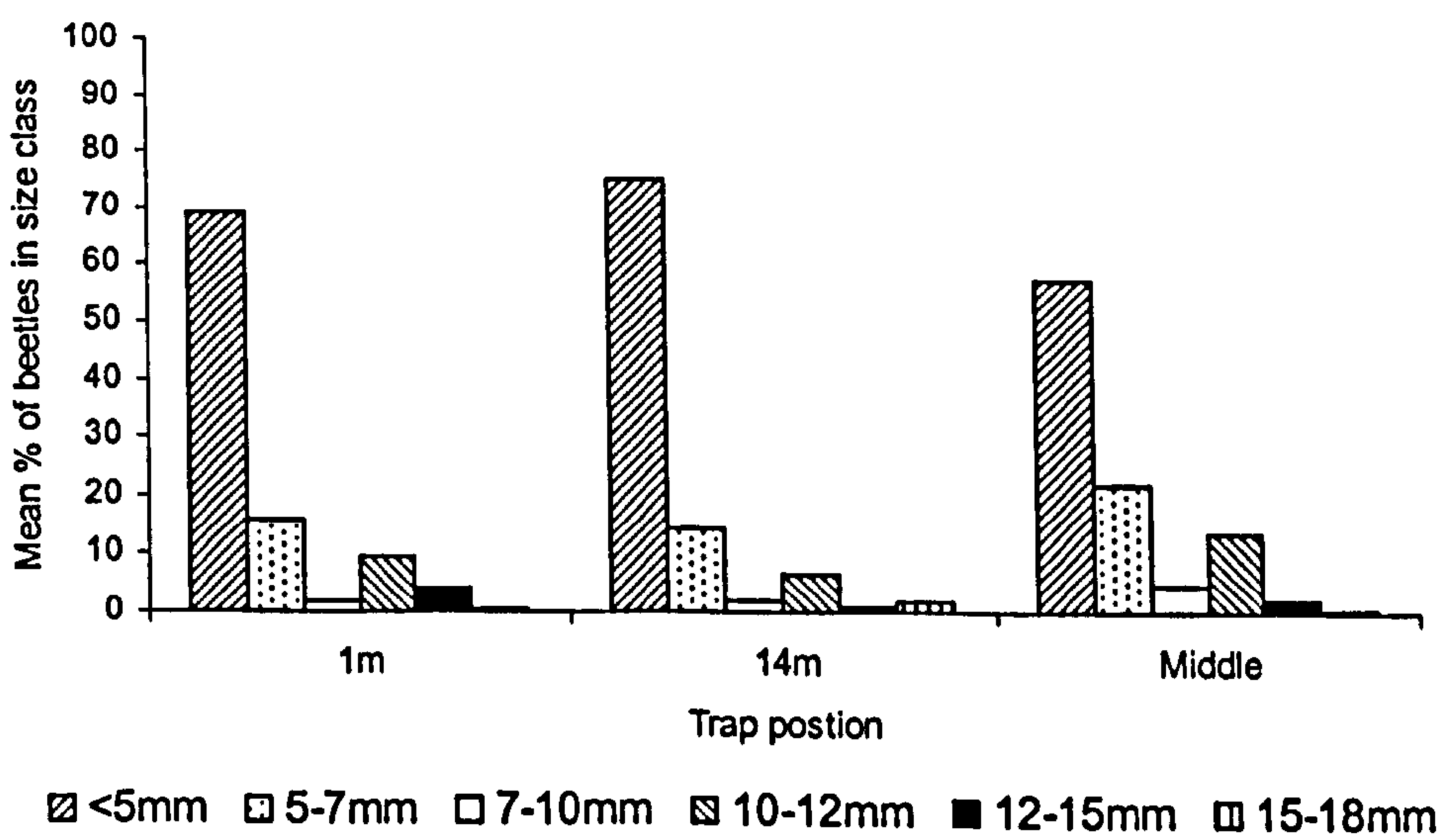

Figure 5.14. Mean proportion of carabid beetles in each size class at each trap position in fields established by conventional tillage in March.

5.5 Discussion

The type of tillage used to establish a wheat crop did not explain any differences in the relative abundance of each group of arthropods, except in one instance for beetle larvae. Each arthropod group is discussed in turn.

Carabid beetles. The results from this investigation appear to contradict some of the previous research where greater numbers of carabid beetles have been recorded in reduced tillage compared with ploughing (Andersen 1999, 2003). The only study that involved similar non-inversion tillage machinery to this study, showed carabid beetles had a mixed species-specific response to tillage treatment (Kendall *et al.* 1995). Other studies, where increases in carabid abundance have been observed with reduced tillage, have compared no tillage or 'light' ploughing with conventional mouldboard ploughing (Blumberg & Crossley 1983, Brust *et al.* 1985, Holland & Reynolds 2003). This may indicate that the NIT machinery involved in this investigation effected carabid beetles in a manner more similar to ploughing than no-tillage. However, like this investigation some studies have reported no effect of tillage on carabid abundance and these were studies that compared a low disturbance impact of no-tillage with ploughing (Tonhasca 1993, Barney & Pass 1986, Carcamo *et al.* 1995). Some studies have shown a higher abundance of carabid beetles in ploughed fields compared with deep tillage cultivators and light or no tillage (Carcamo 1995, Baguette & Hance 1997). The problem with comparing the results from this investigation with previous studies is the different range of reduced or non-inversion tillage methods used; these ranged from no-till to the use of various cultivators, tines or even light ploughing.

The species-specific responses shown in some investigations indicate that different sized beetles may be responding differently to tillage treatments, and this may be important when considering these beetles as a food source for birds. From the investigation of beetle lengths, it can be seen that the greatest proportions of beetles were less than 5 mm in length in March at all trap positions and for both tillage treatments. This is important when considering beetles in the diet of birds, as it is believed that the optimum foraging strategy is to locate a few large beetles rather than a large number of small beetles (Blake *et al.* 1994). Although these results were only taken from one year this shows that for March, small sized beetles, such as some *Bembidion* species, did not appear to be affected by the tillage treatment. However, it may imply that as both NIT and CT fields provide a similarly highly disturbed habitat only beetles of a relatively smaller body size inhabit these fields. This may have changed throughout the year as more species emerged from over-wintering sites. Different species of ground beetles have been shown to have different levels of mobility, with larger beetles usually more mobile than smaller beetles. This may mean they have different abilities to recolonise highly disturbed arable fields.

A greater numbers of carabids were observed near the crop edge (i.e. at 1 m and 14 m from the crop edge) compared with the middle of field in March. This may be a reflection of greater weed cover at the field edges as carabids have been shown to be associated with this factor (Holland *et al.* 1999). It may also be an indication of their emergence and emigration from their over-wintering non-crop habitats, such field boundaries.

There were less carabids trapped where the previous crops were set aside, grass and peas than where they were beans and oilseed rape. This may be a reflection of the inputs involved with growing these crops. It may also be a reflection of the tillage methods used to establish a wheat crop after these crops e.g. due to the associated weed problems it is likely that after grass and set aside the plough would be the preferred establishment method.

Beetle larvae. Tillage was significant in explaining the number of beetle larvae in July in wheat fields where the previous crop was oilseed rape (see Table 5.9). There was a greater abundance of beetle larvae in cereal fields established by ploughing than non-inversion tillage. This seems to contradict the study by Holland and Reynolds (2003) where a lower abundance of Carabid and other Coleopteran (beetle) larvae were found in ploughed plots compared to plots of wheat stubbles and undersown grass leys, using emergence traps. However, Kendall *et al.* (1995) observed that Carabid and Staphylinid beetles and their larvae have species specific responses to ploughing or non-inversion tillage. They showed that the larvae of *Harpalus* spp., *Loricera pilicornis*, and *Pterostichus* spp. were more prevalent on ploughed plots whereas the larvae of *Carabus* spp., *Leistus* spp. and *Nebria brevicollis* were more prevalent on NIT plots. Changes in abundance of each of these species will affect the overall number of beetle larvae observed in NIT and CT fields. One of the species classified by Kendall *et al.* (1995) more prevalent on ploughed plots, *Loricera pilicornis*, showed peak occurrence in the summer. Therefore, the difference observed between the two establishment methods in July may have been due to the increased abundance of one species that favoured ploughed fields.

Pitfall traps are a measure of 'activity-density' (Lang 2000, Thomas *et al.* 1998). This means that pitfall traps measure the relative number of animals in a habitat and the mobility of that animal in relation to its environment. The greater abundance of beetle larvae trapped in the ploughed compared to NIT fields could potentially be due to higher amounts of surface trash (i.e. the residue from the previous crop) on NIT fields, which may have restricted the movement of the beetle larvae. Similar restricted movement of beetle larvae on NIT wheat fields after oilseed rape may have been caused due to a greater density of arable weeds.

The greater number of beetle larvae found on ploughed fields could also be due to lower abundance of predators, such as farmland birds, on the ploughed fields. Previous studies have shown that NIT fields can support a greater abundance of nesting birds (e.g. Basore et al. 1986, Lokemoen & Beiser 1997). An increased presence of these predators on the NIT fields could have led to a decrease in the numbers of beetle larvae which was only detectable towards the end of the breeding season.

Staphylinid beetles. Very few studies have investigated the effect of tillage on staphylinid beetles. In contrast to this investigation, one of the studies that compared no-tillage and ploughing found generally more staphylinid beetles in fields established by reduced tillage methods (Andersen 1999). Distance from the crop edge had a significant effect on the relative abundance of Staphylinid beetles and this distribution changed over the summer months. A greater abundance of beetles were observed at 1 m compared to 14 m and the middle of the field in March, whereas in May the reverse was observed. This may indicate a change in spatial distribution of beetles as they emerge from over-wintering sites and disperse into the fields.

Spiders. In this investigation, no effect of tillage was observed for spider abundance and this contradicts other studies that have shown positive (Blumberg & Crossley 1983, Clark *et al.* 1993) and negative (Marshall *et al.* 2000) effects of no tillage compared with ploughing. Spiders can be influenced by the structural diversity of their habitat (Balfour & Rypstra 1998, Duffey 1993) and surface-active spiders, such as wolf spiders, can be sensitive to disturbance (Holland & Reynolds 2003). Therefore, it may be expected that non-inversion tillage has the potential to support a greater abundance of spiders compared to ploughed field. NIT can increase the structural diversity of arable fields by retaining a greater amount of crop residue on the soil surface and reduce disturbance to the soil which may have beneficial effects on spider prey, such as spring tails (Collembola).

The trap position has explained the variation in some of the arthropod groups. For the beetle families and beetle larvae, this factor was significant only in certain months indicating temporal changes in spatial distribution. It has been shown that weeds decline in abundance from the edge to the centre of fields (Wilson & Aebischer 1995). This may influence some species of beetles and spiders that are associated with weed cover, particularly seed-eating carabid beetles. Wolf spiders (Lycosidae) have been observed to inhabit field edges for this reason (Holland *et al.* 1999). As a greater relative abundance of spiders were observed to be at 14 m from the crop edge and in the middle of the field in July, it is possible that the spiders may have comprised more of the other families such as money spiders (Linyphiidae). This concurs with Holland *et al.* (1999) who observed declines in the abundance of Lycosidae with increases of Linyphiidae from June to July. These spiders are known to use the method of ballooning to disperse which may explain a greater abundance away from the crop edges, although this contradicts other studies that indicate a homogeneous distribution within fields with aggregation to prey such as collembolan or aphids (Harwood *et al.* 2001).

General trends. There are several trends that are similar for most of the groups. Firstly, tillage is not significant in explaining the variation of any of the arthropod groups, with the exception of beetle larvae using a sub-set of the data. There are several reasons that differences with respect to tillage may not have been detected that are common to all arthropod groups. Sampling took place approximately five to nine months after cultivation took place. As many of the surface active arthropods are highly mobile, effects on populations may have been masked by recolonisation from the surrounding landscape. Previous crop was significant in explaining the variation in the numbers of carabid beetles, staphylinid beetles and spiders. Lower numbers of all these groups were caught where the previous 'crop' was set aside, which is surprising because set aside is assumed to be beneficial to wildlife. However, set aside fields can vary greatly and it may be that these fields lacked suitable or sufficient weed cover, or that they were left without plant cover for a longer period than the other fields due to being ploughed earlier in the year. Greater numbers of beetles and spiders were observed in fields that had followed beans. Lower numbers of staphylinid beetles and spiders were seen where the previous crop was oilseed rape or maize, and higher where the previous crops were grass and beans. This may be attributable to the different inputs, such as pesticides, herbicides and fertilizers, associated with different crops that may have residual affects on the arthropods inhabiting the following crop. Previous crop may affect arthropod numbers in several ways. Firstly, the crop itself may influence the abundance and species of arthropods due to factors such as the rate of growth and the structure of the plant (Kennedy & Storer 2000). Secondly, the chemical regime required to grow different crops may have a knock on effect to the next year. The direct and indirect of pesticides on non-target arthropods has been well documented (e.g. Aebischer 1990). Finally, the tillage method used to establish the previous crop in a field may have an effect on beetle larvae. As tillage practices can affect abiotic factors of the soil, such as structure, which may have a long-term impact on the microclimate factors of the soil that are important to arthropods such as soil temperature and moisture.

The spatial distribution differed between arthropod groups and changed temporally. There were no consistent patterns between the groups. Although, where 'distance from crop edge' was a significant factor in early summer (i.e. March), more arthropods, especially carabid and staphylinid beetles, were trapped at the field edges. Whereas later on in the year (i.e. May and July), more arthropods, especially staphylinid beetles and spiders were trapped in the middle of the fields. This may be a reflection of emigration of arthropods from their over wintering sites.

The results from this study indicate that previous crop type and distance from the crop edge are the most important factors that influence the numbers of carabid beetles, staphylinid beetles, beetle larvae and spiders in winter wheat fields. Future studies investigating the effect of tillage should attempt to account for these factors. This may be possible with split fields where both halves of the fields had been subjected to the same crop rotation. Many of the fields used in this study were on commercial farms where NIT methods had not been carried out for a long time; in some instances the NIT fields may have been ploughed the previous year. Further work could investigate the effect of NIT methods separately from integrated farming practices (i.e. lower agrochemical inputs) as previous authors have investigated. Also, it would be interesting to assess the effects of NIT in the long and short-term.

5.6 Summary

- Tillage was not significant in explaining the variation in carabid beetle, staphylinid beetle, beetle larvae or spider numbers in March, May or July with the full data set.
- Tillage was significant in explaining the variation in beetle larvae numbers in July with data from fields where the previous crop was oilseed rape. A greater abundance of beetle larvae were observed in CT than NIT fields.
- Trap position (i.e. distance from the crop edge), year and previous crop were the most common factors that explained the variation in arthropods.
- Future study should be conducted on split fields that have been subjected to the same rotations and where tillage practices have been carried consistently for several years.

Chapter 6

THE EFFECT OF NON-INVERSION TILLAGE ON THE MOVEMENT OF SEEDS

6.1 Summary

The effects of three different types of crop establishment methods on the movement of seeds at the surface of the soil were assessed. Two cultivated seeds, Oilseed Rape *Brassica napus* and Wheat *Triticum* species and a common arable weed, Fat Hen *Chenopodium album*, were used. The seeds were coated in professional fluorescent seed coating to enable ease of counting and to differentiate them from other seeds of the same species already present in the soil. The three types of crop establishment methods were (a) conventional tillage, (b) a non-inversion tillage method using a Smaragd and (c) a non-inversion tillage method using a Vaderstad drill. The conventional tillage consisted of a mouldboard plough and press followed by a power harrow and a Solitaire drill i.e. three passes. The 'Smaragd' cultivator consisted of wide wing shares (V-shaped tines) and discs, followed by a Solitaire drill i.e. two passes. The Vaderstad drill is a combination drill consisting of discs and spring tines as well as a seed drill i.e. one pass.

Twenty thousand Oilseed Rape, Wheat and Fat Hen seeds were placed on the soil surface of twelve plots in a randomised block design. After the cultivation of the plots had taken place, the surface soil was sampled in eight directions from the point of origin. Deep cores were also taken. The soil samples were dried and weighed and the seeds were counted in a dark room using UV light.

Statistical analysis was carried out by Analysis of Variance to assess the variation between tillage treatments on the total numbers of seed, for each of the three seed species, per plot left at for the surface and present in deep cores.

A significantly greater number of seeds remained at the soil surface in both the non-inversion tillage crop establishment methods compared to the conventional tillage. In fact, mouldboard ploughing left a mean of less than 3 seeds per plot for all of the seed species. For all of the seed species, the Vaderstad non-inversion tillage method left a significantly greater number of seeds on the soil surface than the Smaragd non-inversion tillage method.

6.2 Introduction

6.2.1 Seeds and birds

Many farmland bird species rely on seeds as a food source, especially outside the breeding season, in the autumn and winter. Species such as Linnets *Carduelis cannabina* and Yellowhammers *Emberiza citrinella* take, for example, docks, charlock and chickweeds, while bigger species such as Yellowhammer take cereal grains as well as weed seeds (Wilson *et al.* 1996). Increased agricultural intensification has resulted in reduced food resources over the winter which has been identified as having negative impacts on farmland bird populations (see previous chapters). It is therefore important to assess the impacts of different tillage methods on the abundance of seeds at the soil surface.

6.2.2 Seed movement and tillage

Relatively little work has been carried out on the effects of cultivation on weed seeds on arable land compared to the effect on weed seedlings. Research to date has focused on the effects of cultivation on weed seeds, particularly in the context of weed population dynamics and the role of weed seed banks.

Some studies have investigated the effects of tillage on the horizontal (Rew & Cussans 1997, Marshall & Brain 1999) and vertical (Cousens & Moss 1998) movement of seeds in soil. The seeds and tillage types used these studies can be seen in Table 6.1.

Table 6.1. Types of seeds and tillage used in other seed movement experiments.

Reference:	Seeds	Tillage
Marshall & Brain (1999)	Beads Barley Triticale	Mouldboard plough Spring tine Blench harrow Seed drill
Rew & Cussans (1997)	Barley Field Bean Oilseed Rape	Mouldboard plough Spring, straight & flexi-tine Power harrow Seed drill

These two experiments, looking at the horizontal movement of seeds, investigated the movement of different sized seeds or beads by a range of tillage practices that are still used today. However, Rew & Coussens (1997) used the emergence of three seeds types to ascertain movement i.e. counted seedlings as they emerged in the field. The germination of the seeds signifies that they were moved relatively close to the surface, as seed burial depth has been shown to be related to germination (Grundy *et al.* 2003). These results may be of less relevance when looking at seeds as a food source for farmland birds. However, a seed does not have to be viable to be a source of food for farmland birds, and Rew & Coussens (1997) is one example of many experiments with seeds that use this method. In both studies the seeds chosen were all relatively large and cultivated species. Few attempts have been made to assess the effect on smaller arable weeds seeds commonly found in the UK such as Fat Hen *Chenopodium alba L.* The movement of seeds has been observed to be effected by seed size (Rew & Cussans 1997). Although the tillage machinery used in the aforementioned experiments was well described, this level of description is lacking in many scientific papers and can be difficult to compare studies accurately (da Silva & Soares 2000).

Several studies successfully used tracers, which include beads from plastic injection mouldings (Marshall & Brain 1999) and ceramic spheres (Starika *et al.* 1990). Using the ceramic spheres and foxtail millet *Setaria* species, Starika *et al.* (1990) found that mouldboard ploughing moved the seeds to depths of 32 cm compared to 12 cm with a chisel plough. This study showed that a greater amount of seed was left on the soil surface with reduced tillage. They showed that proportion of seed or tracer left in the top 4 cm of the soil was 51% and 48% for the chisel plough and 11% and 4% for the mouldboard plough. A South American study found that only 8% of seeds were recovered from the top 8 cm of the soil after being broadcast on the surface and then ploughed twice and harrowed several times (Soriano *et al.* 1968). The two seed species used in that study, Lucerne *Medicago sativa* and Linseed *Linum usitatissimum*, appeared to be affected in the same way, in terms of their vertical movement in the soil. Cousens & Moss (1990) suggest that ploughing may have little inter-species differences in terms of the way it effects the movements of different seeds, even if they are different shapes and sizes, because ploughing moves seeds in a more uniform manner. In contrast, they suggest that other tillage practices may not affect seeds in such a uniform manner and therefore different seeds may react differently, and also may be affected by soil type and conditions. Cousens & Moss (1990) compared the effects of ploughing and a rigid tine cultivator. They found that for beads broadcast at the soil surface there were more beads in the top 5 cm of soil after tine cultivation in the first two years of cultivation. After this time a 'stable depth distribution' was predicted and this was a relatively even distribution of beads throughout the top 20 cm of soil. When this distribution had been reached, they were predicted to be very similar for both ploughing and tine cultivators up to twenty years if no more seeds/ beads are introduced. The effect of ploughing bring seeds to the soil surface has previously been observed. However, an experiment investigating the effects of ploughing on Johnson grass *Sorghum halepense L.* showed that ploughing appears to be more efficient at burying seeds than bringing them to the surface; they showed that 38% of the grass seeds were recovered from the soil surface compared to 80% recovered from below the soil surface (Van Esso *et al.* 1986).

6.2.3 Aim of chapter

To determine the effect of conventional ploughing and non-inversion tillage crop establishment methods on the horizontal and vertical movement of seeds on arable soil.

6.3 Method

6.3.1 Study site

The experiment was carried out on the Buttery Hill field (OS Grid Reference SJ 195 710) at Harper Adams University College, Shropshire. The experimental area was located within the field's crop area of 5.31 hectares. The field was established with winter wheat, using conventional ploughing methods, in autumn 2002. It was harvested in September 2003. The soil type was sandy loam (Beard 1988).

6.3.2 Soil moisture

As soil moisture can effect the movement of soil during cultivation, soil samples were collected pre-cultivation in each plot. One core per plot (70 mm deep by 73 mm in diameter i.e. volume = 292.98 cm^3) was taken horizontally to the soil surface at a depth of approximately 10 cm to avoid the surface trash. The soil samples were coarse-sieved to remove stones, weighed, oven-dried at 100^0C for 48 hours, or until dry, and then re-weighed.

6.3.3 Experimental design

The experiment was carried out using a randomised block design on 9th December 2003. The site was divided into four blocks. The blocks contained three different tillage treatments and their position within each block was randomly assigned (Figure 6.5). The three treatments used were conventional tillage and two different non-inversion tillage methods (Table 6.2).

Table 6.2. Crop establishment methods in experiment

	Conventional Tillage (Plough)	Non-inversion Tillage (Smaragd)	Non-inversion Tillage (Vaderstad)
Cultivation practice	• Mouldboard Plough and Press • Power harrow • Lemken Solitaire drill	• Smaragd • Lemken Solitaire drill	• Vaderstad Rapid drill
Total number of passes	3	2	1

All plots were cultivated using a Smaragd three weeks before the experiment took place (Figure 6.1). The conventional tillage plots were ploughed and pressed, and cultivated with a power harrow and then drilled with wheat using an Accord drill. One of the non-inversion tillage treatments was cultivated with a Smaragd 9 and then drilled with a Lemken Solitaire. The Smaragd has two rows of wide wing shares which are V-shaped tines that cut, loosen and intensively crumble the soil; these are followed by angled, concave discs in a staggered formation that level and mix the soil and trash. At the back of the Smaragd is tube bar roller that reconsolidates the soil (Figure 6.2). The other non-inversion tillage treatment was drilled with wheat using a Vaderstad Rapid combination drill (Figure 6.3). This has two sets of spring tines and three sets of discs (Figure 6.4). The treatments were randomly assigned within each block and alternate blocks of cultivation treatments were carried out in the same direction (Figure 6.5). The three tillage treatments work the soil in different ways and this can be seen by the trash left at the soil surface (Figure 6.10, Figure 6.11, Figure 6.12).

Figure 6.1. A Smaragd (A. Haley)

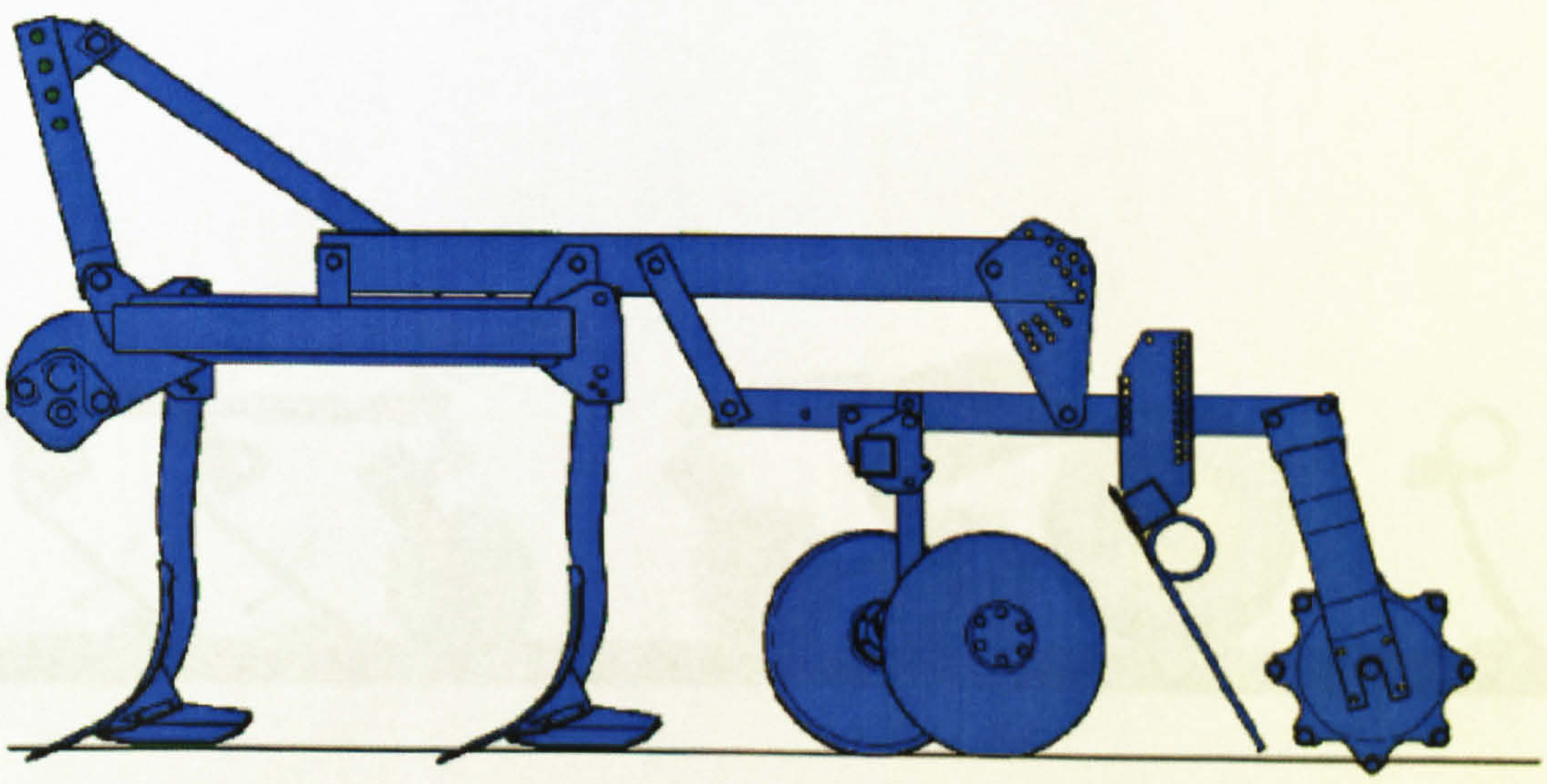

Figure 6.2. A diagram of a Lemken Smaragd 9 (Source: Lemken)

Figure 6.3. A Vaderstad Rapid Drill (H.M.Cunningham)

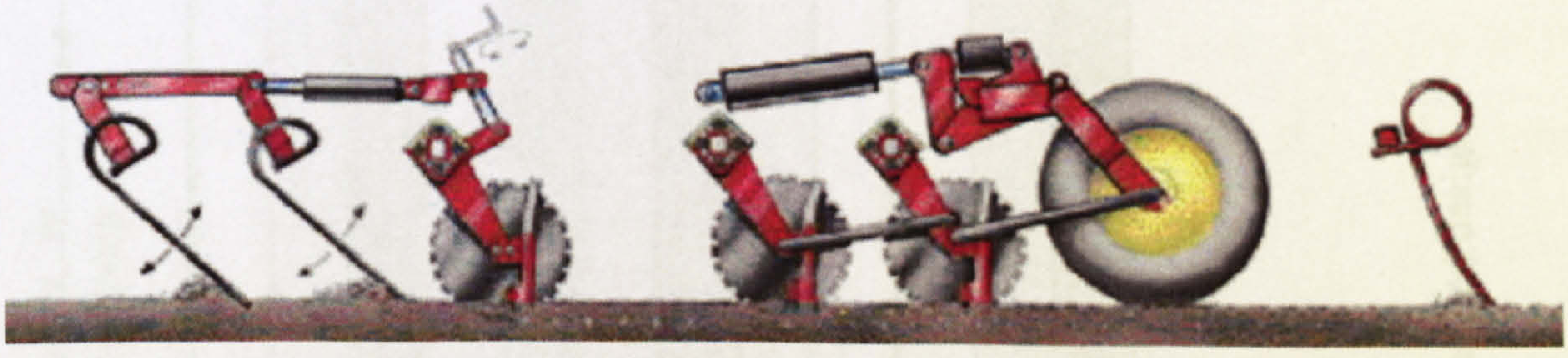

Figure 6.4. A diagram of the rows of discs and tines on a Vaderstad drill (Source: Vaderstad).

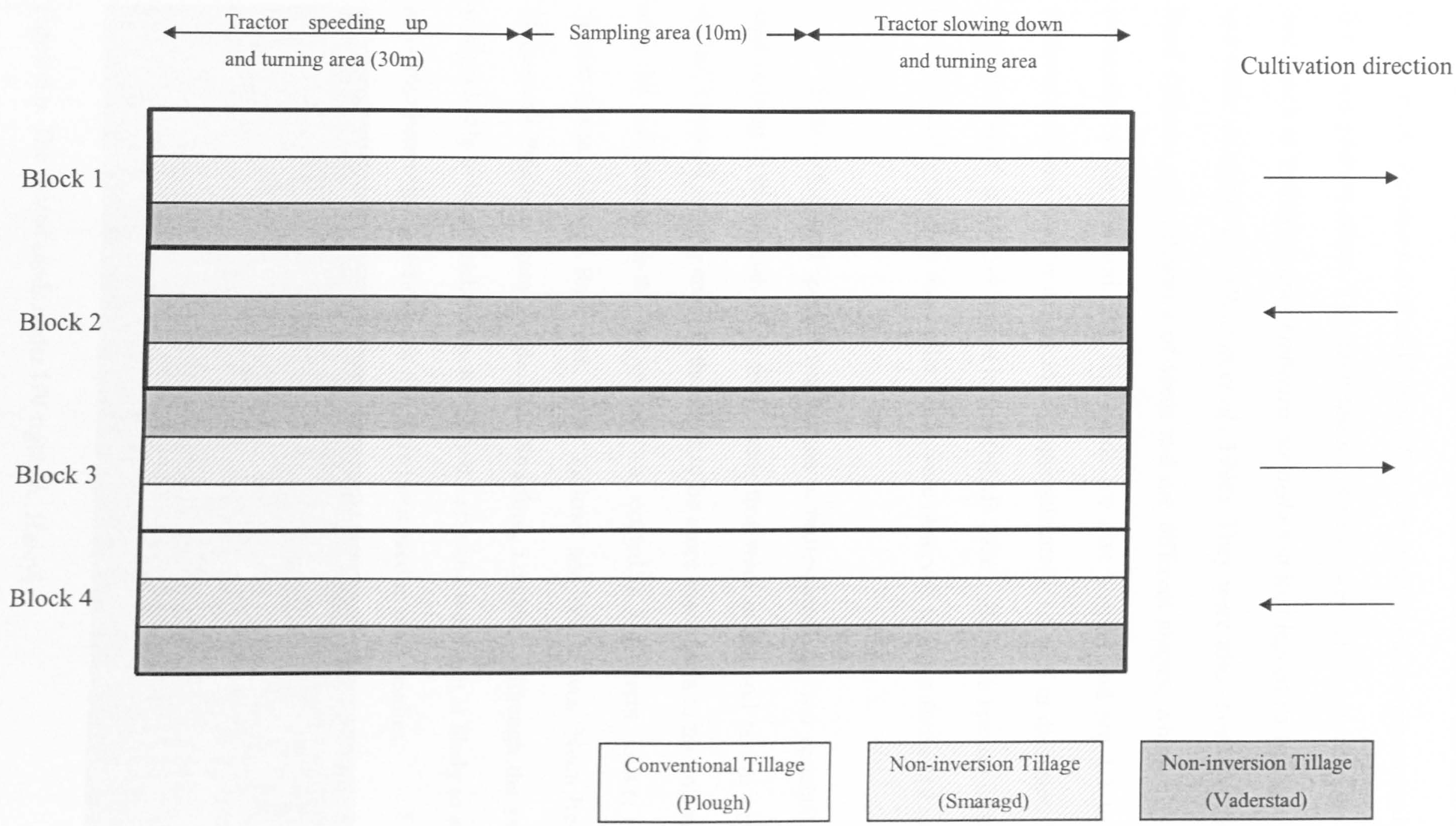

Figure 6.5. The generalised experimental design

6.3.4 Seeds

Three species of seeds were used in this experiment. These were two cultivated species Oilseed Rape *Brassica napus* and Wheat *Triticum* species and a common arable weed Fat Hen *Chenopodium album*. The three species of seeds were chosen as they are all eaten by birds, such as Yellowhammer *Emberiza citrinella* and Red-legged Partridge *Alectoris rufa*, and occur on arable land (Wilson *et al.*, 1996). They were also chosen as they represent three different size categories of seeds and are different shapes, which may affect their movement within the soil. Fat Hen seeds are disc shaped and are 1.3 to 1.5 mm in diameter. Oilseed Rape is spherical and approximately 3.5 mm in diameter. Wheat has a long, oval shape and is 5-9 mm in length (NIAB 1986). Between species differences have been reported previously as smaller seeds were observed to move further (Rew & Cussans 1997).

Each of the seed species was coated in professional, shower resistant, fluorescent seed coating to distinguish them from seeds that were in the soil or the wheat that was drilled. The seed coating enabled the seeds to be more easily seen in the soil samples taken after the cultivations. Each seed species was coated in a different colour; Fat Hen was 'Stellar Green', Oilseed Rape was 'Solar Yellow' and Wheat was 'Neon Red' (Daylight Fluorescent Pigments from Swada Ltd., Stratford, London). Although the surface of the seeds is likely to be altered, and potentially the size and weight, it is likely to simulate seed behaviour better than plastic beads that have been used in other studies.

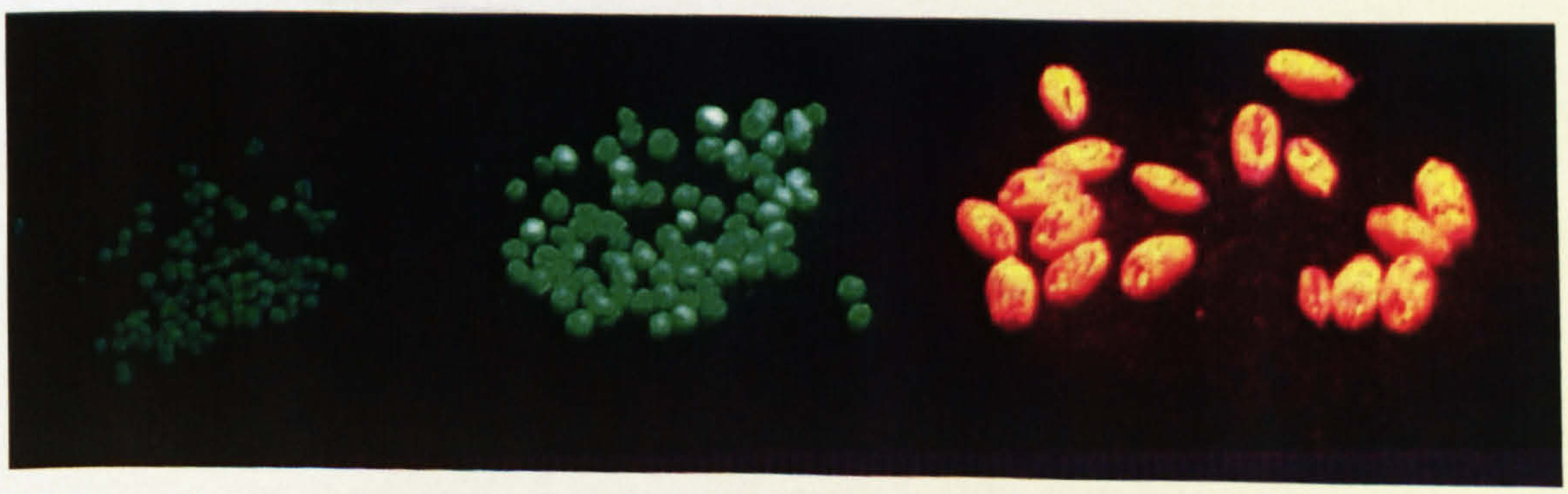

Figure 6.6. The coated seeds under UV light (A. Haley)

To determine the mean weight of each seed species, five batches of 100 seeds were weighed. From this calculation twelve batches of 20,000 seeds of each species were weighed and each batch was broadcast within a 0.5 m^2 quadrat. The quadrat containing the source seeds was located 3 m from the start of the sampling area in each plot and in the middle of the plots laterally. The point of origin of the seed source quadrat was measured from two marker posts either side of the plots pre-cultivation which enabled relocation post cultivation (Figure 6.7). The sampling area was at least 30 m from the edge of the field to allow the tractor to gain a normal cultivation speed for each piece of machinery (Figure 6.5).

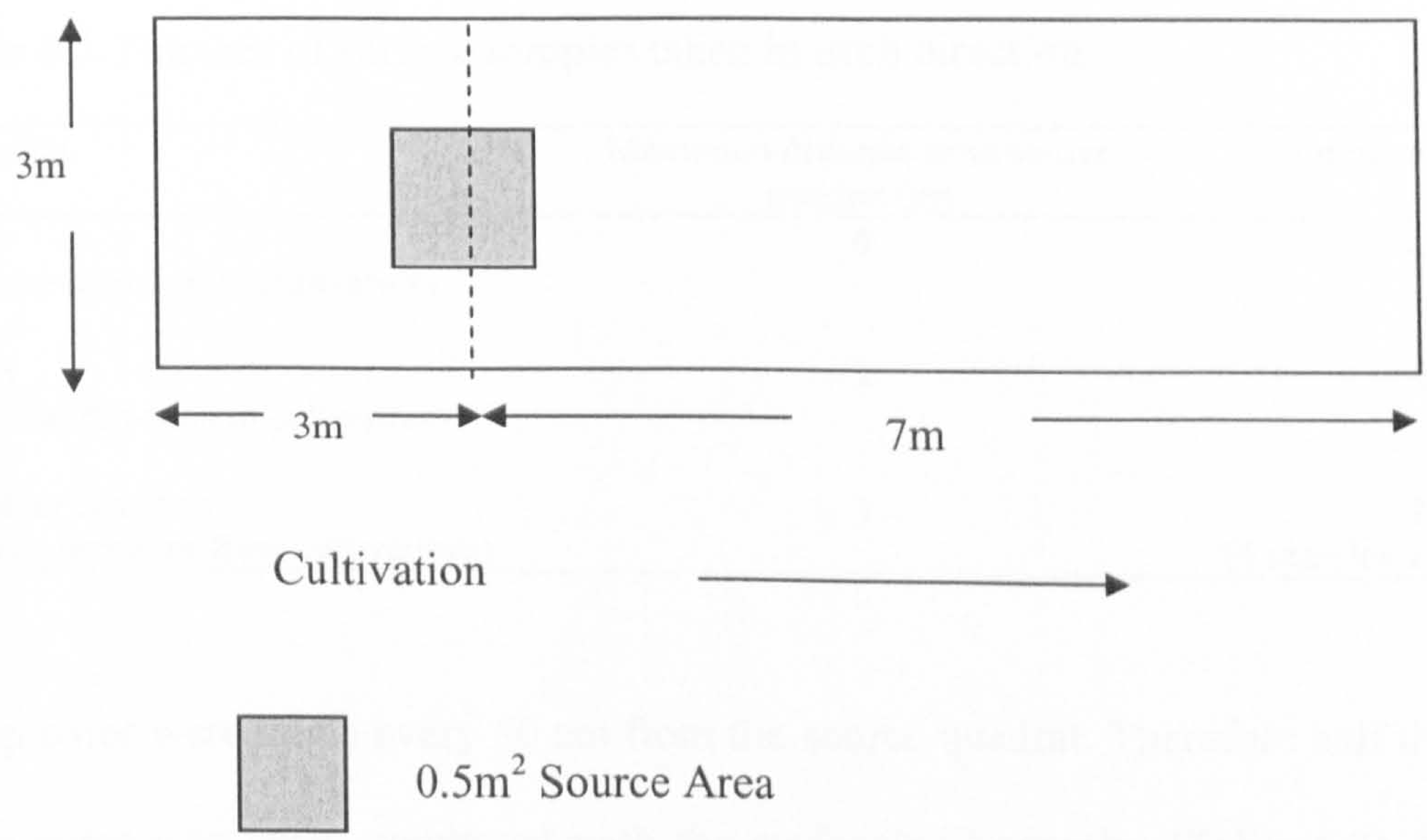

Figure 6.7. Placement of seeds pre-cultivation in each sampling area

After the cultivations had taken place the positions of the seed source quadrats were relocated and soil samples were taken from the soil surface and deep cores were taken. The soil samples consisted of an area of 25 cm^2 by 2 cm deep collected and placed in a labelled bag. The deep cores were taken with a 20 cm deep by 4 cm diameter soil corer.

The quadrats were placed in a line in 8 directions from the source quadrat (Figure 6.8). The directions were defined as North, Northeast, East, Southeast, South, Southwest, West and Northwest. North was the direction of the cultivation. The surface samples were taken contiguously from the source quadrat i.e. four samples per meter. A different number of surface soil samples were taken at the different directions from the source quadrat (Table 6.3, Figure 6.8).

Table 6.3. Number of surface samples taken in each direction

Direction	Maximum distance from source quadrat (m)	Number of samples
North (in same direction as cultivation)	6	24
South (opposite direction to cultivation)	2	8
All other direction (lateral directions from cultivations)	1	24 (4 samples x 6 directions)

Deep cores were taken every 50 cm from the source quadrat. Therefore half the number of deep cores was taken compared with the surface soil samples (Table 6.3). The distance away from the seed source were determined from the works of Marshall & Brain (1999) and Rew & Cussans (1997), who carried out between three and five cultivation passes and surveyed weeds up to 6 m from the origin.

Each soil sample was oven-dried at 80^{0}C for 3 days. The soil samples were emptied individually on to a tray in a dark room and an Ultra-Violet light was moved slowly over the sample. The three seed species were counted separately.

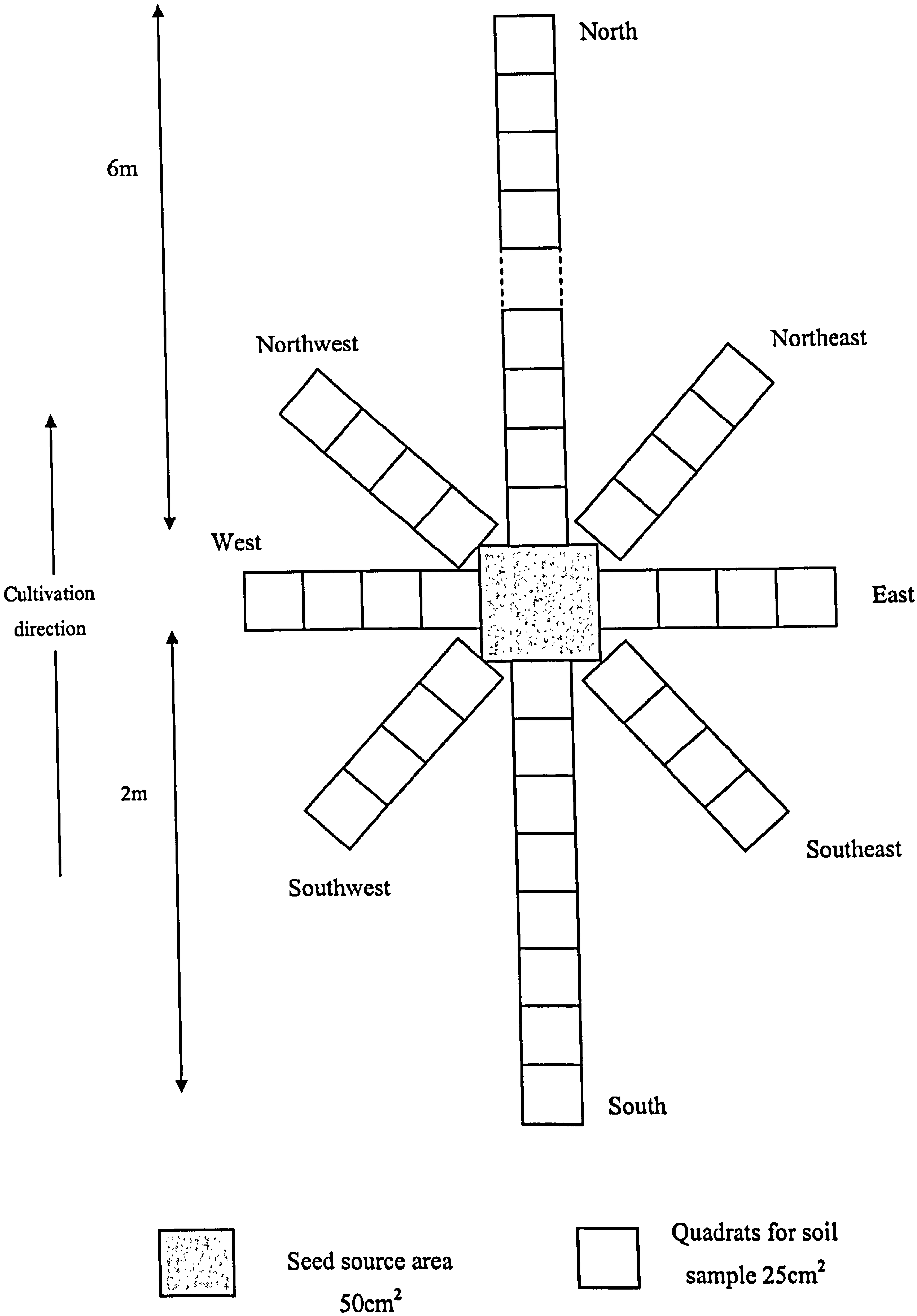

Figure 6.8. Post cultivation surface sampling strategy

6.3.5 Analysis

To assess if there was a difference between tillage treatments in terms of the mean number of seed remaining on the surface, a two-way ANOVA was performed on the total number of each seed species (natural log) left on the surface in each plot. Tillage treatment (a three level fixed factor: Plough, Vaderstad and Smaragd) and seed type (a three level fixed factor: Fat Hen, Oilseed Rape and Wheat) were the two factors analysed and the interaction between them (i.e. Tillage treatment * Seed type). As there are three level factors, where any factors were significant a post-hoc Tukey test was performed to assess which levels of the factors were significantly different. This type of analysis was repeated for the seeds in the deep cores.

To assess if there was a difference in terms of the horizontal movement of seeds between tillage treatments, the natural log of the total number of each seed species remaining on the surface at 0-1 m, 1-2 m, 2-3 m, 3-4 m, 4-5 m and 5-6 m was calculated. A two-way ANOVA was performed testing for the significance of distance travelled, tillage treatment and seed species. Tillage treatment was a two level fixed factor: Vaderstad and Smaragd, containing only the two non-inversion tillage treatments. The Plough treatment results were removed as no seeds were found on the soil surface and this is likely to have affected the AVOVA. Seed species was a three level fixed factor: Fat Hen, Oilseed Rape and Wheat. The distance the seeds travelled was a six level fixed factor: 0-1 m, 1-2 m, 2-3 m, 3-4 m, 4-5 m and 5-6 m from where the seeds were originally place before cultivations. (NB. As the majority of seeds were recorded in the direction of the cultivation, only these results were used in the analysis). The interaction between these factors was only assessed (i.e. Tillage treatment * Seed species * Distance). Where any factors were significant the geometric means and the Least Significant Differences of Means (l.s.d.) were used.

The mean numbers of seeds in each distance category from the origin for each of the eight directions are presented graphically. This was repeated for each of the three seed species. The overall mean number of seeds left at the surface per treatment was also calculated. The graphs are displayed per seed species.

6.4 Results

6.4.1 Water content of the soil

The mean percentage water content was similar between treatments (Figure 6.9).

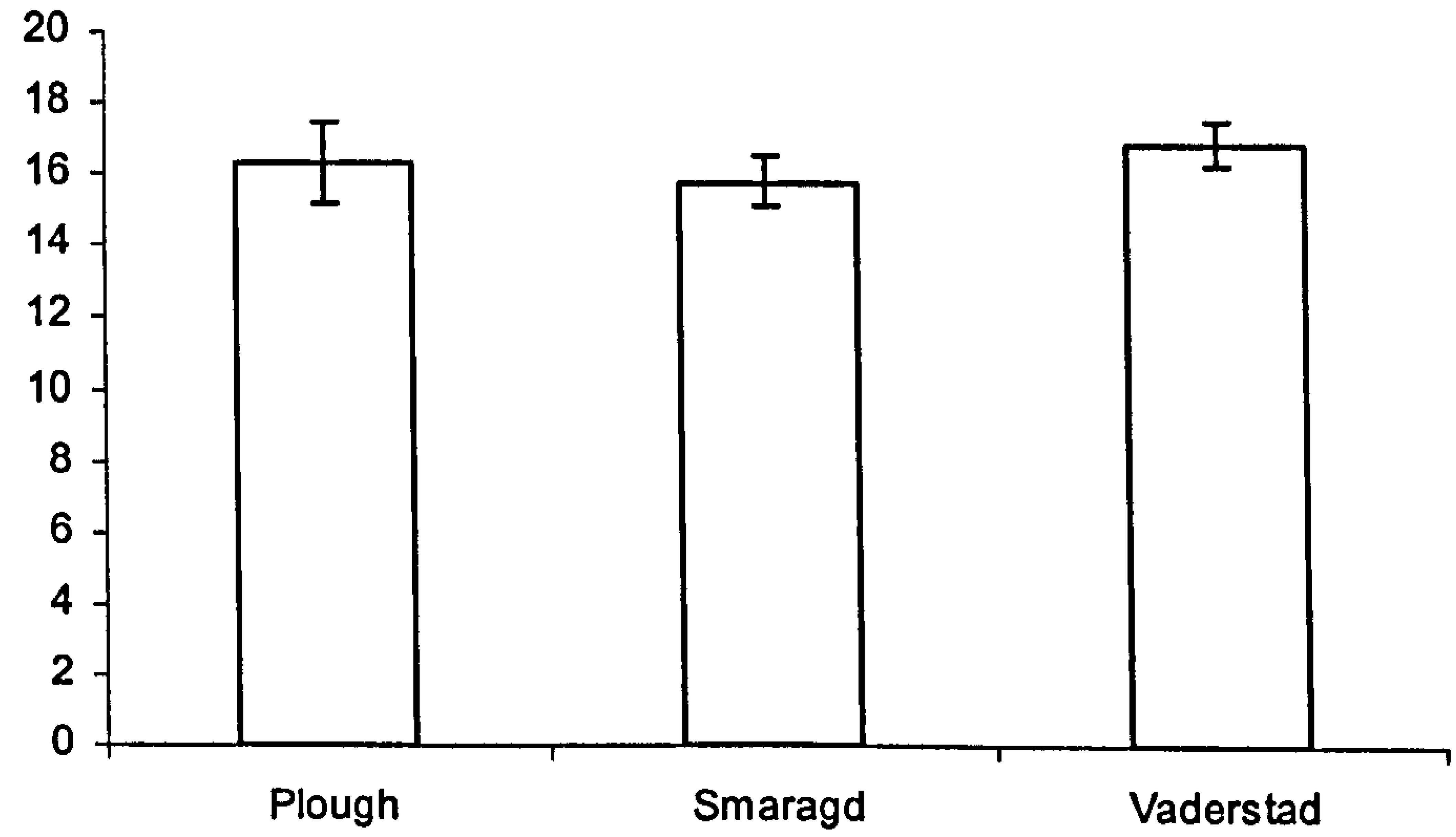

Figure 6.9. Mean water percentage water content in each of the tillage plots pre-cultivation (±SE)

6.4.2 Surface trash

The Smaragd cultivator followed by the Solitaire drill left a greater amount of the previous crops residue (i.e. stubble) at the soil surface (Figure 6.10) than the Vaderstad drill (Figure 6.11). The conventional tillage consisting of the mouldboard plough, power harrow and Solitaire drill left virtually none of previous crops residue (Figure 6.12).

Figure 6.10. Smaragd cultivator and Solitaire drill (C.Murray)

Figure 6.11. Vaderstad drill (C.Murray)

Figure 6.12. Mouldboard, Power harrow and Solitaire drill (C.Murray)

6.4.3 Total number of seeds at the surface

The mean number of seeds remaining at the soil surface after ploughing is negligible, i.e. less than three seeds per plot, for all three species (Figure 6.13). There was a significant difference between the tillage treatments, but not between the seed types or an interaction between tillage and seed type (Table 6.4). Using a Tukey post-hoc test ($p<0.05$), it was seen that there was a significant difference between all three tillage treatment. The Vaderstad left a significantly greater amount of all three seed species on the soil surface than the Smaragd or ploughing (Figure 6.13). The Smaragd left significantly less seeds on the surface than the Vaderstad, but more than ploughing. All seed species acted the same for all tillage treatments.

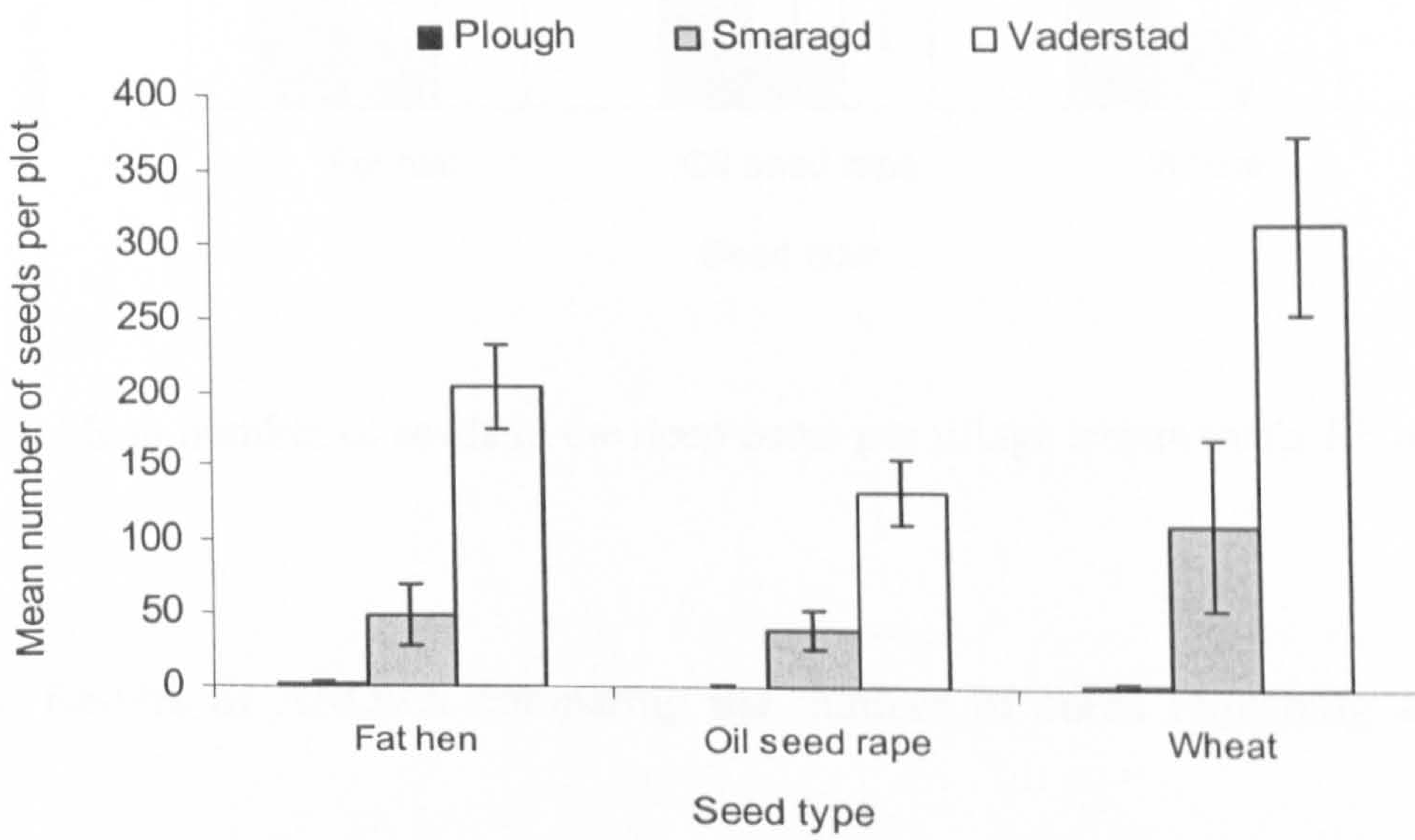

Figure 6.13. Mean number of seeds on the surface per tillage treatment (± SE bars).

Table 6.4. Results of ANOVA comparing the number of seeds remaining at the soil surface.

Source	D.F.	SS	MS	F-value	P-value
Tillage Treatment	2	137.469	68.734	119.43	**0.000**
Seed type	2	2.106	1.053	1.83	0.180
Treatment*Seed type	4	1.430	0.358	0.62	0.651
Error	27	15.539	0.576		
Total	35	156.544			

6.4.4 Total number of seeds in the deep soil cores

No significant differences were observed between tillage treatments or seed types (Figure 6.14 and Table 6.5). No interaction was observed for tillage treatments and seed types (Table 6.5).

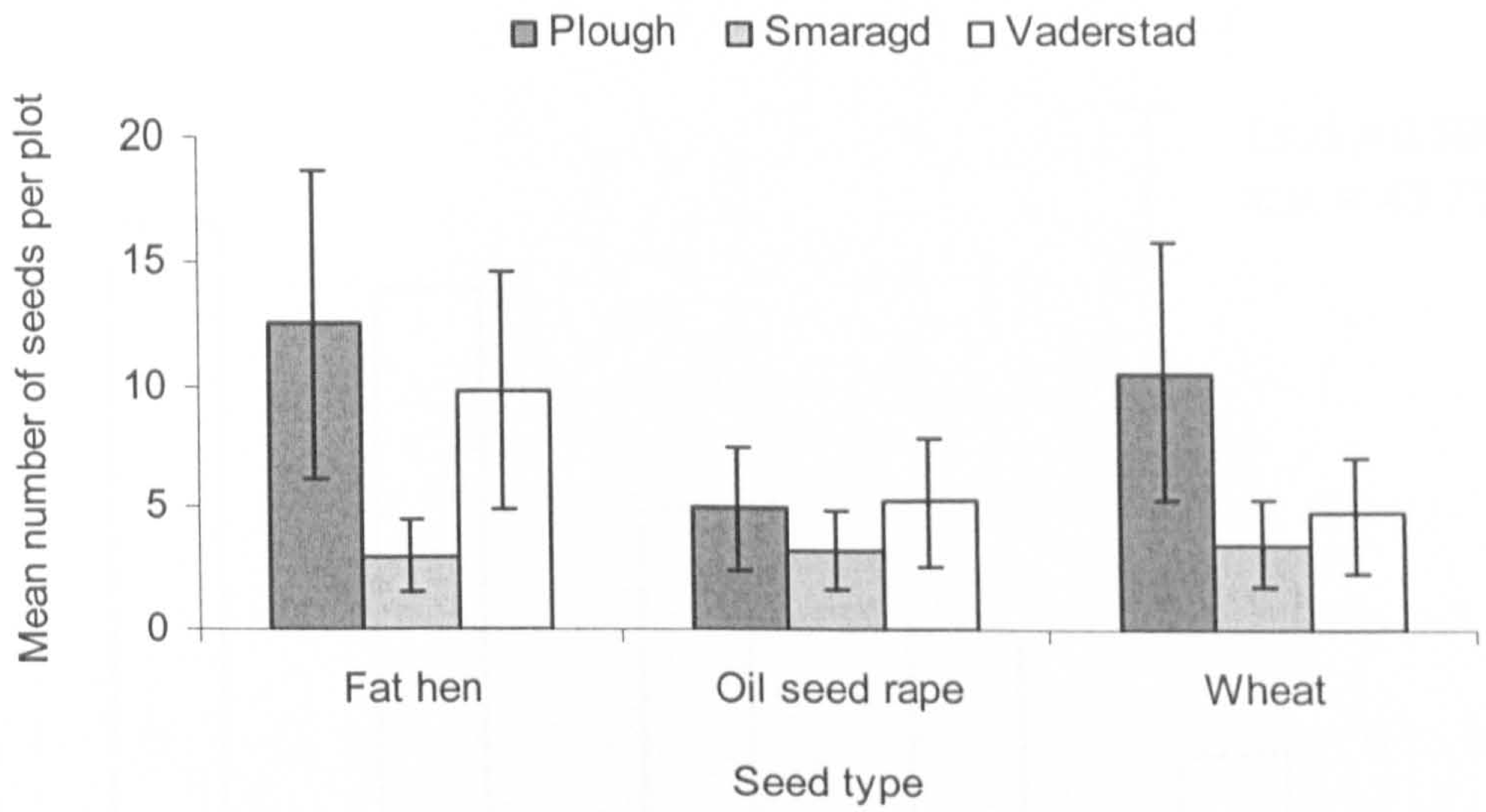

Figure 6.14. Mean number of seeds in the deep cores per tillage treatment (± SE bars).

Table 6.5. Results of ANOVA comparing the number of seeds remaining at the soil surface.

Source	D.F.	SS	MS	F-value	P-value
Tillage Treatment	2	0.6158	0.3079	2.32	0.118
Seed type	2	0.4320	0.2160	1.26	0.216
Treatment*Seed type	4	0.2720	0.0680	0.51	0.728
Error	27	3.5909	0.1330		
Total	35	4.9107			

6.4.5 Horizontal movement in the surface seeds

The mean number of seeds remaining at the soil surface after ploughing is negligible for all three species therefore it was removed from the analysis. There was no significant difference between the tillage treatments, or the seed species or any of the interactions (Table 6.6). The distance seeds travelled significantly declined after 2 m and again after 4 m (Figure 6.15).

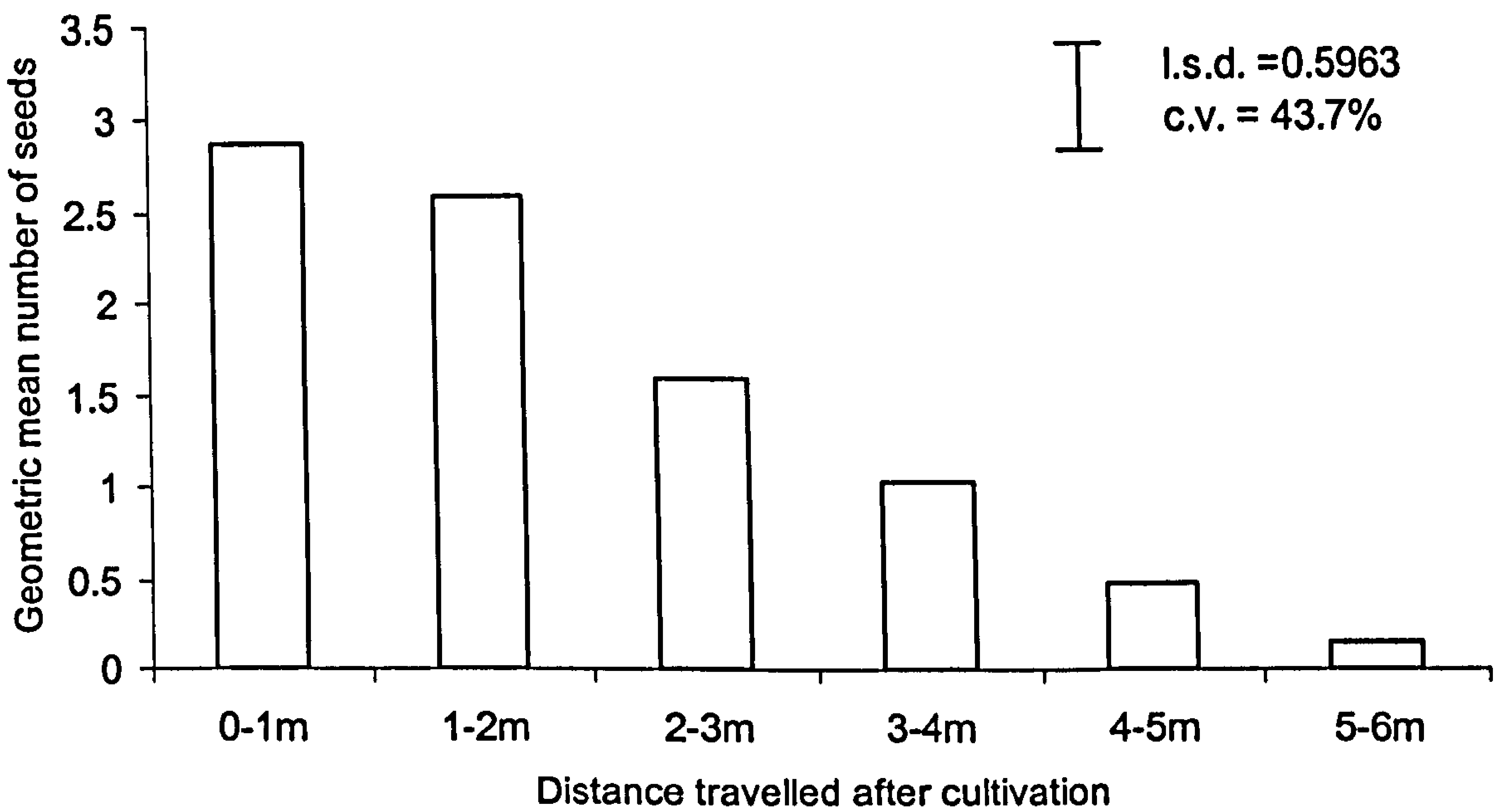

Figure 6.15. Geometric mean number of seeds on the soil surface at each distance (with the l.s.d.).

Table 6.6. Results of ANOVA comparing the number of seeds remaining at the soil surface.

Source of variation	D.F.	S.S.	M.S.	v.r.	F pr.
Distance	5	148.874	29.775	27.44	**<0.001**
Treatment	1	1.303	1.303	1.20	0.276
Species	2	1.261	0.630	0.58	0.561
Distance.Treatment	5	11.978	2.396	2.21	0.059
Distance.Species	10	2.202	0.220	0.20	0.996
Treatment.Species	2	1.676	0.838	0.77	0.465
Distance.Treatment.Species	10	3.826	0.383	0.35	0.964
Residual	105	113.941	1.085		
Total	143	327.837			

6.4.6 Horizontal movement of Fat Hen

The following eight graphs show the mean number of Fat Hen seeds retained at the soil surface at distances from the point of origin. The first four graphs show the movement in the primary sampling directions, with, against and laterally to the cultivation i.e. North, South, East and West (Figure 6.16a, b, c and d). The second four graphs show the secondary sampling directions, i.e. Northwest, Northeast, Southwest and Southeast (Figure 6.17a, b, c and d). As very few seeds were retained at the soil surface after mouldboard ploughing, little comment can be made on the distribution of seeds in these plots. The greatest amount of seeds were moved in the direction of the cultivation i.e. North (Figure 6.16a) although few seeds were observed past 1 m from the origin for any of the tillage treatments. Movement of seeds was very limited (i.e. less than six seeds per quadrat) in the secondary sampling directions Northwest, Southeast and Southwest (Figure 6.17b, c and d) and East (Figure 6.16c). For the Vaderstad tillage, some movement of Fat Hen seeds were seen Northeast, West and South directions to 0.5 m, 0.5 m and 0.75 respectively (Figure 6.17a, Figure 6.16b and d).

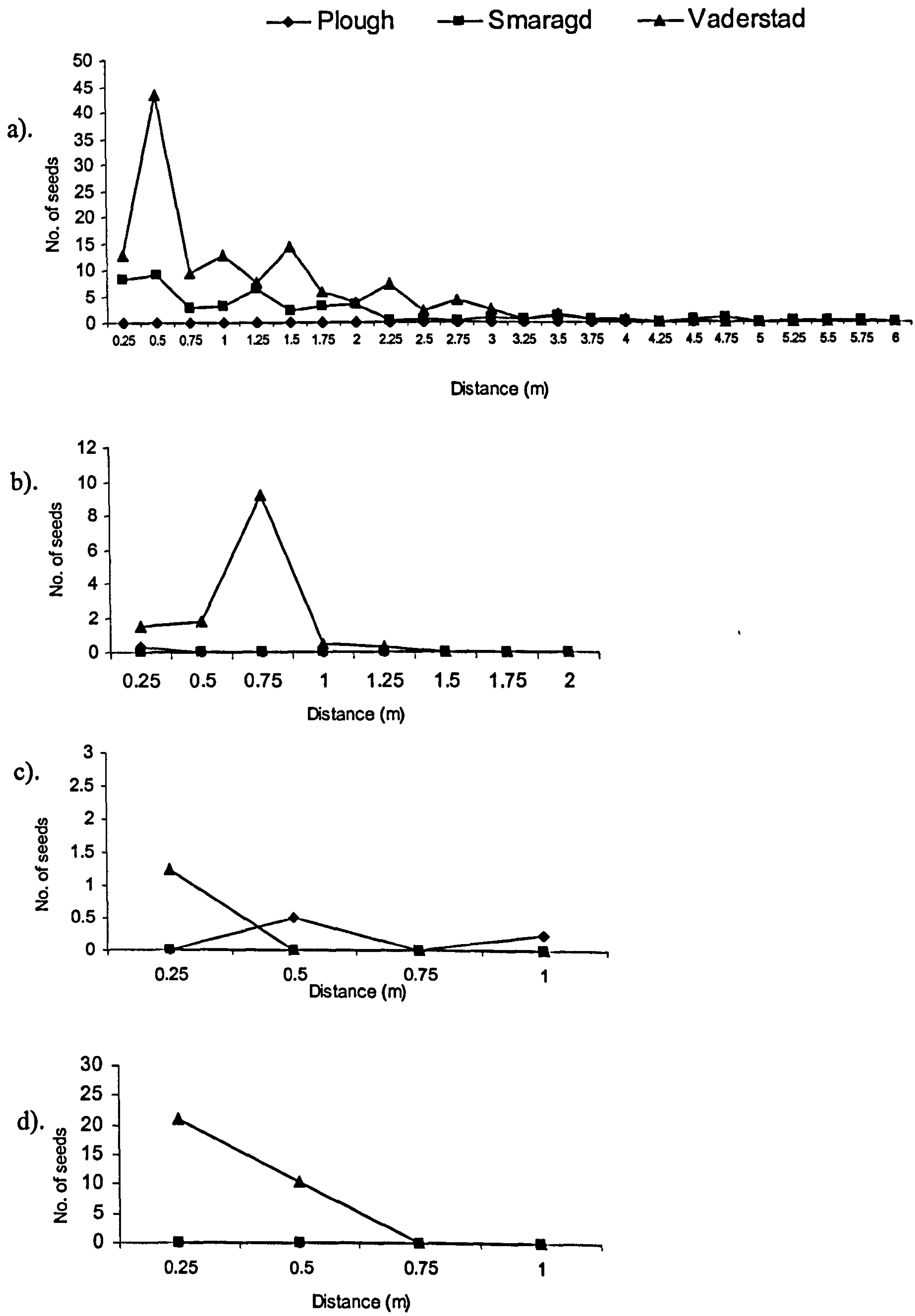

Figure 6.16. Mean number of Fat Hen seeds in the direction of (a) North, (b) South, (c) East and (d) West.

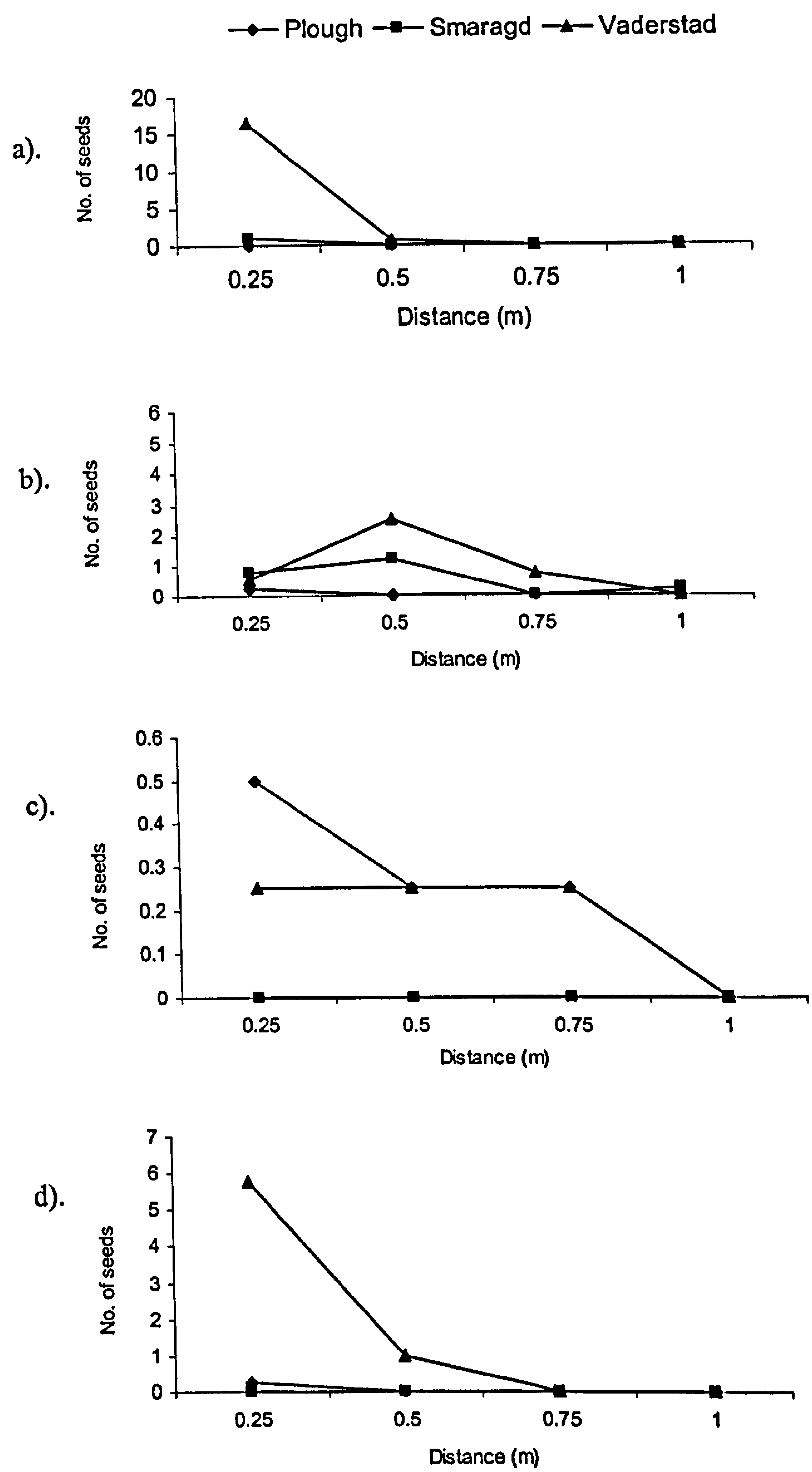

Figure 6.17. Mean number of Fat Hen seeds in the direction of (a) Northeast, (b) Northwest, (c) Southeast and (d) Southwest.

6.4.7 Horizontal movement of Oilseed Rape

The following eight graphs show the mean number of Oilseed Rape seeds retained at the soil surface at distances from the point of origin. The first four graphs show the movement in the primary sampling directions, with, against and laterally to the cultivation i.e. North, South, East and West (Figure 6.18a, b, c and d). The second four graphs show the secondary sampling directions, i.e. Northwest, Northeast, Southwest and Southeast (Figure 6.19a, b, c and d). As very few seeds were retained at the soil surface after mouldboard ploughing, little comment can be made on the distribution of seeds in these plots. The greatest amount of seeds were moved in the direction of the cultivation i.e. North (Figure 6.18a) although few seeds were observed past 5 m from the origin for any of the tillage treatments. Movement of seeds was very limited (i.e. less than six seeds per quadrat) in the secondary sampling directions Northwest, Southeast and Southwest (Figure 6.19b, c and d) and South and East (Figure 6.18b and c). For the Vaderstad tillage, some movement of Oilseed Rape seeds were seen West and Northeast directions to 0.5 m and 0.25 m respectively (Figure 6.18d, Figure 6.19a).

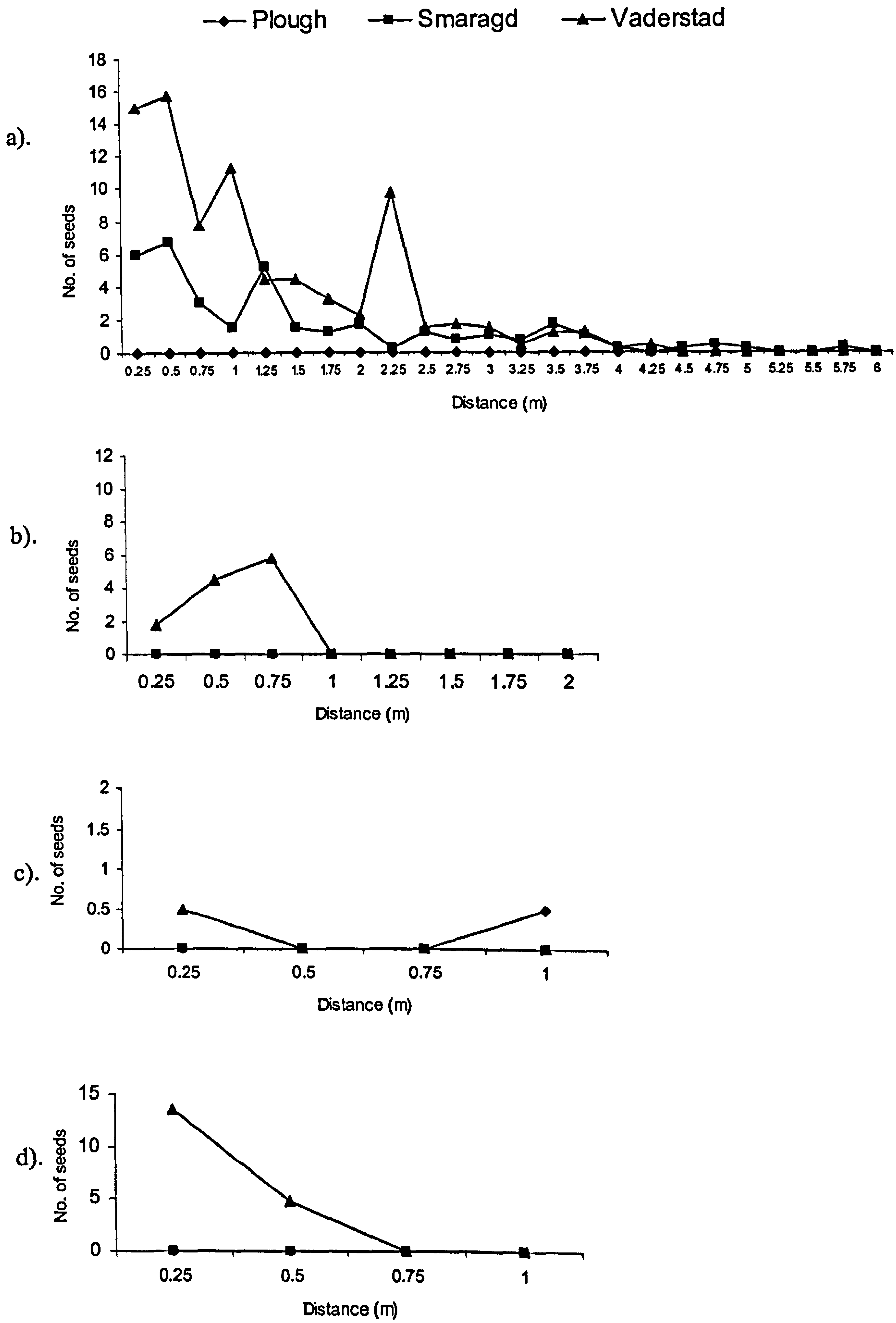

Figure 6.18. Mean number of Oilseed Rape seeds in the direction of (a) North, (b) South, (c) East and (d) West.

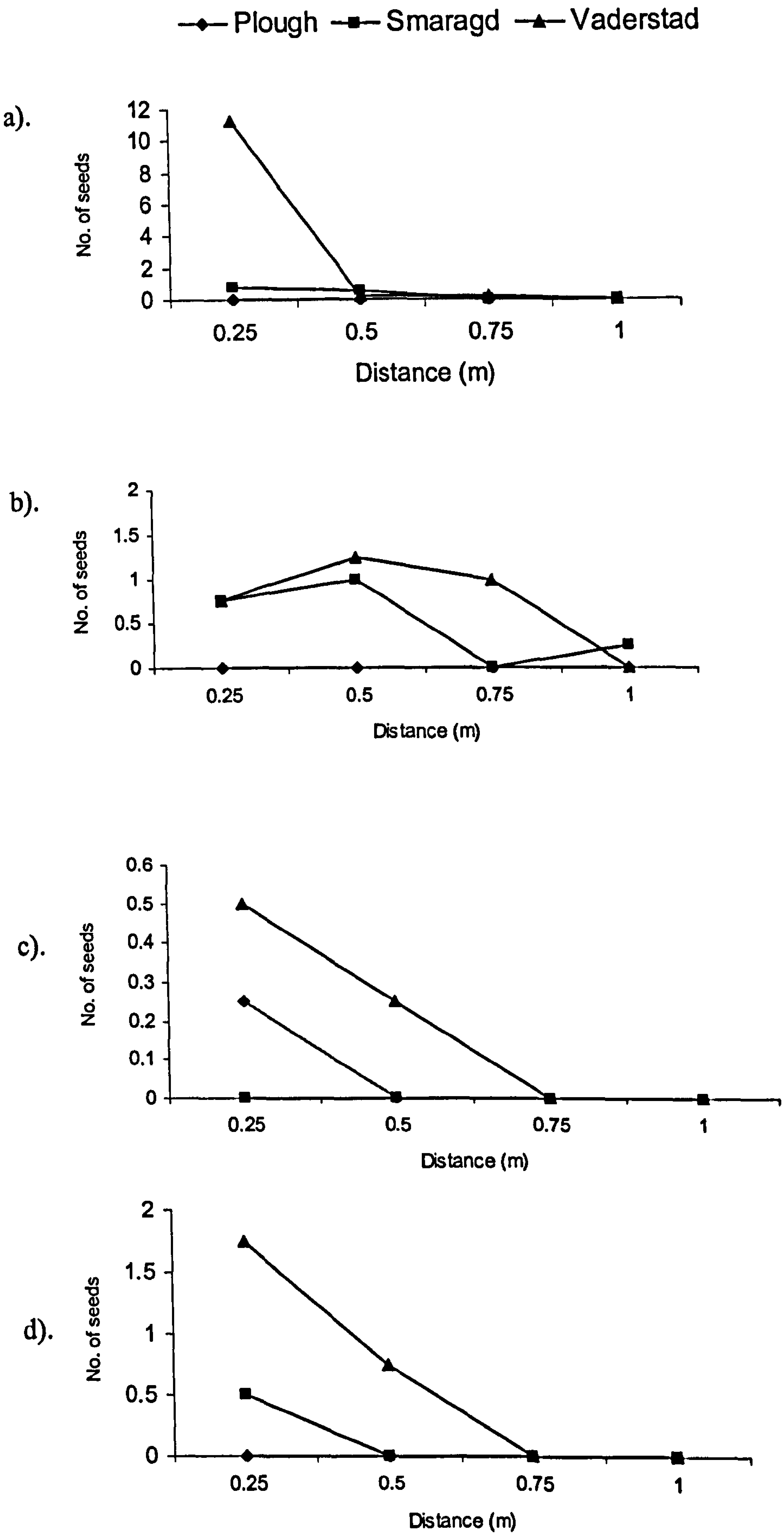

Figure 6.19. Mean number of Oilseed Rape seeds in the direction of (a) Northeast, (b) Northwest, (c) Southeast and (d) Southwest.

6.4.8 Horizontal movement of Wheat

The following eight graphs show the mean number of wheat seeds retained at the soil surface at distances from the point of origin. The first four graphs show the movement in the primary sampling directions, with, against and laterally to the cultivation i.e. North, South, East and West (Figure 6.20a, b, c and d). The second four graphs show the secondary sampling directions, i.e. Northwest, Northeast, Southwest and Southeast (Figure 6.21a, b, c and d). As very few seeds were retained at the soil surface after mouldboard ploughing, little comment can be made on the distribution of seeds in these plots. The greatest amount of seeds were moved in the direction of the cultivation i.e. North (Figure 6.20a) although few seeds were observed past 5 m from the origin for any of the tillage treatments. For the Vaderstad tillage, relatively substantial movement of wheat was observed up to 0.5 m from the origin to the West and Northeast (Figure 6.20d and Figure 6.21a). Movement of seeds was very limited (i.e. less than eight seeds per quadrat) in all other sampling directions South, East, Northwest, Southeast and Southwest (Figure 6.20b and c, Figure 6.21b, c and d).

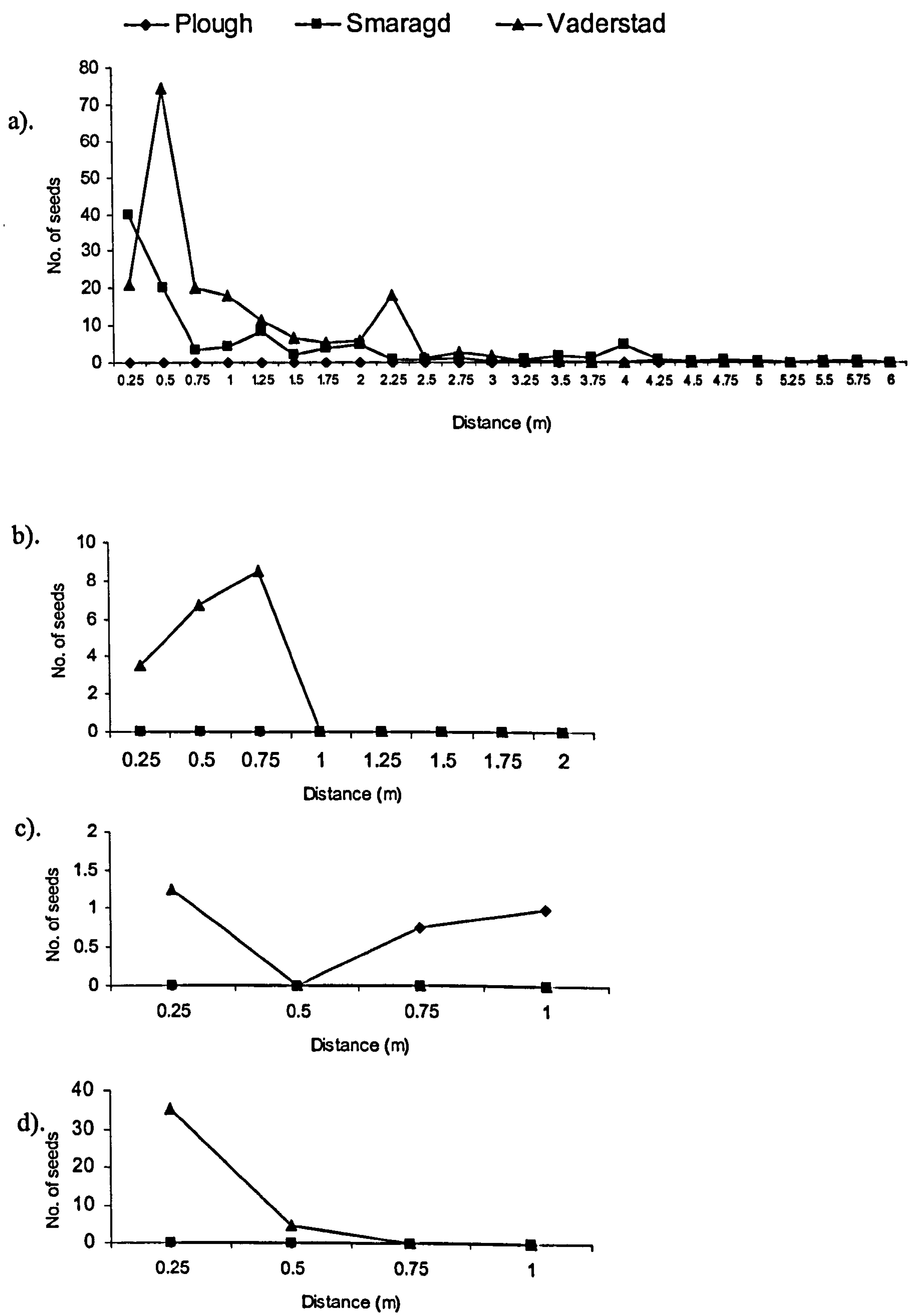

Figure 6.20. Mean number of Wheat seeds in the direction of (a) North, (b) South, (c) East and (d) West.

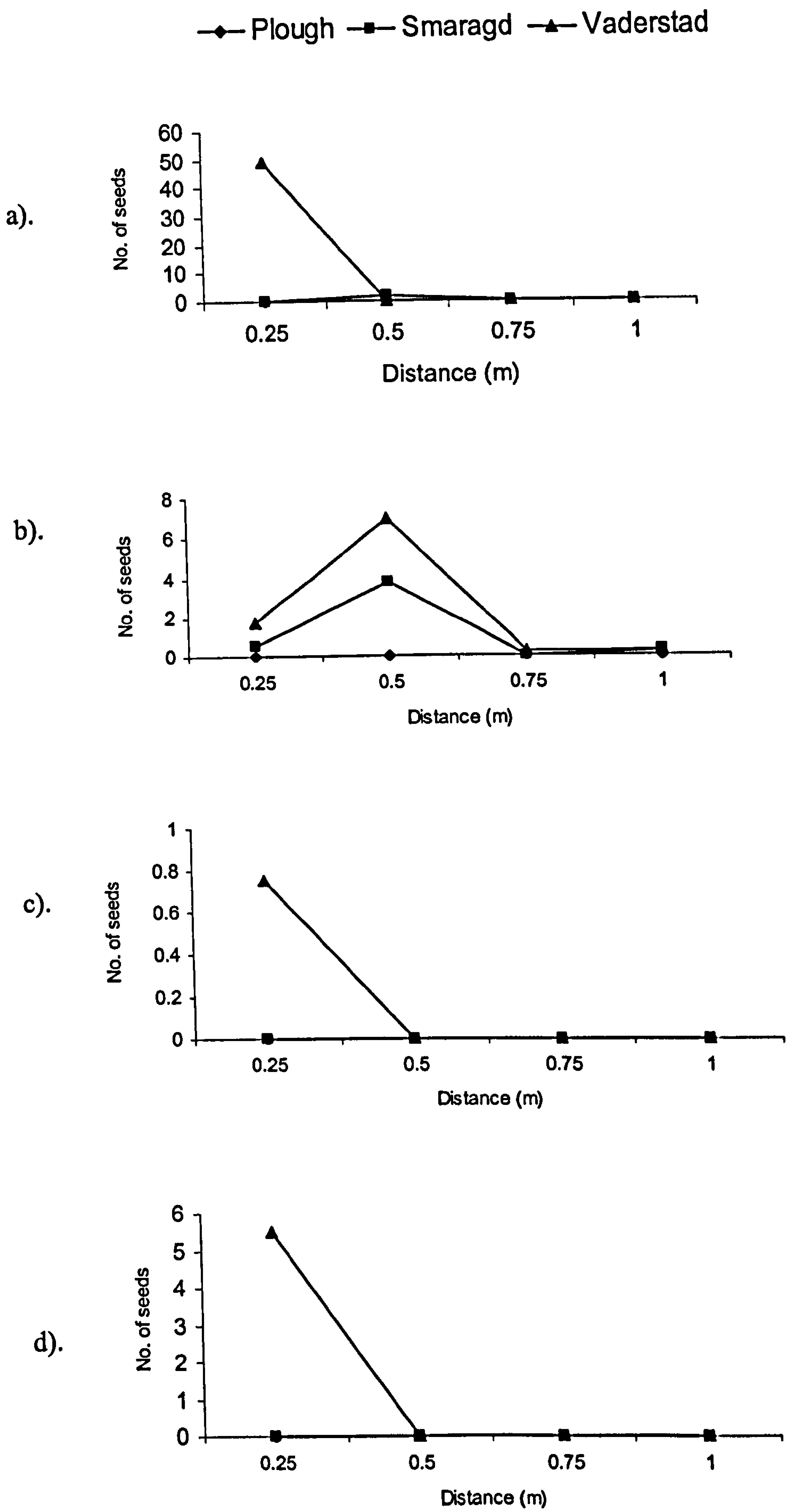

Figure 6.21. Mean number of Wheat seeds in the direction of (a) Northeast, (b) Northwest, (c) Southeast and (d) Southwest.

6.5 Discussion

Vertical movement of seeds. A significantly greater amount of seeds were recovered at the soil surface of plots that had been tilled with non-inversion tillage machinery compared to the ploughed plots. This was expected as Vaderstad and Smaragd do not invert and bury the surface soil. A relatively greater amount of seed remained at the soil surface after the Vaderstad than the Smaragd NIT methods. This could be for the following two reasons or their combined affect. Firstly, the two types of NIT machinery have very different implements to break up the soil without inverting it. The Smaragd has two sets of V-shaped tines that cut and loosen the soil, followed by concave angled discs that mix the soil and crop residue, and then a tube bar roller to consolidate the soil. Whereas the Vaderstad has two sets of spring tines and three sets of discs. From the results it appears that the implements of the Smaragd mix the soil more thoroughly than the discs and spring tines of the Vaderstad. Secondly, the crop establishment using the Smaragd actually involved two passes of machinery. The Smaragd was used to cultivate the soil, but unlike the Vaderstad, it is not combined with a drill, so a Lemken Solitaire drill was used to drill the crop afterwards. Although this drill does not have extra cultivation implements attached, it may have led to extra mixing of the soil and therefore a relatively greater burial of seeds that were on the surface. The extra pass may have alternatively led to a greater horizontal movement of seeds and therefore fewer seeds were recovered in the sampling areas.

Significantly fewer seeds of all species were recovered from the soil surface of the conventionally mouldboard ploughed plots. From the deep cores, a greater number of seeds were not recovered from the ploughed plots. This may be due to the fact that when mouldboard ploughing inverts the soil it is moved over in a lateral direction. Also, the deep soil cores in this study were analysed as one sample i.e. from the soil surface to 20 cm depth. This means that effects of vertical movement may have been masked.

Seeds found in the surface soil layer and the deep cores, show that all three seed species reacted in the same way after mouldboard ploughing. This concurs with suggestions made by Cousens & Moss (1990) that as ploughing is a relatively uniform process seed will be affected in a similar way regardless of size or shape. However, all three seed species reacted in the same way after the non-inversion tillage methods as well. This contradicts Cousens & Moss (1990) who suggested that seeds of different shapes and sizes may be differently affected by reduced forms of tillage. As the three seed species represent three different categories of seed shapes and sizes, it is proposed that the movement of these seeds are representative of many other species found in arable fields.

Horizontal movement of seeds. The number of seeds moved in all directions on the soil surface was minimal in the ploughed plots as very few seeds were retained on the soil surface. The main movement of seeds was with the direction of cultivation for both NIT methods.

Water content of soil. The mean percentage water content for all the plots was 16.30%, and there did not appear to be great variation in the mean percentage water content between each of the plots where the different cultivations were to take place (Figure 6.9). This percentage water content is below the field capacity for this soil type (Miller & Donahue 1990) and therefore provided suitable conditions for tilling.

This study shows how tillage treatments affect seeds that are at the soil surface. The seeds are present at the soil surface due to being deposited after cultivation by seed rain i.e. from weed plants growing after cultivation, seed dispersers such as mammals and birds or from the seed bank during cultivation. This experiment does not account for seeds that are brought up from the seed bank after cultivation.

6.6 Conclusions

- Both non-inversion tillage crop establishment methods left more Fat Hen, Oilseed Rape and Wheat seeds on the soil surface compared to conventional mouldboard ploughing.
- Non-inversion tillage using a Vaderstad drill left a significantly greater amount of all three seed species at the soil surface than NIT using a Smaragd and Solitaire drill.
- Mouldboard ploughing buries virtually all seeds present on the soil surface.
- Different sized and shaped seeds reacted in the same way to the different tillage treatments.
- No differences were found between the tillage treatments in terms of seeds surveyed in deep cores i.e. from the soil surface to 20 cm deep.
- All three seed species reacted the same way to all three cultivation treatments and this means that the results from this experiment may be representative of the movement of many other weed and crop species on arable land.
- The implications that this has on seeds as a food source for is that non-inversion tillage methods will retain a relatively greater amount of seeds at the soil surface. However, the effects of different tillage methods on seeds moved to the soil surface may depend on the presence and distribution of seeds in the seed bank below the soil surface.

Chapter 7

GENERAL DISCUSSION

7.1 Summary of key results

- A greater proportion of fields established by non-inversion tillage (NIT) were occupied by Skylarks *Alauda arvensis*, other granivorous passerines and game birds.
- In the autumn and spring, there were no differences between NIT and CT fields in terms of the abundance and biomass of earthworms or the abundance of weed seeds.
- In the summer months (March, May and July), there were no differences between NIT and CT fields in terms of the abundance of surface active arthropods (beetles, beetle larvae and spiders).
- Cultivation using a mouldboard plough (CT) buries a significantly greater number of weed and crop seeds than non-inversion tillage. Seeds of different shapes and sizes respond in the same way to different tillage practices. Different NIT methods can retain significantly different numbers of seeds at the seed surface.

7.2 Discussion

The effect of non-inversion tillage on farmland birds with respect to each of their food resources (i.e. earthworms, seeds and arthropods) will be discussed in turn. Within each of these sections, the factors that were significant in explaining the variation in the numbers of the bird food groups, when tillage treatment was not significant, are discussed. In addition, other factors that may have influenced the results for each group, such as methodology, are examined.

Farmland birds in winter.

A greater proportion of NIT than ploughed fields were occupied by Skylarks, granivorous passerines and game birds in late winter (i.e. between January and March) but not in the early winter period (i.e. between September and December) (Chapter 2). It is reasonable to assume that most birds observed in arable fields in the day will be there to forage for food. Tillage treatments did not affect the field occupancy of birds in the early winter, closer to the time of crop establishment and associated cultivation practices. At this time of year there may have been a greater abundance of food in other habitats, including those closer to protective cover, so the importance of in-field resources may be relatively lower. Food resources are known to be depleted by late winter (Moorcroft *et al.* 2002). Therefore, NIT fields may have become a more favourable foraging habitat in late winter, despite cereal fields being generally avoided at this time of year (Mason & Macdonald 1999).

In addition to food abundance, field occupancy of birds in winter is known to be linked to various factors such as vegetation structure, field size and field boundary. Field occupancy by birds has been linked to the structure and height of crops (Butler & Gillings In Press). Delgado & Moreira (2002) found a decrease in bird and seed abundance with an increase in crop structural complexity and height. Crop structure and height, or the change of these factors over time, may differ between NIT and CT established crops. Different crop cultivars may grow at different rates which may affect the presence of birds, especially if different cultivars are favoured with different establishment methods. However, at present, no research has been carried out on the suitability of the different cultivars associated with different tillage methods (Chaney, pers. com.)

In winter, Skylarks avoid fields smaller than 2.5 ha (Gillings & Fuller 2001), so fields of this size and below were avoided in this investigation. However, skylarks have also been shown to select fields larger than 7.5 ha in winter (Gillings & Fuller 2001). The average size of field used in the investigation of seeds at the soil surface (Chapter 4), was 7.93 ha for the NIT fields and 6.26 ha for the CT fields. This equates to a greater percentage of CT fields under 7.5 ha (55% of NIT fields and 70% of CT fields were under 7.5 ha). The use of smaller sized CT fields in the seed investigation may not therefore have been totally representative of fields used by Skylarks. On the other hand, for species which do not select open landscapes, smaller fields may have had a greater relative abundance of seed, as they have a greater boundary/field margin area to total field area ratio. Boundaries, field margins and headlands are known to often be higher in seed abundance, so this may have affected the comparisons between the tillage treatments.

Skylarks avoid fields which are enclosed by hedges or trees (Donald *et al.* 2001). These types of variables were not measured in this study. If more of the CT fields were enclosed by tall trees or hedges this may have led to potential inconsistencies. NIT fields may be associated with other habitat factors that affect bird occupancy that were not measured in this study. These may include specific field conditions such as soil type and history (e.g. fields with a history of grass weed problems may not be established by NIT methods), headland management, distance to predator perches and landscape features. As NIT systems leave a greater amount of crop residue at the soil surface, the greater use of NIT fields by granivorous birds seems to contradict other findings, where an increased complexity of vegetation structure required birds to forage over a greater surface area (Whittingham & Markland 2002; Butler & Gillings In Press). However, NIT systems may increase food availability in other ways, such as increasing the patch size of seeds or the frequency of seed patches in a field which may make food location easier.

Farmland birds and earthworms.

Field occupancy by invertebrate-feeding birds, such as thrushes, was not found to be effected by tillage establishment method. One of their major food resources, earthworms, did not differ in abundance or biomass between tillage treatments, in either autumn or spring (Chapter 3). However, generally lower numbers of earthworms were seen in the spring sampling period compared to the autumn. Other studies have shown a greater abundance of earthworms in fields established by no-tillage or direct drill (e.g. Andersen 1987, Schmidt *et al.* 2001). This may mean that the effect of NIT on earthworms is more similar to CT than to no-tillage systems. NIT systems support a greater abundance of earthworms compared to CT fields, when NIT is used within an integrated farming system (IFS) (Hutcheon *et al.* 2001). In this type of system, the agrochemical inputs are reduced in addition to using NIT crop establishment methods. However, increases in earthworm abundance in the IFS were only seen after the systems had been applied for over three years. This suggests that the consistency of use of NIT systems is potentially important for biodiversity, particularly earthworms. Many of the NIT fields used in this investigation had not been long-term NIT established (some had been ploughed the year before). Tillage systems are a combination of cultivation practices and agrochemicals applications used for crop protection and growth. In most cases, the NIT and CT fields had different chemical inputs, particularly the addition of a post-emergence herbicide in the NIT systems. As the tillage treatments were treated as a system, it is not possible to separate the effects of the cultivations or agrochemical applications.

There can also be wide variation in the type of machinery used to establish crops by non-inversion tillage. As defined in this investigation, NIT includes any method of establishing a crop without the use of a mouldboard plough, so NIT methods may have ranged from direct drilling to chisel ploughing or sub-soiling. Direct drilling is where the crop is drilled into the stubble of the previous crop and therefore causes a minimal disturbance to the soil. Chisel ploughing and sub-soiling can be used to break up the plough pan and therefore cause a relatively significant level of disturbance at depths equivalent to ploughing. A greater understanding of how different NIT machinery disturbs the soil and the associated biodiversity is needed.

The previous crop affected the numbers and biomass of earthworms (Table 7.1). The type of organic matter available to earthworms as a food source may be affected by the previous crop. For example, oilseed rape plants are known to contain erucic acid, which has been reported to have adverse effects on animals. Different types of previous crop could have different environmental effects that may have influenced earthworm densities in the sampling year. Crops preceded by set aside were observed to have higher densities and biomass of earthworms than maize or oilseed rape. These higher earthworm densities were probably due to a combination of reduced physical and chemical disturbance, which is known to enhance worm numbers. In addition, set aside fields may have provided a greater amount of cover, in terms of weeds and crop residue, over a longer period of the year than other crops. The associated crop establishment and husbandry methods used to grow the preceding crops also may have affected earthworm abundance. Specific tillage methods and agrochemicals can be associated with particular crops e.g. the use of the herbicide Atrazine (very recently banned) with maize crops or the desiccant diquat (Reglone) used to kill oilseed rape pre-harvest (Ward *et al.* 1985); both these previous crop types were observed to have lower densities and biomass of earthworms than where set aside was the previous crop. The timing of establishment and harvesting of the previous crops may have disturbed the earthworms in different ways.

Table 7.1. Summary of significant terms that explained the variation in the abundance of some bird food resources.

	Significant Term:
Earthworms	Previous crop Field size & Distance from field edge (Spring numbers only)
Arthropods	Distance from field edge Previous Crop Year Tillage (Oilseed rape data set July Beetle Larvae)
Carabid & Staphylinid	Distance from field edge Previous Crop
Beetle larvae	Year Tillage (Oilseed rape data set July Beetle Larvae)
Spiders	Distance from field edge Previous Crop Year
Seeds	Distance from field edge Year

In spring, a greater abundance of earthworms was observed in the middle of the field compared to the crop edge (1 & 8 m from the crop edge). Conditions in the middle of fields can be enhanced for earthworms by inputs, such as the application of manure (Lagerlof *et al.* 2001); although they may be less affected by inorganic fertilisers (Whalen *et al.* 1998). This has been shown to increase earthworm abundance away from the field edges (Lagerlof *et al.* 2001). Also, there may have been an increased predation of earthworms by birds such as thrushes at the crop edges; particularly as these birds are known to feed near to the field boundaries. Long term depletion of earthworms by Starlings has been observed in an exclosure experiment by Whitehead *et al.* (1996).

Farmland birds and surface seeds.

Seed density is known to affect the occupancy of fields by birds. Linnets have been shown to mainly occur on fields with seeds important in their diet at densities of at least 250 seeds m^{-2}, while autumn field occupancy by yellowhammers and grey partridges has been shown to be dependant on cereal grain densities of 50 seeds m^{-2} (Moorcroft *et al.* 2002). Seeds in this investigation were often at lower densities so, even though there was differential use of NIT and CT fields, NIT fields are probably not as good a food a resource as, for instance, stubbles (Chapter 4).

The abundance of seeds was investigated at two points over the cropping season (autumn and spring) which may not have been representative of the whole winter period. However, sampling seeds at these times has been used in previous studies investigating the abundance of seeds in arable fields (Robinson & Sutherland 1999, Moorcroft et al. 2002). Generally, lower numbers of seeds were seen in the spring than the autumn (Chapter 4). This may be a reflection of the depleted abundance of bird food resources throughout the wider countryside in the late winter. Skylarks, granivorous passerines and game birds are known to take weed seeds over the winter (Wilson *et al.* 1999). However, no differences in weed seed abundance between tillage treatments were seen in either autumn or spring. This is particularly surprising, as seeds of a range of sizes and shapes were shown to be consistently buried below the soil surface by conventional ploughing (Chapter 6). However, this cultivation experiment did not take into account the seeds brought up from the lower soil levels, which may indicate that the abundance of seeds at the soil surface in cereal fields was influenced more by the seed bank than the tillage treatments.

Farmland birds and arthropods.

Summer nesting densities and field use of breeding birds was not assessed. However, the abundance of the potential food sources, in terms of the surface-active arthropods, was not found to be different between tillage treatments (Chapter 5). This concurs with experiments carried out on arthropods such as Carabid beetles that have shown species-specific responses to tillage (Baguette & Hance 1997, Holland & Reynolds 2003). Crop management can affect arthropods directly, by causing mortalities, or indirectly by altering their habitat. As previously mentioned, one of the main ways in which NIT differs from CT, apart from the differences in the physical disturbances of cultivation, is the application of a post-emergence herbicide. Autumn applied herbicides have been shown to adversely affect the abundance of arthropods that are important in the summer bird diet (Moreby & Southway 1999). Moreby & Southway (1999) found a significantly reduced plant cover and diversity, and lower numbers of arthropods such as beetles, in the headlands of winter wheat fields between May and July that had been spray compared to unsprayed controls. Therefore, the combination of the physical disturbance by cultivation and chemical disturbance by herbicides may affect different arthropods in different ways. The result could be no overall differences in terms of arthropod abundance, as was found in this investigation.

No factors consistently explained the variation in spiders and beetles over all the months (Table 7.1). However, previous crop type and distance from crop edge were the most common factors. As for earthworms, the previous crop type may affect the abundance of arthropods by affecting the organic matter in the soil, which may have an impact on there prey. As discussed above, the associated crop establishment methods and agrochemical used with different previous crop types may have resulted in differences in arthropod populations the following year. Beetle larvae were seen to be relatively more abundant in wheat fields established by CT than NIT, where the previous crop was oilseed rape. This may be due to the knock on effects of the herbicides associated with NIT. However, it could be a reflection of the limitation of pitfall traps recording the activity-density – as there was less crop residue on the soil surface of CT fields, the movement of the beetle larvae could have been less impaired and therefore higher numbers were trapped.

General methodology and experimental design.

Fields preceded by potatoes were avoided, as the potato harvesting process causes a high level of disturbance to the soil, and it was considered that this would confound any differences between NIT and CT fields. The previous crop was a significant factor in explaining the variation for some of the arthropod groups, as well as earthworm abundance and biomass (Table 7.1). The fields could have been selected on the basis of previous crop to account for this factor. However, logistically it would not have been possible to replicate previous crop sufficiently. Alternatively, far fewer previous crop types could have been chosen, which would have narrowed the focus and restricted the relevance of the results to specific crop types in specific rotations.

Only a sub-set of the fields surveyed for birds were surveyed for their food resources. It may be possible that the fields sampled for the invertebrates and seeds were not representative of the NIT fields where the birds (skylarks, granivorous passerines and game birds) were present.

An alternative experimental design could have been used to account for some of the field specific factors that have been found to be significant in explaining the abundance of invertebrates within fields, such as previous crop type (Table 7.1). Two examples of these are a split-field or small plot design. The disadvantages to these are that they both require intervention and therefore have financial implications. These designs are also inappropriate for carrying out bird surveys which would mean locating additional fields on more farms which was a time consuming process.

The number and size of samples are always a compromise in ecological field studies and were chosen for biological, statistical and logistical reasons. The sampling methodologies, e.g. soil cores and pitfall traps, were chosen to survey invertebrates and seeds that would be available to foraging birds. The numbers of samples taken per field were chosen using previous studies, in addition to the trade-off between the logistical constraints of visiting all the sites within a set period of time, sufficiently replicating the tillage treatments and the time taken to process samples. The invertebrate and seed samples were taken at distances from the crop edge to reflect the bird species that forage at different distances from boundaries. However, due to the logistical constraints, whereby no more samples could have been taken, it may have been advisable to either take a) fewer larger or more intensive samples or b) a greater number of samples on a smaller number of fields. Ten fields of each tillage treatment were considered the maximum that could be surveyed whilst still allowing sufficient replication.

7.3 Conclusions

NIT has clear advantages for the general farmland environment, especially for resource protection (soil and water). It should therefore be encouraged. However, in the context of agri-environment schemes for biodiversity in crop and non-crop habitat, cereal fields established by non-inversion tillage and ploughing may provide similar food resources for birds. However, the occupancy of a greater proportion of NIT fields compared to CT fields by skylarks, other granivorous passerines and game birds seems to contradict this. There are many factors that can influence the occupancy of a field by farmland birds (Figure 7.1).

This thesis has tested the significance of tillage and attempted to account for other factors that are known to be important in affecting the abundance of birds and their food resources. From the results of these investigations, it has become apparent that some of these factors have a greater affect than tillage systems. These factors should be considered for future studies evaluating the significance of tillage on farmland bird food resources.

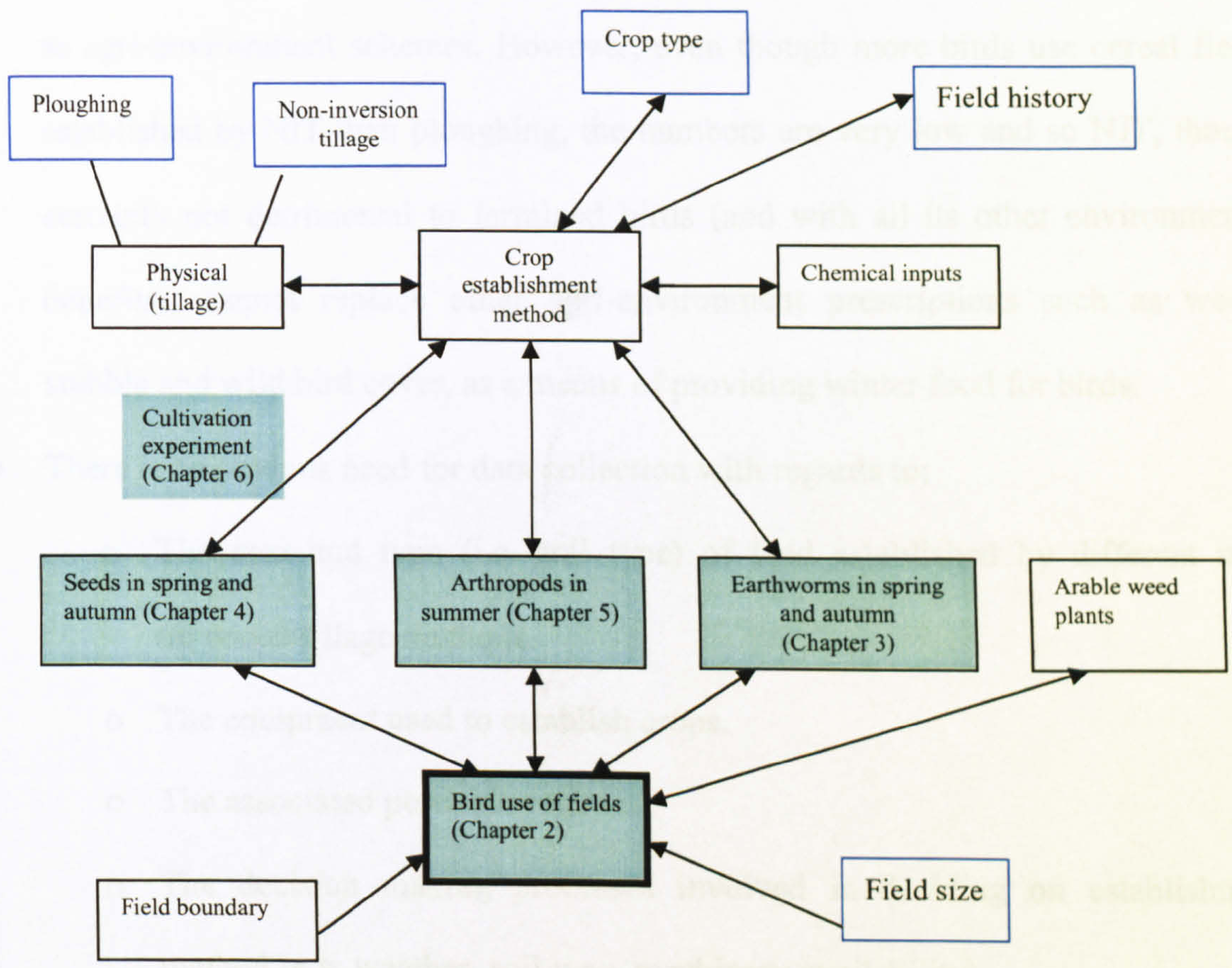

Figure 7.1. Interactions between farmland birds and their food resources.

7.4 Recommendations for future policy & future research directions

- Establishing winter cereals using non-inversion tillage methods appear to attract foraging birds over the winter, and therefore these crop establishment methods should be encouraged within the framework of other beneficial management such as agri-environment schemes. However, even though more birds use cereal fields established by NIT than ploughing, the numbers are very low and so NIT, though certainly not detrimental to farmland birds (and with all its other environmental benefits), cannot replace other agri-environment prescriptions such as weedy stubble and wild bird cover, as a means of providing winter food for birds.
- There is an obvious need for data collection with regards to;
  - The area and type (i.e. soil type) of land established by different non-inversion tillage methods.
  - The equipment used to establish crops.
  - The associated pesticide regime.
  - The decision making processes involved in deciding on establishment method (e.g. weather, soil type, machinery availability).
- Further investigations are needed to;
  - Assess the effect of NIT within a single rotation, to separate out the effect of crop type.
  - Compare different degrees of NIT (including direct drilling).
  - To try to understand why birds respond, when their food resources don't. This could be because the spatial scale of food sampling was not correct to pick up small-scale flushes of food within NIT fields (which would be very difficult to detect), to which the birds were responding. Alternatively, the birds could have been responding to something about the structure of the

fields, rather than food abundance. Behavioural observations would probably be required to sort this out.

- To investigate the effects of non-inversion tillage on other organisms and in other locations throughout Europe.

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APPENDICES

Appendix 1. Study sites in Year 1: 2000-1.

Appendix 2. Study sites in Year 1: 2001-2.

Appendix 3. Study sites in Year 1: 2002-3.

Appendix 4. Analysis explanation.

Appendix 5. Total numbers of birds recorded in NIT and CT fields in each year.

Appendix 6. Total number and weights of earthworms per meter squared at each distance.

Appendix 7. Total number of seeds per meter squared at each distance.

Appendix 8. Total number of arthropods at each distance in July.

Appendix 9. Cunningham *et al.* (in press) The effect of non-inversion tillage on the field usage of UK farmland birds in winter. Bird Study.

Appendix 10. Cunningham *et al.* (in press) Non-inversion tillage and farmland birds: a review with special reference to the UK and Europe. IBIS, 146 (Suppl. 2), 192-202.

Appendix 11. Cunningham *et al.* (2002) The effect of non-inversion tillage on earthworm and arthropod populations as potential food sources for farmland birds. Aspects of Applied Biology, 67, 101-106.

Appendix 1. Study sites in Year 1: 2000-1.

Tillage: NIT = Non-inversion tillage, CT = Conventional tillage. Regions: OX = Oxfordshire, LE = Leicestershire, SH = Shropshire. Crop: WW = winter wheat, WB = winter barley, MA = Maize, OS = oil seed rape, SA = Set-aside, PE = Pea, BE = Bean, OA = Oat.

Region	Farm	Field	Field size (ha)	Tillage	Present Crop	Previous Crop	Pairs
LE	CWS	CWS5	4.73	CT	WW	BE	1
LE	CWS	CWS6	4.95	NIT	WW	BE	1
LE	Lod	A1	8.51	NIT	WB	WW	3
LE	Lod	A2	3.36	CT	WB	WW	3
LE	Lod	B1	7.48	NIT	WW	OS	4
LE	Lod	B2	6.60	CT	WW	OS	4
LE	Lod	C1	11.05	NIT	WW	OS	5
LE	Lod	C2	7.56	CT	WW	OS	5
LE	LN	A	13.87	CT	WW	BE	6
LE	LN	B	8.84	NIT	WW	OA	6
OX	NMT	CAR	6.00	NIT	WW	OS	7
OX	FUL	HAD	6.00	CT	WW	OS	7
OX	NMT	BARN	6.40	NIT	WW	SA	8
OX	FUL	FUL3	8.00	CT	WW	SA	8
OX	FUL	COTT	13.00	NIT	WW	SA	9
OX	FUL	HOLL	13.00	CT	WW	SA	9
OX	HIGH	HLAND	13.08	CT	WW	PE	10
OX	FUL	HOME	13.00	NIT	WW	PE	10
SH	LIL	CP7	14.40	CT	WW	WW	2
SH	LIL	H2	10.00	NIT	WB	WB	2

NB. Only bird surveys carried out in these fields.

Appendix 2. Study sites in Year 2: 2001-2.

Tillage: NIT = Non-inversion tillage, CT = Conventional tillage. Regions: LE = Leicestershire, SH = Shropshire. Crop: WW = winter wheat, WB = winter barley, MA = Maize, OS = oil seed rape, GR= Grass, BE = Beans, SA = Set-aside, PO = Potatoes, PE = Peas, CA = Carrots, SB = Sugar Beet.

Region	Farm	Field	Field size (ha)	Tillage	Present Crop	Previous Crop	Organisms surveyed* B	A	S	E
LE	CWS	CWS12	4.48	NIT	WW	SA	•	•	•	•
LE	CWS	CWS11	4.48	CT	WW	SA	•	•	•	•
LE	CWS	CWS8	4.28	CT	WW	OS	•	•	•	•
LE	CWS	CWS7	5.60	NIT	WW	SA	•	•	•	•
LE	CWS	CWS2	5.27	NIT	WW	GR	•	•	•	•
LE	CWS	CWS1	5.27	CT	WW	GR	•	•	•	•
LE	LOD	LODA1	10.42	NIT	WW	OS	•	•	•	•
LE	LOD	LODA2	5.98	CT	WW	OS	•	•	•	•
LE	LOD	LODB1	10.83	NIT	WW	OS	•	•	•	•
LE	LOD	LODB2	9.14	CT	WW	OS	•	•	•	•
LE	LOD	LODC1	5.31	NIT	WW	BE	•	•	•	•
LE	LOD	LODC2	3.82	CT	WW	OS	•	•	•	•
SH	HARP	BROOK	6.66	NIT	WW	BE	•	•	•	•
SH	HARP	CORN	15.00	CT	WW	WB	•	•	•	•
SH	HARP	FARB	6.30	NIT	WW	BE	•	•	•	•
SH	HARP	TIBB	5.60	CT	WW	SA	•	•	•	•
SH	LIL	CP8	9.80	NIT	WW	BE	•	•	•	•
SH	LIL	CP9	4.16	CT	WW	OS	•	•	•	•
SH	LIL	L14/15	12.27	CT	WW	OS	•	•	•	•
SH	LIL	CP5	22.27	NIT	WW	OS	•	•	•	•
LE	CWS	CWSA	7.69	NIT	WW	SA	•			
LE	CWS	CWSB	2.83	NIT	WW	SA	•			
LE	CWS	CWSC	5.26	NIT	WW	SA	•			
LE	CWS	CWSD	6.88	NIT	WW	SA	•			
LE	CWS	CWSE	6.07	NIT	WW	SA	•			
LE	CWS	CWSF	7.69	NIT	WW	SA	•			
LE	CWS	CWSG	2.83	NIT	WW	SA	•			
LE	CWS	CWSH	7.29	NIT	WW	SA	•			
LE	CWS	CWSJ	6.88	NIT	WW	SA	•			
LE	CWS	CWSK	1.62	NIT	WW	SA	•			
LE	CWS	CWSM	4.86	CT	WW	WW	•			
LE	CWS	CWSN	7.29	CT	WW	WW	•			
LE	CWS	CWSP	7.29	CT	WW	WW	•			
LE	CWS	CWSQ	7.29	CT	WW	WW	•			
LE	CWS	CWSR	11.37	CT	WW	WW	•			
LE	CWS	CWSS	11.37	CT	WW	WW	•			
LE	CWS	CWST	2.43	CT	WW	WW	•			
LE	CWS	CWSU	4.05	CT	WW	WW	•			
LE	CWS	CWSV	4.05	CT	WW	WW	•			
LE	LOD	LODD	10.40	NIT	WW	BE	•			
LE	LOD	LODE	7.54	NIT	WW	BE	•			
LE	LOD	LODF	15.07	NIT	WW	BE	•			
SH	HARP	ADEM	15.00	CT	WW	SA	•			
SH	HARP	COTE	5.10	CT	WW	WW	•			
SH	BELCH	1913a	6.48	NIT	WW	PE	•			
SH	BELCH	9271	23.76	NIT	WB	PO	•			
SH	BELCH	7073	13.99	NIT	WW	PO	•			
SH	BELCH	5792	14.51	NIT	WW	WW	•			
SH	BELCH	8371	14.51	CT	WW	MA	•			
SH	BELCH	9627	9.00	CT	WB	WB	•			
SH	BELCH	9115	17.38	CT	WW	CA	•			
SH	BELCH	5633	10.03	CT	WB	WW	•			

B=Birds, A=Arthropods, S=Seeds, E=Earthworms

Appendix 2 (continued). Study sites in Year 2: 2001-2.

Tillage: NIT = Non-inversion tillage, CT = Conventional tillage. Regions: LE = Leicestershire, SH = Shropshire. Crop: WW = winter wheat, WB = winter barley, MA = Maize, OS = oil seed rape, GR= Grass, BE = Beans, SA = Set-aside, PO = Potatoes, PE = Peas, CA = Carrots, SB = Sugar Beet.

Region	Farm	Field	Field size (ha)	Tillage	Present Crop	Previous Crop	Organisms surveyed*			
							B	A	S	E
SH	CAYNTON	0664b	7.30	CT	WW	SA	•			
SH	CAYNTON	8490a	8.21	NIT	WW	PO	•			
SH	CAYNTON	2286	5.80	NIT	WW	PO	•			
SH	CAYNTON	5774a	11.73	NIT	WW	PO	•			
SH	SLAT	78	9.00	NIT	WW	OS	•			
SH	SLAT	79	10.00	NIT	WW	OS	•			
SH	SLAT	5M	5.60	CT	WB	WW	•			
SH	SLAT	6M	11.80	CT	WB	WW	•			

B=Birds, A=Arthropods, S=Seeds, E=Earthworms

Appendix 3. Study sites in Year 3: 2002-3.

Tillage: NIT = Non-inversion tillage, CT = Conventional tillage. Regions: LE = Leicestershire, SH = Shropshire. Crop: WW = winter wheat, WB = winter barley, MA = Maize, OS = oil seed rape, GR= Grass, BE = Beans, SA = Set-aside, PO = Potatoes, PE = Peas, CA = Carrots, SB = Sugar Beet.

Region	Farm	Field	Field size (ha)	Tillage	Present Crop	Previous Crop	Organisms surveyed*			
							B	A	S	E
LE	CWS	CWS1	3.87	CT	WW	WW	•	•	•	•
LE	CWS	CWS2	3.86	NIT	WW	WW	•	•	•	•
LE	CWS	CWS3	4.66	NIT	WW	GR	•	•	•	•
LE	CWS	CWS4	3.90	CT	WW	GR	•	•	•	•
LE	CWS	CWS13	4.06	NIT	WW	SA	•	•	•	•
LE	CWS	CWS14	3.32	CT	WW	SA	•	•	•	•
LE	CWS	CWS141	7.56	NIT	WW	MA	•	•	•	•
LE	CWS	CWS129	6.57	CT	WW	SA	•	•	•	•
LE	CWS	CWS139	7.75	NIT	WW	MA	•	•	•	•
LE	CWS	CWS128	8.59	CT	WW	SA	•	•	•	•
LE	Loddington	CAB	6.70	NIT	WW	BE	•	•	•	•
LE	Loddington	TOPC	7.28	CT	WW	OS	•	•	•	•
LE	Loddington	LN1	13.87	NIT	WW	OS	•	•	•	•
LE	Loddington	LN2	8.84	CT	WW	OS	•	•	•	•
SH	Dickin	Brickle	8.56	NIT	WW	SA	•	•	•	•
SH	Turner	Turn 1	5.30	CT	WW	PE	•	•	•	•
SH	Dickin	Green	5.72	NIT	WW	BE	•	•	•	•
SH	Turner	Turn 2	5.50	CT	WW	PE	•	•	•	•
SH	Harper	Farb	6.34	CT	WW	WW	•	•	•	•
SH	Belcher	7340	9.09	NIT	WW	WW	•	•	•	•
SH	Caynton	CAN2	11.73	CT	WB	WW	•			
SH	Caynton	CAN4	8.21	CT	WB	WW	•			
SH	Caynton	CAN6	5.75	CT	WW	WB	•			
SH	Caynton	CAN8	12.10	CT	WB	WW	•			
SH	Caynton	CAN10	7.00	CT	WB	WW	•			
SH	Caynton	CAN11	10.90	CT	WB	WW	•			
SH	Puleston	Fr	11.05	CT	WB	WW	•			
SH	Puleston	Wh	15.39	CT	WB	WB	•			
SH	Puleston	FH	9.04	CT	WB	WW	•			
SH	Harper	Heaf	2.44	CT	WW	GR	•			
SH	Harper	Nearb	5.47	CT	WW	GR	•			
SH	Dickin	Mort	2.83	NIT	WW	WW	•			
SH	Dickin	Rough	3.42	NIT	WW	SA	•			
SH	Dickin	Sour	4.00	NIT	WW	BE	•			
SH	Belcher	5792	14.51	NIT	WW	WW	•			
SH	Belcher	1913e	6.88	CT	WB	WW	•			
LE	CWS	140	10.75	NIT	WW	MA	•			
LE	CWS	127	9.83	CT	WW	SA	•			
LE	CWS	126	6.34	CT	WW	SA	•			
LE	CWS	CWS15	4.06	NIT	WW	OS	•			
LE	CWS	CWS16	3.32	NIT	WW	OS	•			
LE	CWS	CWS17	9.71	NIT	WW	OS	•			
LE	CWS	CWS18	5.67	NIT	WW	OS	•			
LE	Loddington	Spring	7.54	NIT	WW	SB	•			
LE	Loddington	Parad	6.96	NIT	WW	BE	•			
LE	Loddington	44Acre	7.98	NIT	WW	SB	•			
LE	Loddington	57Acre	7.08	NIT	WW	BE	•			
LE	Loddington	ParkN	7.50	NIT	WW	SB	•			

B=Birds, A=Arthropods, S=Seeds, E=Earthworms

Appendix 4. Analysis explanation

Explanation of analysis procedure using GLMM for
a). Step-down procedure (birds)
b). Step-up procedure (Arthropods, Earthworms & Seeds)

GLMM. Generalised linear mixed modelling is a form of the more familiar general linear regression model, with both fixed and random factors defined in the same model. A random factor can be considered similar to blocks (Crawley 1993). For the bird analysis farm was defined as the random factor as fields were clustered within farms. For the invertebrate and seed analysis, field was defined as the random factor as samples were clustered within fields. We were not interested in the effect of individual fields or farms, but we want to account for the effects they may have on the data.

Adjusted mean. Where factors were found to have a significant effect on the variation of the response variables, the adjusted means with the standard error are shown. An adjusted mean is required in situations where multiple factors have significant effects on a response variable, such as can be detected in a least squares GLM. Take a case in which both factor A and variable B influence the response variable, Y. Here, it would be misleading to present the simple mean values of Y for different levels of A, as this does not take into account the significant influence of B on those values of Y. Hence, these are only the partial means of Y for A. The adjusted mean values of Y for different levels of A are a computation of the mean values, accounting for the real influence of B on Y. If B is a covariate, this is the difference between assuming a value of 0 (or the intercept) for B and assuming the overall mean value of B, when calculating the mean values of Y for A. Hence, the adjusted mean of A could be bigger or smaller than the partial mean, according to whether the effect of B on Y is positive or negative.

a). Step-down procedure (birds)

A step-down procedure or backwards deletion model is where you start with a full model and delete the least significant, non-significant factor sequentially until the only factors remaining in the model are significant.

<u>Example skylarks in late winter</u>

Response variate: Skylark presence/ absence

Fixed model: Tillage, Previous Crop, Crop Type & Year.

Random model: Defined as Farm identity (i.e. Farm name) as the fields were nested within a field.

Offset: Field area (natural log)

Distribution: Presence/absence data treated as a binary response variable, in a binary logistic regression with logit link.
NOTE: Count data would be treated as a Poisson variable, in a log-linear regression with log link.

Wald statistic: Using the command VDISPLAY [PRINT=Waldtest], prints the further output for all the fixed terms in the model. Wald statistic is given for mixed models and is distributed asymptotically as chi-squared, so can be compared with the chi-squared distribution to assess significance of terms.

Procedure:

1. Each of the five explanatory variables were tested together, i.e. Full model = Tillage + Previous Crop Type + Crop Type + Year.
2. The least significant, non-significant factor was removed from the model until all the factors left in the model were significant.

b). Step-up procedure (Arthropods, Earthworms & Seeds)

A step-up procedure was used for the analysis of the Arthropods, Earthworms & Seeds as opposed to the step-down procedure used for the bird analysis, as additional factor of distance into the field with the invertebrate and seed data led to aliasing.

Response variates:

	Response variables
Arthropods	Number of carabid beetles, staphylinid beetles, beetle larvae and spider
Earthworms	Number and weight*
Seeds	Number of * groups/ species of seeds

Explanatory variables:

Variable	Type	Factor levels
Field area	Continuous variable	
Tillage	2-Level fixed factor	Non-inversion tillage Conventional tillage
Year	2-Level fixed factor	2002 2003
Previous crop	8-Level fixed factor	Winter wheat Winter barley Oil seed rape Set aside Peas Beans Maize Grass
Trap position	3-Level fixed factor	1m from crop edge 14m from crop edge Middle of field
Field	40-Level random factor	2003 – twenty fields 2004 – twenty fields

Fixed model: Field area (natural log), Tillage, Previous Crop, Trap position & Year.

Random model: Defined as Field identity (i.e. field name) as the mean number of invertebrates or seeds at each distance into a field was clustered within a field.

Distribution: Count data (i.e. all response variables except earthworm weights) were treated as a Poisson variable, in a log-linear regression with log link. Earthworm weights* were treated as a Normal variable, in a log-linear regression with identity link.

Wald statistic: Using the command VDISPLAY [PRINT=Waldtest], prints the further output for all the fixed terms in the model. Wald statistic is given for mixed models and is distributed asymptotically as chi-squared, so can be compared with the chi-squared distribution to assess significance of terms.

Example of Spiders in March:

3. Each of the five explanatory variables were tested separately, e.g. Fixed model = Tillage

Fixed term	Wald statistic	d.f.	Wald/d.f.	Chi-sq prob
Tillage	0	1	0	0.952
fieldsize_ln	0.11	1	0.11	0.741
Distance	0.04	2	0.02	0.979
Prev_Crop	21.32	7	3.05	0.003
Year	**10.3**	**1**	**10.3**	**0.001**

4. The most significant factor was retained in the model, in this case Year, and the rest of the four explanatory variables were tested with Year in the model, e.g. Fixed model = Year + Tillage

Fixed term	Wald statistic	d.f.	Wald/d.f.	Chi-sq prob
Year	10.02	1	10.02	0.002
Tillage	0.01	1	0.01	0.935
Year	10.03	1	10.03	0.002
fieldsize_ln	0.12	1	0.12	0.73
Year	10.31	1	10.31	0.001
Distance	0.04	2	0.02	0.979
Year	**12.29**	**1**	**12.29**	**<0.001**
Prev_Crop	**25.3**	**7**	**3.61**	**<0.001**

5. The most significant factor was retained in the model along with Year, in this case Previous Crop, and the rest of the three explanatory variables were tested with Year and Previous Crop in the model, e.g. Fixed model = Year + Previous Crop + Tillage

Fixed term	Wald statistic	d.f.	Wald/d.f.	Chi-sq prob
Year	12.71	1	12.71	<0.001
Prev_Crop	26.3	7	3.76	<0.001
Tillage	1.05	1	1.05	0.306
Year	10.52	1	10.52	0.001
Prev_Crop	25.68	7	3.67	<0.001
fieldsize_ln	0.93	1	0.93	0.336
Year	12.26	1	12.26	<0.001
Prev_Crop	25.22	7	3.6	<0.001
Distance	0.04	2	0.02	0.979

6. None of the three explanatory variables above are significant, so as there are two significant factors in the model, an interaction is tested for, i.e. Fixed model = Year + Previous Crop + Year*Previous Crop

Fixed term	Wald statistic	d.f.	Wald/d.f.	Chi-sq prob
Year.Prev_Crop	1.05	3	0.35	0.788

7. The interaction is not significant, so the minimum adequate model (MAM) is **Year + Previous Crop**

Appendix 5. Total numbers of birds recorded in NIT and CT fields in each year.

Early winter period

Year	Tillage	Skylark	Granivorous passerine	Corvids	Pigeons	Insectivores	Gamebirds	Total no. of birds	Total no. of surveys
1	NIT	8	0	0	0	2	0	10	3
1	CT	3	0	12	0	9	4	28	3
2	NIT	129	69	149	262	31	46	693	91
2	CT	10	3	74	88	50	16	262	69
3	NIT	37	1	17	4	12	17	100	42
3	CT	0	0	30	3	5	4	48	41

Late winter period

Year	Tillage	Skylark	Granivorous passerine	Corvids	Pigeons	Insectivores	Gamebirds	Total no. of birds	Total no. of surveys
1	NIT	47	5	56	138	70	13	329	22
1	CT	26	0	23	0	2	13	64	22
2	NIT	85	100	29	0	5	19	245	51
2	CT	37	3	29	3	1	0	128	40
3	NIT	23	4	15	7	33	5	96	46
3	CT	11	0	46	0	41	2	103	51

Appendix 6. Total number and weights of earthworms per meter squared at each distance.

Year	Tillage	Distance	Total earthworm weight g m^{-2} Spring	Autumn	Total no. of earthworms m^{-2} Spring	Autumn
1	NIT	1m	29.83	43.06	390.49	331.07
1	NIT	8m	27.27	38.43	331.07	377.76
1	NIT	MID	47.70	50.01	602.72	475.38
1	CT	1m	34.37	35.50	373.51	356.54
1	CT	8m	26.10	26.66	339.56	271.65
1	CT	MID	50.21	38.96	606.96	301.36
2	NIT	1m	37.61	67.15	288.62	475.38
2	NIT	8m	32.30	45.50	207.98	288.62
2	NIT	MID	14.81	61.25	165.53	382.00
2	CT	1m	27.33	37.48	280.14	275.89
2	CT	8m	40.49	71.73	309.85	454.16
2	CT	MID	35.82	54.33	246.18	377.76

NIT=Non-inversion tillage; CT=Conventional tillage

Appendix 7. Total number of seeds per meter squared at each distance.

Autumn

Year	Till	Distance	Knotgrass	Chickweed	Forget-me-not	Pansy	Polygon-aceae	Chenopod-iaceae	Grass	Broad-leaved weeds	Total no.
1	NIT	1m	31	10	33	5	163	83	91	394	485
1	NIT	8m	62	2	19	1	115	274	11	442	453
1	NIT	MID	149	30	54	13	169	506	11	823	834
1	CT	1m	69	33	3	28	85	36	6	279	286
1	CT	8m	101	52	7	15	107	46	21	234	255
1	CT	MID	119	67	18	42	131	30	15	309	325
2	NIT	1m	55	58	85	3	81	20	1	268	269
2	NIT	8m	51	19	9	2	58	22	2	114	116
2	NIT	MID	12	21	1	30	30	23	2	118	120
2	CT	1m	16	11	9	0	52	102	4	234	237
2	CT	8m	7	70	1	0	16	50	5	140	145
2	CT	MID	10	68	1	0	17	83	5	188	193

Spring

Year	Till	Distance	Knotgrass	Chickweed	Forget-me-not	Pansy	Polygon-aceae	Chenopod-iaceae	Grass	Broad-leaved weeds	Total no seeds
1	NIT	1m	34	15	37	2	79	71	52	342	395
1	NIT	8m	57	4	20	0	153	239	4	430	434
1	NIT	MID	113	41	32	2	167	277	6	553	559
1	CT	1m	121	88	3	45	153	44	19	434	453
1	CT	8m	112	44	2	7	126	41	30	246	276
1	CT	MID	72	87	40	46	84	40	8	370	378
2	NIT	1m	15	20	4	4	24	23	3	112	115
2	NIT	8m	30	33	1	12	34	15	7	110	117
2	NIT	MID	17	31	3	67	22	26	7	164	171
2	CT	1m	7	9	19	1	14	121	8	219	227
2	CT	8m	9	32	1	0	13	66	5	115	120
2	CT	MID	4	70	0	1	18	60	3	150	153

Appendix 8. Total number of arthropods at each distance in July.

Year	Tillage	Distance	Carabidae	Staphylinidae	Larvae	Spider
1	NIT	1m	645	303	74	997
1	NIT	14m	892	238	54	1460
1	NIT	MID	1467	208	58	1877
1	CT	1m	973	207	100	1602
1	CT	14m	993	272	115	1802
1	CT	MID	1244	225	71	2085
2	NIT	1m	1345	123	9	496
2	NIT	14m	1445	124	23	1023
2	NIT	MID	1614	136	13	1065
2	CT	1m	750	157	17	649
2	CT	14m	1068	173	13	819
2	CT	MID	1431	183	12	1034

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