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Non-inversion tillage and farmland birds: a review with special reference to the UK and Europe

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This paper reviews the current knowledge of the effects of non-inversion tillage (NIT) on farmland birds and their food resources. NIT is a method of establishing a crop without using a mouldboard plough and is becoming increasingly popular in the UK. NIT generally disturbs the soil to shallower depths than conventional tillage and is therefore expected to have beneficial effects on biodiversity on arable land as compared with mouldboard ploughing. The diets of farmland birds change throughout the year, and many species take invertebrates over the breeding season. Seeds are also important for many species of farmland birds throughout the year and especially over the winter months. The effects of NIT on these farmland bird food resources, in particular ground beetles (Coleoptera: Carabidae), spiders (Arachnida: Araneae), earthworms (Annelida) and seeds (arable weeds and cereal crops) are reviewed.

DECLINE OF FARMLAND BIRDS

The decline of UK farmland birds has been well documented (Fuller *et al*. 1995, Siriwardena *et al*. 1998a, Gregory *et al*. 2002, 2004, Newton 2004). Although individual species of farmland birds will respond in different ways, depending on their specific habitat and resource requirements, the intensification of agricultural systems has been identified as a major factor in the decline of many species (Chamberlain *et al*. 2000). Elsewhere in Europe, bird population declines are correlated with the degree of intensification in individual countries (Donald *et al*. 2002). Farmland bird decline is therefore a Europe-wide problem that requires Europe-wide solutions.

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. Through the autumn and winter period many farmland bird species require seeds as a source of food. 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; Fig. 1). Reduced survival appears to be a major factor in the decline of many farmland bird species (Siriwardena *et al*. 1998b, Peach *et al*. 1999) and may be caused by a lack of winter food resources (Siriwardena & Stevens 2004).

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 localized areas with abundant sources of seeds, such as weedy stubbles (Wilson *et al*. 1996b, Robinson & Sutherland 1999, Moorcroft *et al*. 2002), wild bird cover (Stoate *et al*. 2003) and set-aside (Buckingham *et al*. 1999). These habitat types have been included as options in UK agri-environment schemes, such as the Countryside Stewardship Scheme and the Pilot Entry Level Scheme, to encourage uptake on farms in the UK (Evans *et al*. 2002, Bradbury & Allen 2003, Bradbury *et al*. 2004).

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*.

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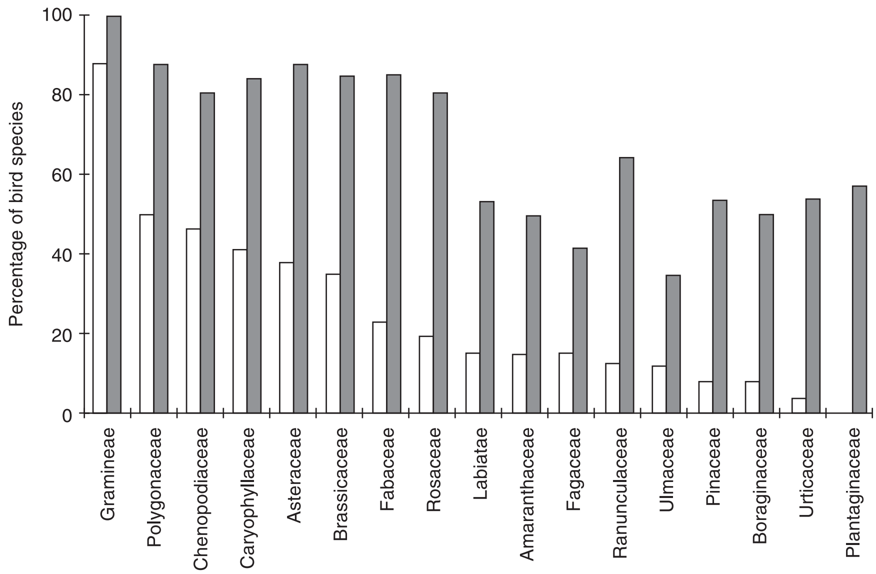

Figure 1. Plant families 'important' (unshaded bars) and 'present' (shaded bars) in the diet of farmland birds (source: Wilson *et al*. 1999).

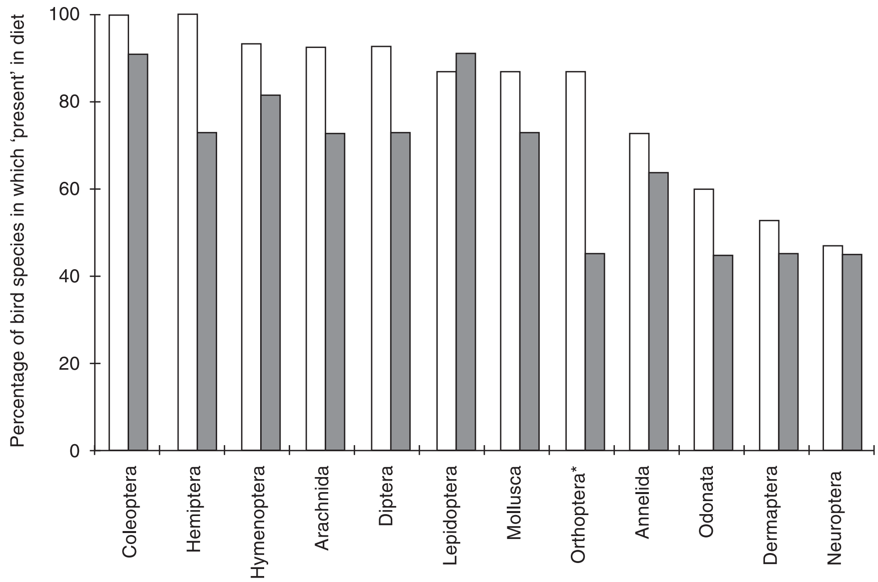

Figure 2. Invertebrate groups 'present' in the diet of declining (unshaded bars) and non-declining (shaded bars) farmland birds (Source: Wilson *et al*. 1999).

1996a, Moorcroft *et al*. 1997, 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; Fig. 2). 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, and soil-dwelling invertebrates, such as earth-worms, are important for species such as Northern Lapwing *Vanellus vanellus* and Song Thrush *Turdus philomelos* (Wilson *et al*. 1996a, Gruar *et al*. 2003). 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).

IMPACT OF CAP REFORM ON FOOD RESOURCES FOR FARMLAND BIRDS

The Common Agricultural Policy (CAP) has encouraged farmers to intensify production methods by subsidizing grain production. Current reforms of the CAP will provide a single farm payment in the future, which will remove the incentive to manage intensively 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.

NON-INVERSION TILLAGE (NIT)

NIT is used to prepare the seedbed for sowing and establishing a crop from the previous year's stubble. NIT 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 NIT, 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. Typically, ploughing would involve soil disturbance to 20–25 cm, whereas NIT would be to depths of 10–15 cm. However, some NIT machinery can have optional tines attached that loosen deeper soil horizons. NIT is also known as reduced tillage, no-till, ECOtillage, minimum tillage (min till) and conservation tillage, the last 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.

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. There are also significant savings in terms of labour and fuel, as compared with conventional mouldboard ploughing (Ball 1989; Table 1).

Table 1. The establishment work rates with non-inversion tillage and conventional ploughing (adapted from: SMI 2004).

Operation	Output (ha/h)	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

Approximately 30% of arable land in the UK has been estimated to have been established by NIT methods (ECAF 2004), despite the fact that 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 and 20%, and Switzerland has the highest estimate of 40%. This gives a total estimated area of 10 054 000 ha of arable land established by NIT in Europe (ECAF 2004).

Advantages and disadvantages of NIT

Significant savings in terms of labour, fuel and time can be made with NIT as compared with conventional mouldboard ploughing (Ball 1989, Sijtsma *et al.* 1998), without incurring losses in yield, at least on some soil types (Chaney *et al.* 1985). Although NIT is gaining in popularity primarily owing to the reduced cost of crop establishment, there are several other benefits from using this method of crop establishment. When implemented successfully, NIT can reduce mineralization and leaching of soil nitrogen, overall herbicide needs and the risk of soil erosion.

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 *Bromus sterilis* (Cannell 1985). For all types of weeds except summer annuals, Andersen (1999) observed a greater weed cover in no-tillage systems compared with 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). NIT allows the retention of ground cover in the form of the previous year's crop residue, which can provide substantial soil and water conservation benefits. Therefore, it is likely that NIT will become a more widespread practice in Europe, independent of any need for additional financial incentives for helping biodiversity (Birkas *et al*. 1989).

Given the economic, agronomic and resource protection benefits described above, it is likely that NIT will prove to be attractive, for both existing EU and Accession countries, to produce competitively priced crops while minimizing environmental impact. If it enhances farmland biodiversity, it could therefore have a Europe-wide role in helping to reverse farmland bird declines.

Disadvantages with establishing crops with NIT methods include disease and pest problems. There may be an increased risk of fungal diseases with NIT systems, which 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 an NIT system are managed correctly this potential problem will be reduced.

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 well-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 agro-ecosystems; 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 gamebird 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, in which discs or tines create slots where 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 lies between no-tillage and conventional tillage, the resultant effect on invertebrates will be intermediate (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 with 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 with 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 (Baguette & Hance 1997, Kladivko 2001).

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, Tarrant *et al*. 1997, Moreby & Southway 1999), 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, we consider that 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 considered that these studies have been carried out in a variety of crops and, in some cases, using a variety of sampling methods (see Tables 2–4).

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 NIT 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 (Blumberg & Crossley 1983, Brust *et al.* 1985, Barney & Pass 1986, Clark *et al.* 1993, Tonhasca 1993). Only two studies in North America investigated the effects of NIT; one compared NIT with conventional tillage (Carcamo 1995), the other compared NIT with 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 (Baguette & Hance 1997, Andersen 1999, 2003, Holland & Reynolds 2003).

In terms of overall carabid abundance, and in some instances diversity, conflicting results have been reported (Table 2). Some studies have not shown differences between no-tillage and conventional tillage (Barney & Pass 1986, Tonhasca 1993), whereas others observed positive effects of no-tillage (Blumberg & Crossley 1983, Brust *et al.* 1985, Andersen 1999) or conventional tillage (Carcamo 1995, Baguette & Hance 1997). The response to tillage at the species level was mixed in several cases (Clark *et al.* 1993, Tonhasca 1993, Carcamo 1995). Different sizes of carabids appeared to respond in different ways to tillage. Species such as *Pterostichus melanarius*, with a body size ranging from 12 to 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 (Adis 1979, Thomas *et al.* 1998). This may explain positive results for conventional compared with 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).

Rove beetles

The few studies that have investigated the effects of tillage on rove beetles (Coleoptera: Staphylinidae) have observed mixed results (Table 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 (Holland & Reynolds 2003).

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 NIT 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 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 Spider *Pardosa milvina* were observed in conventionally tilled plots than conservation-tilled plots in the USA (Marshall *et al.* 2000).

Earthworms

As previously discussed, earthworms (Annelida) are an important food source for several declining farmland birds, such as Song Thrushes and Lapwings (Wilson *et al.* 1996a, Gruar *et al.* 2003). Cultivation, such as mouldboard ploughing, can affect earthworms either directly by causing fatalities or indirectly by changing their habitat or exposing them to

Table 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 dependent on crop type. Less abundant species increased abundance in reduced tillage or no till	Belgium	Maize, sugar beet, winter wheat & barley	Plots (40 × 20 m)	Pitfall traps	Ploughing vs. Light ploughing vs. No ploughing	Baguette and Hance (1997)
+ Total number of carabids lower in ploughed plots compared with undisturbed plots	UK (England)	Wheat stubble or undersown grass leys	Plots (15 × 3 m; 20 × 3 m)	Emergence traps	Winter ploughing vs. Spring ploughing vs. No ploughing	Holland and 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 (50–30 × 12 m)	Pitfall traps	NIT (Dutzi cultivator or Tine disc cultivator) vs. Plough	Kendall *et al.* (1995)
Larval overwintering populations of carabids are affected by ploughing. Autumn-breeding carabids are more likely to be affected by cultivation.	Ireland	Spring and winter barley, winter barley, beet, grass ley and maize	3 Fields	Pitfall traps	Spring and autumn cultivation	Purvis and Fadl (2002)

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

Table 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 with undisturbed plots	UK (England)	Wheat stubble or undersown grass leys	Plots (15 × 3 m; 20 × 3 m)	Emergence traps	Winter ploughing vs. Spring ploughing vs. No ploughing	Holland and 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 and Jepson (1997)
+ Mixed response, but no significant effects	UK (England)	Winter cereal	Plots (50–30 × 12 m)	Pitfall traps	NIT (Dutzi cultivator or Tine disc cultivator) vs. Plough	Kendall *et al.* (1995)

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

predation (Edwards 1977). A number of studies have observed greater earthworm abundance in fields that have been established by direct drill or no-till compared with ploughing, particularly in the upper 10 cm of the soil (Table 4; Edwards 1975, Clapperton 1999). A higher abundance of earthworms was observed in no-till fields compared with NIT methods (Jordan *et al.* 1997). 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 an NIT method because it does not invert the soil, although it does disturb the soil to greater depths than other NIT equipment such as discs and tines. Edwards and 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. Again, a greater abundance and biomass of earthworms has been recorded in fields established by NIT compared with conventional tillage in the UK, but only after these treatments had been applied for 3 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 3 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). 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).

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 various 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, Boatman *et al.* 2004). Here, we will discuss only the research investigating the effect of tillage on the abundance of seeds on or near the soil surface, 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, leaves seeds in the upper 5 cm of the soil. 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).

Birds and NIT

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. There are many other 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. Here, we discuss how the crop establishment method may additionally affect bird abundance and diversity in the summer and winter in a range of situations.

Some studies in North America have observed higher productivity by nesting passerines and higher densities of birds in minimally tilled land compared with conventionally tilled crop land (Lokemoen & Beiser 1997, Martin & Forsyth 2003). These findings are supported in a study showing that fields established by NIT had a greater diversity of birds in the summer, although this was not the case in the autumn, winter or spring (Flickinger & Pendleton 1994).

NIT 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 in Holland (2004), and is less likely to be a threat to nests. Duebbert and Kantrud (1987) have observed that although the nesting density of ducks is quite low on direct-drill winter wheat fields, i.e. 7 per 100 ha, the hatch rate was sufficient to sustain the population.

A recent three-year study has shown that NIT tillage can affect farmland birds in the UK (Cunningham

Table 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 (6.4 × 18 m)	–	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 (6.4 × 18 m and 33 × 13.5 m) And whole fields	Formalin method	Deep plough, chisel plough and direct drill NIT (chisel plough) vs. Plough	Edwards and Lofty (1982)
+ 2.6 times higher in chisel than plough in autumn cultivations	Finland	Spring cereals	Small plots (4 × 15 m)	Formalin method and 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	Hutcheon *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 and 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 and Soil cores	Direct drill (i.e. no-till), tine cultivation and Ploughed	Barnes and 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 (12 × 100 m) extraction	Hand-sorted cores ($25m^2 \times 30$ cm) followed by mustard	Ploughing, layer cultivation (deep NIT) and 2-layer (deep NIT & shallow MBP) ploughing	Emmerling (2001)
No significant differences in abundance & biomass. But more anaeic species in NIT, and more endogeic species in ploughed	Switzerland	Spring maize	Small plots (0.75 ha divided into four 14-m strips)	Hand-sorted cores (0.1 m^3: 0.5 × 0.5 × 0.4 m)	Direct drill vs. Rotary plough	Wyss and Gasstetter (1992)
Rotary cultivation killed 61–68% of worms	Sweden	Ley pasture (grassland) and Barley after pasture	Small plot (40 × 14 m)	Formalin method	Rotary cultivation vs. Uncultivated pasture	Bostrum (1995)
+ 50–100% increases in no-till than ploughed plots	UK (Scotland)	Continuous barley	Small pots (2 ha site with 16 plots)	Formalin method	Deep (30 cm) and normal (20 cm) ploughing, tine cultivation (3 passes of 20 cm) and no tillage	Gerard and 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. For example, 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.

et al. 2002, 2003, in press). Tillage method appears to have a significant effect on field occupancy by certain bird groups. In particular, in late winter, Skylarks, gamebirds and granivorous passerines occupied a greater proportion of fields established by NIT than by conventional tillage.

CONCLUSION

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. Further work is also 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.

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