The implications of improving the conservation value of field margins on crop production

Thesis

THE IMPLICATIONS OF IMPROVING THE CONSERVATION VALUE OF FIELD MARGINS ON CROP PRODUCTION.

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Abstract

The effect of field margin management on crop yield and weed biomass in the crop edge (headland) was investigated. Treatment did not have any significant effect on cereal yields, and taking a one metre strip out of crop production to establish a sterile, natural regeneration or sown strip, did not significantly reduce yields compared to cropping to the field edge. Conservation headlands generally contained greater amounts of weed biomass than fully sprayed headlands, but grain yields were not significantly reduced. Soil compaction affected yield in one of the field experiments, but not the other, where soil density values were fairly uniform. No relationship was found between fertiliser application and yield.

In a survey of cereal headlands, distance from the field boundary was the most important factor affecting yield. Where yield increased with distance from the field boundary, there was a strong linear relationship with log distance ($P<0.001$). Weed dry matter was related to distance, and there was a significant relationship between weed dry matter and grain yield in the first year of the survey ($P<0.001$), but not in the second.

Communities of herbaceous field margin species were established, and the effects of nitrogen fertiliser and sublethal glyphosate application were examined over two years. Cover abundance of grasses was greater than that of dicotyledonous species throughout. *Bromus sterilis* was the most abundant species in 1995, but by 1996 it had been replaced by *Arrhenatherum elatius*. Increasing fertiliser rate had a negative effect on total vegetation cover in 1995, due to individual plants lodging. During 1996, fertiliser application increased the cover abundance of the dominant perennial species *A. elatius* ($P<0.001$), and also the annuals *B. sterilis* and *Galium aparine* ($P<0.05$). Sublethal doses of glyphosate significantly reduced total cover abundance ($P<0.001$), and had a greater effect on grasses compared to dicotyledonous species.

Measurement of spray drift into a hedgerow showed that positioning the end of the tractor-mounted spray boom 2m or 6m away from the crop edge reduced drift into the hedge-bottom compared with spraying up to the crop edge ($P<0.001$).

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Chapter 1. Introduction and Literature Review

1.1 Introduction

The term "field margin" broadly refers to the linear area of habitat that surround the edges of fields and feature prominently within farm landscapes throughout the United Kingdom. As almost any edge type qualifies as a field margin, there has been some ambiguity in their classification. However, for the purpose of this study, widely accepted definitions of arable field margins are illustrated in Figure 1.1 and discussed in detail in the next section. At this point, it is pertinent to note that one of the major features of a field margin is the boundary, and it has been estimated that there are 1,485,000 km of field boundaries within the UK (Barr *et al.*, 1993). Traditionally the function of boundaries was to enclose stock and also to define land ownership, and although this role remains equally important today, there have been significant changes in boundary composition and length.

Changes in agricultural practice during this century have led to many formerly mixed farms becoming entirely arable. This change has accelerated over the last thirty years, and many field boundaries have lost their previous purpose, and been removed to facilitate the operation of large farm machinery. A large proportion of the remaining field boundaries are no longer maintained to the same standard as increased labour costs have led to the decline of traditional, labour intensive techniques such as hedge-laying. Botanical diversity has also decreased, due possibly to pesticide drift, spreading inorganic fertilisers and organic manures into field margins, and soil disturbance by agricultural machinery.

Field margins are important refuges for many plants and animals, and in intensively farmed areas are often the only remnants of semi-natural habitats. They may act as corridors, forming a network through which organisms can move between larger habitat patches.

Headlands, which are the field areas adjacent to field boundaries used for turning of machinery, are frequently regarded as problem areas for crop production because yields are often lower than those from the mid-field (Boatman & Sotherton, 1988; Speller *et al*,. 1992; Sparkes *et al.*, 1994). Higher weed numbers, pest and disease incidence, soil compaction, shading and root competition from hedges and trees are generally blamed (Boatman, 1992a). Many weed species are often more abundant at field edges than within the crop (Marshall, 1989a).

1.2 Field Margin Terminology

There has been some ambiguity in the terms used to describe field margins. This review will follow the classification used by Boatman (1994) (adapted from Greaves & Marshall, 1987), which is represented diagrammatically in Figure 1.1.

Field Boundary

Separates one field from the next, or its adjacent land use and includes the barrier such as a hedge, grass bank, fence, wall, plus hedge bank if present with its associated herbaceous vegetation, plus ditch or drain if present.

Boundary Strip

An area of ground between the boundary and the cropped area of the field. It can include a farm track, a grass strip, an unsown cultivated strip with naturally regenerated flora, and/or a "sterile strip" of bare ground, maintained by cultivation or herbicides.

Crop Margin (Headland)

The outer part of the cropped area of a field, usually the area between the outer edge of the crop and the first tramline (a distance of approximately six metres in all of the fields studied in this report). The term "headland" is commonly used to describe this region, though strictly speaking this refers to the turning area used by agricultural machinery.

Figure 1.1 Principal components of an arable field margin (source Greaves & Marshall, 1987)

1.3 Historical Perspective

Fields demarcated by hedges, walls, ditches or banks have been typical of the British landscape since civilisation began (Rackham, 1986). Pollard *et al.* (1974) mention field systems dating back to the Bronze Age which are still in use today in areas of Cornwall. The Romans were also responsible for some enclosure of land in Britain with evidence of Roman fields in the Fens and S.E. Essex. Excavation of a Roman field system at Farmoor in Oxfordshire has revealed that the fields may have been surrounded by thorn hedges (Rackham, 1986).

During Anglo Saxon and medieval times much of the arable area of England was in the open field system, where land was divided into a number of strips. Each peasant had rights to strips in the arable fields and grazing rights on common pasture (Rackham, 1986; Carter, 1983). As the population increased more land was reclaimed from un-farmed areas such as moorland, heath or fen, and enclosed in small fields. As opposition to enclosure declined, greater areas of land were enclosed, assisted by a series of Parliamentary Enclosure Acts between 1750 and 1850. Parliamentary enclosure during the eighteenth and nineteenth centuries affected twenty five percent of the total surface area of England. A substantial amount of enclosure by public agreement and by piecemeal withdrawal of land from open fields and common land also took place during this period (Chapman & Sheail, 1994). Thus a large proportion of English fields (and hedges) date from this time, especially in the Midlands (Carter, 1983).

1.4 The Boundary

Field boundaries can consist of hedges, fences, walls, banks, grass strips, or ditches. This review will focus mainly on hedges, as they are the predominant boundary type in the areas of experimental study (Shropshire and Leicestershire) and are generally thought to have the highest value in terms of conservation, though other boundary types will be mentioned briefly.

1.4.1 Changes in boundary length

The Countryside Survey 1990 (Barr *et al.*, 1993) identified fences as the most widespread boundary component in Great Britain. Fences alone formed 676 000 km of the total boundary length of 1 485 000 km. A further 398 000 km of boundaries contained fences in conjunction with another boundary feature, thus fences were present in 72% of boundaries overall.

Boundaries containing hedges formed 31% (465 000 km) of the total length of boundaries. Of these, 378 000 km were in England, 54 000 km in Wales and 33 000 km in Scotland. Most hedgerows were in the pastoral landscapes (51% - 238 000 km), but the arable landscape contains a significant length of hedgerows (43% - 210 000 km). Walls and banks are less common boundary features, occurring in 13% and 11% of boundaries respectively.

There was a net decrease in the length of hedgerows by 23% between 1984 and 1990. Most of this loss was due to a change of form of the hedge, for example changing from a managed hedge to a line of trees, but 10% (52 000 km) were completely removed (Barr *et al.*, 1991). The greatest length of hedges were lost in the arable landscapes (27 000 km), although proportionally similar amounts were lost from pastoral landscapes.

Of the total boundary length in 1990, about 11% was composed of new boundaries, where there had been no boundary previously. Seventy nine percent of this new boundary length was composed of fences. Only 7% of new boundaries had a hedge.

1.4.2 Boundary Types

1.4.2.1 Fences

The Countryside Survey 1990 (Barr *et al.*, 1993) found that post and wire fences were the most dominant boundary type in the British countryside in 1990. Fences were found to occur in similar lengths in the arable and pastoral landscapes. Fences increased more in length than any other boundary type between 1984 and 1990.

1.4.2.2 Walls

Stone walls are associated with areas of stone availability, where soil and exposure conditions make it difficult to establish a hedgerow (Mead, 1966). Such areas tend to be in the uplands such as the Peak District and Cumbria, though walls are also a common feature in the Cotswold area of England.

Wall length decreased throughout Great Britain between 1984 and 1990 (Barr *et al.*, 1993) probably due to neglect and lack of management. The Countryside Stewardship Scheme offers a payment rate of £12 - £16 per metre for stone wall restoration (MAFF, 1996), so the length of walls may increase in the future as neglected walls are repaired.

1.4.2.3 Hedges

Hedgerows are the most frequently occurring semi-natural features on lowland farms in Britain, and increasingly represent the few remaining refuges where wildlife can survive in an otherwise intensively managed landscape (Watt & Buckley, 1994).

1.4.2.3.1 Hedge formation

Pollard *et al.*, (1974) summarised several possible ways in which hedges can originate:

1. They may be around woodland assarts, relics of old woodland vegetation managed to form hedges, or hedges planted around woodland with shrubs from the wood.
2. They may be formed from scrub growth along previously unhedged field boundaries, later managed to form hedges.
3. They may have been planted, either as single species or mixed species hedges.
4. They may have originated by combinations of the above possibilities.

1.4.2.3.2 Species composition - woody species

Age and mode of origin of a hedge influence the diversity and composition of its shrub flora more than differences in soil, climate or management. Hooper (1970a) demonstrated that the number of species present in a 30 metre length is strongly correlated with the age of the hedge. He also discovered that Saxon hedges contained about ten woody species, Tudor hedges four, and Enclosure Act hedges one or two. Rackham (1986) gave three possible explanations to the observation that older hedges have more species : Firstly, a hedge acquires more species as it gets older, due to tree and shrub seeds constantly being brought in by birds. These seeds germinate and some may establish. Secondly, in earlier times it was customary to plant hedges with more species than later on. Enclosure Act hedges were generally planted with one species, usually hawthorn (*Crataegus monogyna*). Finally, the older a hedge, the more likely it is to be natural rather than planted, and likely to be mixed from the start.

Although Hooper's relationship of one woody species for every 100 years is broadly correct, the actual number of woody species in relation to age of hedge varies regionally. Old hedges in the north of England would be likely to contain fewer species than similar hedges in the south due to geographical limitations on the distribution of some species, for example field maple (*Acer campestre*) and wayfaring tree (*Viburnum lantana*) which are found only in the south of Britain.

Enclosure Act hedges typically contain one or two species, although regional exceptions do occur. In Shropshire, enclosure hedges contain a variety of species, due to local planting policy. It was common to plant mixed hedges of hawthorn, holly or blackthorn, and some were planted with oak, elm, or beech (Cameron & Pannett, 1980).

Surveys carried out by the Institute of Terrestrial Ecology (ITE) in 1978 and 1990 (Cummins *et al.*, 1992) classified British hedgerows into eleven groups, according to the shrub species they contained. These were :

Mostly planted, non-native species
Wild privet present
Beech dominant
Hawthorn dominant
Mixed hawthorn
Elder/hawthorn
Willow or rose dominant
Mixed hazel predominant
Blackthorn predominant
Elm predominant
Gorse dominant

The most common hedges in Britain are those classified as "hawthorn dominant" (186 000 km) or "blackthorn predominant" (110 900 km) (Cummins *et al.*, 1992).

1.4.3 Herbaceous field margin flora

About 500 species of plant have been recorded as occurring in hedges, but most of these species also occur in alternative habitats such as woodland margins, coppice, scrub and rough grassland (Hooper, 1970b).

Most field boundaries contain a strip of herbaceous vegetation in addition to the boundary structure itself. Boatman & Wilson (1988) surveyed 187 arable field margins in England. The most commonly occurring herbaceous species were *Urtica dioica* (common nettle), *Heracleum sphondylium* (hogweed), *Anthriscus sylvestris* (cow parsley), *Dactlyis glomerata* (cocksfoot), *Arrhenatherum elatius* (false oat grass), and the agricultural weeds *Bromus sterilis* (barren brome), *Elymus repens* (couch), *Cirsium arvense* (creeping thistle), *Galium aparine* (cleavers) and *Convolvulus arvensis* (field bindweed).

Boatman *et al.* (1994) showed that *Anthriscus sylvestris*, *Galium aparine*, *Hedera helix* (ivy), *Heracleum sphondylium*, and *Urtica dioica* were more common in field margins with a hedge present, compared to ones with no hedge. Species such as *Agrostis stolonifera* (creeping bent), *Festuca rubra* (red fescue) and *Holcus lanatus* (Yorkshire fog) were all found to be associated with wide verges, whilst *B. sterilis*, *G. aparine* and *E. repens* were negatively related to verge width (Boatman *et al.*,1994).

The herbaceous species present in a hedge-bottom can be an indicator of a hedge's age. Pollard (1973) found that *Mercuralis perennis* (dogs mercury), *Hyacinthoides non-scriptus* (bluebell), and *Anemone nemorosa* (wood anemone) were strongly associated with old woodland relic hedges.

Marshall (1989a) studied distribution patterns of plants associated with field margins on three arable farms in England. Four distribution patterns were found, indicating the plants likely origins:

Type I : limited to the boundary, for example *Arum maculatum* (cuckoo pint), *Dactylis glomerata* (cocksfoot).

Type II : usually in the crop, though occasionally in the boundary, for example, *Veronica persica* (common field speedwell), *Polygonum aviculare* (knotgrass)

Type III : in the boundary and at decreasing density in the crop, for example *Galium aparine* (cleavers), *Bromus sterilis* (sterile brome).

Type IV : in the crop and boundary with the highest densities in the crop edge, for example *Alopecurus myosuroides* (blackgrass).

Species with Type III distributions are those which may contribute to field weed populations and are therefore of economic importance. Certain common grasses, for example *B. sterilis* (Theaker *et al.*, 1995a) and *E. repens* (Marshall, 1990), are capable of spreading from field edges, though most broad-leaved weeds are maintained in the crop area with the notable exception being *G. aparine*. However, Froud-Williams (1985) found that hedgerow and field populations of *G. aparine* were genetically distinct, and that hedgerow populations were apparently ill suited as arable weeds. Marshall & Arnold (1995) found that there was little relationship between the margin and field weed flora, however, about 25 % of the species they recorded in the margin were also found in the adjacent crop. The species that were found in both crop and margin were mainly annuals.

Cummins *et al.* (1992) found that adjacent land use had the greatest effect on hedgerow ground flora, rather than the type of hedge or the method of its management. The most species-rich hedge-bottoms were found adjacent to grassland, whilst the poorest were alongside arable land. Both very intensive land management and no management at all were found to be deleterious to the number of herbaceous species in hedge-bottoms. Farmers often view field margins as a potential source of pernicious weeds which may spread into adjacent crops. As a result, many have deliberately sprayed hedge-bottoms with broad-spectrum herbicides in an attempt to control this perceived problem. This has removed the perennial species and encouraged problem annuals such as cleavers and sterile brome, not only making the weed problem much worse, but also means spraying is carried out routinely.

Marshall & Smith (1987) questioned 163 cereal growers on their field edge and hedgerow management. A quarter of the respondents managed the headland differently from the rest of the crop, either by drilling at double rate and / or spraying extra pesticides. Sixty percent of farmers questioned used herbicides in the hedge-bottom to control herbaceous vegetation. The main reason for management at the cereal field edge was for weed control.

However, only a small number of species are capable of successful ingress into the adjacent crop, whilst the majority of hedgerow species are not able to effectively colonise the main crop area (Marshall, 1989a; Carnegie & Davies,1993).

About 25% of hedge-bottom species also occurred in the field at 5m or more into the crop (Marshall & Smith, 1987). Marshall (1989a) recorded several hedgerow species which were only found in the crop within 2.5m of the boundary. However, the majority of species specific to the hedgerow flora do not constitute a threat when growing on the crop headland as they are not able to survive intensive cultivations (Roebuck, 1987).

1.4.4 Field Margin Fauna

1.4.4.1 Insects

The structural complexity and biochemical diversity produced by the various woody plants in hedgerows attracts a varied insect fauna (Morris & Webb, 1987). The type of woody plants present in a hedgerow can affect the number of insect species it supports. For example, oak (*Quercus* spp.) supports 284 insect species, hawthorn (*Crataegeous* spp.) 149 species, blackthorn (*Prunus spinosa*) 109 species, whilst elm (*Ulmus* spp.) only has 82 associated insect species, and holly (*Ilex aquifolium*) 7 (Southwood, 1961). Mixed hedges with a variety of shrubs and associated trees are therefore likely to support a diverse range of insect species (Pollard *et al.*, 1974).

A number of insect species also make use of the hedge-bottom flora. Although hedgerows have been regarded as reservoirs for pests and diseases (van Emden, 1965), they also support a number of beneficial species. Some polyphagous predators may contribute to pest suppression in cereal fields. These include the Staphylinidae (rove beetles), Carabidae (ground beetles) and Araneae (spiders) (Wratten, 1988). Many of the most important predators of cereal aphids overwinter in field boundaries, particularly on raised grassy banks and under hedgerows (Sotherton, 1984, 1985). With the loss and impoverishment of many arable field margins, Thomas *et al.* (1991, 1992) suggested creating linear ridges sown with tussocky grass species, within cereal fields to provide overwintering habitat for these predator species. These are now generally referred to as "beetle banks". Collins *et al.* (1996) showed that in three years from its creation, a beetle bank had matured into a suitable overwintering site for polyphagous predators, and provided a comparable habitat to nearby hedge-bottoms. In a separate study, areas of two beetle banks were sown with different grass species. *A. elatius*, *Phleum pratense* and *D. glomerata* were found to support the highest densities of predator species (Collins *et al.*, 1996).

Field margins are important butterfly habitats, with 51 % of British butterfly species occurring in arable field margins (Dover, 1994). Amongst species likely to be breeding on herbaceous vegetation in field margins are *Maniola jurtina* (meadow brown), *Pyronia tithonus* (gatekeeper), *Aglais urticae* (small tortoiseshell) and *Pieris napi* (green-veined white). Feber *et al.* (1994) found that more *Maniola jurtina* butterflies were associated with grassy boundary strips than with other field edge habitats. Margins sown with a wildflower mixture and left uncut during the summer attracted the highest number of *M. jurtina* as this species preferred nectar sources which were found in these treatments, whilst treatments sprayed with glyphosate became progressively less attractive to butterflies.

Fussell & Corbett (1992) found that bumble bees (*Bombus spp.*) preferred feeding on nectar from perennial plants of later successional stages rather than annual plants of newly disturbed land. Plants such as *Vicia* spp.(vetches), *Centaurea* spp. (knapweeds), *Cirsium* and *Carduus* thistles and *Lamium album* (white dead-nettle), which are commonly found in undisturbed areas such as field margins, are a useful nectar source for bumble bees.

Many insect pests, which may also carry diseases, overwinter on plants in the field margin before moving into the crop in the spring (Deane, 1989). Some aphid species overwinter as eggs on perennial plants found in hedges, for example, *Rhopalosiphum padi* (the bird-cherry aphid) on bird-cherry (*Prunus padus*). Aphids can also live on grasses and transmit barley yellow dwarf virus (BYDV) from them to cereals (Marshall & Smith, 1987). Wright *et al.* (1984) found that aphids reproduced significantly better on some grasses than others. Smith *et al.* (1984) found that *B. sterilis*, *P. annua* and *A. fatua* were all good aphid hosts. *B.sterilis* was also found to be a good host for BYDV (Marshall & Smith, 1987). Although aphids are a serious pest of cereals they are also important links in the food chain which enable their natural enemies and those of other pests to survive.

Field margins harbour other pest species apart from aphids. For instance, *Psylliodes chrysocephala* (flea beetle) a pest of rape and other brassicas overwinters on wild brassicas in hedgerows (Deane, 1989).

1.4.4.2 Birds

The research on the importance of field margins to birds has particularly emphasised the importance of hedgerows (Lakhani, 1994). Field margins on arable land can form important refuges for birds of woodland origin (Hooper, 1970c; Pollard *et al.*, 1974). Although hedgerows are the most significant field margins for birds, they are not the most important habitat on farmland. Scrub, woodland, copses and spinneys may support larger numbers of birds (O'Connor, 1987).

A major value of field margins on farmland is to add spatial and structural heterogeneity to the landscape (O'Connor,1987). Arnold (1983) found the volume of hedges to be of particular significance to birds, irrespective of the shape of the hedge. Green *et al.* (1994) conducted a survey of passerine birds during the breeding season in hedgerows in lowland England and found that most species preferred tall hedges with many trees. Bird incidence was significantly related to hedge width for nine of the species studied, and also multiplied with increasing numbers of woody species in the sample length of hedgerow. Macdonald & Johnson (1995) also found that the best hedgerows for bird diversity were likely to be mature and sizeable, supporting a variety of woody species. Hedges may be used as song posts, nest sites, feeding areas, roosts, to provide shelter from predators, and to act as corridors between patches of other habitats (O'Connor, 1987). The variety of ways in which birds use hedgerows is determined by structural diversity, which also influences the attractiveness to different bird species (Pollard *et al.*, 1974). Well trimmed hawthorn hedges were less attractive than overgrown ones with outgrowths which provide suitable song posts, especially for species such as chaffinch that sing from taller song posts. However, some bird species avoid tall hedges e.g. yellowhammer (Green *et al.*, 1994), and linnet (Macdonald & Johnson, 1995).

Parish *et al.* (1994) examined the effect of the structure and the management of field boundaries, adjacent crop type and agricultural husbandry on birds. The presence of adjacent permanent pasture on both sides of a hedge had a positive effect on the number of species recorded.

1.4.4.3 Mammals

Hedgerows and field margins provide valuable resources for small mammals such as shrews, voles and wood mice (Tew *et al.*, 1994). Wood mice (*Apodemus sylvaticus*), are also able to exploit the surrounding open fields, and showed a specific preference for unsprayed and selectively sprayed headland plots over normally sprayed plots (Tew *et al.*,1992). Povey *et al.* (1993) concluded that small mammals, particularly wood mice, were significant predators of grass weed seeds in field margins. The presence of boundary features such as hedges and ditches were found to be more important to small farmland rodents than field margin management practices (Smith *et al.*, 1993).

There is concern that field margins may harbour larger mammals, such as rabbits, which are serious agricultural pests causing considerable damage by grazing in young crops (Deane, 1989). Tapper & Barnes (1986) found that hares often used hedges and woodland as sheltering areas.

1.5 The Boundary Strip

Field boundary strips can include narrow sterile strips established and maintained either by the application of a residual herbicide or regular use of a rotary cultivator, wildlife fallow margins which are cultivated but not cropped, expanded hedgerow and scrub margins created by allowing the hedge to spread into the field, and the establishment of grass margins (Suggett, 1993).

Greaves & Marshall (1987) questioned 163 farmers attending the 1985 Royal Agricultural Show. Just over 30% of farmers maintained boundary strips around the edges of cereal fields. Most of the farmers used boundary strips to prevent weed ingress into the crop, while some also cited reduction of harvest problems and wildlife benefits as additional reasons.

In order to prevent weed invasion from the field boundary, the concept of a sterile strip between boundary and crop was proposed (Bond, 1987; Fielder, 1987). Uncropped boundary strips can be maintained by cultivation or by use of residual herbicides or application of foliar herbicides such as glyphosate or glufosinate ammonium (Bond, 1987; Fielder & Roebuck, 1987; Boatman & Wilson, 1988).

Boatman & Wilson (1988) conducted trials on 0.5 m wide sterile strips around the edge of a winter wheat crop. Strips of cultivated ground were left unsprayed, or were sprayed with different levels of atrazine, a soil acting residual herbicide. The strips sprayed with atrazine gave good control of annual weed species in the early part of the season, though a large number of *B. sterilis* seedlings were present by the end of September.

Rew *et al.* (1992a) concluded that the severity of *B. sterilis* infestations in field margins could be reduced by avoidance of fertiliser misplacement, coupled with herbicide treated or mechanically cultivated sterile strips.

The establishment of diverse perennial plant communities on arable field margins has considerable potential benefits for both annual weed control and wildlife (Watt *et al.*, 1990). Smith & Macdonald (1989) extended the width of arable field margins at the University Farm at Wytham, Oxford from 0.5 m to 2 m by fallowing strips of cultivated land. In these strips the sward was allowed to regenerate naturally, or a mixture of wild grasses and forbs was sown. The sown swards were found to be richer in plant and invertebrate species and produced more rapid and effective weed control for equivalent management effort than naturally regenerated swards (Smith *et al.*, 1994). Marshall & Nowakowski (1995) showed that application of graminicides to a sown grass and wildflower strip controlled several species of invading grass weeds, and allowed a diverse sward to develop. Subsequently mown areas were able to maintain a high diversity, possibly as a result of reduced fertility caused by removal of plant material.

Milsom *et al.* (1994) evaluated the effects of three types of uncropped boundary strip treatments on weed ingress over a five year period. The boundary strip treatments investigated were a sown perennial ryegrass sward, rotovated and herbicide maintained sterile strips, and a control (winter wheat). Four weed species characteristic of field margins were used as indicators of weed ingress. The boundary strips were found to influence the rate of weed ingress, but did not halt it. There was no evidence that a particular boundary treatment performed better than the others.

1.6 The Crop Margin (headland)

1.6.1 Differences in yield and management between the headland and the midfield

Crop yields from the headland area are often lower than the midfield. The headland area often requires special management to reduce the risk of yield loss and at the same time minimise harmful effects on the local environment (Fielder, 1987). The headland is used for turning agricultural machinery during cultivation, drilling, spraying and harvesting operations, which may lead to soil compaction, crop damage and double application of seed, fertilisers and pesticides. Shading by tall boundary vegetation and competition from tree and shrub roots may cause additional yield losses. However, the crop may benefit from the shelter effect of hedges which may increase yields (Marshall, 1967).

Boatman & Sotherton (1988) found that on average, headlands yielded 18 % less grain than the midfield, although the difference in yield ranged from a 67 % reduction to a 25 % increase. In three spring barley crops, Boatman (1992a) found that headland yields ranged from 25 % higher to 15 % lower than the midfield. In a study of five fen peat fields, Speller *et al.*, (1992) reported yields of winter wheat to be 13.6 % lower from the area 1-7 m from the field edge, compared to the area 20-26 m from the field edge. Sparkes *et al.* (1994) found that headland yields were 11 % lower than the midfield yield in a commercial winter wheat crop, whilst headland yields were 22 % greater than the midfield for a spring barley crop. Headland yield decreases of 16 % for spring barley and 5 % for winter wheat were recorded by Fisher *et al.* (1988). Decreases in yield from the headland area compared to the midfield have also been found in non-cereal crops such as sugar beet (de Snoo, 1994; Sparkes *et al.*, 1994) and potatoes (de Snoo, 1994).

1.6.2 Conservation Headlands

Studies of *Perdix perdix* (grey partridge) have revealed an 80 % decline in populations since 1952, with pesticide use being implicated as a major cause (Potts, 1985). In 1984 the Cereals and Gamebirds Research Project began working on the problems associated with wild gamebird production on intensive arable farms (Sotherton *et al*, 1989). Previous studies (e.g. Potts, 1980) had found that the main factor causing a decline in grey partridge populations was chick mortality. Partridge chick survival was shown to be linked to the availability of sufficient quantities of the preferred insects (beetles, Lepidoptera and sawfly larvae and plant bugs) essential to the survival of the young birds. Many of these preferred insects were found to be most abundant at the edges of cereal fields where wild gamebird chicks have been shown to forage (Green, 1984). Certain pesticides can detrimentally affect these non-target species (Sotherton, 1991; Campbell *et al.*, 1997). Increased herbicide use over the last forty years has removed the host plants of many of these phytophagous insects and use of insecticides to control aphids in cereal crops has caused the direct mortality of other species (Boatman & Sotherton, 1988).

As a solution to the problem, the Game Conservancy developed the concept of selectively sprayed cereal crop headlands known as "conservation headlands". In this system the outermost section of the spray boom (usually 6m) is switched off when spraying around these headlands with non-selective herbicides or insecticides, or the headland areas are sprayed separately with more selective compounds. The remainder of the field is sprayed with the full range of pesticides. The selective use of herbicides increases the numbers of many broad-leaved weed species and the densities of preferred chick food insects (Sotherton,1985; Sotherton *et al.*, 1989). In response to the improved food supply the mean brood size of both pheasant and partridges is significantly increased.

Conservation headlands have also proved beneficial to other forms of wildlife, including non-target polyphagous predators (Chiverton & Sotherton, 1991), butterflies (Dover *et al.*, 1990; Dover, 1994) and small mammals (Tew *et al.*, 1994).

Conservation headlands have also been found to be of benefit to rare arable weeds (Wilson, 1993). A survey by the Botanical Society of the British Isles (BSBI) found that many formerly common arable weed species were in severe decline or had become extinct.(Smith, 1986). Increases in the use of herbicides, the development of cereal varieties responsive to increased nitrogen applications, changes in crop rotations and in crop husbandry methods have been the most important factors in the recent changes to Britain's arable weed flora (Wilson, 1991). The greatest diversity of cornfield flowers is usually found within 6 m of the crop edge (Wilson, 1989), and reduced inputs to this area such as when conservation headlands are used has been shown to be beneficial to the survival of rare arable weeds (Wilson, 1993).

1.6.2.1 Agricultural Consequences of Conservation Headlands

Generally headland yields have been found to be slightly lower than the midfield (section 1.6.1). Boatman & Sotherton (1988) found that conservation headlands yielded on average 8 % less than fully sprayed headlands. Similar results were recorded by Fisher *et al.* (1988), where conservation headlands in spring barley yielded 13 % less than fully sprayed headlands, and 9 % less in winter wheat, though in this study some fungicides were also withheld from the headlands. In a comparison of sprayed and unsprayed headlands in the

Netherlands, de Snoo (1994) found that winter wheat yields were 13 % lower from the unsprayed areas.

However, studies of the effects of weed control in spring barley crops have shown a negative response to herbicide use in some cases, where untreated crops produced a greater yield than those where weeds were chemically controlled (Boatman, 1992a; Davies, 1988; Jensen, 1985). Conservation headlands have been shown to contain significantly greater amounts of weeds than fully sprayed headlands (Chiverton, 1993; Chiverton & Sotherton, 1991).

In addition to possible yield reductions, conservation headlands could also have effects on grain quality and moisture content, and increase harvesting difficulties (Boatman & Sotherton, 1988).

1.7 Effects of agrochemical application on field margin flora

The degeneration of field boundary flora is often blamed on disturbance caused by the misplacement of fertiliser and non-selective herbicides (Fielder & Roebuck, 1987; Marshall & Smith, 1987; Marshall, 1988).

1.7.1 Herbicide Application

Marshall (1989b) investigated the effect of a range of herbicides and plant growth regulators on four common hedgerow shrubs (hawthorn, blackthorn, ash and elder) grown in pots. The herbicides tested included selective broad-leaved weed herbicides, wild-oat herbicides, soil-acting herbicides, glyphosate and plant growth regulators. Hawthorn was the most tolerant, with the other three species showing different susceptibilities. Wild oat herbicides had the least effect on the four shrub species, whilst mecoprop, chlorsulfuron, metsulfuron-methyl, fluroxypyr and glyphosate were most damaging. The growth regulators mefluidide and chlormequat and the herbicides diclofop-methyl, difenzoquat and ethofumesate increased height in the hawthorn plants.

Herbicide use has increased greatly over the last forty years, and there has been increasing concern that spray drift from farmland could affect the flora of adjacent semi-natural areas. Plants are likely to be exposed in non-crop habitats adjoining fields primarily from direct over-spray and drift during, and/or volatilisation after application (Freemark & Boutin, 1995).

It is well known that herbicides cause damage to native species when applied at recommended rates (Marshall, 1988; Marshall & Birnie, 1985; Willis, 1988; Yemm & Willis, 1962). However, the effects of sublethal doses found in spray drift are less certain.

Damage symptoms to plants from herbicides can be difficult to determine, especially when applied at low doses. Symptoms such as discoloration, chlorosis, necrosis, stunting and poor growth could also be caused by drought, pest attack or disease. At the individual plant level, herbicides may have an indirect effect by altering the competitive balance between neighbours. On a population or community scale, impacts may occur through a change in flowering performance, seed production and seed viability, seed germination and seedling establishment. Some of these effects may take several years to become apparent.

Marrs *et al.* (1989) tested five herbicides (asulam, glyphosate, MCPA, mecoprop and a mixture of chlorsulfuron and metsulfuron-methyl) against a range of native species which were placed at different distances downwind of the sprayer. The maximum safe distance at which no lethal effects were found was 6m from the sprayer.

In a separate study Marrs *et al.* (1991a) investigated the effects of spray drift of glyphosate, mecoprop and MCPA on native species of different age and placed in short, medium-height and tall grassland. Many of the plants were damaged immediately after spraying, but had recovered by the end of the season. In general younger plants were more affected than older ones. The structure of the surrounding vegetation influenced the response of some species.

In a third experiment plant communities of eight native dicotyledons, with or without *Lolium perenne*, grown in microcosms were exposed to repeated applications of spray drift of three herbicides (Marrs *et al.*, 1991b). The effects of the herbicide drift on foliar symptoms of plant damage and end of season yield were assessed in each of two years. Growth of two species (*Stachys sylvatica* and *L. perenne*) was enhanced near the sprayer, whilst six other species showed a reduction in growth. *Lychnis flos-cuculi*, *Primula veris* and *Ranunculus acris* all suffered from a reduction in flowering performance.

1.7.2 Fertiliser Misplacement and Field Boundaries

Nitrogen fertiliser use has increased dramatically over the past fifty years (Burrell *et al.*, 1990; Chalmers *et al.*, 1990). Many farmers inadvertently apply fertiliser to the field boundary in the process of fertilising the crop with broadcaster type applicators such as spinning disc and oscillating spout spreaders. These types of spreaders, which are the most commonly used by farmers, are most likely to cause problems of fertiliser misplacement into the boundary (Boatman,1992b; Rew *et al.*, 1992b). Taking precautions such as using a headland deflector can prevent misapplication, but results in a somewhat uneven spread over the headland area (Rew *et al.*, 1992b). Pneumatic and liquid distributors are more accurate than broadcasters, and if properly calibrated will not misplace fertiliser into the field boundary.

Application of nitrogen fertiliser generally decreases species diversity in agro-ecosystems (Mahn, 1984, 1988; Grundy *et al.*, 1991, 1992), and in grassland communities (Green, 1972; Tilman, 1982, 1988; Mountford *et al.*, 1993). The impact of nitrogen fertilisers on field margin communities is less well understood. Application of nitrogen fertiliser to hedge bank vegetation did not alter botanical composition over a three year period, but did increase vegetative and reproductive output of *B. sterilis* (Boatman *et al.*, 1994; Theaker *et al.*, 1995b; Rew *et al.*, 1995).

The majority of work on the effect of fertiliser and competition has focused on the interactions between crops and weeds. The type of nitrogen fertiliser used can affect species composition (Pysek & Leps, 1991). Some weeds are more competitive with the crop because they are better at utilising available nitrogen in the soil, and are able to compete with the crop. Species such as *Stellaria media, Galium aparine*, (Mahn, 1984), *Avena fatua* (Wright & Wilson, 1992) and *Bromus sterilis* (Rew *et al.*, 1992a) increase their growth rate in response to nitrogen application. Comparisons within the same genus have shown that the relative growth rate of annuals is often higher than that of perennials in response to nitrogen application (Muller & Garnier, 1990). This may give nitrophilous annuals such as *G. aparine* and *B. sterilis* growing in field margins a competitive advantage over perennial species.

1.8 Aims of present study

Previous studies on field margin management have focused mainly on wildlife conservation, and relatively little effort has been made at quantifying the effects of field margin management on crop production. The aims of this investigation were to quantify the effects of field margin management strategies, such as sterile strips, natural regeneration, sown strips and conservation headlands on crop productivity in winter cereal fields. The study also aims to provide information on the relative importance of herbicide drift and fertiliser misapplication on the botanical composition of field margins.

Chapter 2. The effects of field margin management on crop yield

2.1 Introduction

The headland area or crop margin is generally considered to be problematic for crop production since yields are often lower than those from the mid-field (Boatman & Sotherton, 1988; Speller *et al.*, 1992; Sparkes *et al.*, 1994), though in some cases the sheltering effect of hedges can lead to increased yields (Marshall, 1967). Low crop yields within headlands are generally attributed to greater weed abundance, pest and disease incidence, soil compaction, shading and root competition from hedges and trees (Boatman & Sotherton, 1988), but little research has been carried out on the relative importance of these factors.

Despite the obvious disadvantages of cropping on a headland, support payments still make this area attractive for growing cereals. However, the role of the headland area may change in the future since the Ministry of Agriculture, Fisheries and Food (MAFF) has recently added an arable field margins option to its Countryside Stewardship scheme, where either a 2 m or a 6m un-cropped margin is positioned alongside the field boundary (MAFF, 1996). Compensatory payments are made to the farmer, although there is little information concerning crop yields at field margins on which to base these calculations. In addition to the 2 m or 6 m un-cropped margin, the first 6 m of a cereal crop adjacent to the margin must be managed as a conservation headland where soil type and conditions allow. Payments for six metre wide conservation headlands or uncropped strips are also available in certain Environmentally Sensitive Areas in the UK.

Six metre wide buffer strips surrounding watercourses are required for a large number of pesticides, for example chlorothalonil, metsulfuron-methyl and bromoxynil plus ioxynil. There is a need to understand the implications of yield loss if buffer strips become statutory next to all types of field margin, not just those containing an aquatic element.

It is well known that many weed species are more abundant in field boundaries than in the main cropped area (Marshall, 1989a; Wilson & Aebischer, 1995). Some farmers have attempted to eliminate weeds at field edges by spraying close to the base of hedges or other boundaries with broad spectrum herbicides such as glyphosate. This practice has exacerbated problems by encouraging competitive annual weeds such as *Galium aparine* and *Bromus sterilis* (Marshall & Smith, 1987; Boatman, 1992c).

Conversely some workers have suggested that the crop edge can be modified for conservation purposes by treating such weeds with selective herbicides which leave less competitive broad-leaved weeds to encourage game birds, particularly grey partridge (*Perdix perdix*), (Rands, 1985; Sotherton, 1991). Partridge chicks feed almost exclusively on insects associated with arable broad-leaved weeds during the early stages of their life. Crop edges treated in this way are termed "conservation headlands". In some cases, conservation headland management has caused a reduction in yield compared to fully sprayed headlands (Boatman, 1992a; Boatman & Sotherton, 1988; de Snoo, 1994; Fisher *et al.*, 1988), but estimates of yield loss vary, and studies differ in the types of pesticide used or excluded, for example, in some cases, fungicides were also withheld from the crop margin.

The aims of the current study are to provide information on the effects of different field margin management practices on crop production and weed biomass within cereal headlands using field experimentation, and to investigate the relationship between cereal yield and distance from the field edge via quantitative surveys.

2.2 Materials And Methods

2.2.1 Field experiments

Replicated field experiments were conducted within winter cereal headlands over two years, at Harper Adams College, Newport, Shropshire (SJ 707195) (Plate Ia) and the Allerton

Research and Educational Trust, Loddington, Leicestershire (SK 797011) (Plate Ib), to investigate the effects of field margin management practices on crop production. Both experiments were in winter wheat in 1993/4; in 1994/5 the Shropshire site was again winter wheat, whilst the Leicestershire site was in winter barley. The soil type was a sandy loam at the Shropshire site, and clay at the Leicestershire site. The boundary type at both sites was a hedge less than 2m in height.

Six treatments were applied to a one metre strip adjacent to the boundary hedge, in combination with two treatments (fully sprayed headland or a conservation headland; Sotherton, 1991) applied to the outer six metres of crop, referred to as the headland. Conservation headland management consisted of withholding broad-spectrum herbicides in order to encourage dicotyledonous weed growth. Specific graminicides were applied as required for the control of black-grass (*Alopecurus myosuroides*) and wild oats (*Avena spp.*), and amidosulfuron was used for control of cleavers (*Galium aparine*) at Shropshire. Fungicides were applied as for the rest of the crop. Site and cropping details are given in Table 2.1. Plots (14m long at Shropshire and 10m long at Leicestershire) of each treatment were arranged randomly alongside the field boundary in a single block. This was then replicated to give three blocks in total (Figure 2.1). The entire experiment was replicated at both sites.

The six management treatments studied were :

(i) cropping up to the field boundary with a fully sprayed headland	(CES)
(ii) cropping up to the field boundary with a conservation headland	(CEC)
(iii) a 1 metre wide sterile strip with a fully sprayed headland	(SSS)
(iv) a 1 m wide sterile strip with a conservation headland	(SSC)
(v) a 1 m wide natural regeneration strip with a fully sprayed headland	(NR)
(vi) a 1 m wide grass/wildflower strip with a fully sprayed headland	(WF)

The following species were included in the grass/wildflower mixture :-

Grasses - *Dactylis glomerata* (cocksfoot) (1 gm^2), *Festuca rubra* (red fescue) (1 gm^2), dicotyledonous species - *Taraxacum officinale* (dandelion), *Centaurea scabiosa* (greater knapweed), *Centaurea nigra* (black knapweed), *Anthriscus sylvestris* (cow parsley), *Torilis japonica* (upright hedge parsley), *Lamium album* (white dead nettle), *Stachys sylvatica* (hedge woundwort), *Prunella vulgaris* (selfheal), *Geranium pratense* (meadow crane's-bill), *Malva moschata* (musk mallow), *Vicia sativa* (common vetch), *Vicia cracca* (tufted vetch) and

Hypericum perforatum (perforate St John's-wort) (dicotyledonous species 2 gm^2 total, using equal quantities of each species). The species mixture was chosen to include a variety of species, which would commonly be found in field margins in the study areas. The grass/wildflower mixture was broadcast by hand into rotovated and raked soil on 6 April 1994 at the Leicester site and 8 April 1994 at the Shropshire site. The strips were re-sown on 6 September 1994 at the Leicester site, due to being accidentally ploughed up.

Quadrats (0.25 m^2) were marked out in the plots at distances of 0-0.5, 1-1.5, 2-2.5, 3-3.5, 4-4.5, and 11.5-12 m from the edge of the field margin in all treatments in 1994 for destructive dry matter assessments of crop and weeds at growth stages (GS) 31, 59 (Zadoks *et al.*, 1974) and harvest (Figure 2.2). In 1995 an additional quadrat was sited at 5-5.5m from the edge of the field margin in the crop to edge and sterile strip treatments, but quadrats were only taken at 0-0.5 and 1-1.5 m in the natural regeneration and grass/wildflower strip treatments. In 1995, due to the experimental layout, the 0-1 m area of the "crop to edge treatments" were sown by hand at the Leicestershire site, and using a plot drill at the Shropshire site, whereas the rest of the plots were sown using conventional farm machinery. At the Leicestershire site all vegetation within the quadrats was cut by hand at ground level and the crop and weeds separated, dried and weighed at GS31 in 1994, and at GS59 and harvest in 1994 and 1995. At the Shropshire site in 1994, quadrats were harvested by hand at GS31 and GS59, but at final harvest, a plot combine was used. In

1995 quadrats were harvested by hand as for the Leicestershire site. See Table 2.2 for exact sampling dates.

Crop and weed material was separated on each occasion, and at growth stages 31 and 59 the whole crop and the weeds were dried and weighed. At the final harvest, weeds were dried and weighed, but the crop was threshed mechanically using a Hege ear thresher, and the grain cleaned, dried and weighed to determine yield.

In March 1995, a cone penetrometer was used to measure soil compaction in a transect from 0 - 11 m into the field at both sites (Anderson *et al.*, 1980). Fertiliser traps were positioned at ground level along a transect perpendicular to the field boundary at each site prior to fertiliser application in March 1995. Cardboard boxes (0.25 m^2 at Shropshire, and 1 m^2 at Leicestershire) were used as traps, and were positioned continuously from the field boundary to 12 m into the crop. Fertiliser was applied using a pneumatic spreader at Shropshire and a twin disc spreader at Leicestershire, the prills collected and weighed. Fertiliser application was only assessed on one occasion at each site.

Vegetation cover

Permanent quadrats (0.25 m^2) were established in the plots at the same distance from the crop edge as the destructive quadrats, and also in the field boundary (Figure 2.2). Percentage cover of plants in the cropped area and in the boundary vegetation was recorded in November 1993 using a 50 x 50cm quadrat, and thereafter at GS 31, GS59 and just prior to harvesting. As for the destructive samples, during 1995 the NR and WF treatments were only sampled in the field boundary, and at 0 and 1 m.

Soil seed bank assessments

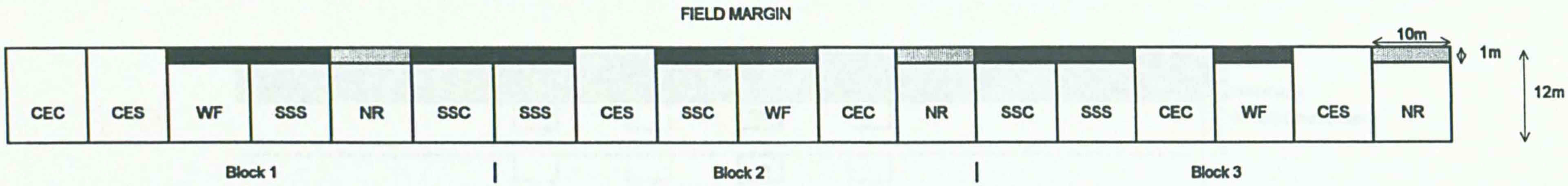
Soil samples were taken in November 1993 to provide baseline information on species diversity within the soil seed bank. Six soil cores (2.5 cm diameter and 20 cm depth) were collected from each plot, two in the field margin, two 1-2 m from the field edge and two 10-12 m from the field edge. The soil cores were placed in half sized seed trays and positioned randomly on a bench in a glasshouse. The samples were watered regularly, and periodically emerging seedlings were identified and removed, the soil disturbed, and the trays re-randomised. The trays were maintained until March 1995, after which they were discarded, as most of the soil had been lost through the drainage holes in the seed trays.

Plate Ia The Shropshire field experiment site (May 1994).

Plate Ib The Leicestershire field experiment site (April 1994).

Table 2.1 Crop, cultivar and husbandry details for crops in which the two field experiments were sited.

Year	1994		1995	
Site	Leicestershire	Shropshire	Leicestershire	Shropshire
Crop	winter wheat	winter wheat	winter barley	winter wheat
Cultivar	Hereward	Hunter	Fighter	Hunter
Drilling Date	16 October	20 October	23 September	14 October
Fertiliser : N	206	140	168	150
(kg/ha) P	54	-	74	-
K	54	-	49	-
Herbicides (g ai/ha) sprayed headland	tralkoxydim (194) fenoxaprop-P-ethyl (60) fluroxypyr (200) metsulfuron-methyl (6)	fluroxypyr (200) metsulfuron-methyl (6)	diclofop-methyl (611) fenoxaprop-P-ethyl (27) difenzoquat (764) fluroxypyr (200) metsulfuron-methyl (6)	bromoxynil (196) ioxynil (196) mecoprop-P (938)
conservation headland	tralkoxydim (194) fenoxaprop-P-ethyl (60)	amidosulfuron (30)	diclofop-methyl (611) fenoxaprop-P-ethyl (27) difenzoquat (764)	amidosulfuron (30)
Fungicides	fenpropimorph (223) fenpropidin (224) tebuconazole (252) triadimenol (126) chlorothalonil (226)	flusilazole (160) tebuconazole (125) tiademenol (165)	carbendazim (62) flusilazole (123) propiconazole (26)	carbendazim (78) flusialzole (156) tebuconazole (37.5) propiconazole (47)
Insecticides		-	-	-



CODE	TREATMENT
CES	Cropping up to the field boundary with a fully sprayed headland
CEC	Cropping up to the field boundary with a conservation headland headland
SSS	A 1m wide sterile strip with a fully sprayed headland
SSC	A 1m wide sterile strip with a conservation headland
NR	A 1m wide natural regeneration strip with a fully sprayed headland
WF	A 1m wide grass/wildflower strip with a fully sprayed headland

Figure 2.1 Plot layout used at the Leicestershire experimental site (not to scale) (a similar layout was used at the Shropshire site, but plots were 14m long)

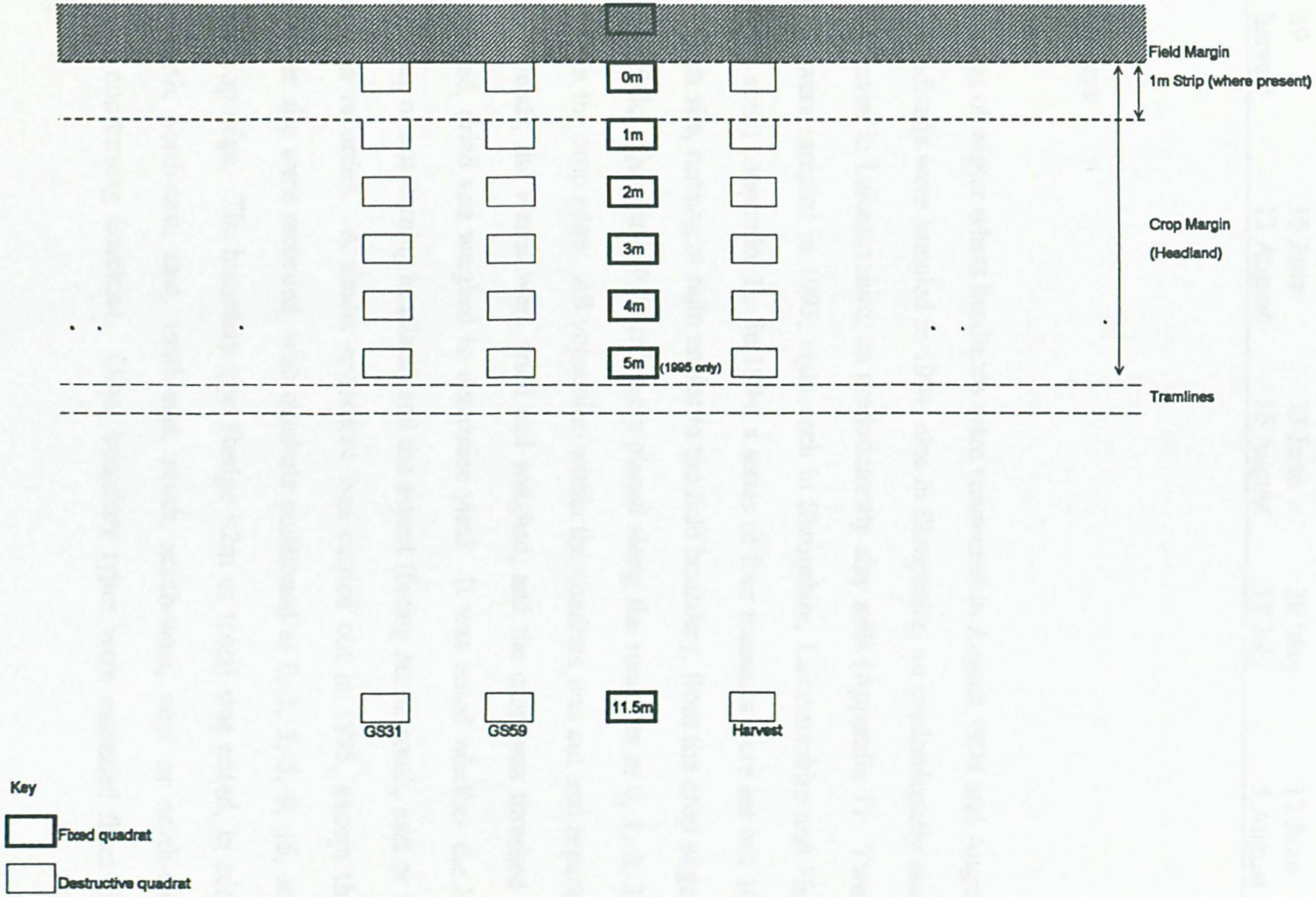


Figure 2.2 Location of permanent and destructive quadrats with in a plot (not to scale).

Table 2.2 Sampling dates at the Leicestershire and Shropshire sites in 1994 and 1995.

	1994		1995	
Growth Stage	Leicestershire	Shropshire	Leicestershire	Shropshire
31	28 April	25 April	-	-
59	16 June	13 June	30 May	17 June
harvest	13 August	15 August	19 July	5 August

2.2.2 Surveys

Two surveys of winter wheat headlands were conducted in August 1994 and August 1995. Sixteen headlands were sampled in 1994, nine in Shropshire, on predominantly sandy loam soils, and seven in Leicestershire, on predominantly clay soils (Appendix 1). Twenty four headlands were sampled in 1995, eight each in Shropshire, Leicestershire and Hampshire (calcareous soils) (Appendix 1). In 1994, a series of four transects were set out 10 metres apart at each site, running at right angles to the field boundary, from the crop edge to 11.5 m into the field. Quadrats (0.25 m^2) were placed along the transects at 0, 1, 2, 3, 4, and 11.5 m from the crop edge. All vegetation within the quadrats was cut and separated into crop and weeds, the weeds were dried and weighed, and the crop was threshed and the grain cleaned, dried and weighed to determine yield. It was noted whether the headland was a turning or non-turning headland, and the aspect (facing north, south, east or west) of the site was recorded. A similar procedure was carried out in 1995, except that three transects per site were recorded, with quadrats positioned at 0, 1, 3, 5, 9, 15, and 30 m from the crop edge. The boundary type (hedge <2m or trees) was noted, in addition to aspect (north, north-east, east, south-east, south, south-west, west or north-west) and turning or non-turning headland. Other boundary types were excluded from the 1995 sample.

2.2.3 Statistical analyses

Field Experiments

Field experiment results at each site for each year were considered separately. The data were analysed by ANOVA, with treatment as a factor. During 1994, all six treatments were analysed for each site, but in 1995, only the crop to edge and sterile strip treatments were measured fully, and only the results for these treatments are presented. Residual values were plotted against expected normal quantiles and fitted values. These plots indicated that yield data were normally distributed, but weed dry matter data were not. A $\log_e (x+1)$ transformation produced a distribution closer to normality, so weed dry matter data were $\log_e (x+1)$ transformed. Distance from the field boundary was also $\log_e (x+1)$ transformed. The relationships between crop biomass and crop yield, and weed biomass with $\log_e (x+1)$ distance from the field boundary were analysed by linear regression. Linear regression was also used to analyse the relationship between crop biomass and weed biomass at GS31 and GS59, and grain yield and weed biomass at harvest. The relationship between crop yield at harvest and soil compaction (to 15 cm depth) and fertiliser spread pattern was also studied using linear regression analysis. The vegetation cover data were arcsin transformed to stabilise variance, and analysis of variance was performed. Species were separated into life history groups of annual grasses, perennial grasses, annual dicotyledons and perennial dicotyledons within the field boundary, and of grasses and dicotyledonous species within the field area. T-tests were used to compare the amount of sown and un-sown species present in the wildflower/grass strip treatment.

Surveys

Factorial analysis of variance (ANOVA) was performed on the survey data to determine the effect of site and distance from the crop edge on grain yield and weed dry matter. As for the field experiments, weed dry matter data and distance were $\log_e (x+1)$ transformed.

Survey weed and yield data for 1994 (16 sites) and 1995 (24 sites) were also analysed using a series of backward-stepwise multiple linear regressions. Data from the transects at each site were pooled to provide mean weed and crop dry matter values at each distance from the boundary, providing data sets of 96 values in 1994 and 168 in 1995.

The effect of $\log_e$ (x+1) distance on $\log_e$ (x+1) weed biomass and the effect of $\log_e$ (x+1) distance and $\log_e$ (x+1) weed biomass on crop yield were then determined in separate analyses by stepwise deletion of the least significant terms from the maximal model (Crawley, 1993). Mean crop yield and weed biomass values for each distance were then pooled to provide a single value for each survey site. The analyses were repeated to determine the effect of boundary aspect, turning/non-turning headland and boundary type (1995 only) factors on $\log_e$ (x+1) weed biomass and crop dry matter yield.

2.3 Results

2.3.1 Field experiments

Crop dry matter at GS 31

Crop dry matter at GS 31, which was only assessed in 1994, showed considerable variation at each site, ranging from 29-98 g/m^2 at Leicestershire and 49-159 g/m^2 in Shropshire. As no herbicide treatments had been applied by this stage, it was not appropriate to compare fully sprayed and conservation headland treatments, so the differences between crop to edge treatments (CES and CEC), and strip treatments (SSS, SSC, NR and WF) were explored. When all quadrat distances were included in the analyses, there were significant differences between the crop to edge and strip treatments at the Leicestershire site ($P<0.05$), with the crop to edge treatments containing significantly more crop dry matter. However, this greater amount of crop dry matter in the crop to edge treatments was due to the extra area of crop sown at 0-0.5m, and when these quadrates were excluded from the analyses, there were no significant differences between treatments. Mean crop dry matter increased linearly with $\log_e(x+1)$ distance from the field boundary, and this was significant at the Shropshire site ($P<0.001$) (Table 2.3).

Weed dry matter at GS 31

As no herbicide treatments had been applied by this date, it was not appropriate to compare fully sprayed and conservation headland treatments, so the differences between crop to edge treatments (CES and CEC), and strip treatments (SSS, SSC, NR and WF) were investigated, but no significant differences were observed. Distance ($\log_e x+1$) from the field boundary did not have a significant effect on $\log_e (x+1)$ weed dry matter.

Crop dry matter at GS 59

There were no significant differences between treatments at the Leicestershire site in both years, and the Shropshire site in 1994 whether the 0-0.5 m samples were included in the analyses or not, therefore the extra area of crop sown in the crop to the edge treatments was not contributing significantly to the overall crop biomass. However, at the Shropshire site in 1995, the CEC treatment produced significantly less crop biomass than other treatments measured ($P<0.001$) (Table 2.5 & Figure 2.3). Crop dry matter biomass was compared between the two conservation headland treatments (CEC and SSC) and their corresponding fully sprayed treatments (CES and SSS) using analysis of variance. Crop dry matter was generally higher from fully sprayed treatments, and this was significant at the Shropshire site in both years (1994; $P<0.05$, 1995; $P<0.01$) (Tables 2.4, 2.6 & 2.7). Mean crop biomass increased linearly with $\log_e (x+1)$ distance from the boundary, but was only significant at Shropshire in 1994 ($P<0.001$) (Table 2.3).

Weed dry matter at GS 59

There were no significant differences between treatments for $\log_e (x+1)$ weed dry matter at either site in 1994. At the Shropshire site in 1995 there was significantly more weed dry matter in the crop to edge conservation treatment compared to the crop to edge sprayed and sterile strip treatments ($P<0.001$) (Table 2.8 & Figure 2.4), whilst at the Leicestershire site the conservation headland treatments contained significantly more weed dry matter than the fully sprayed treatments (Table 2.9 & Figure 2.5). Comparisons between fully sprayed and conservation headlands showed that $\log_e (x+1)$ weed dry matter was significantly higher within the conservation headland treatments in Leicestershire in 1994 ($P<0.01$) (Tables 2.5 & 2.10) and at both sites in 1995 (Leicestershire; $P<0.001$, Shropshire; $P<0.01$) (Tables 2.4, 2.11 & 2.12). There was a significant negative relationship between $\log_e (x+1)$ weed dry matter and $\log_e$ (x+1) distance from the field boundary at the Shropshire site in 1994 ($P<0.01$) (Table 2.3).

Grain yield at final harvest

Analysis of variance of grain yield showed no significant differences between treatments for grain yield, irrespective of whether the extra area of crop sown in the crop to edge treatments was included in the analyses or not, therefore this extra metre of crop was not having a significant effect on overall yield. Mean grain yields were compared between fully sprayed and conservation headland treatments, but there were no significant differences between the two, though yields tended to be higher from fully sprayed treatments at the Leicestershire site (Table 2.4). Mean crop biomass tended to increase linearly with $\log_e$ (x+1) distance from the field boundary and was significant at Leicestershire in 1994 and Shropshire in 1995 ($P<0.05$) (Table 2.3). This factor was not measured at Shropshire in 1994.

Weed dry matter at final harvest

Treatment had a significant effect on weed dry matter at harvest at the Leicestershire site in both years ($P<0.001$) (Tables 2.13 & 2.14) and at the Shropshire site in 1995 ($P<0.01$) (Table 2.15). Weed dry matter was not recorded at the Shropshire site in 1994. At the Leicestershire sites, the conservation headland treatments (CEC and SSC) contained significantly more weed dry matter than the sprayed treatments (Figures 2.6 & 2.7), but at the Shropshire site in 1995 the greatest amount of weed dry matter occurred in the CEC treatment (Figure 2.8). Comparisons between conservation and fully sprayed treatments showed that $\log_e$ (x+1) weed dry matter was significantly higher on conservation headlands at the Leicestershire site in both years ($P<0.001$) (Tables 2.4, 2.16 & 2.17). Mean $\log_e$ (x+1) weed biomass was not significantly related to $\log_e$ (x+1) distance from the boundary.

Weed - Yield Relationships

At GS31 in 1994 there was a significant negative relationship between crop biomass and $\log_e(x+1)$ weed biomass at the Leicestershire site. At GS59 this relationship was significant at both sites during both years (Shropshire 1994; $P<0.01$, 1995; $P<0.001$, Leicestershire 1994 & 1995; $P<0.001$). At harvest there was a significant relationship between grain yield and $\log_e(x+1)$ weed biomass at the Leicestershire site in 1994 ($P<0.01$) and at both sites in 1995 ($P<0.001$) (Table 2.18).

Table 2.3 Linear regression parameters for mean crop biomass (g/m^2) at GS31 and GS59, mean crop grain yield (t/ha) at harvest, mean $\log_e$ (x+1) weed biomass (g/m^2) at GS31, GS59 and harvest against $\log_e$ (x+1) distance (m) from the field boundary in 1994 and 1994.

			Leicestershire				Shropshire			
	Year	Growth Stage	Intercept	Slope	SE slope	Prob	Intercept	Slope	SE slope	Prob
Crop	1994	GS31	42.95	2.07	4.7	ns	58.34	34.05	3.56	<0.001
		GS59	543.3	47.3	37.4	ns	528.26	91.54	5.23	<0.001
		Harvest	5.14	0.86	0.15	<0.01	-	-	-	-
	1995	GS59	470.00	111.2	53.5	ns	570.90	139.00	65.2	ns
		Harvest	4.25	1.06	0.69	ns	2.52	1.12	0.33	<0.05
Weed	1994	GS31	2.09	-0.30	0.27	ns	2.23	0.07	0.12	ns
		GS59	3.33	-0.67	0.40	ns	4.03	-0.58	0.10	<0.01
		Harvest	2.64	-0.12	0.29	ns	-	-	-	-
	1995	GS59	3.44	-0.36	0.29	ns	3.25	-0.34	0.20	ns
		Harvest	2.48	-0.17	0.38	ns	2.73	-0.81	0.38	ns

Table 2.4 Mean crop and log$_e$ (x+1) weed dry matter (g/m^2) at gs59 and crop grain yield (t/ha) and log$_e$ (x+1) weed dry matter (g/m^2) at harvest for fully sprayed (CES + SSS) and conservation headland (CEC + SSC) treatments in 1994 and 1995.

			Leicestershire			Shropshire		
	Year	Growth Stage	Fully Sprayed	Conservation	SE	Fully Sprayed	Conservation	SE
Crop	1994	GS59	616	594	25.7	683	627	19.3
		Harvest	6.43	6.06	0.21	6.00	6.16	0.05
	1995	GS59	664	661	14.4	848	781	17.0
		Harvest	6.28	5.98	0.19	4.22	4.50	0.17
Weed	1994	GS59	2.10	3.04	0.23	3.10	3.14	0.15
		Harvest	1.20	3.32	0.25	-	-	-
	1995	GS59	1.53	4.04	0.28	2.24	3.06	0.21
		Harvest	0.51	3.81	0.15	1.42	1.30	0.24

Table 2.5 ANOVA table for crop dry matter production between treatments at the Shropshire site at GS59 in 1995.

Source	df	F value	Probability
Block	2	5.09	
Treatment	3	6.24	<0.001
Residual	66		
Total	71		

Table 2.6 ANOVA table for crop dry matter production between fully sprayed and conservation headlands at the Shropshire site at GS59 in 1994.

Source	df	F value	Probability
Block	5	2	
Treatment	1	4.19	<0.05
Residual	53		
Total	59		

Table 2.7 ANOVA table for crop dry matter production between fully sprayed and conservation headlands at the Shropshire site at GS59 in 1995.

Source	df	F value	Probability
Block	5	4.52	
Treatment	1	7.88	<0.01
Residual	65		
Total	71		

Table 2.8 ANOVA table for $\log_e$ (x+1) weed dry matter production between treatments at the Shropshire site at GS59 in 1995.

Source	df	F value	Probability
Block	2	10.42	
Treatment	3	6.67	<0.001
Residual	78		
Total	83		

Table 2.9 ANOVA table for $\log_e$ (x+1) weed dry matter production between treatments at the Leicestershire site at GS59 in 1995.

Source	df	F value	Probability
Block	2	0.51	
Treatment	3	8.71	<0.001
Residual	78		
Total	83		

Table 2.10 ANOVA table for $\log_e$ (x+1) weed dry matter production between fully sprayed and conservation headlands at the Leicestershire site at GS59 in 1994.

Source	df	F value	Probability
Block	5	2.42	
Treatment	1	8.50	<0.01
Residual	53		
Total	59		

Table 2.11 ANOVA table for $\log_e$ (x+1) weed dry matter production between fully sprayed and conservation headlands at the Leicestershire site at GS59 in 1995.

Source	df	F value	Probability
Block	5	0.78	
Treatment	1	40.27	<0.001
Residual	65		
Total	71		

Table 2.12 ANOVA table for $\log_e$ (x+1) weed dry matter production between fully sprayed and conservation headlands at the Shropshire site at GS59 in 1995.

Source	df	F value	Probability
Block	5	6.84	
Treatment	1	7.80	<0.01
Residual	65		
Total	71		

Table 2.13 ANOVA table for $\log_e$ (x+1) weed dry matter production between treatments at the Leicestershire site at harvest in 1994.

Source	df	F value	Probability
Block	2	2.92	
Treatment	5	9.22	<0.001
Residual	100		
Total	107		

Table 2.14 ANOVA table for $\log_e$ (x+1) weed dry matter production between treatments at the Leicestershire site at harvest in 1995.

Source	df	F value	Probability
Block	2	2.27	
Treatment	3	33.93	<0.001
Residual	78		
Total	83		

Table 2.15 ANOVA table for $\log_e(x+1)$ weed dry matter production between treatments at the Shropshire site at harvest in 1995.

Source	df	F value	Probability
Block	2	4.42	
Treatment	3	5.15	<0.01
Residual	78		
Total	83		

Table 2.16 ANOVA table for $\log_e(x+1)$ weed dry matter production between fully sprayed and conservation headlands at the Leicestershire site at harvest in 1994.

Source	df	F value	Probability
Block	5	2.76	
Treatment	1	37.09	<0.001
Residual	53		
Total	59		

Table 2.17 ANOVA table for $\log_e(x+1)$ weed dry matter production between fully sprayed and conservation headlands at the Leicestershire site at harvest in 1995.

Source	df	F value	Probability
Block	5	1.40	
Treatment	1	263.82	<0.001
Residual	65		
Total	71		

Table 2.18 Linear regression parameters for crop biomass (g/m^2) at GS31 and GS59 against $\log_e$ (x+1) weed biomass (g/m^2) and crop grain yield (t/ha) at harvest against $\log_e$ (x+1) weed biomass (g/m^2) in 1994 and 1994.

		Leicestershire				Shropshire			
Year	Growth Stage	Intercept	Slope	SE slope	Prob	Intercept	Slope	SE slope	Prob
1994	GS31	58.13	-6.58	2.77	<0.05	76.00	8.08	6.36	ns
	GS59	721.8	-48.4	10.7	<0.001	770.3	-36.1	12.1	<0.01
	Harvest	6.726	-0.251	0.09	<0.01	-	-	-	-
1995	GS59	702.5	-22.0	6.45	<0.001	933.9	-54.7	10.5	<0.001
	Harvest	6.53	-0.29	0.08	<0.001	4.89	-0.47	0.07	<0.001

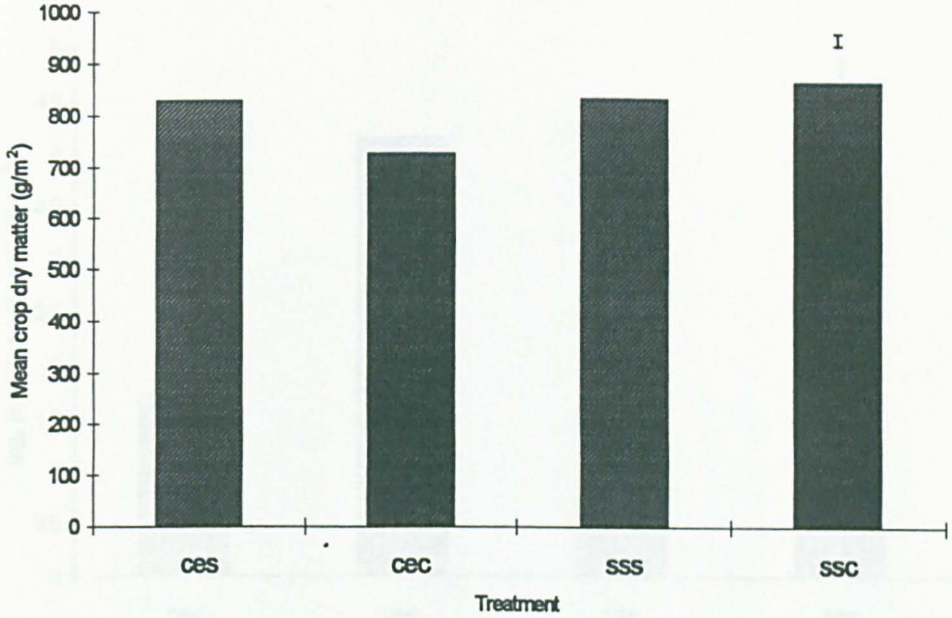


Figure 2.3 The effects of field margin management treatment on mean crop dry matter (g/m^2) at GS59 at the Shropshire site in 1995. Vertical bar represents SE.

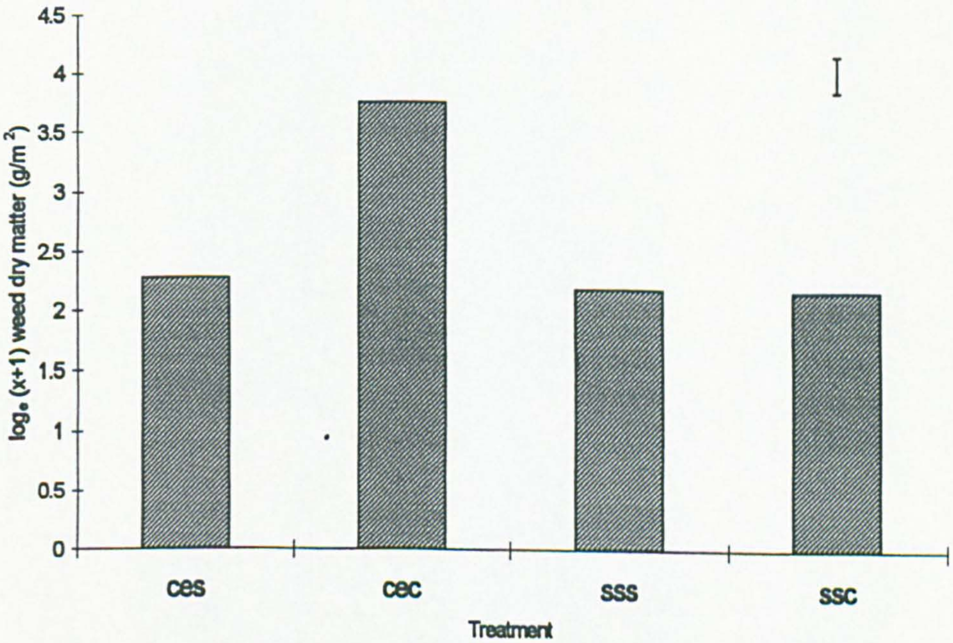


Figure 2.4 The effects of field margin management treatment on mean $\log_e$ (x+1) weed dry matter (g/m^2) at GS59 at the Shropshire site in 1995. Vertical bar represents SE.

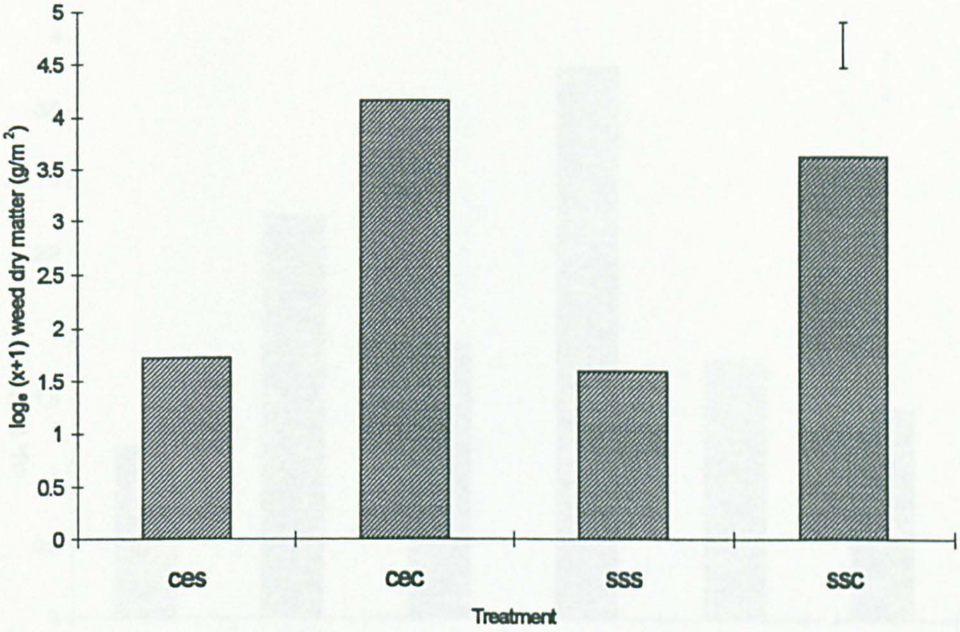


Figure 2.5 The effects of field margin management treatment on mean $\log_e$ (x+1) weed dry matter (g/m^2) at GS59 at the Leicestershire site in 1995. Vertical bar represents SE.

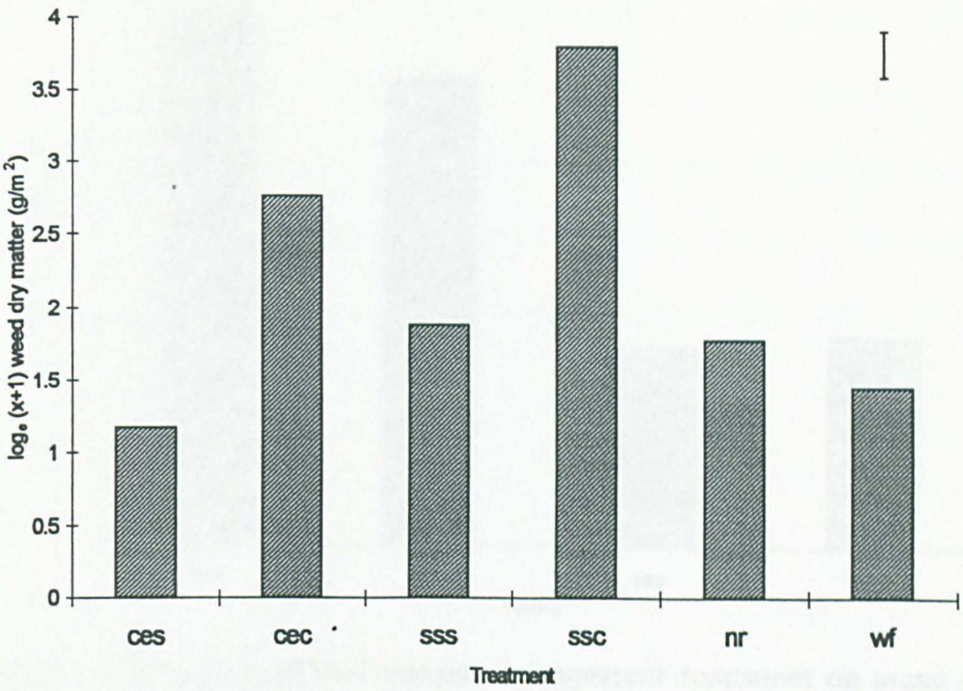


Figure 2.6 The effects of field margin management treatment on mean $\log_e$ (x+1) weed dry matter (g/m^2) at harvest at the Leicestershire site in 1994. Vertical bar represents SE.

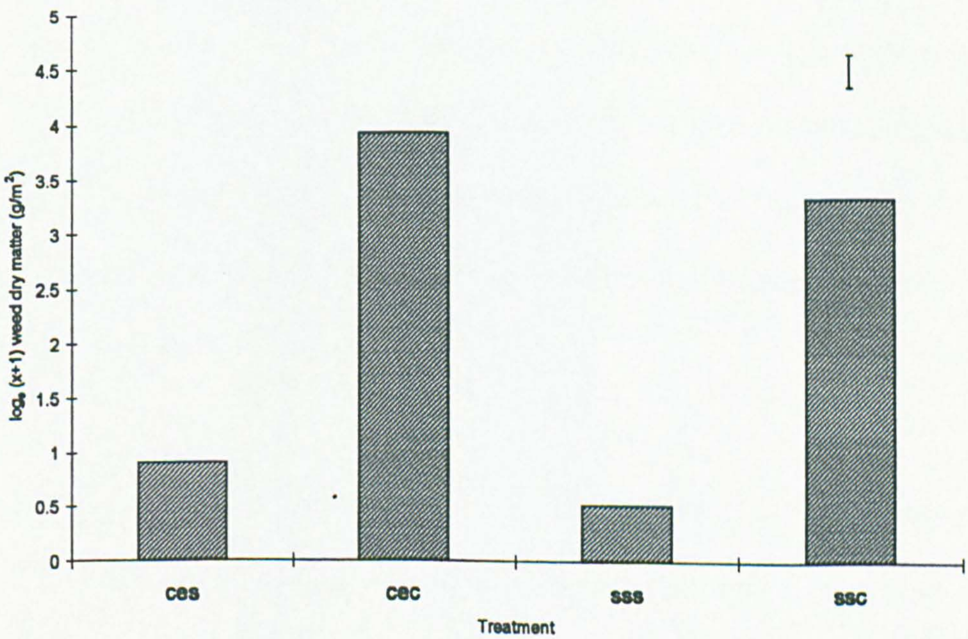


Figure 2.7 The effects of field margin management treatment on mean $\log_e$ (x+1) weed dry matter (g/m^2) at harvest at the Leicestershire site in 1995. Vertical bar represents SE.

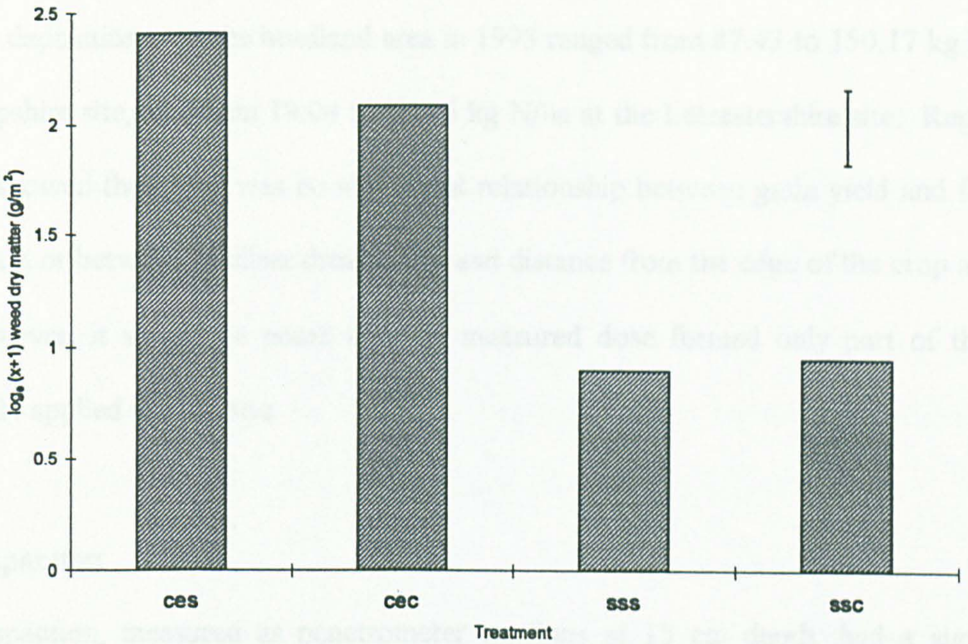


Figure 2.8 The effects of field margin management treatment on mean log$_e$ (x+1) weed dry matter (g/m^2) at harvest at the Shropshire site in 1995. Vertical bar represents SE.

Fertiliser distribution

Fertiliser deposition over the headland area in 1995 ranged from 87.43 to 150.17 kg N/ha at the Shropshire site, and from 19.04 to 55.06 kg N/ha at the Leicestershire site. Regression analysis showed that there was no significant relationship between grain yield and fertiliser distribution or between fertiliser distribution and distance from the edge of the crop at either site. However, it should be noted that the measured dose formed only part of the total fertiliser N applied at each site.

Soil compaction

Soil compaction, measured as penetrometer readings at 15 cm depth, had a significant negative effect on grain yield ($P<0.05$) at the Shropshire site in 1995, and accounted for 76% of the variation in yield (Figure 2.9). However, at the Leicestershire site there was no significant relationship between soil compaction and grain yield. There was no significant relationship between soil compaction and distance from the field boundary at either site.

Vegetation cover

The species recorded in the field boundary were separated into life history groups of perennial grasses, annual grasses, perennial dicotyledons and annual dicotyledons. There were no significant differences between plots before treatments were applied to the adjacent field area, and treatment had no effect on the cover of life history groups in the field margin at any assessment date.

Species in the cropped area were separated into grasses and dicotyledonous species, but consisted of mainly annual species. The most commonly occurring dicotyledonous species were *Galium aparine*, *Myostis arvensis*, *Polygonum aviculare*, *Sonchus oleraceus* and *Viola arvensis*, whilst the most frequently occurring grass weeds were *Alopecurus* *myosuroides* at the Leicestershire site and *Elymus repens* and *Poa annua* at the Shropshire site. The effect of treatment and distance from the field margin was generally significant from GS59 1994 onwards (Tables 2.19 - 2.22), and the results generally reflected the destructive assessments of weed dry matter recorded at the same time, though differences between treatments for weed dry matter assessments were not always significant. The percentage cover of dicotyledonous species tended to be greatest in conservation headland treatments, whilst the least cover of grasses tended to occur in treatments with a sterile strip. Cover tended to decline with distance from the field edge in most cases.

Within the sown grass/wildflower strip, the most frequently observed sown species was *D. glomerata*, followed by *F. rubra*, very few of the sown dicotyledonous species established at either site. At the Shropshire site, sown species had a greater percentage cover than un-sown species at GS59 and harvest in 1995 ($P<0.001$). There were no significant differences between the cover of sown and un-sown species at the Leicestershire site, except at GS59 in 1995, when there was a greater cover of un-sown species ($P<0.001$).

Soil seed bank

Very low numbers of seedlings emerged from the soil samples taken, and statistical analysis was not appropriate. A list of species found is given in Appendix 2.

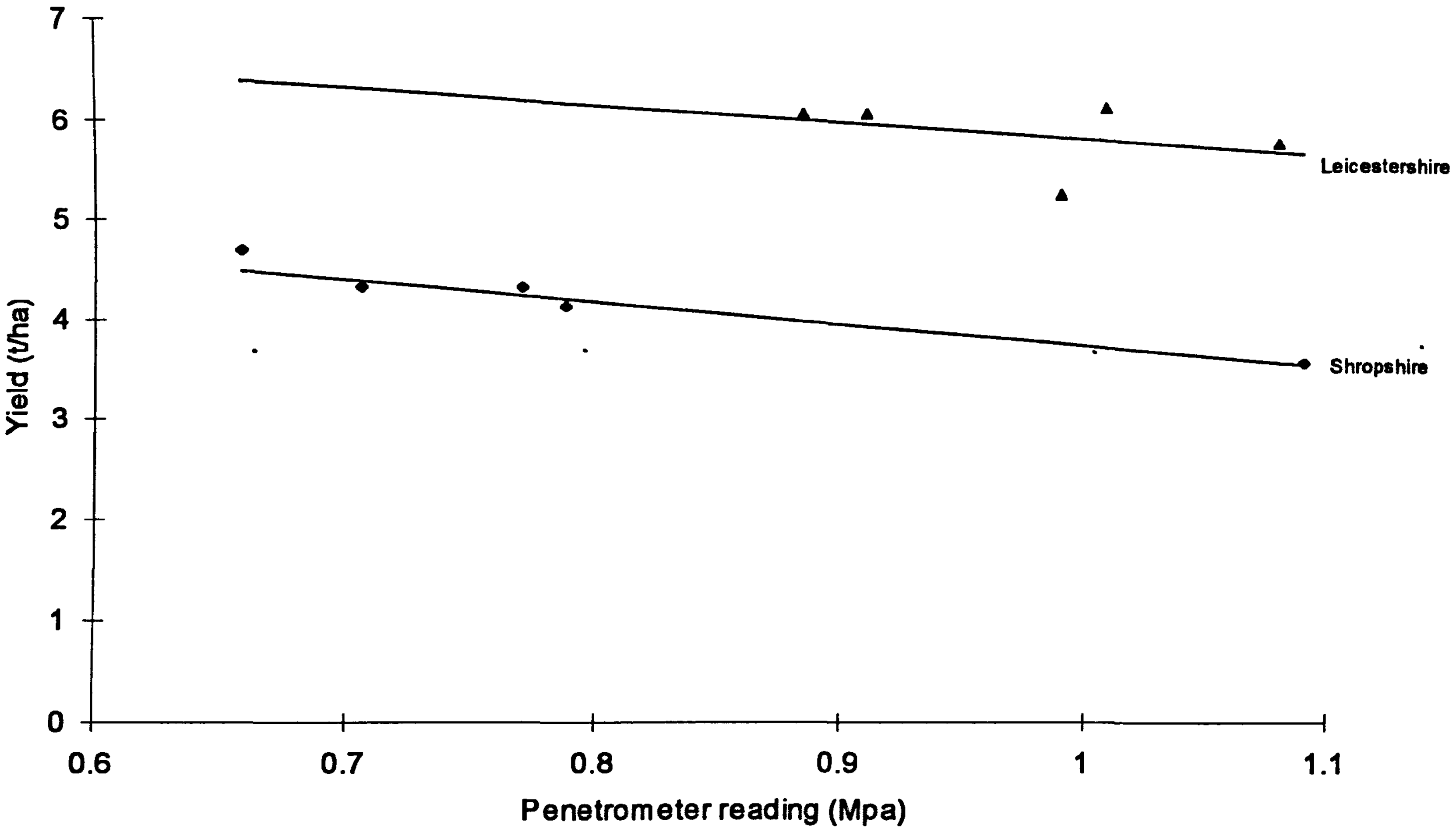


Figure 2.9 Relationship between grain yield and soil compaction for Shropshire (y=5.92-2.16x, R^2=0.76) and Leicestershire (y=7.48-1.66x, R^2=0.13) sites.

Table 2.19 ANOVA table for percentage cover (arcsin transformed) results at GS59 in 1994.

		Grasses				Dicotyledonous Species			
		Leicestershire		Shropshire		Leicestershire		Shropshire	
Source	df	F value	Prob	F value	Prob	F value	Prob	F value	Prob
block	2			6.05		9.04		38.51	
treatment	5	3.65	<0.01	4.78	<0.001	15.39	<0.001	4.10	<0.01
distance	5	7.45	<0.001	4.24	<0.01	4.83	<0.001	27.82	<0.001
treat x dist	25	1.52	ns	1.64	ns	1.54	ns	4.88	<0.001
residual	70								
total	107								

Table 2.20 ANOVA table for percentage cover (arcsin transformed) results at Harvest in 1994.

		Grasses				Dicotyledonous Species			
		Leicestershire		Shropshire		Leicestershire		Shropshire	
Source	df	F value	Prob	F value	Prob	F value	Prob	F value	Prob
block	2	0.32		0.56		14.25		24.20	
treatment	5	1.60	ns	2.91	<0.05	15.78	<0.001	12.33	<0.001
distance	5	24.06	<0.001	7.44	<0.001	6.25	<0.001	13.06	<0.001
treat x dist	25	0.82	ns	2.48	<0.01	1.50	ns	5.65	<0.001
residual	70								
total	107								

Table 2.21 ANOVA table for percentage cover (arcsin transformed) results at GS59 in 1995.

		Grasses				Dicotyledonous Species			
		Leicestershire		Shropshire		Leicestershire		Shropshire	
Source	df	F value	Prob	F value	Prob	F value	Prob	F value	Prob
block	2	0.07		3.24		4.92		3.08	
treatment	3	0.69	ns	6.10	<0.001	47.15	<0.001	5.28	<0.01
distance	6	2.51	<0.05	13.86	<0.001	3.55	<0.01	2.64	<0.05
treat x dist	18	2.05	<0.05	2.71	<0.01	2.35	<0.01	0.48	ns
residual	54								
total	83								

Table 2.22 ANOVA table for percentage cover (arcsin transformed) results at Harvest in 1995.

		Grasses				Dicotyledonous Species			
		Leicestershire		Shropshire		Leicestershire		Shropshire	
Source	df	F value	Prob	F value	Prob	F value	Prob	F value	Prob
block	2	1.44		1.12		3.97		5.11	
treatment	3	5.41	<0.01	2.98	<0.05	57.33	<0.001	11.37	<0.001
distance	6	13.86	<0.001	1.42	ns	4.48	<0.001	2.04	ns
treat x dist	18	5.63	<0.001	1.55	ns	3.00	<0.001	0.92	ns
residual	54								
total	83								

2.3.2 Survey of winter wheat headlands in 1994 and 1995

Analysis of Variance

Grain yield varied significantly ($P<0.001$) between sites in both years, with the crop yield adjacent to the boundary ranging from 2 t/ha to 9.4 t/ha in 1994 and from 0.8 t/ha to 10.2 t/ha in 1995 (Appendix 1). Log_e (x+1) weed dry matter also varied significantly ($P<0.001$) between sites.

Stepwise Multiple Linear Regression Analysis

The principal significant variable determining crop yield was $\log_e$ (x+1) distance from the boundary and this accounted for 30% of the variation in 1994 and 43% in 1995 ($P<0.001$) (Table 2.23). Mean crop yield increased linearly with $\log_e$ (x+1) distance in both years (Figures 2.10 & 2.11). Log_e (x+1) weed dry matter also significantly affected crop yield during 1994 ($P<0.001$) despite only accounting for a further 6% of the variation, but was not significant in 1995. However, it must be noted that $\log_e$ (x+1) weed dry matter was significantly negatively correlated with crop yield in both years (1994; $P<0.001$ & 1995; $P<0.001$). When the overall mean crop yield per site was calculated for all distances from the boundary, neither $\log_e$ (x+1)weed dry matter, type of headland (turning/non-turning), aspect or boundary type (1995 only) had any significant effect on crop yield (Table 2.23).

Log_e (x+1) distance from the boundary had a significant impact on $\log_e$ (x+1) weed dry matter in both years of the survey accounting for 34% and 51% of the variation. Weed biomass declined linearly with increasing $\log_e$ (x+1) distance from the crop edge (Figures 2.10 & 2.11).

Site aspect was also significant in 1994 ($P<0.05$) and east and west facing sites produced almost 50% more weed biomass than those facing north or south. In 1995, aspect was not significant, but again west facing sites produced the greatest weed biomass. The type of headland (turning/non-turning) or boundary type (only recorded in 1995) had no significant effect on $\log_e(x+1)$ weed dry matter (Table 2.23).

Table 2.23 Backwards stepwise multiple regression results for field survey data collected in 1994 and 1995.

Explanatory variable	Number of replicates included in analysis	Y variable : crop yield				y variable : $\log_e$ (x+1) weed dry matter			
		Variance	% variation accounted for	F value	Significance	Variance	% variation accounted for	F value	Significance
1994									
Log_e(x+1) distance from boundary	96	92.37	30%	41.03	<0.001	60.05	34%	48.26	<0.001
Log_e(x+1) weed dry matter	96	17.91	6%	8.60	<0.001	-	-	-	-
Log_e(x+1) weed dry matter	16	2.70	13%	2.20	NS	-	-	-	-
Aspect (N,S,E,W)	16	1.66	8%	1.33	NS	1.59	49%	3.91	<0.05
Headland type (turning/non-turning)	16	0.001	<1%	0.0008	NS	0.01	<1%	0.03	NS
1995									
Log_e(x+1) distance from boundary	168	414.87	43%	124.78	<0.001	237.51	51%	169.83	<0.001
Log_e(x+1) weed dry matter	168	2.56	<1%	0.75	NS	-	-	-	-
Log_e(x+1) weed dry matter	24	0.008	<1%	0.13	NS	-	-	-	-
Aspect (N,S,E,W)	24	0.009	<1%	0.90	NS	2.88	14%	1.196	NS
Headland type (turning/non-turning)	24	0.003	<1%	0.003	NS	0.014	<1%	0.10	NS
Boundary type (hedge <2m or trees)	24	0.004	<1%	0.32	NS	2.33	10%	2.54	NS

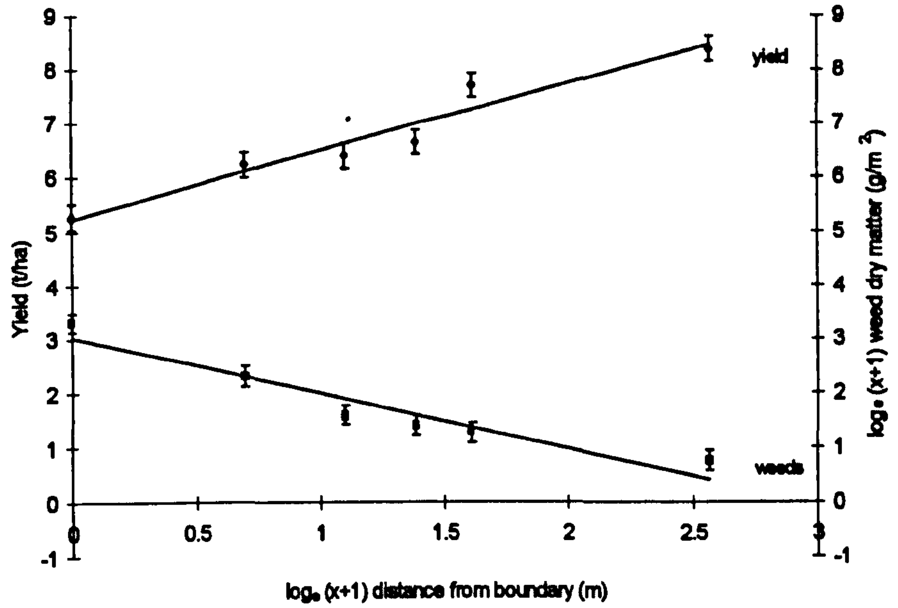


Figure 2.10 The effects of log$_e$ (x+1) distance from the boundary on mean crop grain yield and log$_e$ (x+1) weed dry matter (±SE) based on field survey performed in 1994 (crop yield : $y=5.22+1.26x$, $R^2=0.94$ and weed dry matter : $y=3.02-1.02x$, $R^2=0.92$)

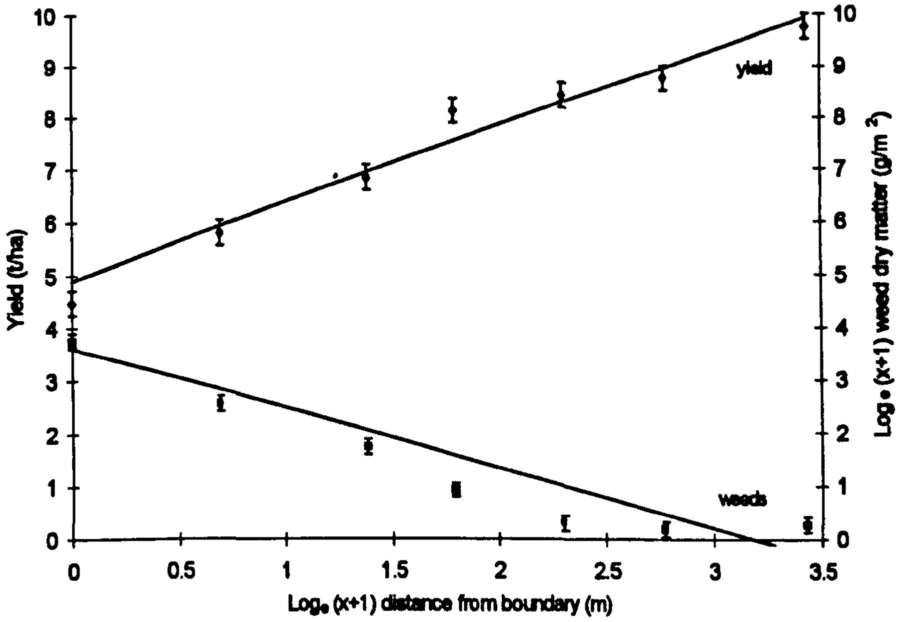


Figure 2.11 The effects of log$_e$ (x+1) distance from the boundary on mean crop grain yield and log$_e$ (x+1) weed dry matter (±SE) based on field survey performed in 1995 (crop yield : $y=4.89+1.47x$, $R^2=0.98$ and weed dry matter : $y=3.60-1.13x$, $R^2=0.90$)

2.4 Discussion

The field margin management treatments (crop to edge, sterile strip, natural regeneration strip and wildflower/grass strip) had little effect on crop dry matter or grain yield. At GS31 in 1994 the crop to edge treatments produced more crop dry matter than other treatments, but this was due to the extra 1m of crop sown in the CES and CEC treatments, and when this extra amount of crop was excluded from the analyses there were no significant differences between treatments. At GS59 in 1995 the CEC treatment at the Shropshire site produced significantly less crop dry matter than other treatments, but this was probably due to a significantly greater amount of weed dry matter in these plots compared to other treatments. There were no significant differences between treatments for grain yield at final harvest, and the extra 1m of crop sown in the CES and CEC treatments was not significantly contributing to the overall yield. May *et al.* (1994) similarly found no significant difference between winter wheat yields in a study comparing cropping to the field edge with wildflower, sterile, grass and natural regeneration strips.

Since cropping up to the field margin did not significantly improve grain yields, the farmer would not be losing much yield by taking this area out of production and allowing it to regenerate naturally or sowing it with a seed mixture. Marshall & Smith (1987) proposed using a strip of sown perennial vegetation to act as a barrier to weed dispersal and create new habitat for fauna and flora. Boundary strips sown with a wildflower mixture have been shown to increase plant and invertebrate abundance, and also contribute towards weed control, though in situations where a diverse and attractive flora are in the vicinity of the boundary strip, natural regeneration would be more cost effective and desirable (Smith *et al.*, 1994). The sterile strip concept was proposed by Bond (1987) to segregate the crop and field boundary area, to eliminate the re-introduction of weed seeds to the crop area and to facilitate combine harvesting. Boatman & Wilson (1988) found that an atrazine strip was effective in controlling *B.sterilis* and other annuals in the early part of the season, but that seeds of *B.sterilis* were able to establish from seed shed by plants in the hedge-bottom during late summer. The areas of greatest botanical interest have been shown to occur in the outermost strip of cereal fields (Wilson & Aebisher, 1995) and the presence of a sprayed sterile strip would prevent the establishment and survival of rare species in this particular zone.

Crop dry matter was significantly higher from fully sprayed treatments at the Shropshire site at GS59 in both years, but by harvest there were no significant differences between grain yields from fully sprayed or conservation headlands, though at the Leicestershire site conservation headlands tended to yield slightly less than fully sprayed treatments. Where there were significant differences between treatments for weed dry matter, conservation headlands contained greater amounts of weed dry matter than fully sprayed treatments. Conservation headland yields were 5.8% lower in 1994 and 4.8% lower in 1995 than yields of equivalent fully sprayed treatments at the Leicestershire site, within the ranges reported in other similar studies (Boatman, 1992a; Boatman & Sotherton, 1988; de Snoo, 1994). Fisher *et al.* (1988) reported greater yield reductions from conservation headlands, but fungicides were also withheld in addition to herbicides in this study, and probably accounted for the higher yield reductions. At the Shropshire site the conservation headland treatments produced slightly higher yields than their fully sprayed counterparts, but at this site weed levels were similar between treatments, and probably accounted for the similar cereal yields.

Previous studies have shown that yields tend to be lower from crop margins or headlands compared to the rest of the field, though in some cases headland yields have been similar or higher than those from the midfield (Boatman, 1992a; Boatman & Sotherton, 1988; de Snoo, 1994; Speller *et al.*, 1992; Sparkes *et al.*, 1994). Where yields have been measured at different distances into the field there has been a general trend for yields to increase with distance (Speller *et al.*, 1992; Sparkes *et al.*, 1994). In the present study, distance from the field boundary was the most important factor affecting yield in the surveys, and there was a relationship between yield and distance apparent in the field experiments. The linear relationship between yield with log distance showed no sign of levelling off within the range of distances measured, even up to 30m from the crop edge in the 1995 survey.

Weed dry matter was negatively related to distance from the crop edge in both surveys, but in the field trials there was only a significant relationship between weed dry matter and distance at the Shropshire site at GS59 in 1994. There was a significant negative relationship between yield and weed biomass at harvest where this was measured in the field trials, and in the 1994 survey. Similar relationships have been reported elsewhere (Boatman, 1992a; Christensen *et al.*, 1994). The trend for increased weed amounts at crop edges may be partly responsible for lower yields in these areas, though poor crop establishment due to other factors such as soil compaction could encourage growth of weed seedlings.

Boundary type (hedge or trees) and turning or non-turning headland had no significant effect on crop yield or weed biomass in the surveys. Aspect had no significant effect on crop yield, but significantly more weed biomass was found in east and west facing sites compared to those facing north or south in the 1994 survey.

There was a significant relationship between soil compaction and grain yield at the Shropshire site, but at the Leicestershire site there was little variation between samples. Sparkes *et al.* (1994) also measured soil density at different distances from field boundaries, and found that penetrometer cone resistance was high and yield was reduced in the tramlines and also in areas used for turning spraying and cultivation machinery. The effect of soil compaction on crop yields has been previously reported (e.g. Eriksson *et al.*, 1974; Soane *et al.*, 1982; Hakansson *et al.*, 1988), but more work is needed to establish its importance relative to other factors in cereal headlands.

The measurements of fertiliser distribution pattern showed the wide variation in application rates which can occur under normal agricultural conditions, as demonstrated by Rew *et al.* (1992b). However, no significant effect on yield was observed, though only a single fertiliser application was measured. Further work on this aspect is needed.

To summarise, the aim of the work reported in this chapter was to determine the effect of field margin management treatments on cereal yield and weed levels in crop margins, and investigate the relationship between yield and distance from the field edge.

Field margin management treatment did not have a significant effect on yield, and yields were not significantly reduced by taking 1m out of production for the establishment of a boundary strip. Conservation headland management did not result in significantly lower yields, though where yields were reduced, weed levels were higher in conservation headlands than in fully sprayed headlands. Soil compaction affected yield in one field experiment, but not in the other. No relationship was found between the pattern of fertiliser application and yield. Cereal yields were shown to be linearly related to log distance from the crop edge, up to at least 30m. Weed dry matter was also negatively related to distance in the surveys.

Chapter 3. Effects of Fertiliser and Herbicide Application on Herbaceous Field Margin Communities

3.1 Introduction

Many arable field margins have species poor floras, often dominated by undesirable annual weeds such as *B. sterilis* and *G. aparine*. Disturbance, caused by close cultivation, spray drift, deliberate herbicide application, and fertiliser misplacement have been implicated in causing this decline in diversity (Marshall 1988; Smith & Macdonald, 1989; Wilson, 1993).

Approximately 85 % of fertiliser is applied to agricultural land in solid form, using broadcast distributors and pneumatic applicators. This method of application can give an uneven spread of fertiliser and localised overdosing, with some fertiliser being distributed into non crop areas such as field margins (Rew *et al.*,1992b). Consequently, fertiliser misplacement into field boundaries may result in higher levels of nitrogen being available for use by field margin vegetation (Theaker *et al.*, 1995b).

It has been demonstrated that annuals generally respond more rapidly to nitrogen application than perennials of the same genus, although some overlap does occur (Grime & Hunt, 1975; Muller & Garnier, 1990). Annuals such as *S. media*, *G. aparine* (Mahn, 1984), and *B. sterilis* (Rew *et al.*, 1992a) have been shown to increase growth rate in comparison with other species in response to nitrogen application. Fertiliser misplacement into field margins may cause higher levels of available nitrogen which could provide annuals with a competitive advantage over perennials. However, established perennials in a sward can prevent annuals from establishing themselves by seed, as in a dense stand of perennials there will be few gaps large enough for annuals to germinate in, and small annual seedlings are unable to compete with large established perennials for resources such as light and water.

Generally application of nitrogen fertiliser has been shown to decrease species diversity by altering competitive balances, whilst increasing biomass per plant, in grassland communities (Tilman, 1982; Mountford *et al.*; 1993) and in weed communities within cereal crops (Mahn, 1984, 1988; Grundy *et al.*, 1991, 1992).

Herbicide spray drift from farmland could also adversely affect native plant species growing in adjacent field margins. A range of plants commonly found in field margins are known to be susceptible to a number of broad spectrum herbicides applied at field rate (Marshall & Birnie, 1985). Marrs *et al.* (1991a) found that five dicotyledonous species, common to field margins and woodlands, showed damage symptoms after being exposed to spray drift, but that there was no significant reduction in growth by the end of the season. In a glasshouse based study, Breeze *et al.* (1992) demonstrated that glyphosate drift was the most toxic out of four herbicides tested on a range of wild plant species. Herbicide spray drift also may create gaps in established field margin vegetation which could affect local community stability and species turnover. In particular, gaps are rapidly exploited by existing annual components of the vegetation, such as *B. sterilis* and *G. aparine*.

Mahn (1984) suggested that changes in agricultural weed communities which are often attributed to long term herbicide use may also be due to an increase in inorganic fertiliser input. This could also apply to semi natural areas such as field margins, however the combined effect of nitrogen fertiliser and herbicide on the performance of such a community has not been previously evaluated.

A factorial experiment was established to determine the potential effects of nitrogen fertiliser misplacement and sublethal levels of a broad spectrum herbicide (glyphosate) on a simulated field margin community and to identify the relative importance of these two factors on herbaceous field margin communities over time. It was decided to create simulated field margin communities because of the difficulty of finding areas of naturally occurring field margins with uniform vegetation cover. The species sown were chosen to represent different life histories which might typically be found in naturally occurring field margin communities, based on results of the Countryside Survey 1990 (Barr *et al.*, 1993). The simulated field margin communities consisted of *Arrhenatherum elatius* (false oat grass) - a perennial grass reproducing by seed, *Elymus repens* (common couch) - a perennial grass, reproducing mainly vegetatively, *Bromus sterilis* (sterile brome) - an annual grass reproducing by seed, *Silene latifolia* (white campion) - a perennial dicot reproducing by seed, *Ranunculus repens* (creeping buttercup) -a perennial dicot, reproducing mainly vegetatively and *Galium aparine* (cleavers) - an annual dicot reproducing by seed. The aim was to identify the relative importance of fertiliser misplacement and sublethal doses of herbicide on herbaceous field margin communities over time.

3.2 Materials And Methods

The experimental site was located on a sandy loam soil at Harper Adams, Shropshire (grid reference SJ702190) (Plate II). Following ploughing of the experimental site in April 1994, and two passes with a rotary cultivator, the experiment was laid out in four replicate blocks, each containing twelve 2 x 3 m plots, separated by a 0.7 m walkway. Plots were sown by hand on 3 May 1994 with a mixture of *Arrhenatherum elatius* (1 g/m^2), *Elymus repens* (1.3 g/m^2), *Bromus sterilis* (4 g/m^2), *Silene latifolia* (0.6 g/m^2), *Ranunculus repens* (2 g/m^2) and *Galium aparine* (2.8 g/m^2) obtained from Herbiseed (Herbiseed, The Nurseries, Billingbear

Park, Wokingham, RG40 5RY). Seed rates were chosen according to seed size, except for *R. repens*, where seed rate was increased because of known poor germination. Plots were hand weeded during the first year of establishment to remove annuals that had germinated, such as *Matricaria matricarioides*. and *Senecio vulgaris*. After that period, invading species were allowed to establish.

The experimental treatments were:

Nitrogen fertiliser : 0, 50, 200 kg N/ha (as ammonium nitrate, 34.5 % N).

The 0 and 50 kg rates were applied by hand on 16 March in 1995 and 18 March in 1996 The 200 kg rate was applied as a split dressing with half applied on 16 March and half on 23 March in 1995, and half applied on 18 March and half on 25 March in 1996.

Herbicide : 0 g, 45 g (1/8 field rate), 90 g (1/4 field rate) and 180 g (1/2 field rate) a.e./ha glyphosate (Roundup Biactive 356 g a.e./l).

Glyphosate was chosen as it is known to be active against both annual and perennial grass and dicotyledonous species. Herbicide was applied on 2 June 1995 and 14 May 1996 using an Oxford Precision Sprayer, at an overall volume rate of 200 litres / ha.

The treatments were arranged in a factorial structure, producing twelve treatment combinations in total (Table 3.1) with four replicates of each. Treatments were assigned to plots in a randomised block design (Figure 3.1).

Table 3.1 Fertiliser (F) and herbicide (H) treatment combinations.

Treatment	Nitrogen (kg N/ha)	Glyphosate (g a.e. / ha)
F0H0	0	0
F50H0	50	0
F200H0	200	0
F0H45	0	45
F50H45	50	45
F200H45	200	45
F0H90	0	90
F50H90	50	90
F200H90	200	90
F0H180	0	180
F50H180	50	180
F200H180	200	180

Monitoring of the plots started in March 1995, before any fertiliser or herbicide treatments were applied, using a point quadrat. Three 1 m high point quadrat frames containing ten pins were positioned randomly in each plot, each pin lowered through the sward, and all living plant material touching the pins was recorded to species and at 5cm height intervals (Plate III) (Brown & Gange, 1989; Gibson *et al.*, 1987). Recordings were made of sown species and invading species. This allowed accurate assessment of cover abundance and plant architecture in a non-destructive manner. The procedure was repeated at monthly intervals from March to August 1995, once in December 1995, and at monthly intervals from March to August 1996.

Plate II Simulated field margin plant communities (June 1995).

Plate III Using point quadrat frame to record cover abundance of vegetation.

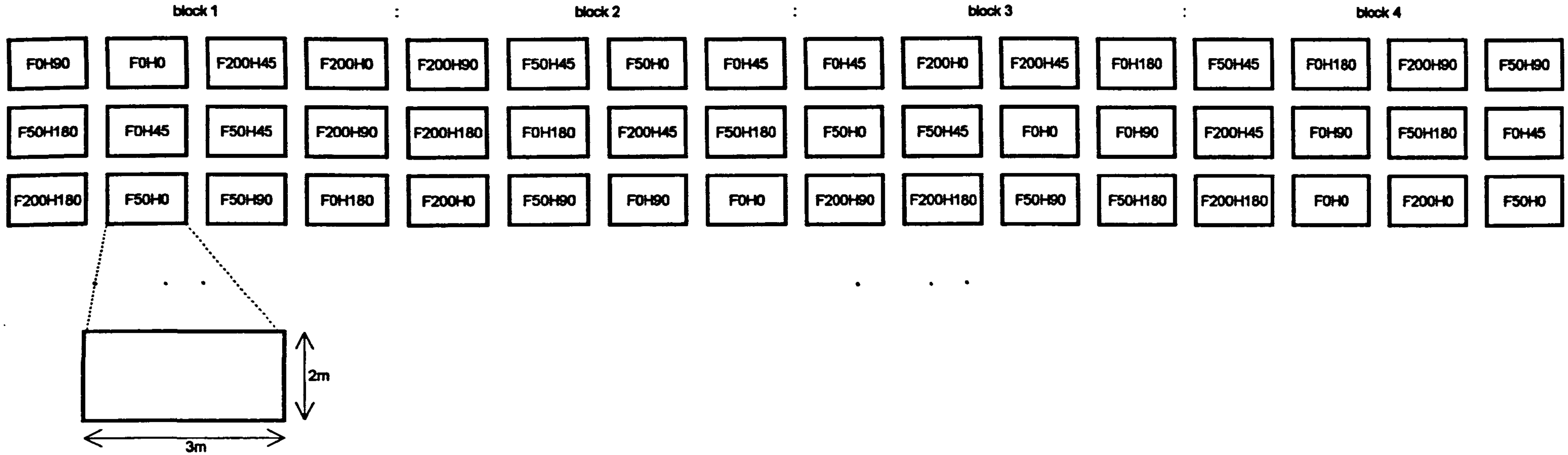


Figure 3.1 Plot layout at the study site (not to scale) (see Table 3.1 for treatment details)

Statistical Analyses

The cover abundance data or "total touches" were analysed using multivariate repeated measures analysis of variance (RM ANOVA or profile analysis) with fertiliser and herbicide as factors and month of sampling as the repeated measures factor. Individual treatment means were compared using planned comparisons (contrast analysis) with sequential Bonferroni corrections, where appropriate (Scheiner & Gurevitch, 1993; Rice, 1989).

The results have been split into a number of sections for analysis and ease of interpretation : March 1995 - pre-treatment; April to May 1995 - fertiliser applied; June to August 1995 - fertiliser and herbicide; December 1995 - overwinter; March 1996 - pre-treatment 1996; April to May 1996 - fertiliser applied; June to August 1996 fertiliser and herbicide applied. The data were analysed as the total mean cover abundance for each sown species, and individual species were also combined into life history groupings of grasses and dicotyledonous species, and annuals and perennials to examine general trends.

3.3 Results

The first seedlings began to emerge approximately two weeks after sowing. Visually, there was almost 100% cover within plots six weeks after sowing. During the first year a large number of seedlings of unsown species appeared in the plots (mainly *Tripleurospermum inodorum*, *Senecio vulgaris*, and *Papaver rhoeas*), these were carefully removed by hand weeding during 1994, but thereafter any invading species were allowed to remain. *A. elatius*, *E. repens*, *B. sterilis*, and *S. latifolia* all established well, but *R. repens* and *G. aparine* failed to establish evenly in all of the plots and were only present in low numbers.

3.3.1 Mean Total Cover Abundance

March 1995

At the initial assessment date in March 1995, prior to any fertiliser or herbicide treatments being applied, there was no significant difference between the mean total number of touches for any of the treatment combinations..

April - May 1995

There was a significant increase in mean total cover abundance between the April and May ($P<0.001$) (Table 3.2) (Figure 3.2). Fertiliser had no significant effect on cover abundance over the same period.

June - August 1995

Month of sampling had a significant effect ($P<0.001$) (Table 3.3), with total cover abundance declining from June to August (Figure 3.2). Fertiliser also had a significant effect on total number of touches ($P<0.001$) (Table 3.3) and total cover abundance decreased with increasing fertiliser rate (Figure 3.3). There was a significant fertiliser x month of sampling interaction ($P<0.05$) (Table 3.3). Mean total cover abundance was significantly reduced by the addition of 200kg N fertiliser in June when compared to unfertilised control plots (Contrast analysis $F_{1,36}=7.98$, $P<0.05$), but in July and August there was no effect of fertiliser on cover abundance (Figure 3.3). Herbicide application also had a significant effect on total number of touches from June to August 1995 ($P<0.001$) (Table 3.3, Figure 3.4). There were significantly fewer touches in the plots receiving 180 g a.e. of glyphosate when compared to all other treatments. The interaction between herbicide x month of sampling was also significant ($P<0.05$) (Table 3.3). Herbicide significantly reduced mean cover abundance within the 180g a.e. glyphosate plots in June, July and August (Contrast analysis $F_{1,36}$=26.15, P<0.001) when compared to the zero application rate. Vegetation cover abundance was also reduced by herbicide applications of 45 and 90 g in July, but this was only significant for the lower rate (Contrast analysis $F_{1,36}$=8.32, P<0.05). By August, vegetation cover abundance was not significantly different between the zero, 45 and 90g treatments (Figure 3.4). There was no significant interaction between fertiliser and herbicide.

December 1995

There were no significant effects of treatments on the total cover abundance at the December 1995 assessment.

March 1996

Similarly there were no significant treatment effects on the total number of touches in March 1996.

April - May 1996

There was a significant difference between the two dates (P<0.001) (Table 3.4), with touches increasing significantly from April to May (Figure 3.2). The effect of fertiliser was significant (P<0.001) (Table 3.4), with the total number of pin touches increasing with increasing fertiliser rate (Figure 3.5). There was a significant fertiliser x month of sampling interaction (P<0.001) (Table 3.4). Contrast analysis showed that the total number of touches increased significantly with the addition of fertiliser in May when compared to the unfertilised plots ($F_{1,36}$=28.83,P<0.001), and that there were significantly more touches at the 200 kg rate compared to the 50 kg rate of N ($F_{1,36}$=15.18,P<0.001) (Figure 3.5).

June - August 1996

There was a significant month of sampling effect ($P<0.001$) (Table 3.5), with total touches declining over time from June to August (Figure 3.2). Fertiliser had no significant effect on the total number of touches over this period. There was a significant herbicide effect ($P<0.001$) (Table 3.5), with total.touches declining significantly with increasing herbicide rate (Figure 3.6). There was a significant interaction between herbicide and month of sampling ($P<0.001$) (Table 3.5). During June, total number of touches was significantly reduced for herbicide treated plots when compared to untreated plots across all levels of fertiliser (Contrast analysis $F_{1,36}=41.75, P<0.001$) (Figure 3.6). Total number of touches was also reduced for the 90 and 180 g rates compared to the 45 g rate (Contrast analysis $F_{1,36}=17.83$, $P<0.01$)) (Figure 3.6). In July there were significantly fewer touches in plots receiving the 180 g rate when compared to the zero rate, across all levels of fertiliser (Contrast analysis $F_{1,36}=4.18$, $P<0.05$) (Figure 3.6). There was a significant month of sampling x fertiliser x herbicide interaction ($P<0.05$) (Table 3.5). During June, there was significantly greater total cover abundance in fertilised plots at the zero level of herbicide compared to other treatments, but in July and August this was not significant.

Table 3.2 ANOVA for total touches April - May 1995.

		Total Touches	
Source	df	F value	Probability
Fertiliser (F)	2	0.06	n.s.
Month (M)	1	278.36	P<0.001
M x F	2	0.01	n.s.
Error	45		

Table 3.3 Repeated measures ANOVA for total touches June - August 1995.

			Total Touches	
Source	df	F value	Probability	Wilks' lambda
Fertiliser (F)	2	20.50	P<0.001	-
Herbicide (H)	3	10.25	P<0.001	-
F x H	6	1.97	n.s.	-
Error	36			
Month (M)	2	454.96	P<0.001	0.4
M x F	6	2.58	P<0.05	.076
M x H	6	2.86	P<0.05	0.65
M x F x H	12	0.86	n.s.	0.76
Error	72			

Table 3.4 ANOVA for total touches April - May 1996.

		Total Touches	
Source	df	F value	Probability
Fertiliser (F)	2	24.28	P<0.001
Herbicide (H)	3	2.51	n.s.
F x H	6	1.94	n.s.
Error	36		
Month (M)	1	651.68	P<0.001
M x F	2	13.52	P<0.001
M x H	3	1.62	n.s.
M x F x H	6	0.68	n.s.
Error	36		

Table 3.5 Repeated measures ANOVA for total touches June - August 1996.

		Total Touches		
Source	df	F value	Probability	Wilks' lambda
Fertiliser (F)	2	0.20	n.s.	-
Herbicide (H)	3	10.36	P<0.001	-
F x H	6	1.65	n.s.	-
Error	36			
Month (M)	2	232.76	P<0.001	0.07
M x F	6	0.81	n.s.	0.91
M x H	6	6.49	P<0.001	0.41
M x F x H	12	1.97	P<0.05	0.56
Error	72			

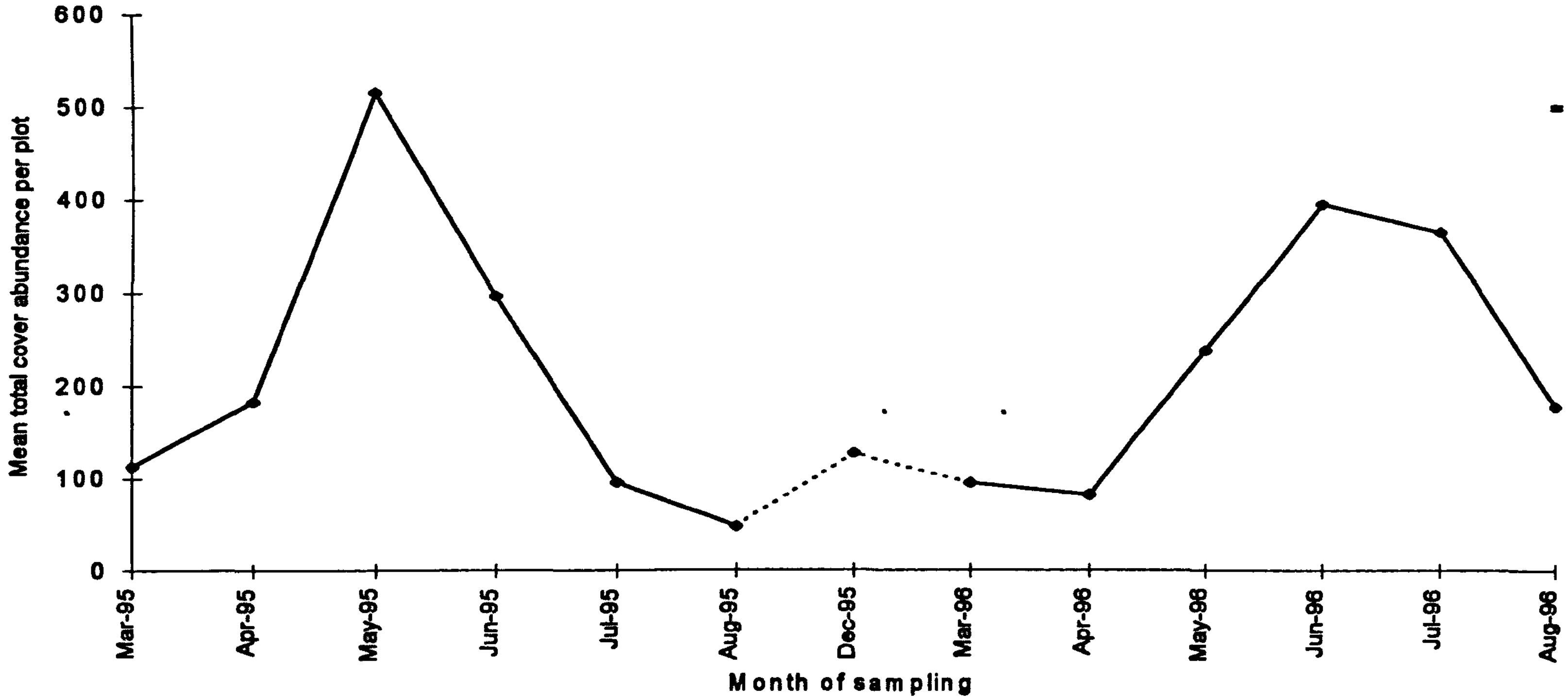


Figure 3.2 **Mean total cover abundance per plot from March 1995 to August 1996 (mean across all treatments). Vertical bar represents SE.**

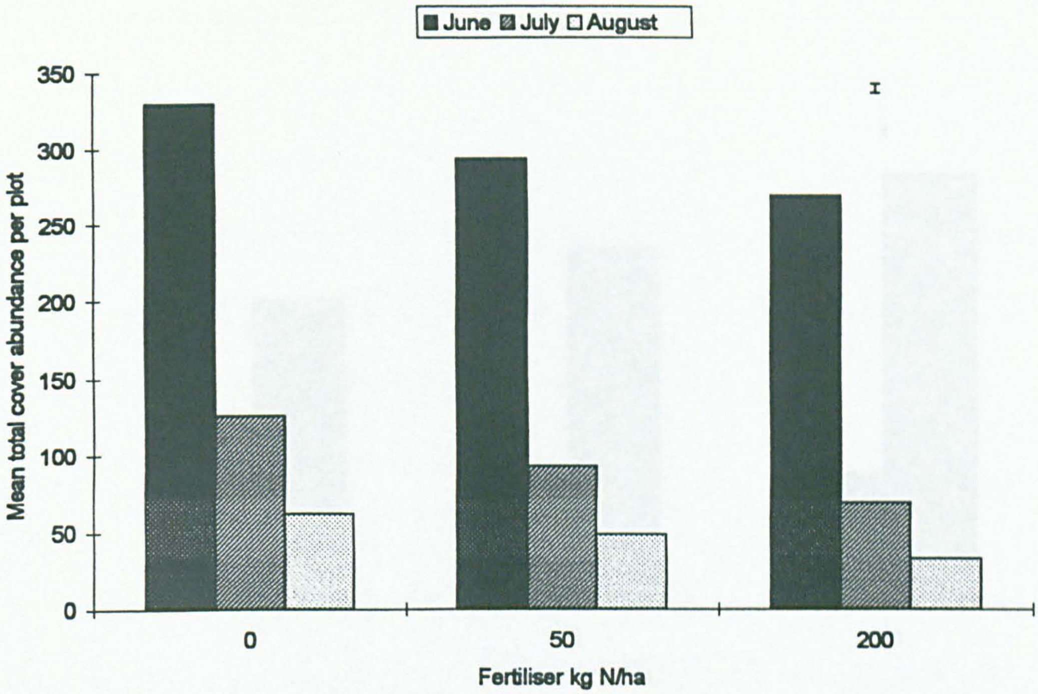


Figure 3.3 The effects of different fertiliser levels (averaged over herbicide levels) x month of sampling on mean total cover abundance per plot from June to August 1995. Vertical bar represents SE for interaction.

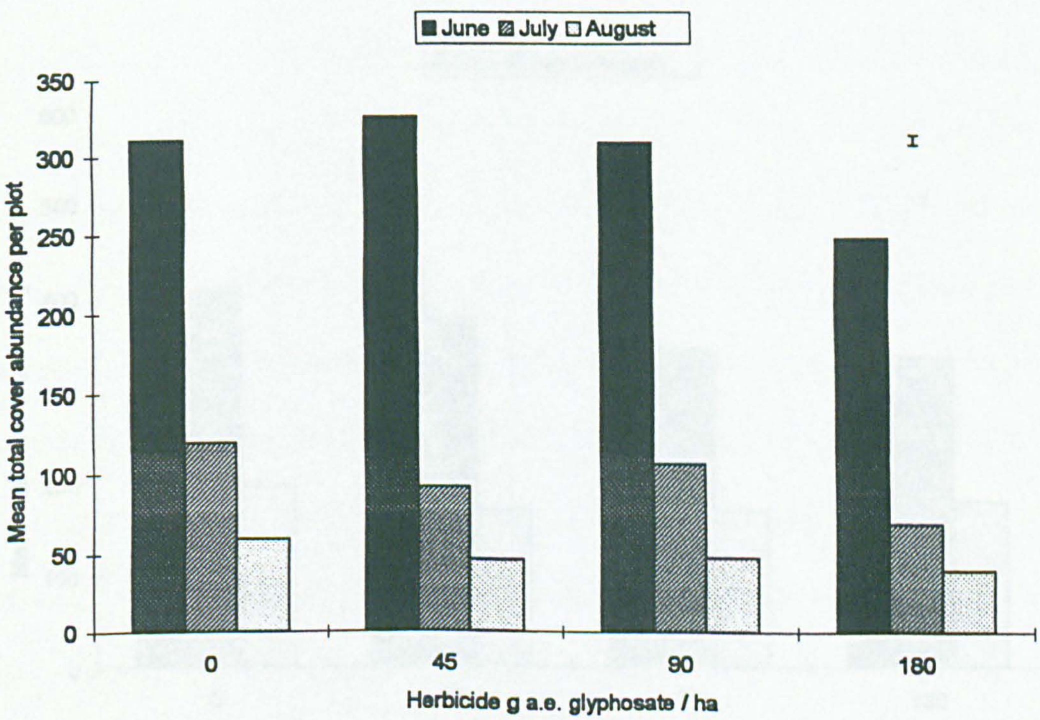


Figure 3.4 The effects of different herbicide levels (averaged over fertiliser levels) x month of sampling on mean total cover abundance per plot from June to August 1995. Vertical bar represents SE for interaction.

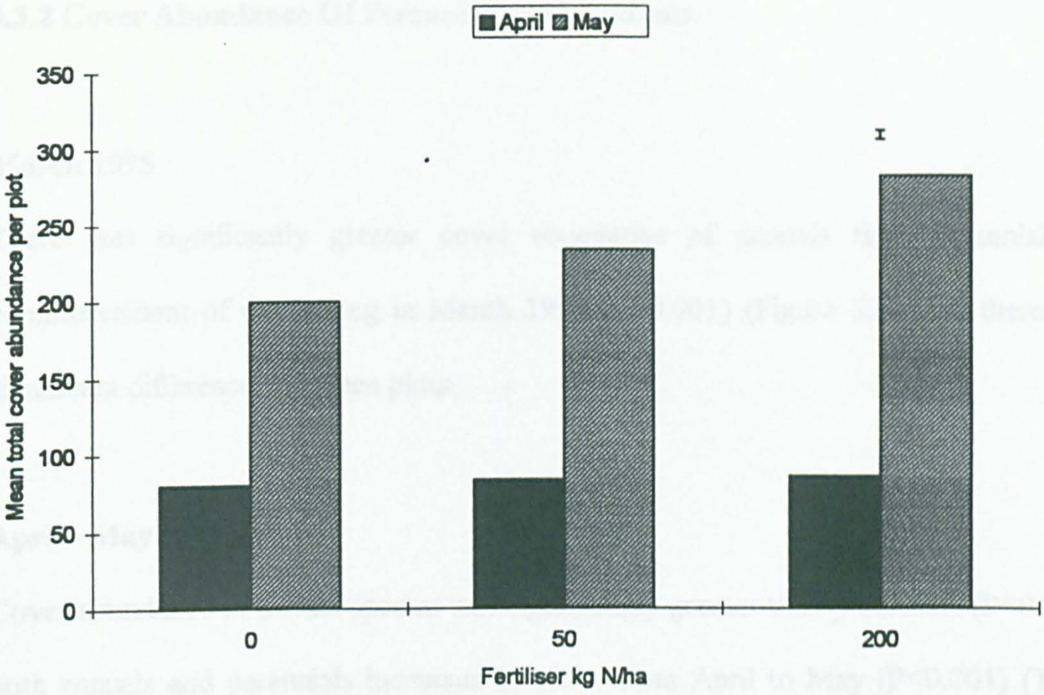


Figure 3.5 The effects of different fertiliser levels (averaged over herbicide levels) x month of sampling on mean total cover abundance per plot from April to May 1996. Vertical bar represents SE for interaction.

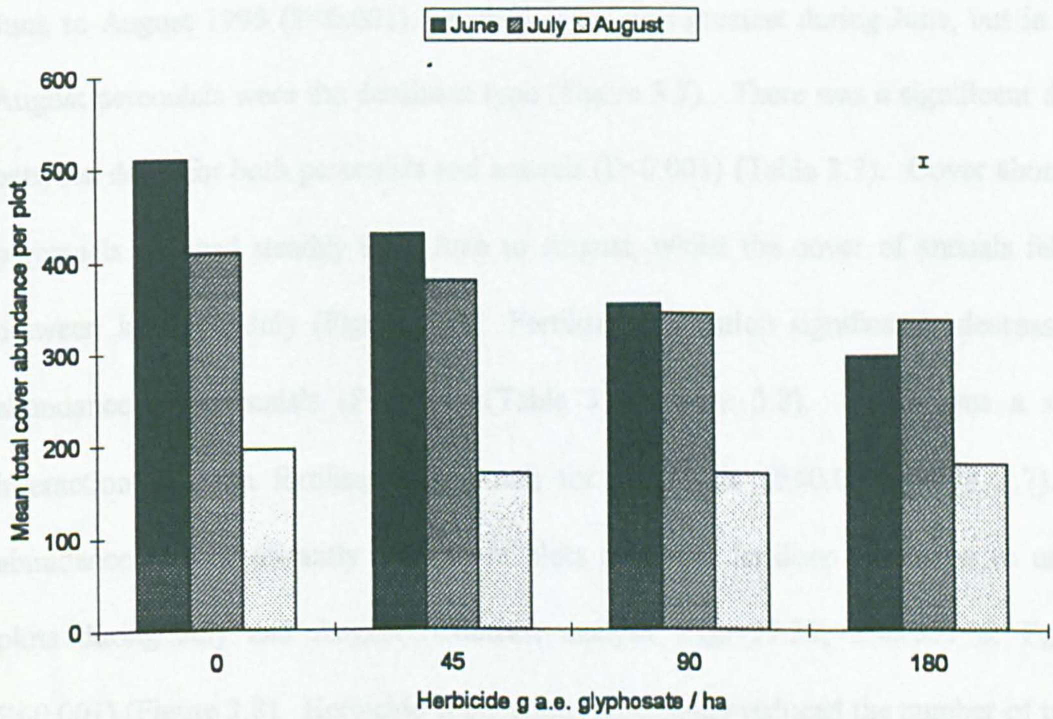


Figure 3.6 The effects of different herbicide levels (averaged over fertiliser levels) x month of sampling on mean total cover abundance per plot from June to August 1996. Vertical bar represents SE for interaction.

3.3.2 Cover Abundance Of Perennials And Annuals

March 1995

There was significantly greater cover abundance of annuals than perennials at the commencement of monitoring in March 1995 ($P<0.001$) (Figure 3.7), but there were no significant differences between plots.

April - May 1995

Cover abundance of annual species was significantly greater than perennials ($P<0.001$), and both annuals and perennials increased in cover from April to May ($P<0.001$) (Table 3.6, Figure 3.7).

June - August 1995

There were significant differences in the cover abundance of annuals and perennials from June to August 1995 ($P<0.001$). Annual cover was greatest during June, but in July and August perennials were the dominant type (Figure 3.7). There was a significant difference between dates for both perennials and annuals ($P<0.001$) (Table 3.7). Cover abundance of perennials declined steadily from June to August, whilst the cover of annuals fell sharply between June and July (Figure 3.7). Fertiliser application significantly decreased cover abundance of perennials ($P<0.001$) (Table 3.7, Figure 3.8). There was a significant interaction between fertiliser and month for perennials ($P<0.05$) (Table 3.7). Cover abundance was significantly reduced in plots receiving fertiliser compared to unfertilised plots during July and August (Contrast analysis $F_{1,36}=37.37$, $P<0.001$ & $F_{1,36}=27.07$, $P<0.001$) (Figure 3.8). Herbicide application significantly reduced the number of touches of perennials at the 45 and 180 g rates compared to the zero and 90 g rates ($P<0.001$) (Table

3.7, Figure 3.9). Cover abundance of annuals was significantly decreased at the 180 g rate of glyphosate compared with the 45 and 90 g rates ($P<0.05$) (Table 3.7, Figure 3.10).

December 1995

There were no significant differences between the cover abundance of annuals and perennials. There were no significant differences between treatments for the cover abundance of annuals and perennials.

March 1996

Perennial species had a greater cover abundance than annuals ($P<0.001$) (Figure 3.7). There were no significant differences between treatments.

April - May 1996

There were significantly more perennials than annuals ($P<0.001$) (Figure 3.7). Cover abundance increased significantly for both perennials and annuals between April and May ($P<0.001$) (Table 3.8, Figure 3.7). Fertiliser application significantly increased cover abundance of perennials ($P<0.001$) (Table 3.8, Figure 3.11). There was a significant interaction between fertiliser and month of sampling ($P<0.001$) (Table 3.8). Contrast analysis showed that during May, cover abundance of perennials was significantly greater in plots which had received 200 kg N compared to those which had received none or only 50 kg N ($F_{1,36}=27.43$, $P<0.001$) (Figure 3.11). There was a significant fertiliser x herbicide interaction for annual cover ($P<0.05$) (Table 3.8). At the zero level of herbicide there were significantly more touches of annuals at the 50 kg rate of fertiliser compared to plots where no fertiliser had been applied. In plots which had received 45 g glyphosate the previous June, there were significantly more touches at the 50 kg rate of N, whilst for those which had had 90 g herbicide, the greatest cover abundance occurred at the zero level of fertiliser

(Figure 3.12). At the 180 g rate of herbicide there were no significant differences between fertiliser rates, though fertilised plots did have a greater cover abundance of annuals than unfertilised ones.

June - August 1996

There were significantly more perennials than annuals from June to August 1996 ($P<0.001$) (Figure 3.7). There was a significant difference between the cover abundance of perennials and annuals from June to August ($P<0.001$) (Table 3.9). The cover of perennials declined form June to August, whilst the cover of annuals remained constant from June to July before declining in August (Figure 3.7). Herbicide application significantly reduced the cover abundance of perennials ($P<0.001$) (Table 3.9, Figure 3.13). There was a significant interaction between herbicide and month of sampling for perennials ($P<0.001$) (Table 3.9). Contrast analysis showed that during June, cover abundance was significantly reduced by herbicide application ($F_{1,36}=32.90$, $P<0.001$), and that there was a significant difference between the 180 g rate of herbicide and the zero, 45 and 90 g rates ($F_{1,36}=40.97$, $P<0.001$). During July, herbicide application significantly reduced cover abundance in the 90 and 180 g rates of herbicide compared to the zero rate, and cover abundance was also significantly lower in the 180 g rate than in the 45 g rate ($F_{1,36}=15.79$, $P<0.05$), whilst in August the number of touches was significantly reduced at the 180 g rate of herbicide compared to untreated plots ($F_{1,36}=9.36$, $P<0.05$) (Figure 3.13).

Table 3.6 ANOVA for perennials and annuals form April to May 1995.

		Perennials		Annuals	
Source	df	F value	Probability	F value	Probability
Fertiliser (F)	2	0.48	n.s.	0.26	n.s.
Month (M)	1	85.24	<0.001	215.57	<0.001
M x F	2	1.21	n.s.	0.18	n.s.
Error	45				

Table 3.7 Repeated measures ANOVA for perennials and annuals June - August 1995.

		Perennials			Annuals		
Source	df	F value	Probability	Wilks' lambda	F value	Probability	Wilks' lambda
Fertiliser (F)	2	17.91	<0.001	-	2.74	n.s.	-
Herbicide (H)	3	7.95	<0.001	-	3.82	<0.05	-
F x H	6	1.43	n.s.	-	1.20	n.s.	-
Error	36						
Month (M)	2	124.06	<0.001	0.12	268.89	<0.001	0.06
M x F	6	3.02	<0.05	0.73	1.31	n.s.	0.87
M x H	6	1.65	n.s.	0.77	1.81	n.s.	0.75
M x F x H	12	0.80	n.s.	0.77	1.60	n.s.	0.62
Error	72						

Table 3.8 ANOVA for perennials and annuals April - May 1996.

		Perennials		Annuals	
Source	df	F value	Probability	F value	Probability
Fertiliser (F)	2	10.66	P<0.001	0.68	n.s.
Herbicide (H)	3	1.41	n.s.	0.25	n.s.
F x H	6	0.58	n.s.	2.82	P<0.05
Error	36				
Month (M)	1	432.06	P<0.001	28.14	P<0.001
M x F	2	15.03	P<0.001	0.18	n.s.
M x H	3	1.33	n.s.	0.24	n.s.
M x F x H	6	0.16	n.s.	1.17	n.s.
Error	36				

Table 3.9 Repeated measures ANOVA for perennials and annuals June - August 1996.

		Perennials			Annuals		
Source	df	F value	Probability	Wilks' lambda	F value	Probability	Wilks' lambda
Fertiliser (F)	2	2.27	n.s.	-	3.03	n.s.	-
Herbicide (H)	3	22.49	P<0.001	-	1.36	n.s.	-
F x H	6	0.40	n.s.	-	2.04	n.s.	-
Error	36						
Month (M)	2	77.59	P<0.001	0.18	65.85	P<0.001	0.21
M x F	6	1.02	n.s.	0.89	1.03	n.s.	0.89
M x H	6	4.61	P<0.001	0.51	1.42	n.s.	0.79
M x F x H	12	0.92	n.s.	0.75	1.14	n.s.	0.70
Error	72						

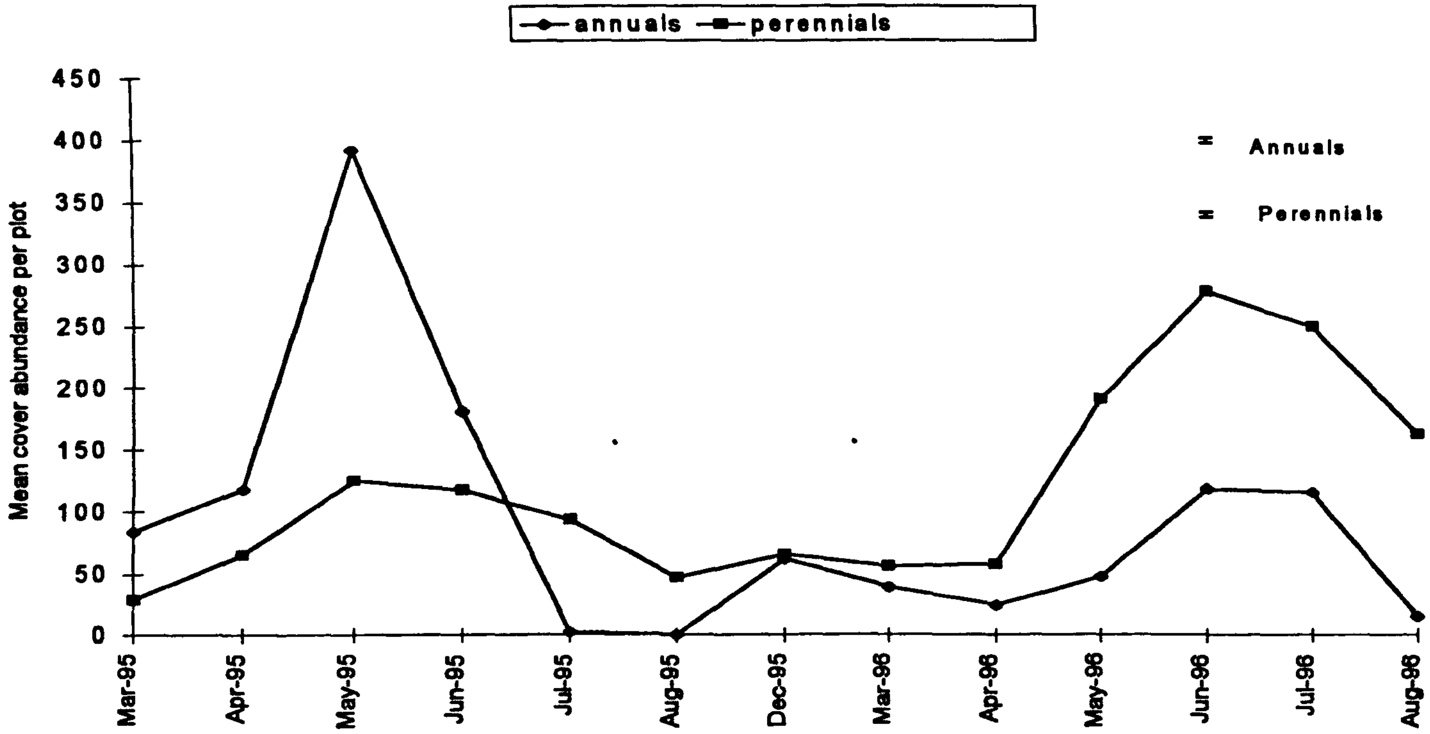


Figure 3.7 Mean cover abundance of perennials and annuals per plot from March 1995 to August 1996 (mean across all treatments). Vertical bars represent SE's.

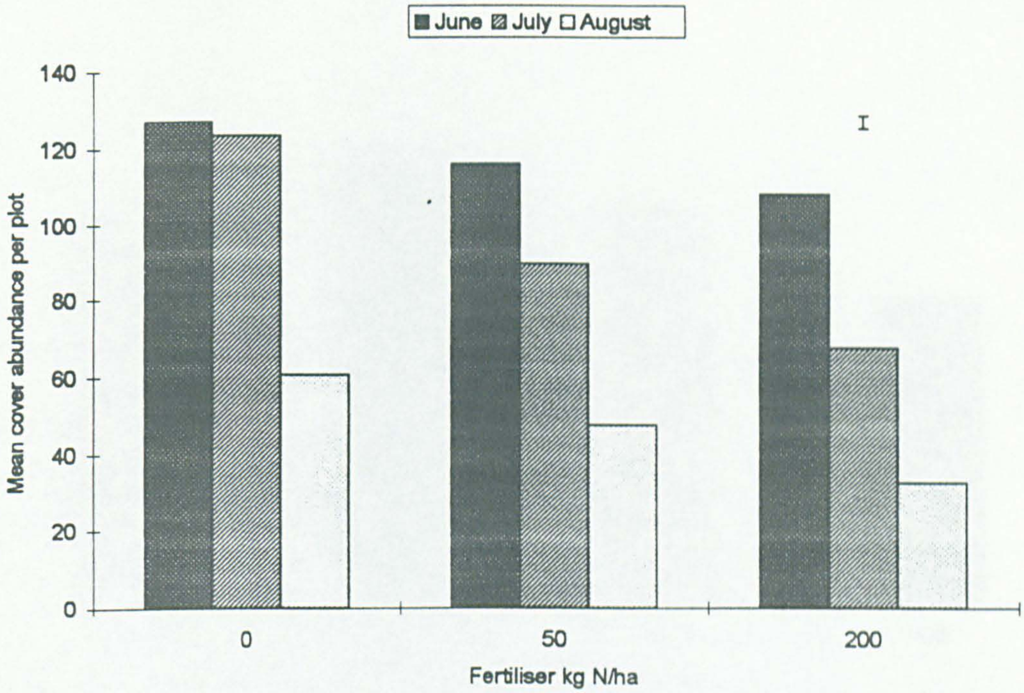


Figure 3.8 The effects of different fertiliser levels (averaged over herbicide levels) month of sampling on the mean cover abundance of perennials per plot from June August 1995. Vertical bar represents SE for interaction.

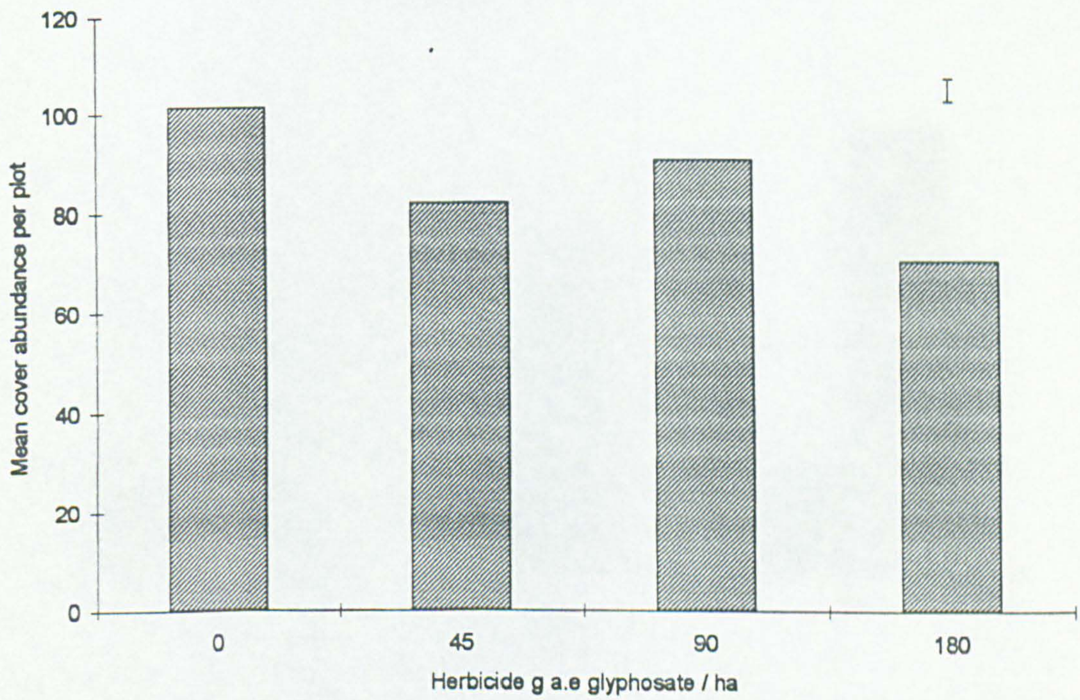


Figure 3.9 The effects of different herbicide levels (averaged over fertiliser level on the mean cover abundance of perennials per plot from June to August 199 Vertical bar represents SE

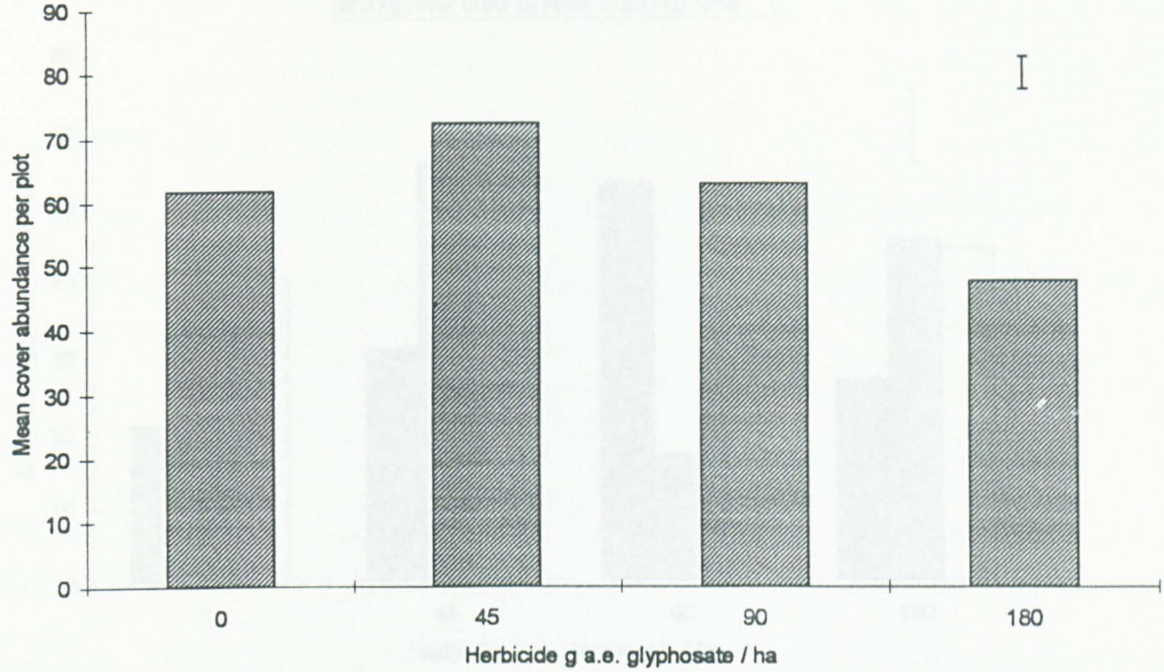


Figure 3.10 The effects of different herbicide levels (averaged over fertiliser levels) on the mean cover abundance of annuals per plot from June to August 1995. Vertical bar represents SE

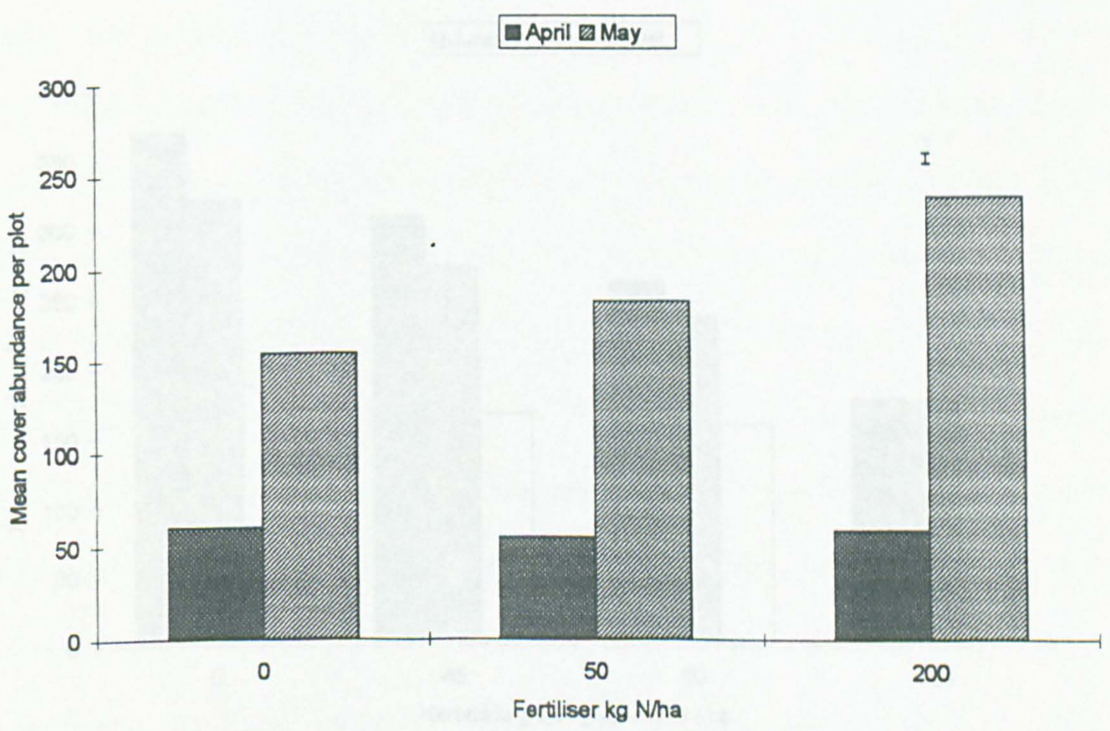


Figure 3.11 The effects of different fertiliser levels (averaged over herbicide levels) x month of sampling on the mean cover abundance of perennials per plot from April to May 1996. Vertical bar represents SE for interaction.

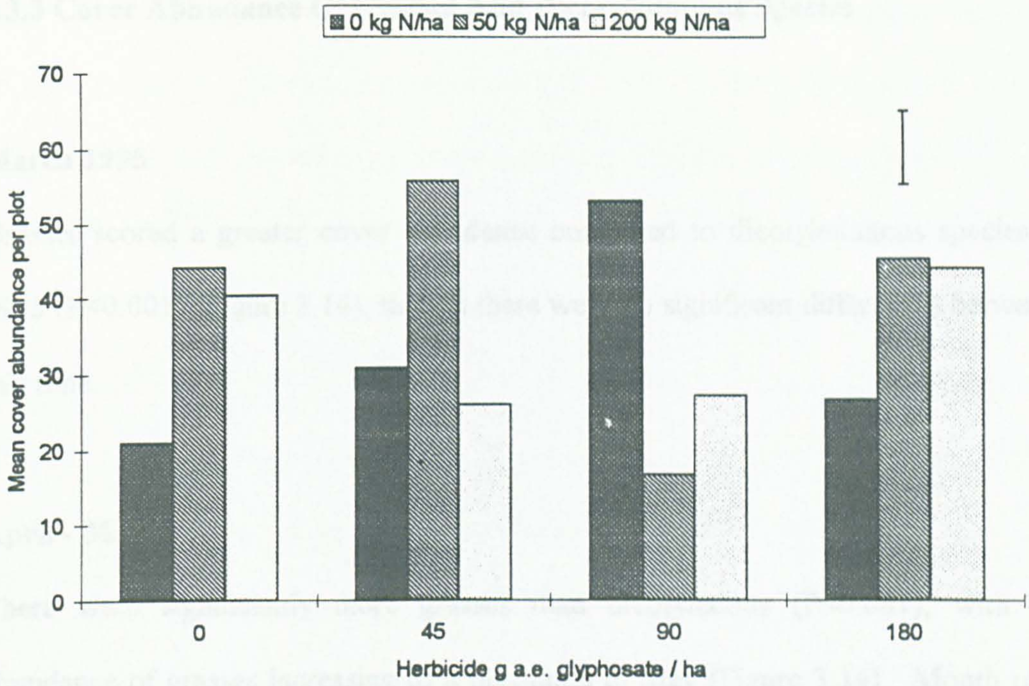


Figure 3.12 The effects of different fertiliser and herbicide levels on the mean cover abundance of annuals per plot from April to May 1996. Vertical bar represents SE for interaction.

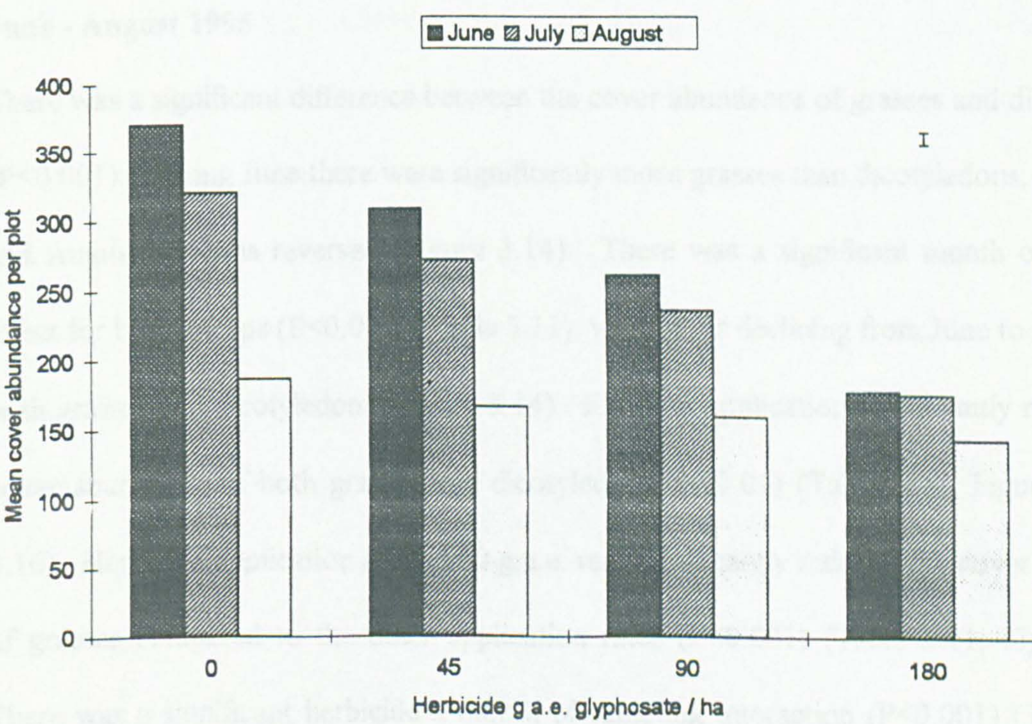


Figure 3.13 The effects of different herbicide levels (averaged over fertiliser levels) x month of sampling on the mean cover abundance of perennials per plot from June to August 1996. Vertical bar represents SE for interaction.

3.3.3 Cover Abundance Of Grasses And Dicotyledonous Species

March 1995

Grasses scored a greater cover abundance compared to dicotyledonous species in March 1995 ($P<0.001$) (Figure 3.14), though there were no significant differences between plots at this time.

April - May 1995

There were significantly more grasses than dicotyledons ($P<0.001$), with the cover abundance of grasses increasing to a maximum in May (Figure 3.14). Month of sampling had a significant effect ($P<0.001$) (Table 3.10), with cover abundance increasing from April to May (Figure 3.14). Fertiliser application had no significant effect on cover abundance of either grasses or dicotyledons.

June - August 1995

There was a significant difference between the cover abundance of grasses and dicotyledons ($P<0.001$). During June there were significantly more grasses than dicotyledons, but in July and August this was reversed (Figure 3.14). There was a significant month of sampling effect for both groups ($P<0.001$) (Table 3.11), with cover declining from June to August for both grasses and dicotyledons (Figure 3.14). Fertiliser application significantly reduced the cover abundance of both grasses and dicotyledons ($P<0.01$) (Table 3.11, Figures 3.15 & 3.16). Herbicide application at the 180 g a.e. rate significantly reduced the cover abundance of grasses compared to the other application rates ($P<0.001$) (Table 3.11, Figure 3.17). There was a significant herbicide x month of sampling interaction ($P<0.001$) (Table 3.11) for grasses. Contrast analysis revealed that in June there were significantly fewer touches in the 180 g plots compared to all other levels of herbicide rate ($F_{1,36}=15.63$, $P<0.01$) (Figure

3.17). During July plots receiving no herbicide had significantly greater cover abundance of grasses compared to herbicide treated plots ($F_{1,36}=22.29$, $P<0.001$) (Figure 3.17), whilst in August there were significantly more grasses on herbicide untreated plots compared to those which had received the 180 g rate ($F_{1,36}=10.32$, $P<0.05$) (Figure 3.17).

December 1995

There were once again significantly more grasses than dicotyledons ($P<0.001$) (Figure 3.14). There were significantly more dicotyledons recorded in plots which had received 180 g a.e. of glyphosate ($P<0.05$) (Table 3.12, Figure 3.18).

March 1996

Grasses were significantly more abundant than dicotyledons ($P<0.001$). There was a significant fertiliser x herbicide interaction for both grasses and dicotyledons ($P<0.05$) (Table 3.13). For grasses, there was a significant decrease in cover abundance at the 50 and 200 kg rates of N in plots receiving 45 g a.e. glyphosate (Figure 3.19). At the zero and 180 g rates of glyphosate, fertiliser application increased cover abundance, whilst at the 90 g rate of glyphosate increasing fertiliser application decreased cover abundance, though none of these differences were significant. Dicotyledonous species showed a significant decrease in cover abundance in response to increasing fertiliser application where no herbicide had been applied (Figure 3.20). A similar response was shown at the 180 g level of glyphosate, though differences were not significant. At the 45 g rate of herbicide, cover abundance was significantly increased at the 200 kg rate of N, compared to the zero and 50 kg rates (Figure 3.20). Increasing fertiliser rate also increased cover abundance at the 90 g rate of herbicide, though not significantly.

April - May 1996

Grasses were significantly more abundant than dicotyledons from April to May 1996 ($P<0.001$) (Figure 3.14). Cover abundance of both grasses and dicotyledons increased significantly between April and May ($P<0.001$) (Table 3.14, Figure 3.14). Fertiliser application significantly increased cover abundance of grasses ($P<0.001$) (Table 3.14, Figure 3.21). There was a significant interaction between fertiliser and month of sampling. Contrast analysis showed that in May fertiliser application significantly increased cover abundance compared to the zero level of fertiliser ($F_{1,36}=13.78$, $P<0.01$) (Figure 3.21). There was also a significant increase in cover abundance at the 200 kg rate of N compared to the 50 kg rate ($F_{1,36}=11.94$, $P<0.01$) (Figure 3.21). There was a herbicide effect carried over from the previous year, where there were significantly more touches of dicotyledons recorded in plots which had received 180 g a.e. glyphosate ($P<0.05$) (Table 3.14, Figure 3.22). There was a significant fertiliser x herbicide interaction for grass species ($P<0.05$) (Table 3.14). At zero and 180 g rates of herbicide, fertiliser application significantly increased cover abundance, whilst at the 90 g rate of herbicide, cover was reduced at the 50 kg rate on nitrogen (Figure 3.23).

June - August 1996

Grasses were significantly more abundant than dicotyledons throughout this period ($P<0.001$) (Figure 3.14). There was a significant month of sampling effect for grasses and dicotyledons ($P<0.001$) (Table 3.15, Figure 3.14). Grasses were at their most abundant in June, and then started to die back, whilst dicotyledons peaked in July before declining in abundance during August. Fertiliser had no significant effect during this period. Herbicide application significantly reduced the cover abundance of grasses ($P<0.001$) (Table 3.15, Figure 3.24). There was also a significant herbicide x month of sampling interaction for grasses. Contrast analysis showed that during June herbicide application significantly reduced cover abundance compared to the zero rate of herbicide ($F_{1,36}$=32.95, P<0.001), and that cover abundance was significantly reduced at the 180 g rate compared to the 0, 45 and 90 g rates ($F_{1,36}$=31.04, P<0.001) (Figure 3.24). During July, cover abundance was significantly reduced at the 180 g rate compared to the zero or 45 g rates ($F_{1,36}$=12.26, P<0.01 & $F_{1,36}$=8.57, P<0.05) (Figure 3.24). During August cover abundance was significantly reduced at the 180 g rate of herbicide compared to the zero level ($F_{1,36}$=8.21, P<0.05). There was a significant interaction between fertiliser, herbicide and month for grasses (P<0.01) (Table 3.15). During June, there was a greater cover abundance of grasses in plots which had received fertiliser but no herbicide, but by July and August there were no significant differences between treatments.

Table 3.10 ANOVA for grasses and dicotyledonous species April - May 1995.

		Grasses		Dicotyledonous Species	
Source	df	F value	Probability	F value	Probability
Fertiliser (F)	2	0.22	n.s.	1.09	n.s.
Month (M)	1	230.69	P<0.001	68.01	P<0.001
M x F	2	0.08	n.s.	0.79	n.s.
Error	45				

Table 3.11 Repeated measures ANOVA for grasses and dicotyledonous species June - August 1995.

		Grasses			Dicotyledonous Species		
Source	df	F value	Probability	Wilks' lambda	F value	Probability	Wilks' lambda
Fertiliser (F)	2	8.22	P<0.01	-	6.64	P<0.01	-
Herbicide (H)	3	11.27	P<0.001	-	0.04	n.s.	-
F x H	6	2.14	n.s.	-	0.98	n.s.	-
Error	36						
Month (M)	2	316.12	P<0.001	0.05	86.80	P<0.001	0.17
M x F	6	1.76	n.s.	0.83	1.72	n.s.	0.83
M x H	6	5.07	P<0.001	0.49	1.14	n.s.	0.83
M x F x H	12	0.99	n.s.	0.73	0.74	n.s.	0.79
Error	72						

Table 3.12 ANOVA for grasses and dicotyledonous species December 1995.

		Grasses		Dicotyledonous Species	
Source	df	F value	Probability	F value	Probability
Fertiliser (F)	2	0.16	n.s.	0.20	n.s.
Herbicide (H)	3	1.57	n.s.	3.60	P<0.05
F x H	6	1.71	n.s.	0.75	n.s.
Error	36				

Table 3.13 ANOVA for grasses and dicotyledonous species March 1996.

		Grasses		Dicotyledonous Species	
Source	df	F value	Probability	F value	Probability
Fertiliser (F)	2	0.13	n.s.	0.40	n.s.
Herbicide (H)	3	0.64	n.s.	2.83	n.s.
F x H	6	2.76	P<0.05	3.20	P<0.05
Error	36				

Table 3.14 ANOVA for grasses and dicotyledonous species April - May 1996.

		Grasses		Dicotyledonous Species	
Source	df	F value	Probability	F value	Probability
Fertiliser (F)	2	11.25	P<0.001	2.03	n.s.
Herbicide (H)	3	1.27	n.s.	3.44	P<0.05
F x H	6	3.24	P<0.05	1.31	n.s.
Error	36				
Month (M)	1	324.70	P<0.001	171.17	P<0.001
M x F	2	8.73	P<0.001	3.00	n.s.
M x H	3	0.57	n.s.	0.75	n.s.
M x F x H	6	1.23	n.s.	0.29	n.s.
Error	36				

Table 3.15 Repeated measures ANOVA for grasses and dicotyledonous species June - August 1996.

		Grasses			Dicotyledonous Species		
Source	df	F value	Probability	Wilks' lambda	F value	Probability	Wilks' lambda
Fertiliser (F)	2	0.24	n.s.	-	0.90	n.s.	-
Herbicide (H)	3	13.26	P<0.001	-	0.55	n.s.	-
F x H	6	1.59	n.s.	-	0.55	n.s.	-
Error	36						
Month (M)	2	172.07	P<0.001	0.09	45.43	P<0.001	0.27
M x F	6	1.92	n.s.	0.81	1.10	n.s.	0.89
M x H	6	4.34	P<0.001	0.53	2.15	n.s.	0.71
M x F x H	12	2.50	P<0.01	0.49	1.46	n.s.	0.64
Error	72						

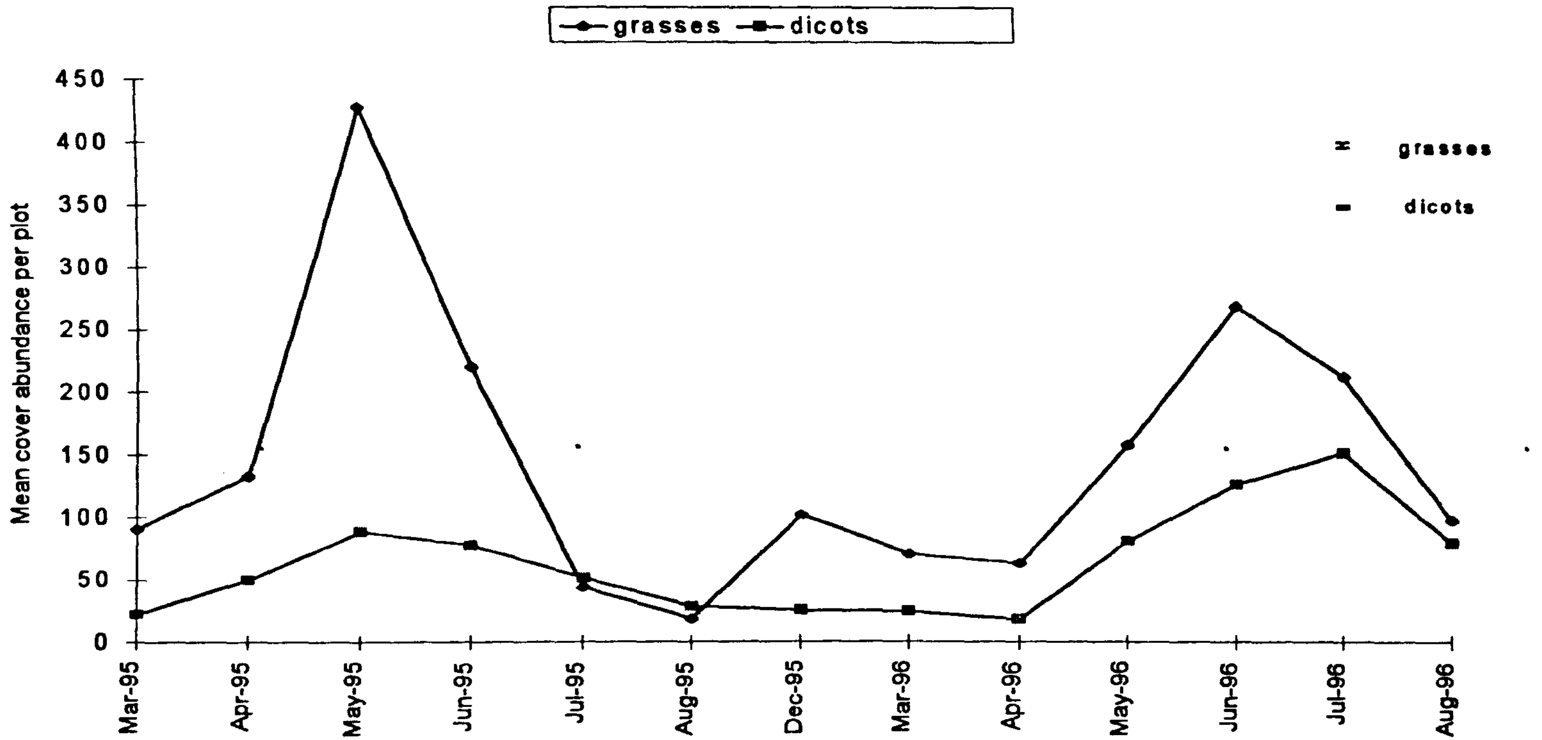


Figure 3.14 Mean cover abundance of grasses and dicotyledonous species per plot from March 1995 to August 1996 (mean across all treatments). Vertical bars represent SE's.

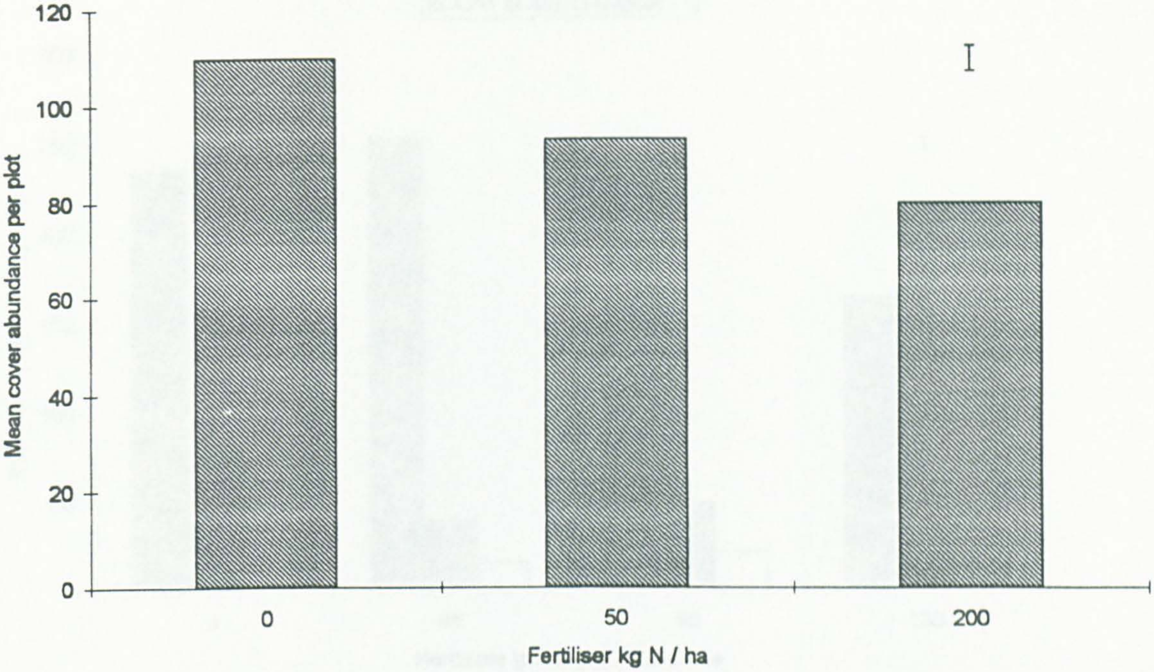


Figure 3.15 The effects of different fertiliser levels (averaged over herbicide levels) on the mean cover abundance of grasses per plot from June to August 1995. Vertical bar represents SE

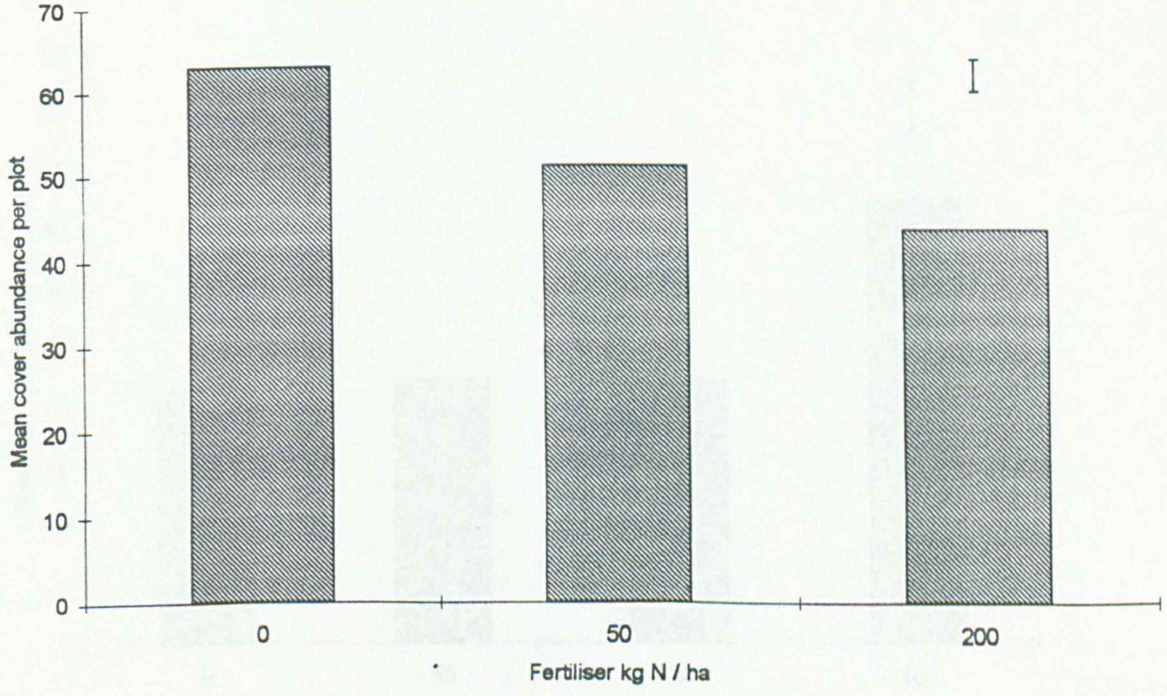


Figure 3.16 The effects of different fertiliser levels (averaged over herbicide levels) on the mean cover abundance of dicotyledonous species per plot from June to August 1995. Vertical bar represents SE.

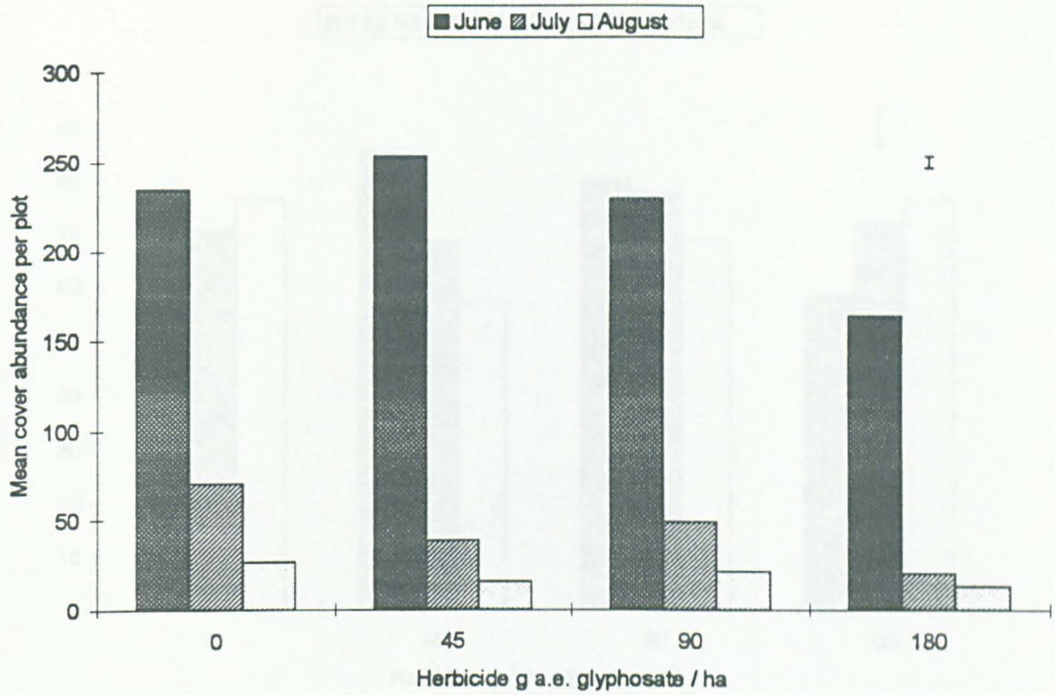


Figure 3.17 The effects of different herbicide levels (averaged over fertiliser levels) x month of sampling on the mean cover abundance of grasses per plot from June to August 1995. Vertical bar represents SE for interaction.

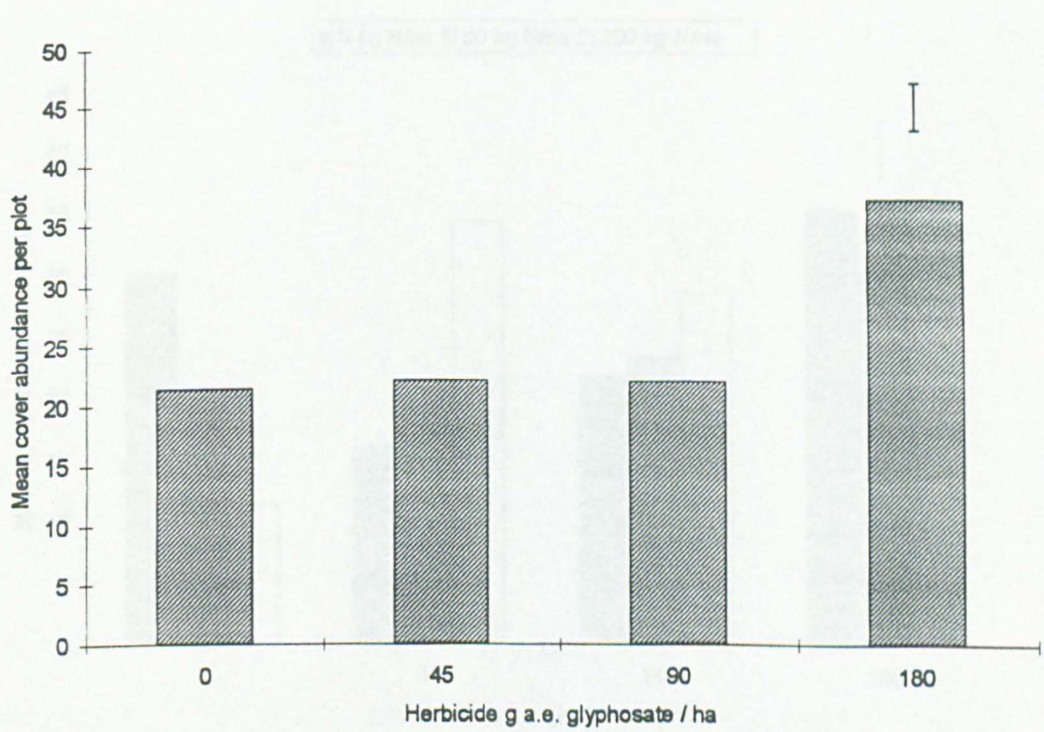


Figure 3.18 The effects of different herbicide levels (averaged over fertiliser levels) on the mean cover abundance of dicotyledonous species per plot in December 1995. Vertical bar represents SE.

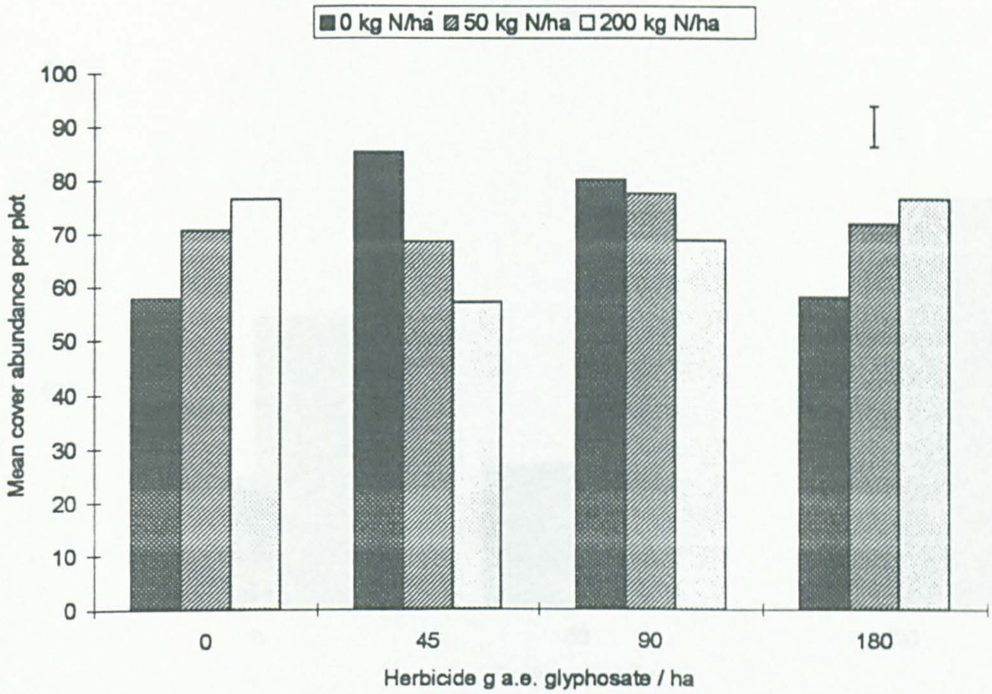


Figure 3.19 The effects of different fertiliser and herbicide levels on the mean cover abundance of grasses per plot in March 1996. Vertical bar represents SE for interaction.

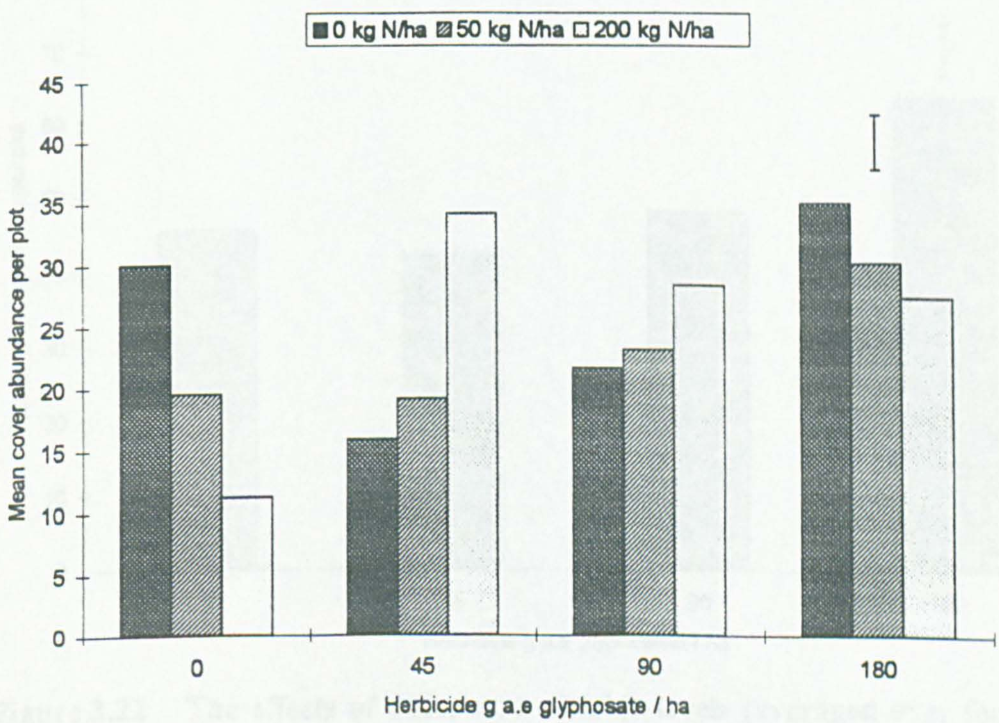


Figure 3.20 The effects of different fertiliser and herbicide levels on the mean cover abundance of dicotyledonous species per plot in March 1996. Vertical bar represents SE for interaction.

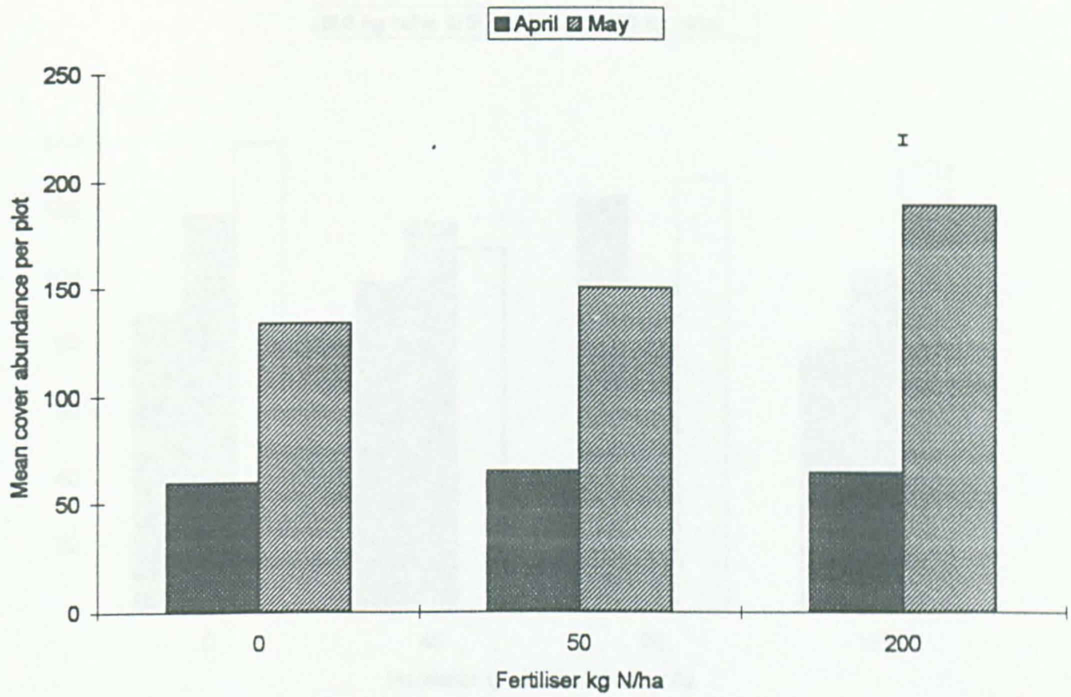


Figure 3.21 The effects of different fertiliser levels (averaged over herbicide levels) x month of sampling on the mean cover abundance of grasses per plot from April to May 1996. Vertical bar represents SE for interaction.

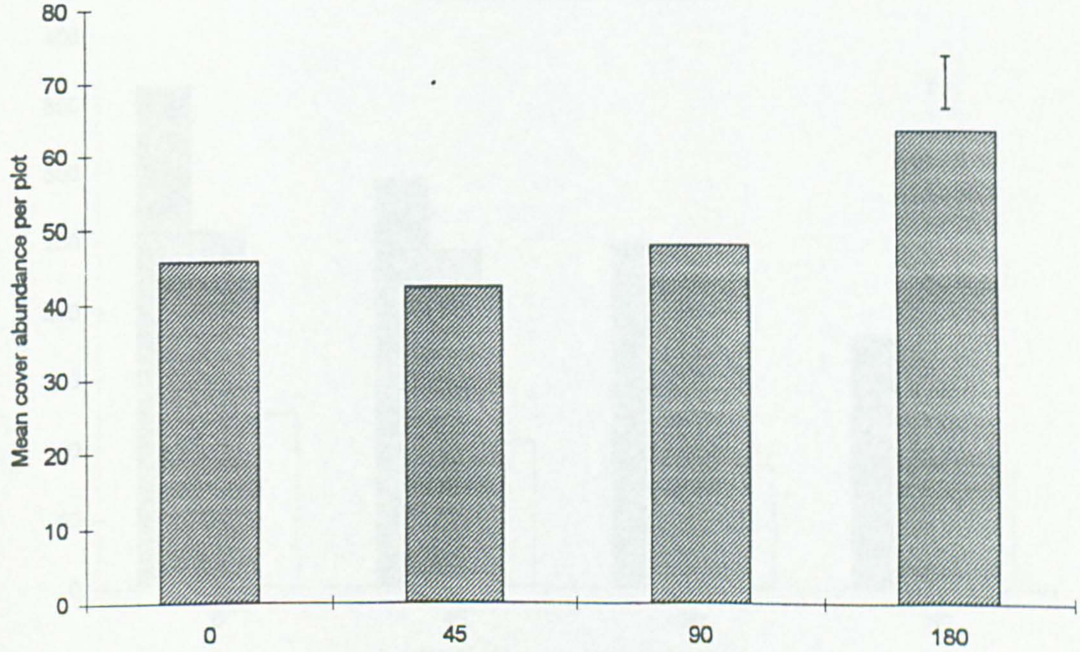


Figure 3.22 The effects of different herbicide levels (averaged over fertiliser levels) on the mean cover abundance of dicotyledonous species per plot from April to May 1996. Vertical bar represents SE.

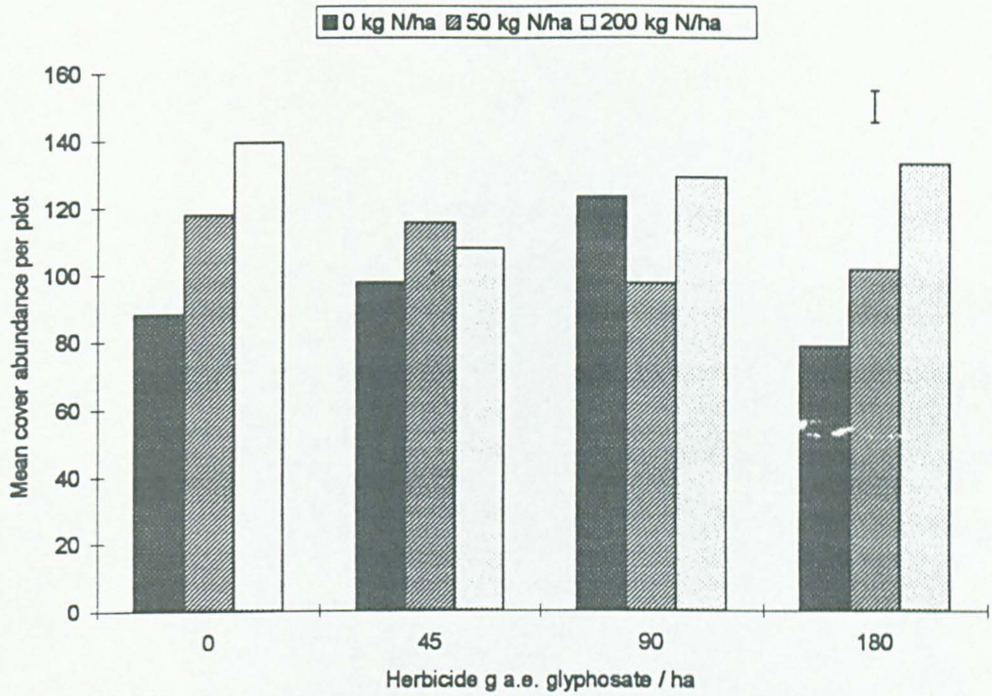


Figure 3.23 The effects of different fertiliser and herbicide levels on the mean cover abundance of grasses per plot from April to May 1996. Vertical bar represents SE for interaction.

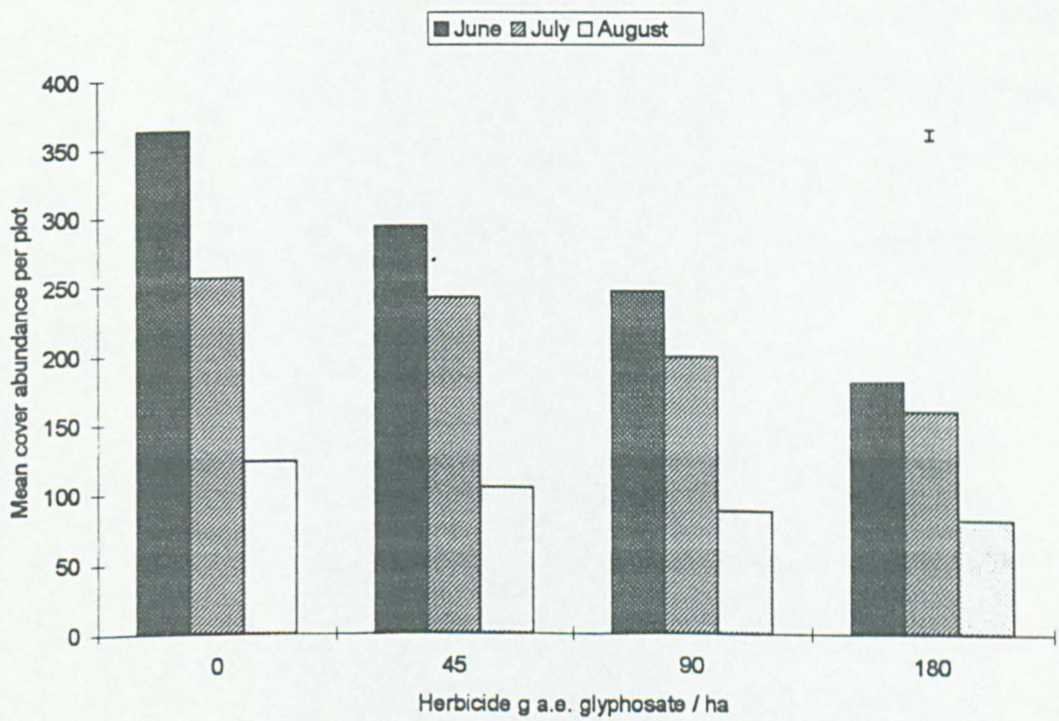


Figure 3.24 The effects of different herbicide levels (averaged over fertiliser levels) x month of sampling on the mean cover abundance of grasses per plot from June to August 1996. Vertical bar represents SE for interaction.

3.3.4 Cover Abundance Of Individual Sown Species

March 1995

At the initial assessment date in March 1995, prior to any fertiliser or herbicide application, there were no significant differences between plots. There was a significant difference between the numbers of each species which had established within the plots, with all plots containing significantly more *B. sterilis* and *S. latifolia* ($P<0.001$) than any of the other sown species (Figure 3.25).

April - May 1995

There was a significant difference between the cover abundance of each of the sown species ($P<0.001$), *B. sterilis* was the most abundant species, and accounted for 75% of all the touches recorded in May 1995 (Figure 3.25). The number of touches increased from April to May for all species (Figure 3.25 a-f) and there was a significant month of sampling effect for *A. elatius*, *B. sterilis*, *S. latifolia* ($P<0.001$) and *E. repens* ($P<0.01$) (Table 3.16). Application of fertiliser had no significant effect on the cover abundance of any single sown species in this period.

June - August 1995

B. sterilis was the dominant species during June (Figure 3.25c), but by July cover abundance had declined to almost zero. *S. latifolia* was the dominant species in July and August (Figure 3.25d). There was a significant month of sampling effect for all species ($P<0.001$) other than *G. aparine* which was only present in low amounts (Table 3.17). Touches generally declined for all species from June to August, apart from *E. repens*, which increased from June to July, and then decreased again in August (Figure 3.25a-f). Fertiliser application had a significant main effect only on *S. latifolia* ($P<0.01$) (Table 3.17). The number of touches declined with fertiliser dose, and there was a significant difference between the zero and 200 kg N rate ($P<0.01$)(Figure 3.26). Fertiliser x month of sampling was significant for *A. elatius* ($P<0.05$) (Table 3.17). Contrast analysis showed that mean *A. elatius* cover was significantly reduced in July by the addition of fertiliser ($F_{1,36}=9.63$, $P<0.05$) over all levels of herbicide when compared to unfertilised plots (Figure 3.27). Herbicide application had the greatest effect on grass species. There was a significant herbicide main effect on *A. elatius* ($P<0.001$) (Table 3.17), and cover was reduced with increasing glyphosate rate (Figure 3.28). Herbicide application also had a significant main effect on *E. repens* and *B. sterilis* ($P<0.05$) (Table 3.17), and cover was generally reduced with increasing herbicide dose. (Figures 3.29 & 3.30). There was a significant interaction between herbicide and month of sampling for *A. elatius* ($P<0.001$) (Table 3.17). During June and July, mean cover was significantly reduced for herbicide treated plots when compared to untreated plots across all levels of fertiliser (Contrast analysis $F_{1,36}=9.05$, $P<0.05$ & $F_{1,36}=19.92$, $P<0.01$) (Figure 3.28). There were no significant fertiliser x herbicide interactions.

December 1995

During December, *B. sterilis* was again the most frequently recorded species ($P<0.001$) (Figure 3.25c). Both fertiliser and herbicide formed a significant interaction on *R. repens* cover ($P<0.05$) (Table 3.18), however, very low numbers of *R. repens* were recorded. At the zero, 45 and 180 g rates of herbicide, the greatest number of touches were recorded at the zero fertiliser level, but at the 90 g rate of herbicide there were significantly more touches at the 50 kg N rate (Figure 3.31). Herbicide application had a significant effect on cover abundance of *G. aparine* ($P<0.05$) (Table 3.18). There were significantly more touches of *G. aparine* in plots receiving 180 g glyphosate (Figure 3.32), but only low numbers were recorded in all plots.

March 1996

B. sterilis was the most abundant species in March 1996 ($P<0.001$) (Figure 3.25c). The only significant treatment effect during March 1996 was a fertiliser x herbicide interaction for *S. latifolia* ($P<0.05$) and *R. repens* ($P<0.01$) (Table 3.19). For *S. latifolia*, at the zero herbicide rate, fertiliser had a negative effect on cover abundance, whilst at the 45 and 90 g rates of herbicide there were no significant fertiliser effects, but at the 180 g rate of herbicide, there were significantly more touches at the 50 kg rate of fertiliser (Figure 3.33). For *R. repens*, at the 90 g rate of herbicide, there were significantly more touches at the 200 kg rate of fertiliser compared to the zero rate, but at the 180 g rate of herbicide this was reversed (Figure 3.34).

April - May 1996

There was a significant difference between the cover abundance of the sown species during April and May ($P<0.001$). *A. elatius* was the most abundant species during these two months (Figure 3.25a), followed by *S. latifolia* (Figure 3.25d). There was a significant difference between the two months for *A. elatius*, *E. repens*, *S. latifolia*, *G. aparine* ($P<0.001$) and *R. repens* ($P<0.01$) (Table 3.20), with cover increasing for all species from April to May (Figure 3.25a-f). There were also significant fertiliser effects for *A. elatius* ($P<0.001$) and *G. aparine* ($P<0.05$) (Table 3.20), and plots receiving the 200 kg rate of nitrogen contained significantly more touches compared to the zero or 50 kg rate (Figures 3.35 & 3.36). There was a significant fertiliser x month of sampling interaction for *A. elatius* ($P<0.001$) (Table 3.20). Mean cover was significantly increased on plots receiving 200 kg N compared to the zero or 50 kg rate in May (Contrast analysis $F_{1,36}=34.18$, P<0.001) (Figure 3.35). There was a significant fertiliser x month of sampling interaction for *G. aparine*, with significantly more touches being recorded in the 200 kg N plots compared to the zero plots ($F_{1,36}$=7.58, P<0.05) during May (Figure 3.36). There was also a significant interaction between fertiliser and month of sampling for *B. sterilis* (P<0.05) (Table 3.20). Contrast analysis showed that there were significantly fewer touches in the zero fertiliser treatments compared to the 50 kg treatments in April ($F_{1,36}$=6.32, P<0.05), whilst in May there were significantly fewer touches in the 200 kg N plots compared to the zero and 50 rates ($F_{1,36}$=7.13, P<0.05) (Figure 3.37). There were significant herbicide effects for *E. repens* (P<0.01) and *R. repens* (P<0.05) (Table 3.20), though no herbicide had been applied since June 1995. For *E. repens* there were significantly fewer touches at the 45 and 180 g rates compared to the zero rate, whilst for *R. repens* there were significantly fewer touches at the 45 g rate compared to the zero or 180 g rates, though only low numbers were recorded in all treatments.

June - August 1996

There was a significant difference between the cover abundance of the sown species (P<0.001). During June, *A. elatius* was the most abundantly recorded species (Figure 3.25a), followed by *B. sterilis* and *S. latifolia* (Figures 3.25c,d). However, during July and August, cover of *A. elatius* and *B. sterilis* declined, and *S. latifolia* became the dominant species (Figure 3.25d). There was a significant month of sampling effect for all species (P<0.001 *A. elatius*, *B. sterilis*, *S. latifolia*, *R. repens*, *G. aparine*; P<0.01 *E. repens*) (Table 3.21). Cover generally declined with time for all species (Figure 3.25 a-f). Fertiliser had a significant effect on *G. aparine* (P<0.05) (Table 3.21), with cover increasing significantly in plots receiving 200 kg N (Figure 3.38). There was a significant interaction between fertiliser and month for *S. latifolia* (P<0.05) (Table 3.21). Contrast analysis showed that cover was increased significantly at the 50 kg rate of N compared to the zero and 200 kg rates across all levels of herbicide during July ($f_{1,36}$=5.67, P<0.05) (Figure 3.39). Herbicide main effect was significant for *A. elatius* (P<0.001) (Table 3.11), with cover declining with increasing herbicide dose rate (Figure 3.40). There was a significant interaction between fertiliser, herbicide and month of sampling for *R. repens* (P<0.05) (Table 3.21). *R. repens* tended to be most abundant in plots receiving no fertiliser and 180 g a.e. glyphosate per ha in June and August, but in July the greatest cover abundance was in the zero fertiliser, 45 g a.e. glyphosate per ha treatment. However, only low numbers of *R. repens* were recorded in any treatment.

Table 3.16 ANOVA for sown species April - May 1995.

		A. elatius		*E. repens*		*B. sterilis*	
Source	df	F value	Probability	F value	Probability	F value	Probability
Fertiliser (F)	2	0.42	n.s.	0.75	n.s.	0.31	n.s.
Month (M)	1	12.17	P<0.001	8.52	P<0.01	203.96	P<0.001
M x F	2	1.78	n.s.	0.31	n.s.	0.31	n.s.
Error	45						

		S. latifolia		*R. repens*		*G. aparine*	
Source	df	F value	Probability	F value	Probability	F value	Probability
Fertiliser (F)	2	0.91	n.s.	1.27	n.s.	0.99	n.s.
Month (M)	1	63.46	P<0.001	0.48	n.s.	0.29	n.s.
M x F	2	0.29	n.s.	1.06	n.s.	2.01	n.s.
Error	45						

Table 3.17 Repeated measures ANOVA for sown species June - August 1995.

Source	df	*A. elatius* F value	*A. elatius* Probability	*A. elatius* Wilks' lambda	*E. repens* F value	*E. repens* Probability	*E. repens* Wilks' lambda	*B. sterilis* F value	*B. sterilis* Probability	*B. sterilis* Wilks' lambda
Fertiliser (F)	2	2.01	n.s.	-	2.07	n.s.	-	2.65	n.s.	-
Herbicide (H)	3	8.32	P<0.001	-	3.85	P<0.05	-	4.10	P<0.05	-
F x H	6	0.75	n.s.	-	1.29	n.s.	-	1.22	n.s.	-
Error	36									
Month (M)	2	96.06	P<0.001	0.15	9.39	P<0.001	0.65	273.10	P<0.001	0.06
M x F	6	2.78	P<0.05	0.74	2.00	n.s.	0.81	1.40	n.s.	0.86
M x H	6	4.51	P<0.001	0.52	1.63	n.s.	0.77	2.16	n.s.	0.71
M x F x H	12	1.23	n.s.	0.68	0.92	n.s.	0.74	1.89	n.s.	0.57
Error	72									

Source	df	*S. latifolia* F value	*S. latifolia* Probability	*S. latifolia* Wilks' lambda	*R. repens* F value	*R. repens* Probability	*R. repens* Wilks' lambda	*G. aparine* F value	*G. aparine* Probability	*G. aparine* Wilks' lambda
Fertiliser (F)	2	5.84	P<0.01	-	1.06	n.s.	-	0.36	n.s.	-
Herbicide (H)	3	0.02	n.s.	-	1.25	n.s.	-	0.63	n.s.	-
F x H	6	1.09	n.s.	-	2.24	n.s.	-	0.56	n.s.	-
Error	36									
Month (M)	2	78.73	P<0.001	0.18	10.47	P<0.001	0.63	3.17	n.s.	0.85
M x F	6	1.98	n.s.	0.81	0.60	n.s.	0.94	0.45	n.s.	0.95
M x H	6	1.14	n.s.	0.83	0.78	n.s.	0.88	1.41	n.s.	0.80
M x F x H	12	0.92	n.s.	0.75	1.09	n.s.	0.71	0.57	n.s.	0.83
Error	72									

Table 3.18 ANOVA table for sown species December 1995.

		A. elatius		*E. repens*		*B. sterilis*	
Source	df	F value	Probability	F value	Probability	F value	Probability
Fertiliser (F)	2	0.86	n.s.	0.13	n.s.	0.59	n.s.
Herbicide (H)	3	0.41	n.s.	0.34	n.s.	1.18	n.s.
F x H	6	1.63	n.s.	1.90	n.s.	0.57	n.s.
Error	36						

		S. latifolia		*R. repens*		*G. aparine*	
Source	df	F value	Probability	F value	Probability	F value	Probability
Fertiliser (F)	2	0.32	n.s.	3.97	P<0.05	1.81	n.s.
Herbicide (H)	3	2:28	n.s.	2.45	n.s.	4.33	P<0.05
F x H	6	0.69	n.s.	3.09	P<0.05	0.46	n.s.
Error	36						

Table 3.19 ANOVA table for sown species March 1996.

		A. elatius		*E. repens*		*B. sterilis*	
Source	df	F value	Probability	F value	Probability	F value	Probability
Fertiliser (F)	2	1.26	n.s.	0.42	n.s.	0.10	n.s.
Herbicide (H)	3	1.79	n.s.	2.40	n.s.	0.42	n.s.
F x H	6	1.71	n.s.	1.74	n.s.	0.76	n.s.
Error	36						

		S. latifolia		*R. repens*		*G. aparine*	
Source	df	F value	Probability	F value	Probability	F value	Probability
Fertiliser (F)	2	0.55	n.s.	1.15	n.s.	1.70	n.s.
Herbicide (H)	3	0.59	n.s.	1.93	n.s.	0.58	n.s.
F x H	6	2.38	P<0.05	3.51	P<0.01	0.69	n.s.
Error	36						

Table 3.20 ANOVA table for sown species April - May 1996.

		A. elatius		*E. repens*		*B. sterilis*	
Source	df	F value	Probability	F value	Probability	F value	Probability
Fertiliser (F)	2	14.66	P<0.001	0.27	n.s.	2.99	n.s.
Herbicide (H)	3	0.36	n.s.	4.45	P<0.01	0.55	n.s.
F x H	6	0.48	n.s.	0.85	n.s.	2.30	n.s.
Error	36						
Month (M)	1	162.95	P<0.001	16.74	P<0.001.	2.54	n.s.
M x F	2	14.85	P<0.001	3.21	n.s.	4.30	P<0.05
M x H	3	0.59	n.s.	1.06	n.s.	1.16	n.s.
M x F x H	6	0.53	n.s.	1.11	n.s.	1.19	n.s.
Error	36						

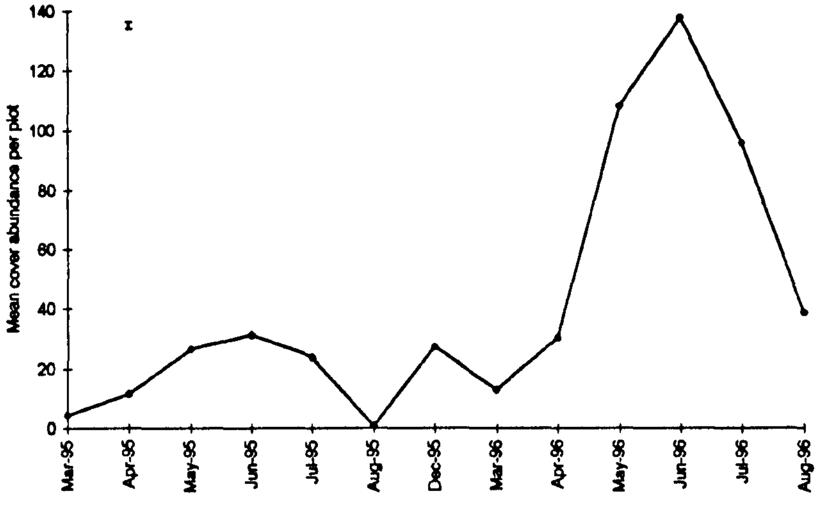
		S. latifolia		*R. repens*		*G. aparine*	
Source	df	F value	Probability	F value	Probability	F value	Probability
Fertiliser (F)	2	0.91	n.s.	2.84	n.s.	3.58	P<0.05
Herbicide (H)	3	1.50	n.s.	4.04	P<0.05	0.86	n.s.
F x H	6	1.77	n.s.	1.89	n.s.	0.45	n.s.
Error	36						
Month (M)	1	149.26	P<0.001	9.95	P<0.01	30.07	P<0.001
M x F	2	1.51	n.s.	1.46	n.s.	4.46	P<0.05
M x H	3	0.47	n.s.	0.89	n.s.	0.86	n.s.
M x F x H	6	0.54	n.s.	0.83	n.s.	0.21	n.s.
Error	36						

Table 3.21 Repeated measures ANOVA for sown species June - August 1996.

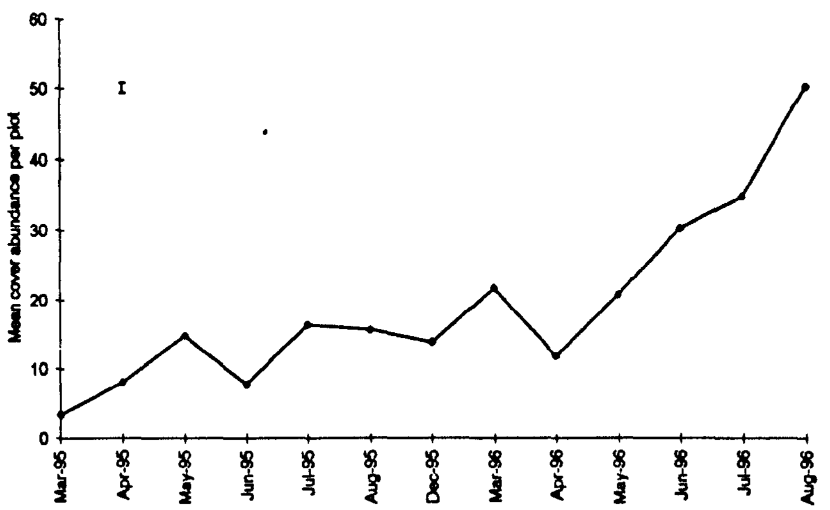
Source	df	*A. elatius*			*E. repens*			*B. sterilis*		
		F value	Probability	Wilks' lambda	F value	Probability	Wilks' lambda	F value	Probability	Wilks' lambda
Fertiliser (F)	2	0.81	n.s.	-	1.46	n.s.	-	3.18	n.s.	-
Herbicide (H)	3	13.46	P<0.001	-	2.22	n.s.	-	0.25	n.s.	-
F x H	6	0.36	n.s.	-	0.54	n.s.	-	2.16	n.s.	-
Error	36									
Month (M)	2	44.05	P<0.001	0.28	7.74	P<0.01	0.69	65.55	P<0.001	0.21
M x F	6	0.82	n.s.	0.91	0.70	n.s.	0.92	1.82	n.s.	0.82
M x H	6	2.23	n.s.	0.71	1.00	n.s.	0.85	1.87	n.s.	0.74
M x F x H	12	0.69	n.s.	080	1.31	n.s.	0.67	1.39	n.s.	0.65
Error	72									

Source	df	*S. latifolia*			*R. repens*			*G. aparine*		
		F value	Probability	Wilks' lambda	F value	Probability	Wilks' lambda	F value	Probability	Wilks' lambda
Fertiliser (F)	2	1.29	n.s.	-	2.59	n.s.	-	3.40	P<0.05	-
Herbicide (H)	3	0.46	n.s.	-	0.79	n.s.	-	1.61	n.s.	-
F x H	6	0.72	n.s.	-	1.37	n.s.	-	0.82	n.s.	-
Error	36									
Month (M)	2	35.06	P<0.001	0.33	9.39	P<0.001	0.65	9.56	P<0.001	0.65
M x F	6	3.28	P<0.05	0.71	1.16	n.s.	0.88	0.50	n.s.	0.94
M x H	6	2.07	n.s.	0.72	0.36	n.s.	0.94	1.03	n.s.	0.84
M x F x H	12	1.38	n.s.	0.65	2.07	P<0.05	0.54	1.11	n.s.	0.71
Error	72									

a) *Arrhenatherum elatius*



b) *Elymus repens*



c) *Bromus sterilis*

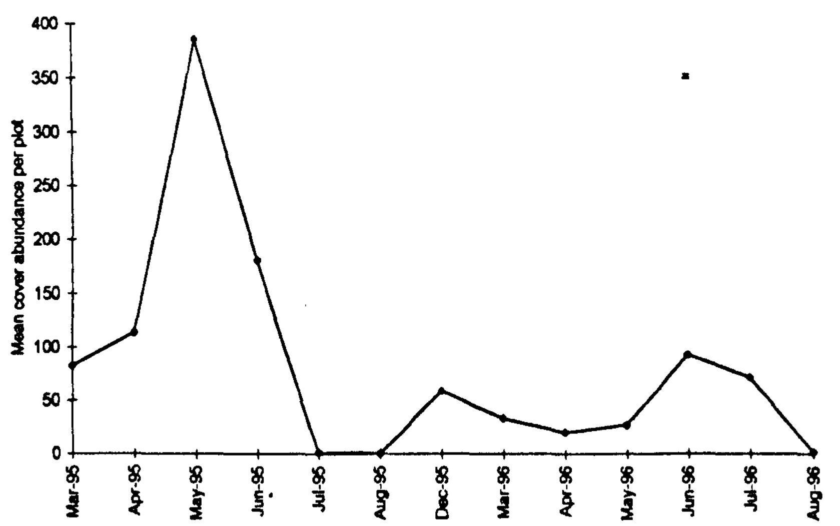
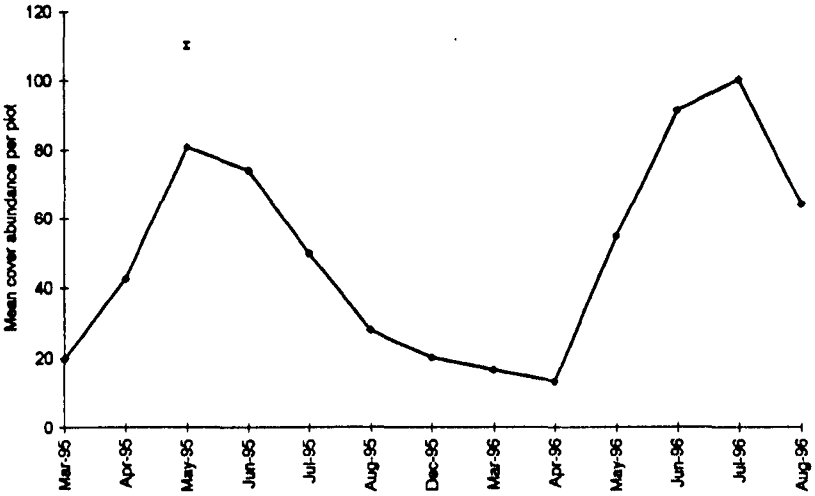
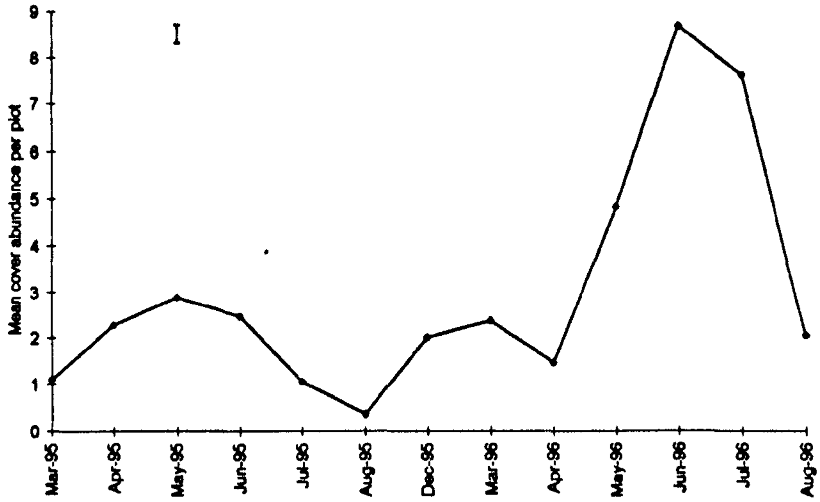


Figure 3.25 Changes in mean cover abundance of sown species per plot from March 1995 to August 1996 (means across all treatments). (Note different vertical scales).

d) ***Silene latifolia***



e) ***Ranunculus repens***



f) ***Galium aparine***

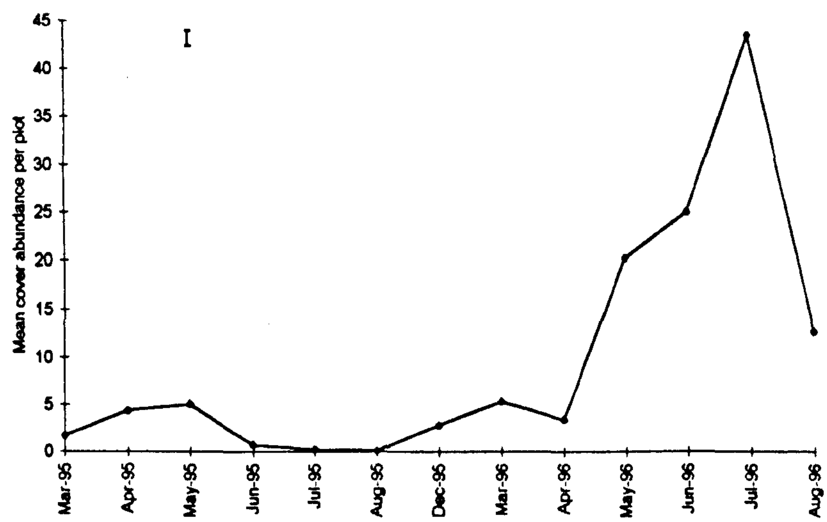


Figure 3.25 continued. Changes in mean cover abundance of sown species per plot from March 1995 to August 1996 (means across all treatments). (Note different vertical scales).

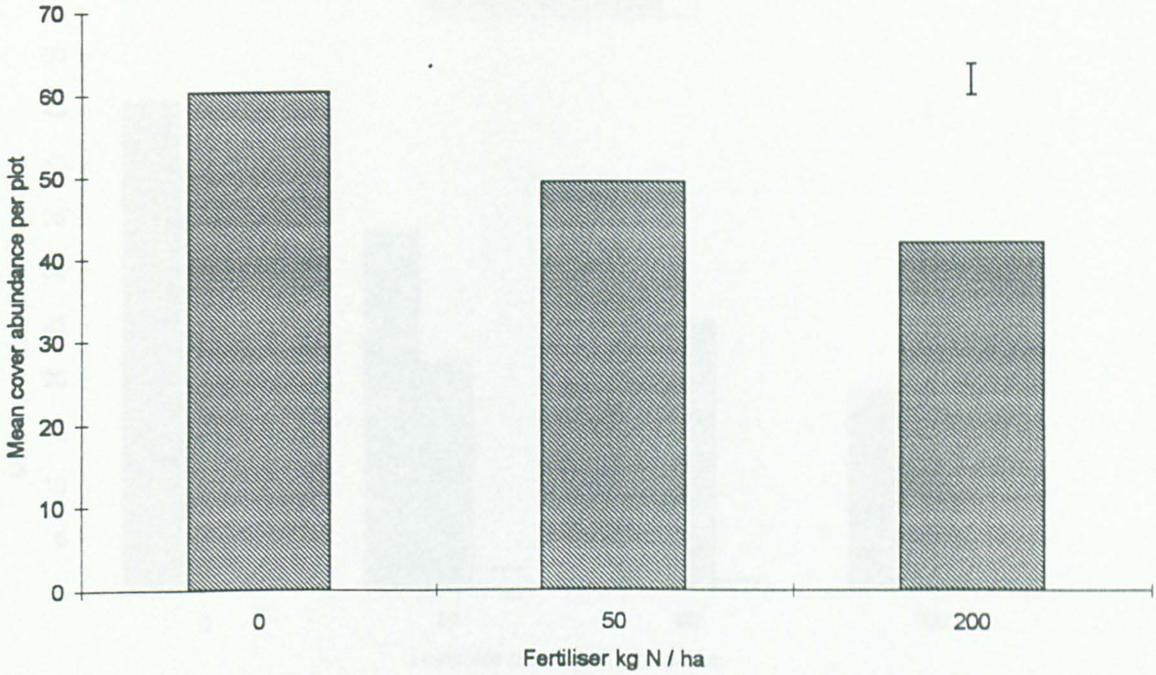


Figure 3.26 The effects of different fertiliser levels (averaged over herbicide levels) on the mean cover abundance of *Silene latifolia* per plot from June to August 1995. Vertical bar represents SE.

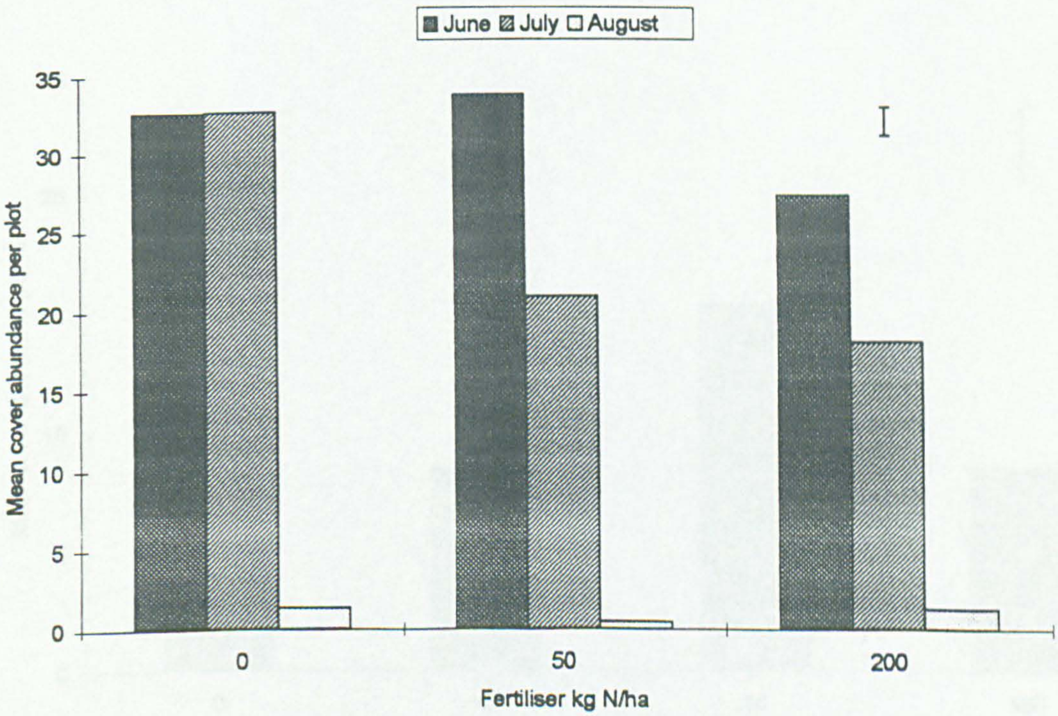


Figure 3.27 The effects of different fertiliser levels (averaged over herbicide levels) x month of sampling on the mean cover abundance of *Arrhenatherum elatius* per plot from June to August 1995. Vertical bar represents SE for interaction.

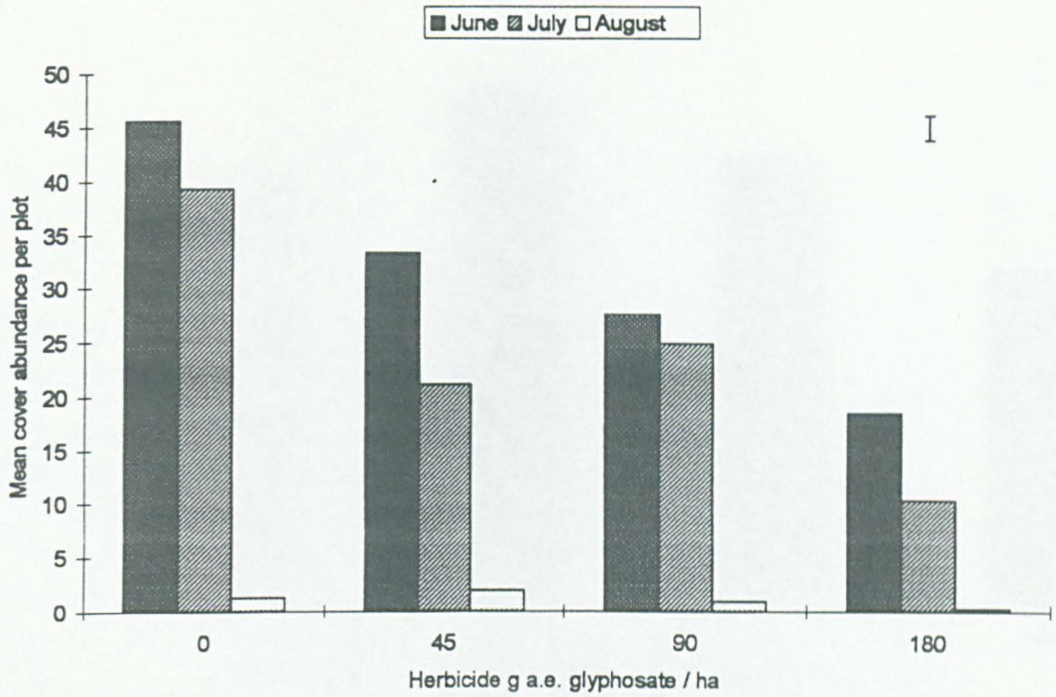


Figure 3.28 The effects of different herbicide levels (averaged over fertiliser levels) x month of sampling on the mean cover abundance of *Arrhenatherum elatius* per plot from June to August 1995. Vertical bar represents SE for interaction.

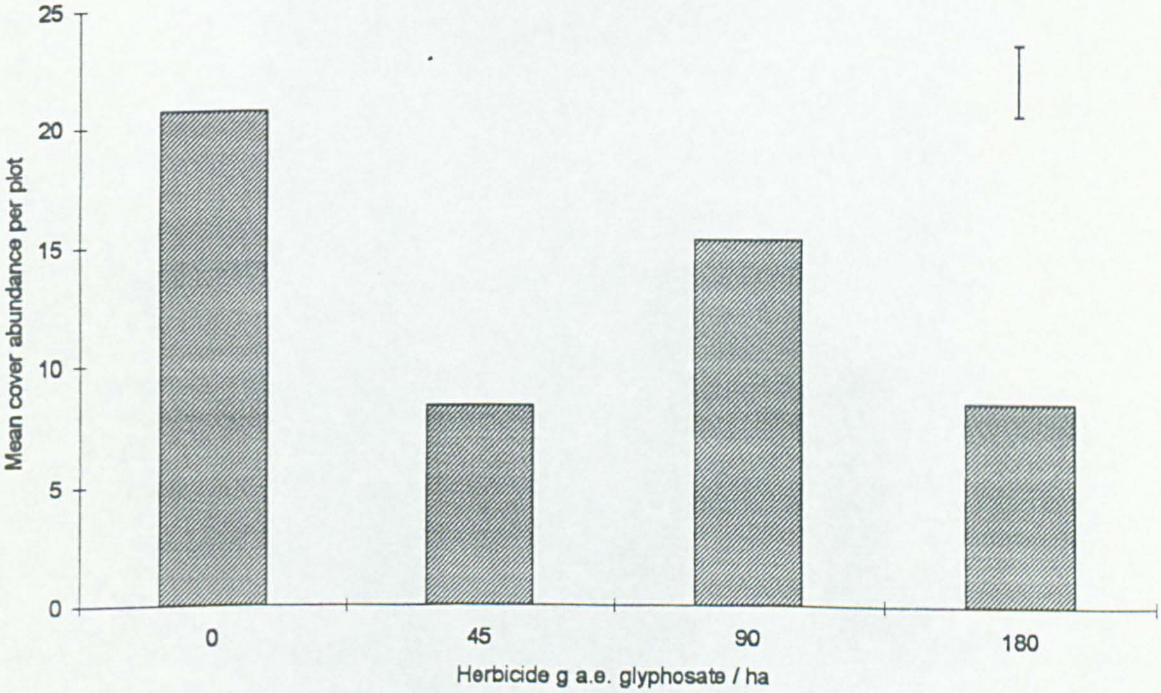


Figure 3.29 The effects of different herbicide levels (averaged over fertiliser levels) on the mean cover abundance of *Elymus repens* per plot from June to August 1995. Vertical bar represents SE.

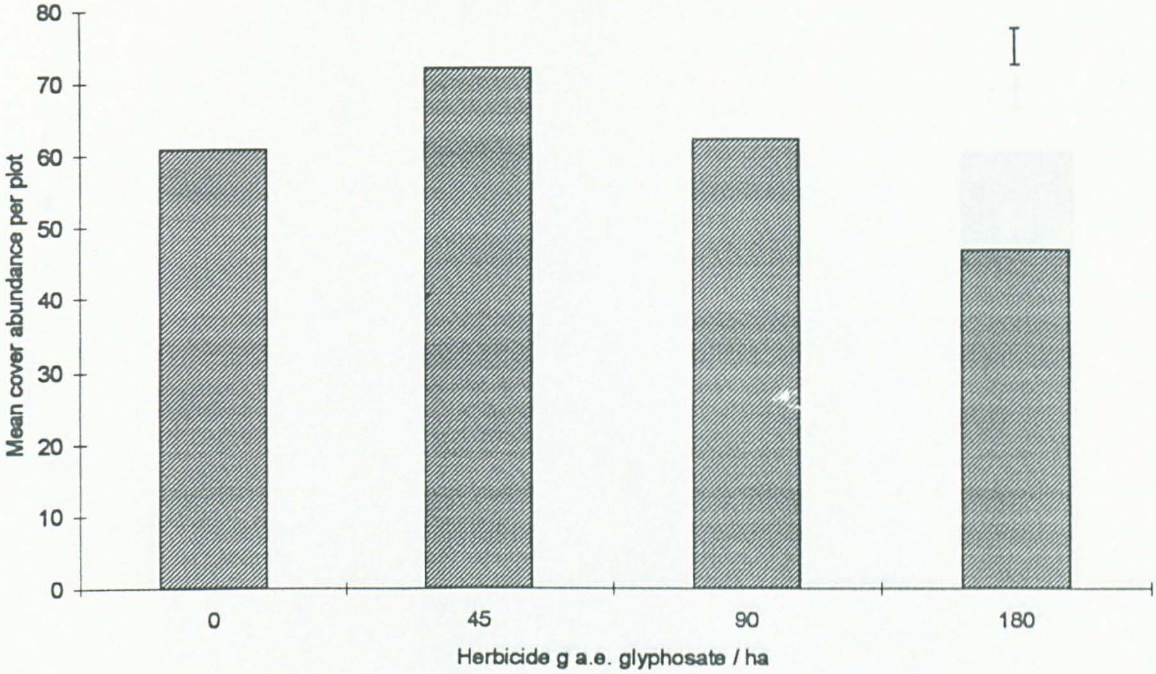


Figure 3.30 The effects of different herbicide levels (averaged over fertiliser levels) on the mean cover abundance of *Bromus sterilis* per plot from June to August 1995. Vertical bar represents SE.

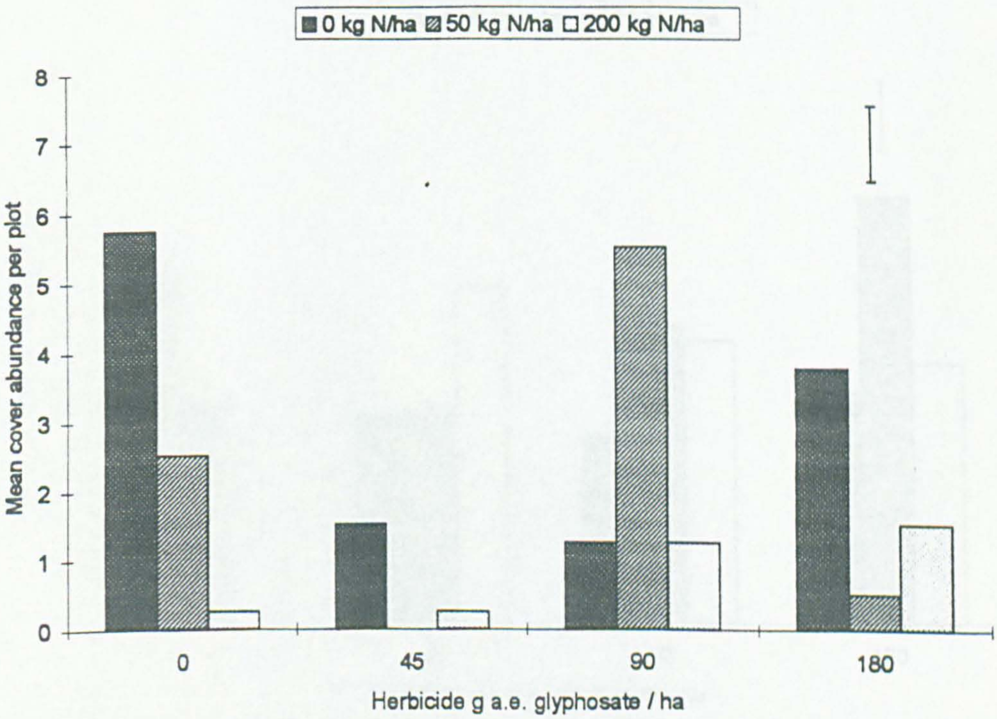


Figure 3.31 The effects of different fertiliser and herbicide levels on the mean cover abundance of *Ranunculus repens* per plot in December 1995. Vertical bar represents SE for interaction.

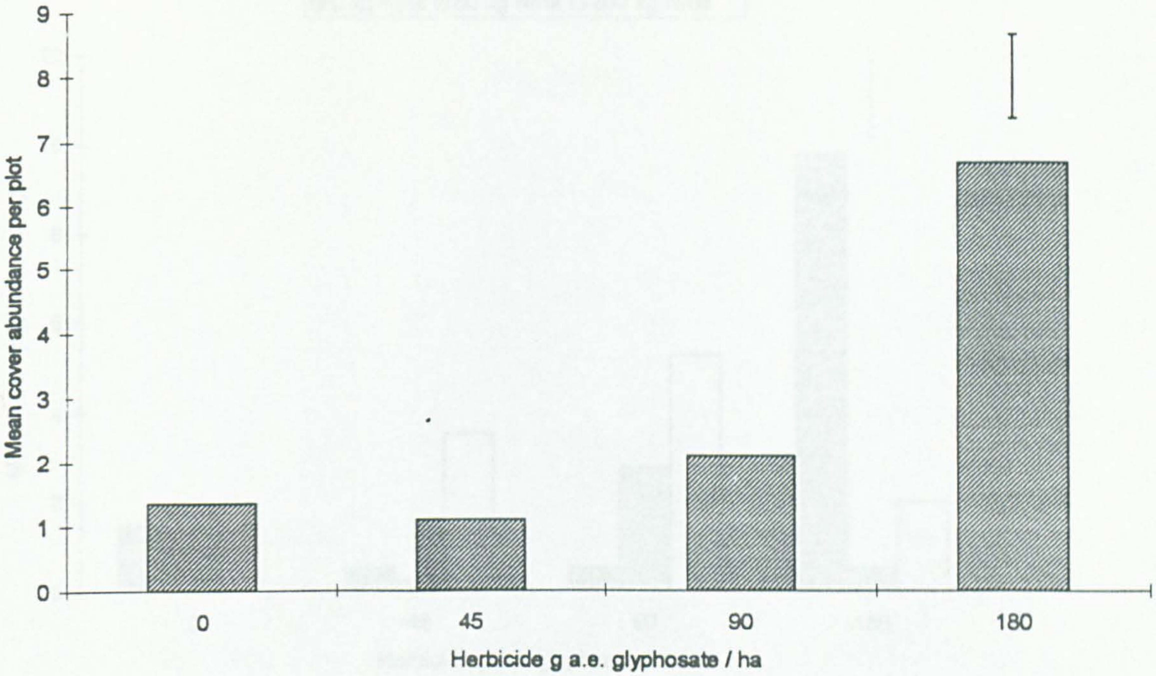


Figure 3.32 The effects of different herbicide levels (averaged over fertiliser levels) on the mean cover abundance of *Galium aparine* per plot in December 1995. Vertical bar represents SE.

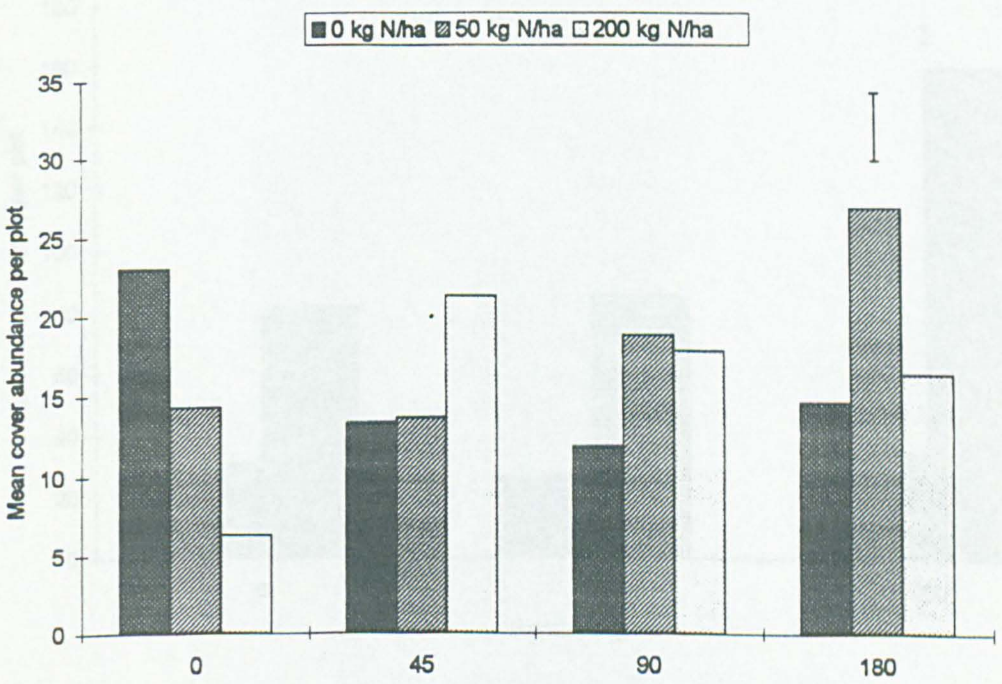


Figure 3.33 The effects of different fertiliser and herbicide levels on the mean cover abundance of *Silene latifolia* per plot in March 1996. Vertical bar represents SE for interaction.

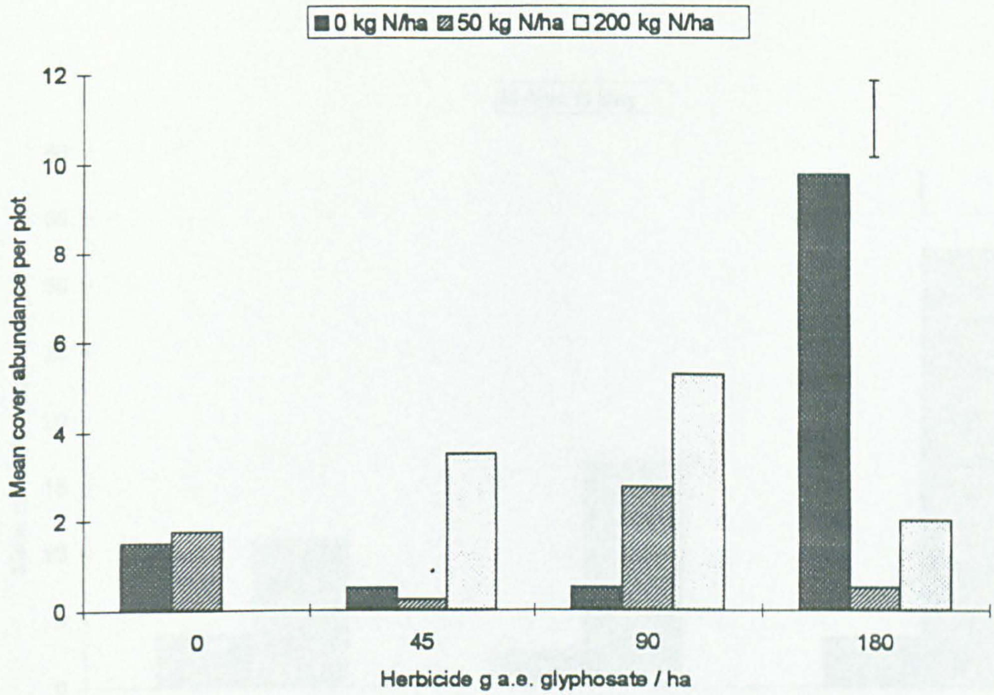


Figure 3.34 The effects of different fertiliser and herbicide levels on the mean cover abundance of *Ranunculus repens* per plot in March 1996. Vertical bar represents SE for interaction.

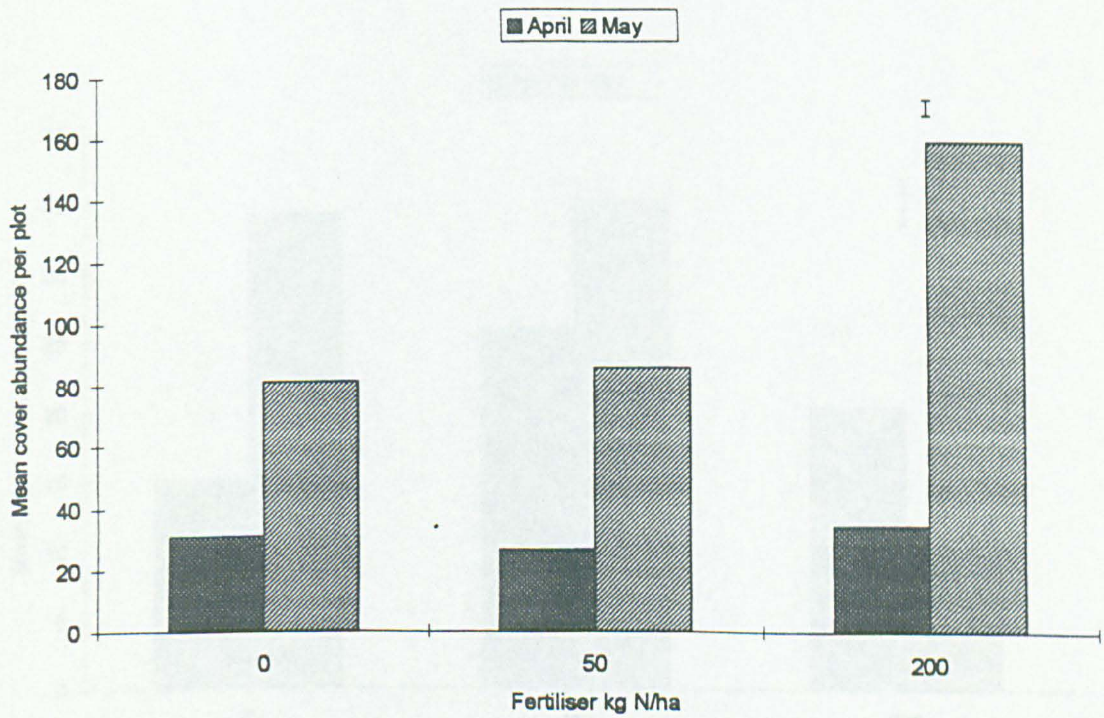


Figure 3.35 The effects of different fertiliser levels (averaged over herbicide levels) x month of sampling on the mean cover abundance of *Arrhenatherum elatius* per plot from April to May 1996. Vertical bar represents SE for interaction.

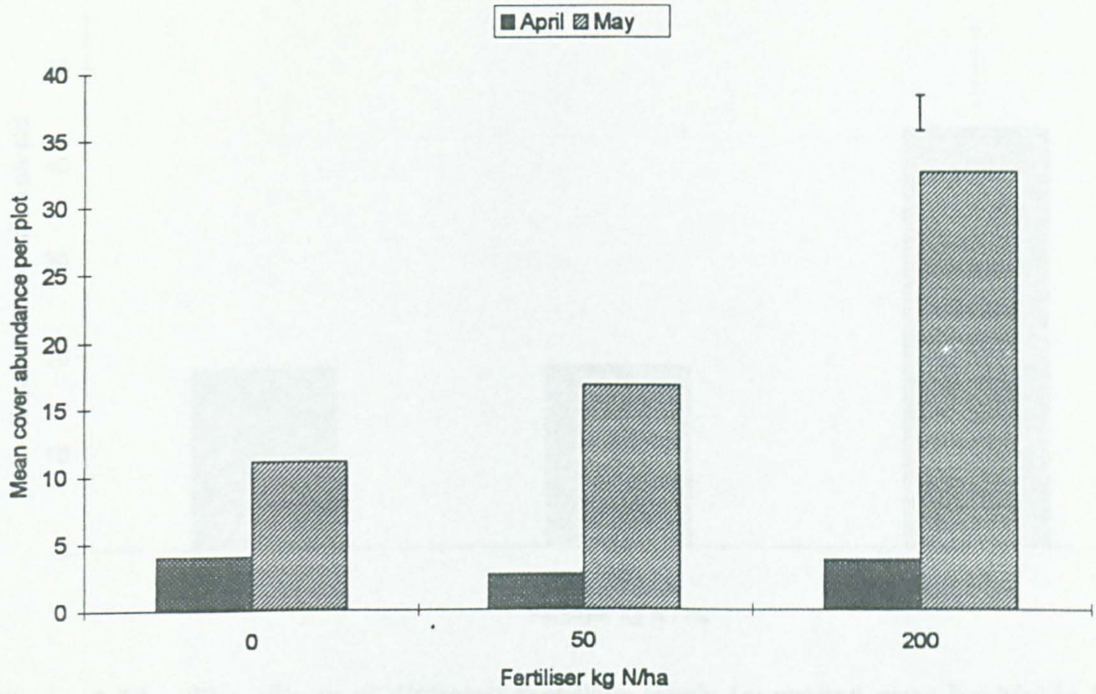


Figure 3.36 The effects of different fertiliser levels (averaged over herbicide levels) x month of sampling on the mean cover abundance of *Galium aparine* per plot from April to May 1996. Vertical bar represents SE for interaction.

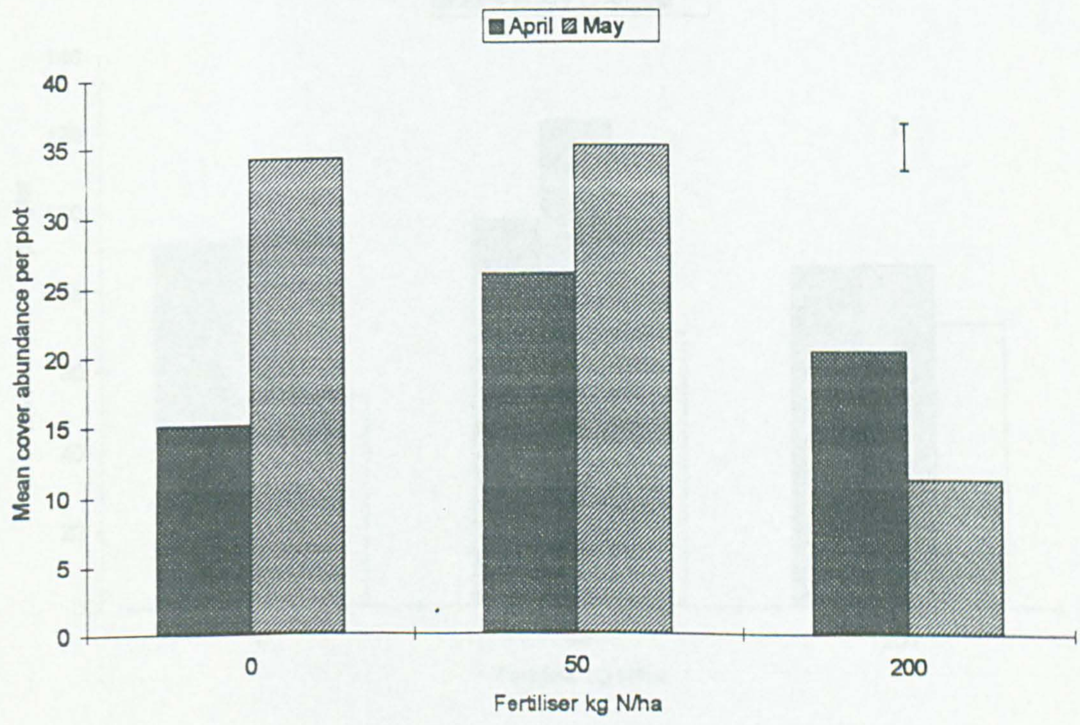


Figure 3.37 The effects of different fertiliser levels (averaged over herbicide levels) x month of sampling on the mean cover abundance of *Bromus sterilis* per plot from April to May 1996. Vertical bar represents SE for interaction.

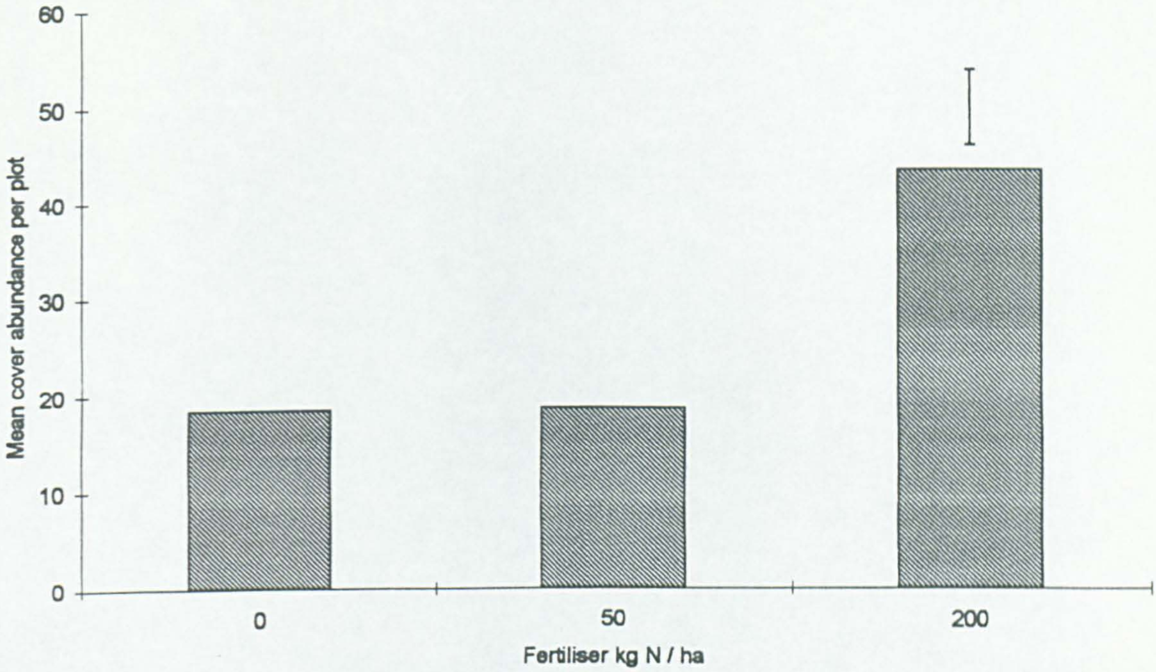


Figure 3.38 The effects of different fertiliser levels (averaged over herbicide levels) on the mean cover abundance of *Galium aparine* per plot from June to August 1996. Vertical bar represents SE.

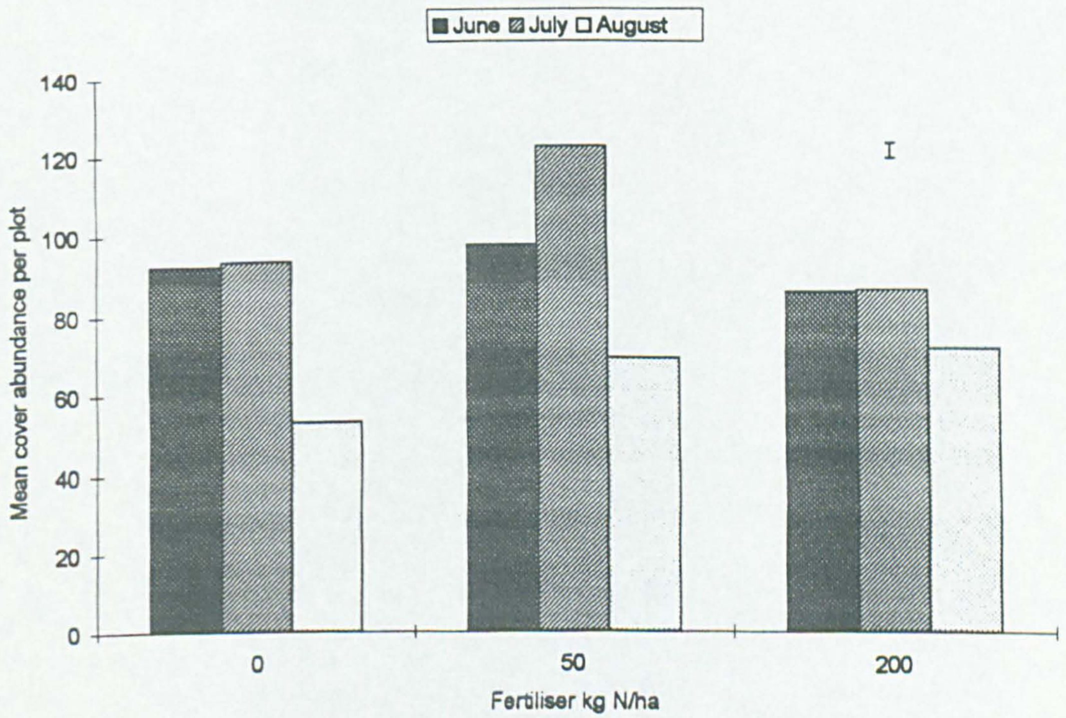


Figure 3.39 The effects of different fertiliser levels (averaged over herbicide levels) x month of sampling on the mean cover abundance of *Silene latifolia* per plot from June to August 1996. Vertical bar represents SE for interaction.

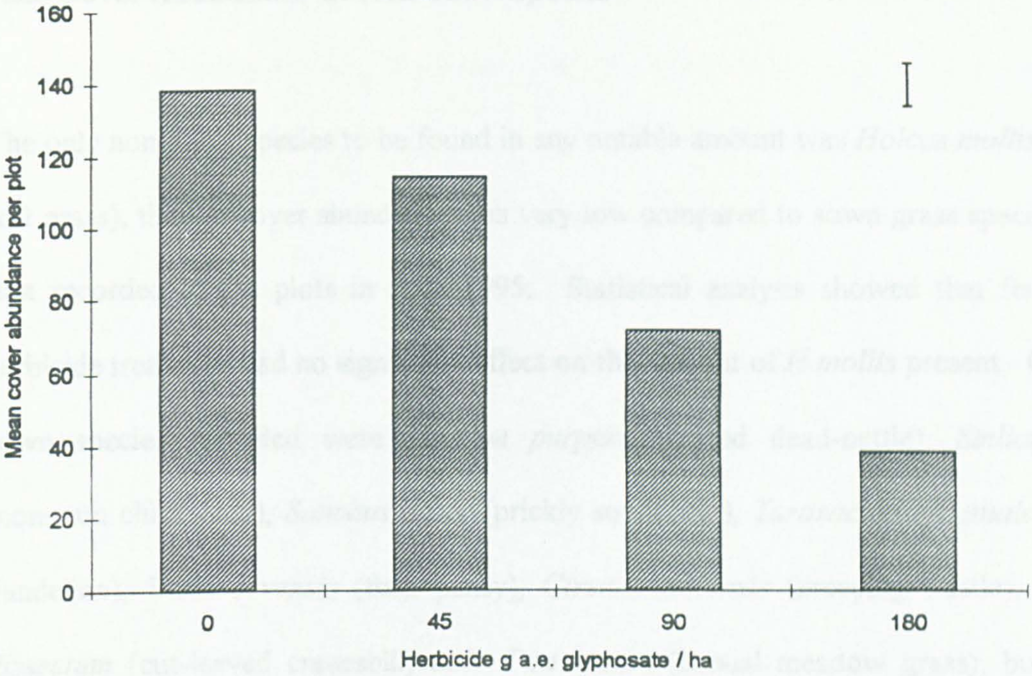


Figure 3.40 The effects of different herbicide levels (averaged over fertiliser levels) on the mean cover abundance of *Arrhenatherum elatius* per plot from June to August 1996. Vertical bar represents SE.

3.3.5 Cover Abundance Of Non-Sown Species

The only non-sown species to be found in any notable amount was *Holcus mollis* (creeping soft grass), though cover abundance was very low compared to sown grass species. It was first recorded in the plots in June 1995. Statistical analysis showed that fertiliser and herbicide treatment had no significant effect on the amount of *H.mollis* present. Other non-sown species recorded were *Lamium purpureum* (red dead-nettle), *Stellaria media* (common chickweed), *Sonchus asper* (prickly sowthistle), *Taraxacum officinale* (common dandelion), *Viola arvensis* (field pansy), *Cirsium arvensis* (creeping thistle), *Geranium dissectum* (cut-leaved cranesbill) and *Poa annua* (annual meadow grass), but numbers found were too low for statistical analyses.

3.4 Discussion

The sequence of vegetation development within the simulated field margin communities followed a typical old-field succession pattern over the two years of the experiment (Bazzaz, 1968). Plant cover generally increased over time and was at its greatest in either May (1995) or June (1996). Annuals were the dominant vegetation type in the first year of the experiment (1995), but this situation was reversed in 1996 and perennial species became the primary vegetation types. Grass cover was greater than dicot cover in both years of the experiment, but on the final sample date in 1996, there was little difference between the two. The annual grass *B. sterilis* was the dominant species in 1995 but declined in 1996 as *A. elatius*, *E repens*, *R. repens* and *G. aparine* increased in abundance. The remaining sown species, *S. latifolia*, was present in similar amounts in either year.

The response of individual species within the simulated field margin communities to fertiliser and herbicide application was variable and the resultant interactions were complex. Generally, increasing fertiliser levels had a negative effect on the total cover of vegetation in the first year (1995) of the experiment. This is most likely due to individual plants lodging and the point quadrat frame recording fewer overall touches. Had a destructive sample been taken at this time, the observed differences in biomass between fertilised and unfertilised plots may not have been apparent. By the following Spring (1996), the situation was reversed and fertilised plots had the greatest cover abundance with the highest application rate (200 kg /ha) providing the most number of touches. However, from June 1996 onwards, there were no differences in total touches for the fertiliser treatments.

Annuals and perennials were differentially affected by the fertiliser application. In 1995, perennial species suffered the greatest amount of lodging and their cover abundance was subsequently reduced. Perennial grass species such as *A. elatius* and *E repens* were particularly affected. Annuals, dominated mainly by *B. sterilis*, were relatively unaffected by lodging as the *B. sterilis* was naturally senescing at this time. By May 1996, the fertiliser application resulted in a more typical response and the cover abundance of grasses, dominated by the perennial species *A. elatius* and *E repens*, was significantly increased by fertiliser application. The cover of *B. sterilis* was also initially increased, in April 1996, but by May 1996, there was no difference in cover between unfertilised and fertilised treatments. Fertiliser application caused a reduction in cover abundance of *S.latifolia* between June and August 1995, due to lodging, whilst in July 1996, greatest cover abundance was observed in plots receiving 50 kg N/ha. In 1996, the cover abundance of *G.aparine* was increased by the addition of fertiliser.

In the long-term Park Grass experiment established in 1856, the addition of nitrogen has led to a greater grass dominance, and to lower legume and forb relative abundances (Tilman *et* *al.*, 1994). Mountford *et al.* (1993), who studied the effects of a range of nitrogen levels on the vegetation of hay meadows on a Somerset peat moor, also found that fertiliser encouraged grasses to dominate in a sward.

In a study of three perennial grasses, Mahmoud & Grime (1976), found that *A. elatius* was more competitive than *Agrostis tenuis* and *Festuca ovina*, and this effect was greatest at high nutrient levels. The greater competitive ability of *A. elatius* was attributed to its ability to be able to compete for light. Berendse *et al.* (1992) found that in a pot experiment *A. elatius* replaced *F. rubra* in fertilised treatments, but in unfertilised treatments *F. rubra* replaced the more N requiring *A. elatius*, especially where a cutting treatment was also implemented. These results confirmed their findings from a long term field study on the two species. Previous studies have shown that *E. repens* increased under high nitrogen conditions when in competition with other species (Tilman 1988; Marshall. 1990). Melman & van Strien (1993) also found that *E. repens* was favoured by a high nitrogen supply to ditch bank vegetation. However, this was not apparent in this study, herbicide application may have suppressed the competitive ability of *E. repens*, as herbicide application reduced its cover abundance in both years. Theaker *et al.* (1995b) found that native populations of *B. sterilis* responded to nitrogen application by producing fewer, but larger panicles, though there were no overall effects on percentage cover or reproductive output. Rew *et al.* (1995) showed that *B. sterilis* was more aggressive than *F. rubra*, *H. lanatus* and *P. trivialis* during vegetative growth when nitrogen was applied, though this effect disappeared after *B. sterilis* had flowered. However, Dunkley & Boatman (1994) showed that frequency and distribution of *B. sterilis* was reduced in the presence of *A. elatius*.

Sublethal herbicide application significantly reduced total cover abundance in both years, with the highest rate of application having the most marked effect. In 1995, there was a sharp decrease in cover abundance in all treatments between the June and July sampling dates, and this may have been caused in part by the exceptionally dry weather experienced at this time. Herbicide application at the 180 g a.e. glyphosate / ha decreased the cover abundance of both annual and perennial species in 1995. However, in 1996 only perennials were affected, with the effects becoming more severe with increasing herbicide rate. Herbicide application reduced the cover of grasses in both years, with the highest rate causing the greatest reduction. However, the dicot species sown appeared to be relatively unaffected by herbicide application, and in the December 1995 assessment, there were significantly more dicotyledons in treatments which had received the 180 g a.e. glyphosate in the previous June. This was probably because grasses were more severely affected by herbicide application at this rate, and dicotyledons were then able to out compete them. Herbicide application in 1995 reduced the cover of the grasses *A. elatius*, *E. repens* and *B. sterilis*, though the dicot species were not affected. At the December 1995 assessment, significantly more *G. aparine* was observed in plots which had received 180 g a.e. glyphosate / ha. *G. aparine* tends to occur in bare ground beneath hedgerow shrubs, and it may not have been able to establish effectively in a sward with other species, but gaps created in the 180 g glyphosate treatments by the death of grass species may have created suitable conditions for *G. aparine* to germinate. Establishment and survival of species in sown swards and natural communities occurs in gaps, especially larger gaps caused by disturbance. Light intensity is thought to be an important factor in this (Grime 1979; Grubb, 1979). It may have been that the taller grass species were sheltering the shorter dicot species from some of the herbicide. Deposition patterns within vegetation are known to be complex, and in some cases the effect of surrounding vegetation cover can influence the response of a species to herbicide drift (Marrs *et al.*, 1989). In 1996, herbicide application only had a significant effect on the dominant grass *A. elatius*, and as in the previous year, cover abundance was reduced by herbicide application. Herbicide application only had a relatively small effect on *B. sterilis* in 1995, as at the time of application, this species was already seeding. Boatman *et al.* (1995) found that seed germination of *B. sterilis* was severely reduced by glyphosate application to parent plants during late May/June. *B. sterilis* regeneration was much lower in the following season in herbicide treated plots, but cover was also reduced in herbicide untreated plots, suggesting that competition from other species was also having an effect on *B. sterilis* regeneration from seed. Grasses are generally more susceptible to glyphosate than dicotyledons, which may explain the lack of effect on *S. latifolia*, *G. aparine* and *R. repens*, though Marrs *et al.* (1989) found a number of dicotyledonous species to be sensitive to glyphosate application, albeit at higher concentrations than in the present study. The effects of sublethal levels of herbicide could accumulate slowly as a result of repeat applications, and further study would be needed to evaluate this.

There was a significant interaction between fertiliser and herbicide for annual species between April and May 1996, though no herbicide had been applied since June 1995. At the zero and 180 g a.e. glyphosate / ha rates, fertilised plots had a greater cover abundance of annuals than unfertilised ones, but at the 45 g / ha rate of glyphosate most touches occurred at the 50 kg rate of fertiliser, and at the 90 g / ha rate of glyphosate the unfertilised plots had the most annuals. There was a significant interaction between fertiliser and herbicide for both grasses and dicotyledons in March 1996. In treatments where the cover abundance of grasses deceased there was a corresponding increase in dicotyledonous species, and similarly where there were more grasses there were fewer dicotyledons. Therefore if a treatment was adversely affecting grasses, then dicotyledonous species were able to exploit this, and vice versa. There was a significant fertiliser x herbicide interaction for *S. latifolia* in March 1996. Where no herbicide had been applied, fertiliser application tended to increase cover abundance, suggesting that in treatments where grasses had been suppressed by glyphosate application, *S. latifolia* was able to respond positively to fertilis application.

There was a significant month of sampling x fertiliser x herbicide interaction in the June August period for total cover abundance, which was caused by a greater cover abundance fertilised plots at the zero level of herbicide in June. The majority of this cover was of gra species, and there was a similar three way interaction for grasses.

To summarise, the aim was to study the effects of fertiliser misplacement and subleth doses of herbicide on herbaceous field margin communities over time.

Disturbance of field margin vegetation is generally perceived to result in a shift from benign perennial flora to an increased dominance of annual weedy species. Yet, in this cas a general shift from annual to perennial species was observed. However, the plar communities studies had only been established for ten months before monitoring began, an may still have been undergoing a successional process.

Fertiliser appeared to have a negative effect in the first year of monitoring, but this resu was difficult to evaluate due to plants lodging, and perhaps a destructive sampling metho measuring plant biomass would have given a more accurate representation of fertilise effects at this time. In the second year fertiliser had a positive effect on the cover of th dominant perennial species *A. elatius*, and also the annuals *G. aparine* and *B. sterili* though this effect was not quite as apparent. Herbicide application appeared to favour dicc species, and where grasses were suppressed by glyphosate application, suitable condition could arise for the establishment of *G. aparine*, which would then be able to thrive unde increasing fertiliser levels, to produce a situation all too familiar in many poorly manage field margins. However, further assessments over a longer period would be needed to see this is the case.

Chapter 4. Measurement of Spray Drift into a Hedgerow

4.1 Introduction

Spray drift has been defined as the aerial transport of a pesticide away from its intended target area (Cooke, 1993). Spray drift can be classified into three types : Droplet drift - caused by spray drifting during application, vapour drift - caused by volatilisation and drift of a pesticide after it has landed on the target crop, and blow - caused by strong winds blowing granules or dust away from their target area (Dudley, 1989). Droplet drift is probably the most important type of spray drift, and is investigated further here.

Conventional hydraulic sprayers are used for 90 % of crop spraying in the UK (Davis & Williams, 1993). Air-assisted spraying of orchards produces large amounts of drift, as many small droplets are projected upwards (Elliot & Wilson, 1983). However, downward air-assisted spraying of sugar beet can reduce drift by up to 50 % (May, 1991).

The size of spray droplets largely determines the way they are carried by air currents and deposited (Davis & Williams, 1993). Large droplets fall more rapidly in still air than smaller ones, and also have more momentum, and when they are projected downwards from a nozzle they decelerate more slowly, and are more likely to reach their target before acquiring the velocity of the surrounding air. Conventional hydraulic sprayers produce a mixture of droplet sizes from less than 50 μm to more than 500 μm. Thirty percent of the total spray volume is likely to consist of droplets between 50 μm and 150 μm, which are most sensitive to weather and application conditions in their susceptibility to evaporation and drift (Davis & Williams, 1993).

Spray droplets are deposited on surfaces by sedimentation through the action of gravity, and by inertial impacation, where they are carried onto surfaces of any orientation by air currents (Davis & Williams, 1993). As air currents are directed round an obstruction, heavier droplets may impact on it, while lighter ones are more likely to be carried round.

The primary effect of a hedge is to alter the wind speed in the area immediately adjoining the hedge (Helps, 1994). The extent to which wind speed is reduced is proportional to the height, permeability, length and position of the hedge (Marshall, 1967). When wind reaches a solid barrier such as a wall, the moving air is diverted upwards and over it, producing turbulent conditions behind it, and a rapid return to free wind speed. However, with a permeable barrier such as a hedge, some of the air filters through it, so there is a lower pressure difference between the two sides, and a more gradual return to free wind speeds. A hedge of 40 % permeability has been shown to reduce wind speeds significantly on the leeward side for a distance equivalent to 8 to 12 times the height of the hedge (Marshall, 1967).

Marrs *et al.* (1989), studying a range of native plant species and five different herbicides, found that damage and reduced performance were confined to less than 10m downwind of the sprayer, but that death and most severe symptoms were confined to the 0 to 4m zone. They recommended that buffer zones of 6 to 10m should be used to protect susceptible habitats such as field margins. The effect of surrounding vegetation on herbicide capture was found to be complex (Marrs *et al.*, 1991a), and there was no consistent relationship between surrounding grassland height and susceptibility to herbicide. The use of buffer zones provides a realistic method for protecting the environment from herbicide drift, and if spraying is accurate and carried out properly, there should be no damage to sensitive plants or vegetation (Marrs *et al.*, 1993). Cuthbertson & Jepson (1988) found that a 70-75% reduction in spray drift occurs at most heights in a hedgerow by the inclusion of an unsprayed 6m headland strip.

Most studies simulating herbicide drift deposition have been carried out in the development of more efficient sprayers, and to avoid economic damage to neighbouring crops from herbicides. However, the effect of hedges on herbicide spray drift has been less well studied.

The method used for quantifying spray drift into a hedgerow was an adaptation of the method Taylor *et al.* (1989) used for measuring drift within the centre of a field. Airborne spray drift was sampled using pipecleaners, which have been shown to have a high collection efficiency (Miller, 1993), in conjunction with a fluorescent tracer dye to be able to measure spray droplet deposition. Displaced spray in the hedge-bottom was collected on strips of filter paper and selected plant species.

4.2 Materials And Methods

An experiment was carried out in a winter barley crop (GS25, crop height approximately 15cm), at Harper Adams Agricultural College to measure pesticide drift into a hedgerow. The hedge was approximately 1.5m high and 1.5m wide, with a 1m wide strip of hedge-bottom vegetation consisting mainly of perennial grasses and dicotyledonous species, with a mean height of ca. 20 cm. The spray applications took place on 29 March 1996, when the wind was blowing in a westerly direction towards the study hedge. A tractor mounted Hardi Twin Stream (MA8000) sprayer, with a 12 m long boom fitted with 24 Hardi 4110-20 (flat fan, BCPC medium spray quality) nozzles was used to apply the spray. The spray application rate of 240 l/ha (simulating a herbicide treatment) was achieved with a 7.2 km tractor speed and a 2 bar spray pressure. Boom height was approximately 1m. The spra tracer used was a solution of fluorescein (sodium fluorescein, Hogg Laboratory Supplies at a rate of 100 g / 800 l water, with a non-ionic wetting and spreading agent (Agra Zeneca) at 0.1% v.v..

There were three treatments, all using conventional hydraulic spraying :-

1) Conventional spraying - end of sprayer boom at crop edge

2) 2m - spray withheld from outer 2m (achieved by switching off 4 nozzles on boor nearest hedge). This treatment would be equivalent to a sterile strip, and/or a natura regeneration or wildflower strip.

3) 6m - spray withheld from outer 6m (achieved by switching off 12 nozzles on boon nearest hedge - one boom section). This treatment would be equivalent to a conservation headland.

A line of drift masts was positioned along either side of the hedge, with three masts in each line, each 5 m apart. The layout of the experiment is shown in Figure 4.1. Masts on the windward side of the hedge were 5 m high, whilst leeward side masts were 4.5 m high Pairs of pipecleaners (15 cm long) were mounted horizontally on the masts at designated intervals. On the windward masts the first pair of pipecleaners were placed at 0.25 m above ground level, with further pairs positioned at 0.5, 0.75 and 1 m. From 1 m to 5 m pipecleaners were positioned at 0.5 m intervals. On the leeward masts, pipecleaners were positioned at 0.5 m intervals form 0.5 to 4.5 m.

With the wind perpendicular to the hedge, the sprayer made six passes of the masts (three in each direction) for each treatment. Wind speed at a height of 1m was recorded during spray application using a vane probe anemometer. After each treatment, pipecleaners were carefully removed from the masts, placed in vials and stored in the dark to prevent any photo-degradation of the fluorescein tracer. Tracer was recovered from the pipecleaners by washing them in 20 ml of water (plus Agral at 0.1 % v.v.), and allowing them to soak overnight. The tracer concentration of the liquid in each of the vials was then determined by fluorimetry. Samples were analysed in a Perkin-Elmer LS30 luminescence spectrometer with 490 nm and 515 nm excitation and emission wavelengths. Calibration was against samples from the original spray solution. As mean wind speed was different for each treatment application, results were divided through by wind speed to give spray deposition per m/s, so allowing comparisons to be made between the three sprayer distances and then the relative quantities, size and height of the drifting spray clouds determined. The results are expressed as $\mu l/cm^2$ per m/s per pass.

As well as measuring spray drift, the displaced spray was also measured in order to determine spray deposition into the hedge-bottom. Displaced spray is defined as the ground deposits occurring form a lateral movement of spray droplets outside the working width (12 m). Displaced spray was collected on 1m x 5 cm strips of filter paper attached to wooden boards, which were positioned at three positions on the windward side of the hedge. The filter papers were placed at ground level in the hedge-bottom vegetation, extending from the base of the hedge out towards the field, so that one end of the filter paper was adjacent to the hedge, whilst the other end was next to the crop edge. The strips were divided into 12.5 cm lengths, and spray deposits were extracted using the same methods used for the pipecleaners. Tracer concentrations were determined by fluorimetry. The results are expressed as $\mu l/cm^2$ per m/s per pass.

Plants of *Arrhenatherum elatius* (false oat grass), *Bromus sterilis* (barren brome) and *Ranunculus repens* (creeping buttercup) growing in pots, were placed in the centre of the hedge-bottom vegetation at the base of each windward mast, approximately 50 cm from the hedge base and 50 cm from the crop edge. The pot grown plants were of similar height to the surrounding hedge-bottom vegetation. Immediately after spraying, the leaves were removed from the plants, and placed into vials containing 20 ml de-ionised water (plus 0.1 %v.v. Agral). The leaves were left overnight, and then removed from the vials, and leaf areas were measured using a leaf area meter. The tracer concentration in the liquid was analysed by fluorimetry as for the pipecleaners. The results are expressed as $\mu l/cm^2$ per m/s per pass.

Factorial analysis of variance was used to analyse the data. Sprayer distance and height on the mast were used as factors for spray deposits collected on pipecleaners, sprayer distance and position in the hedge-bottom in the displaced spray trial, and sprayer distance and species in the plant deposition study. Data for the displaced spray trial were $\log_e$ transformed to produce a normal distribution. All other data followed a normal distribution.

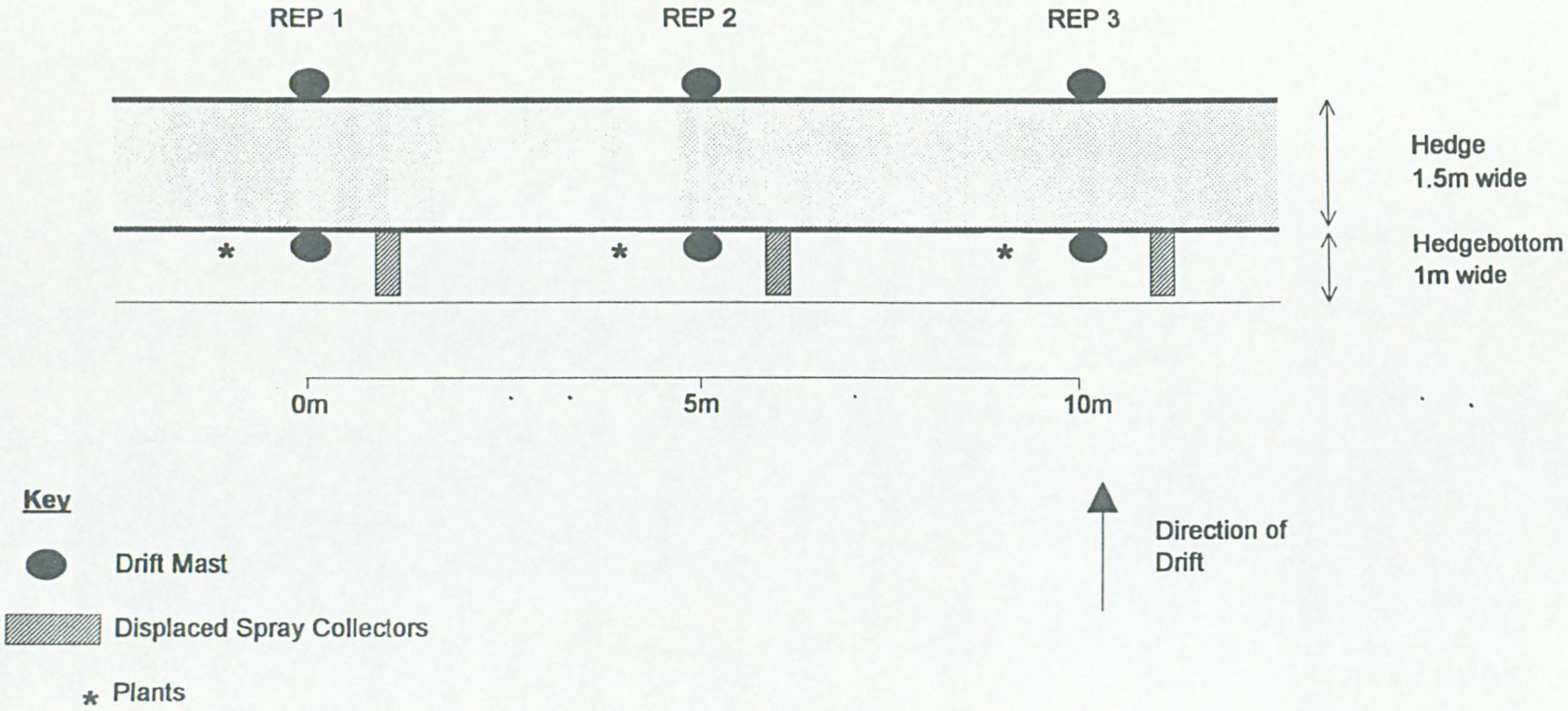


Figure 4.1 Plan of sampling strategy to measure spray drift into a hedgerow (not to scale).

4.3 Results

Wind speed measured at boom height was 2.20 m/s in treatment 1, when the end of the sprayer boom was at the crop edge, 1.97 m/s in treatment 2, when spray was withheld from the outer 2m, and 2.71 m/s in treatment 3 when spray was withheld from the outer 6m. However, as all results have been normalised for wind speed (by dividing through by the relevant wind speed) comparisons can be made between different treatments.

4.3.1 Deposition on pipecleaner collectors

Windward side masts

There was a significant difference between replicates ($P<0.001$), with significantly less drift deposited on pipecleaners which were situated on the first drift mast. The effects of distance of the boom and the height of collector were both highly significant ($P<0.001$) (Table 4.1). Spraying from a distance of 2m and 6m both significantly reduced mean drift deposition on the whole of the mast compared to spraying from 0m. Spraying from 6m reduced drift by 39 % compared to the control, whilst spraying from 2m reduced drift by 8% compared to the control, spraying from 6m away also significantly reduced drift compared to the 2m distance (Figure 4.2). Drift deposition was significantly reduced as height of collector increased, and more spray was deposited on collectors positioned below boom height. There were no significant differences between pipecleaner collectors positioned at 0.25m and 0.5m, but these two positions were significantly different compared to all other heights. There were significant differences between collectors at 0.75m and 1.5m, between 1m and 2m, between 1.5m and 2m, between 2 and 2.5m, between 2.5 and 3.5m and between 3 and 3.5m. There were no significant differences between collectors positioned from 3.5 to 5m (Figure 4.3). There was a significant interaction between distance of sprayer boom and height of collector (P<0.001) (Table 4.1). Up to a height of 0.5m, there was significantly less deposition with the 2m and 6m treatments compared to the 0m treatment. From 0.75m to 2m, there was significantly less deposition with the 6m treatment compared to both the 2m and 0m treatments, but there were no significant differences between the 0 and 2m treatments. At a height of 2.5m, there was a significant difference between the 6m and 0m treatments, but the 2m was not significantly different from either. At heights of 3 to 5m sprayer distance had no significant effect (Figure 4.4).

Table 4.1 ANOVA table for windward masts.

Source	df	F value	Probability
Replicate	2	8.64	P<0.001
Distance from sprayer	2	72.44	P<0.001
Height of collector	11	50.76	P<0.001
Distance x Height	22	5.80	P<0.001
Residual	178		
Total	215		

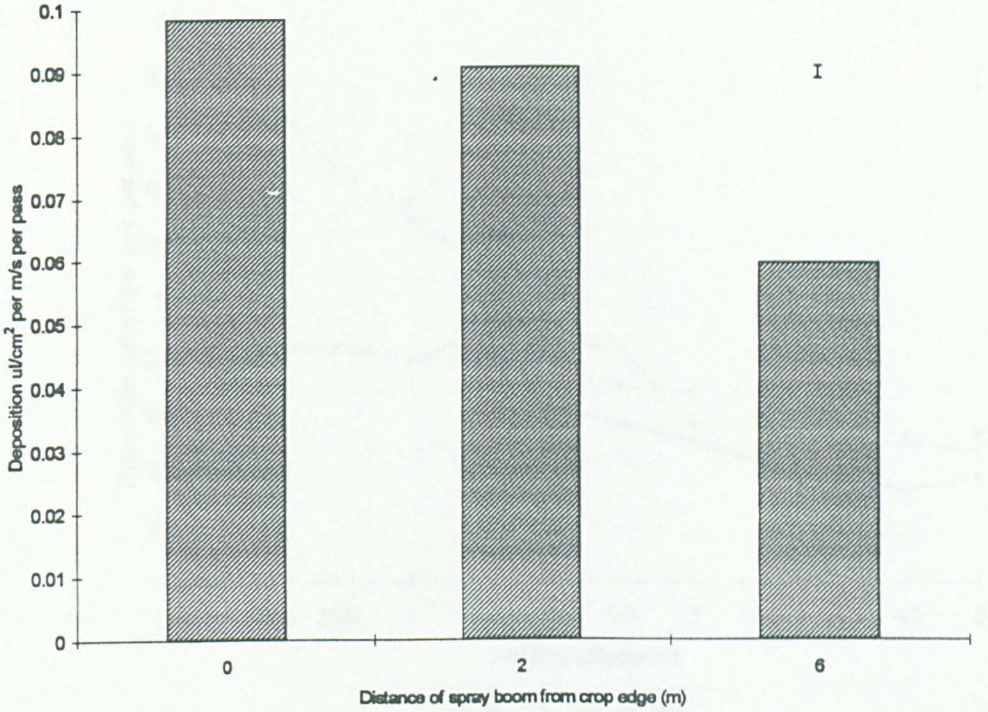


Figure 4.2 Mean volume deposition rate ($\mu l/cm^2$) of spray formulation on pipecleaner collectors placed on masts on windward side of hedge when spray was applied 0, 2 and 6 m away from crop edge (application rate 240 l/ha). Vertical bar represents SE.

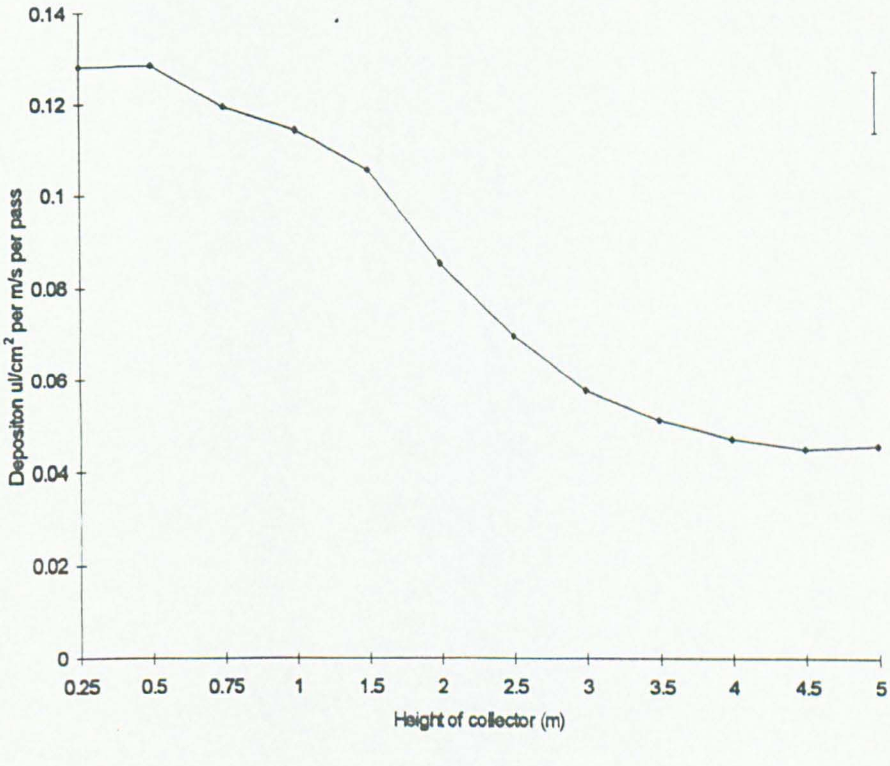


Figure 4.3 Mean volume deposition rate ($\mu l/cm^2$) of spray formulation on pipecleaner collectors placed at different heights along the windward side of the hedgerow. Spray application rate 240 l/ha. Vertical bar represents SE.

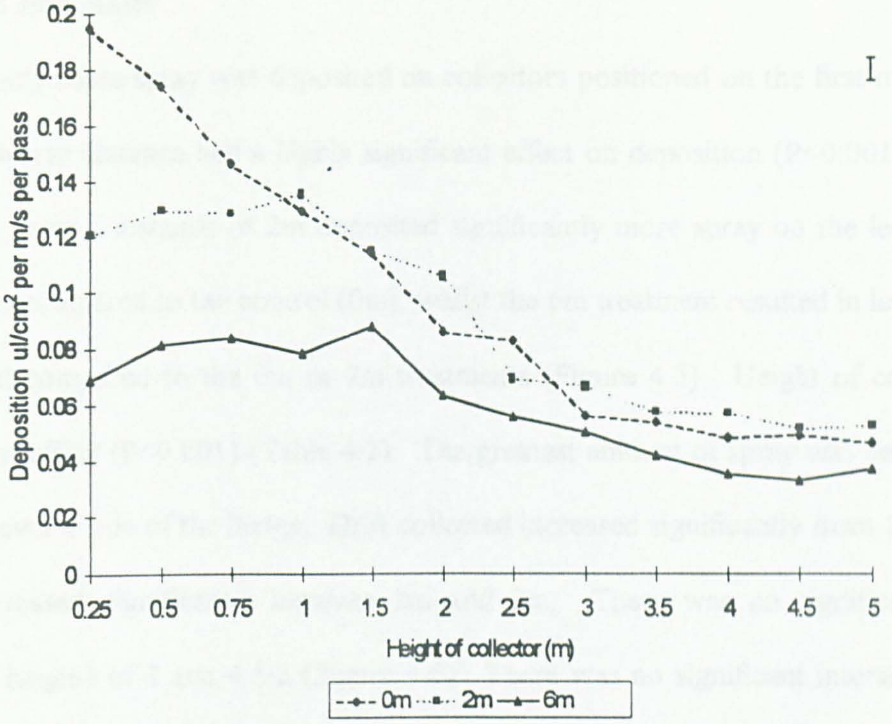


Figure 4.4 Mean volume deposition rate (µl/cm²) of spray formulation on pipecleaner collectors placed at different heights on windward side of hedge when spray applied 0, 2 and 6 m away from the crop edge (application rate 240 l/ha). Vertical bar represents SE.

Leeward side masts

Significantly more spray was deposited on collectors positioned on the first mast ($P<0.05$). Sprayer boom distance had a highly significant effect on deposition ($P<0.001$) (Table 4.2). Spraying from a distance of 2m deposited significantly more spray on the leeward side of the hedge compared to the control (0m), whilst the 6m treatment resulted in less spray being deposited compared to the 0m or 2m treatments (Figure 4 5). Height of collector had a significant effect ($P<0.001$) (Table 4.2). The greatest amount of spray was deposited at 2m on the leeward side of the hedge. Drift collected increased significantly from 1m to 2m, and then decreased significantly between 2m and 3m. There was no significant difference between heights of 3 and 4.5m (Figure 4.6). There was no significant interaction between sprayer distance and height of collector on the leeward side of the hedge.

Table 4.2 ANOVA table for leeward masts.

Source	df	F value	Probability
Replicate	2	4.57	P<0.05
Distance from sprayer	2	35.15	P<0.001
Height of collector	8	16.48	P<0.001
Distance x Height	16	0.96	n.s.
Residual	133		
Total	161		

A one way analysis of variance showed that significantly more drift was deposited on the windward side of the hedge than the leeward side ($F_{1,371}=15.01$, $P<0.001$) (Figure 4.7).

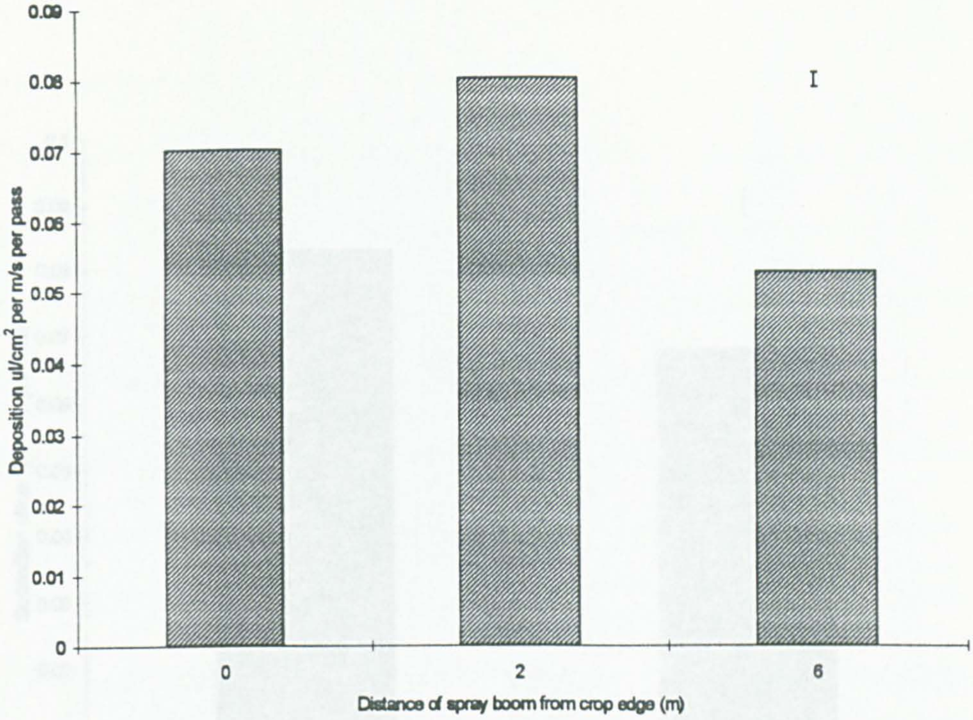


Figure 4.5 **Mean volume deposition rate (μl/cm²) of spray formulation on pipecleaner collectors placed on masts on leeward side of hedge when spray was applied 0, 2 and 6 m away from crop edge (application rate 240 l/ha). Vertical bar represents SE.**

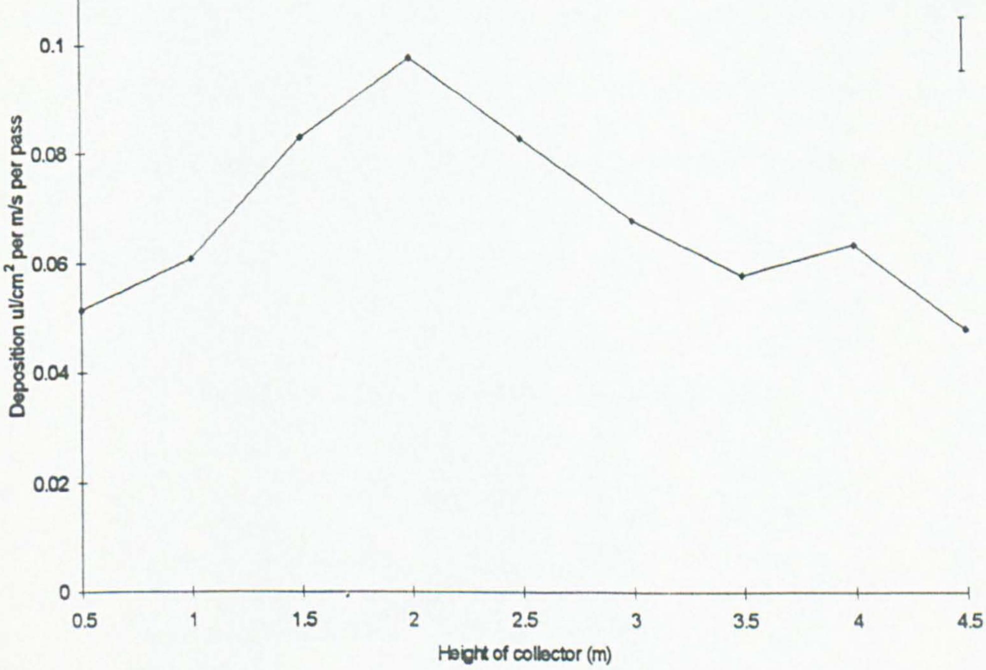


Figure 4.6 **Mean volume deposition rate (μl/cm²) of spray formulation on pipecleaner collectors placed at different heights along the leeward side of the hedgerow. Spray application rate 240 l/ha. Vertical bar represents SE.**

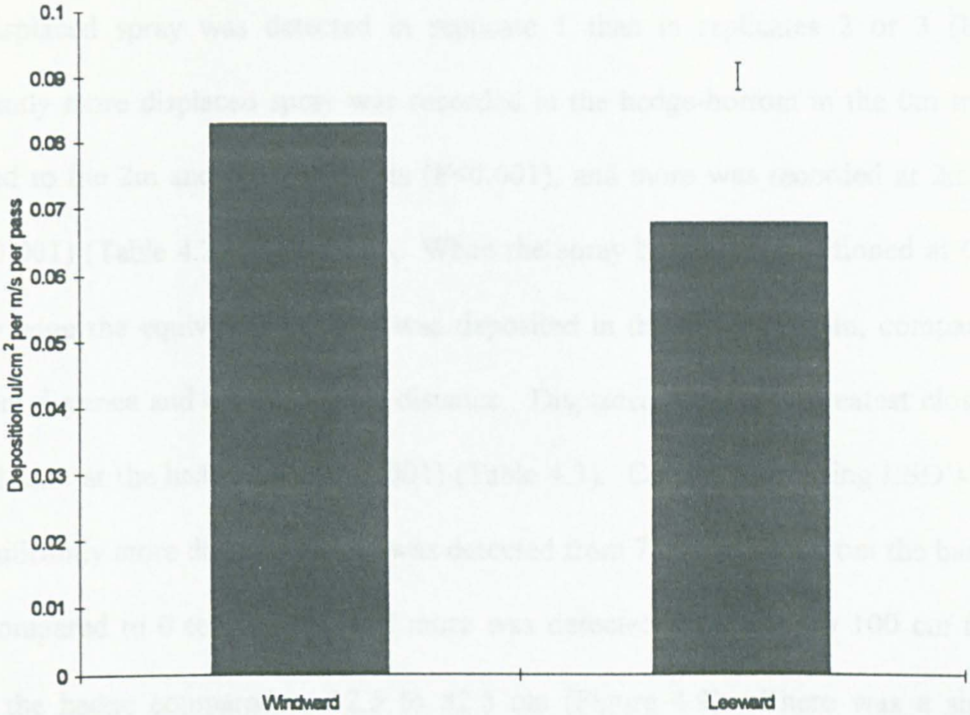


Figure 4.7 Mean volume deposition rate ($\mu l/cm^2$) of spray formulation on pipecleaner collectors placed on windward and leeward sides of hedge (application rate 240 l/ha). Vertical bar represents SE.

4.3.2 Displaced Spray

More displaced spray was detected in replicate 1 than in replicates 2 or 3 (P<0.01). Significantly more displaced spray was recorded in the hedge-bottom in the 0m treatment compared to the 2m and 6m treatments (P<0.001), and more was recorded at 2m than at 6m (P<0.001) (Table 4.3) (Figure 4.8). When the spray boom was positioned at 0m from the crop edge the equivalent of 9l/ha was deposited in the hedge-bottom, compared to 4 l/ha at 2m distance and 0.9 l/ha at 6m distance. Displaced spray was greatest close to the field and least at the hedge base (P<0.001) (Table 4.3). Comparisons using LSD's showed that significantly more displaced spray was detected from 75 to 100 cm from the base of the hedge compared to 0 to 12.5 cm, and more was detected from 82.5 to 100 cm from the base of the hedge compared to 12.5 to 82.5 cm (Figure 4.9). There was a significant interaction between spray boom distance and position in hedge-bottom (P<0.001) (Table 4.3). From 0 to 37.5 cm from the base of the hedge there were no differences between treatments, but between 37.5 and 62.5 cm, significantly less displaced spray was recorded in the 6m treatment compared with the 0 and 2m treatments, whilst between 62.5 and 100 cm, significantly more spray was displaced in the 0m treatment compared to both the 2m and 6m treatments, which were not significantly different from each other (Figure 4.10).

Table 4.3 ANOVA table for displaced spray.

Source	df	F value	Probability
Replicate	2	21.89	P<0.01
Distance from sprayer	2	312.26	P<0.001
Position in hedge-bottom	7	24.54	P<0.001
Distance x Position	14	9.62	P<0.001
Residual	46		
Total	71		

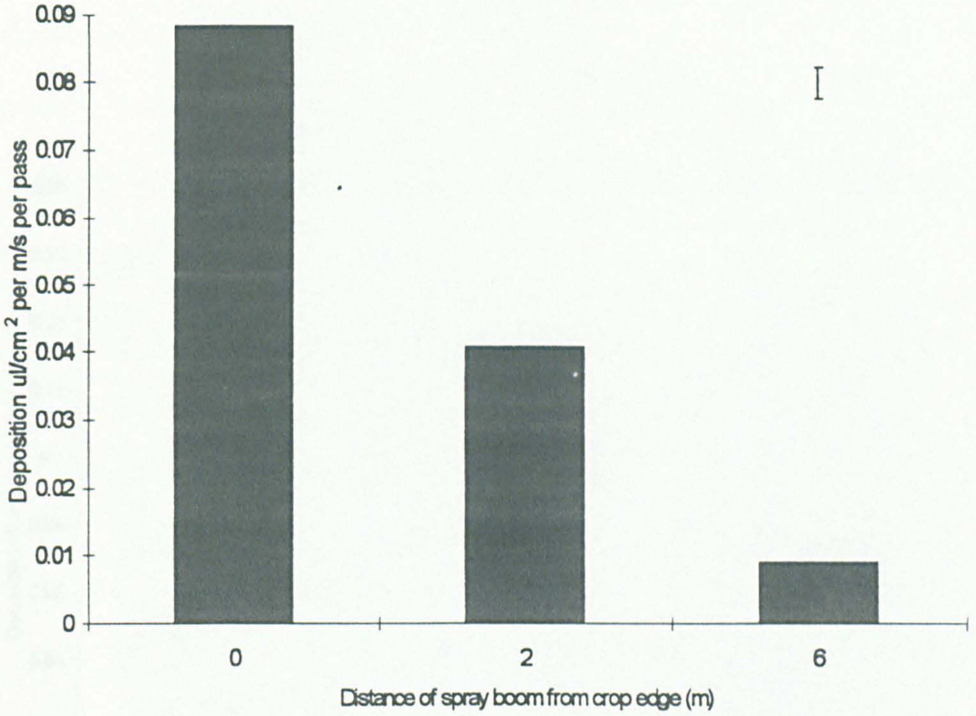


Figure 4.8 Mean displaced spray formulation (μl/cm^2) collected on filter paper strips in hedge-bottom on windward side of hedge when spray was applied 0, 2 and 6 m away from crop edge (application rate 240 l/ha). Vertical bar represents SE.

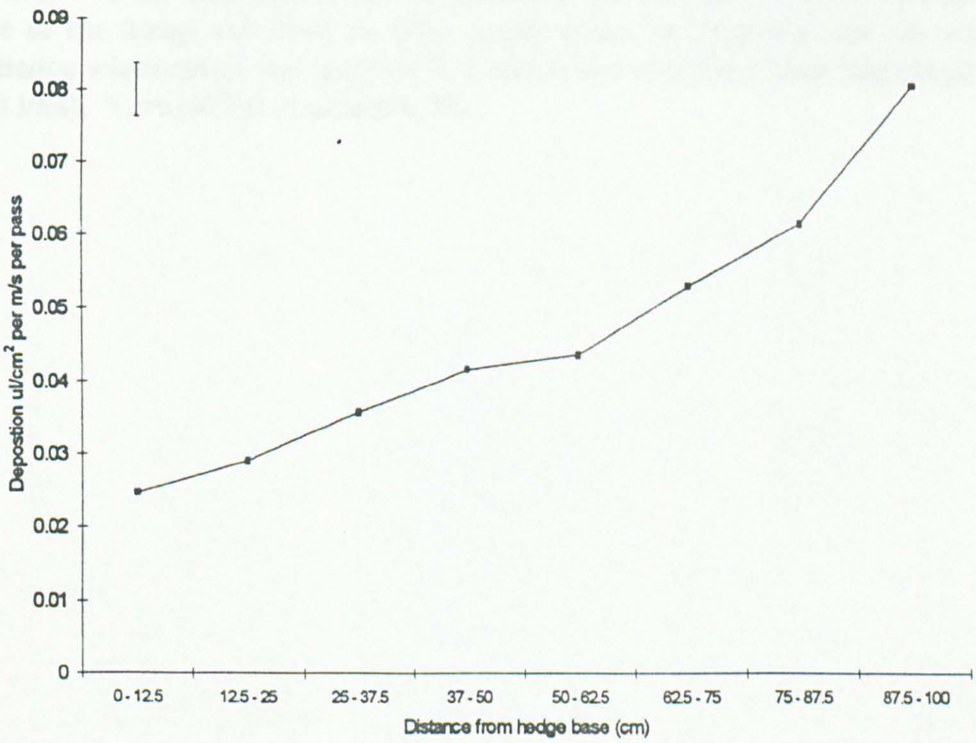


Figure 4.9 Mean displaced spray formulation (μl/cm^2) at different distances from the base of the hedge collected on filter paper strips in hedge-bottom on windward side of hedge (application rate 240 l/ha). Vertical bar represents SE.

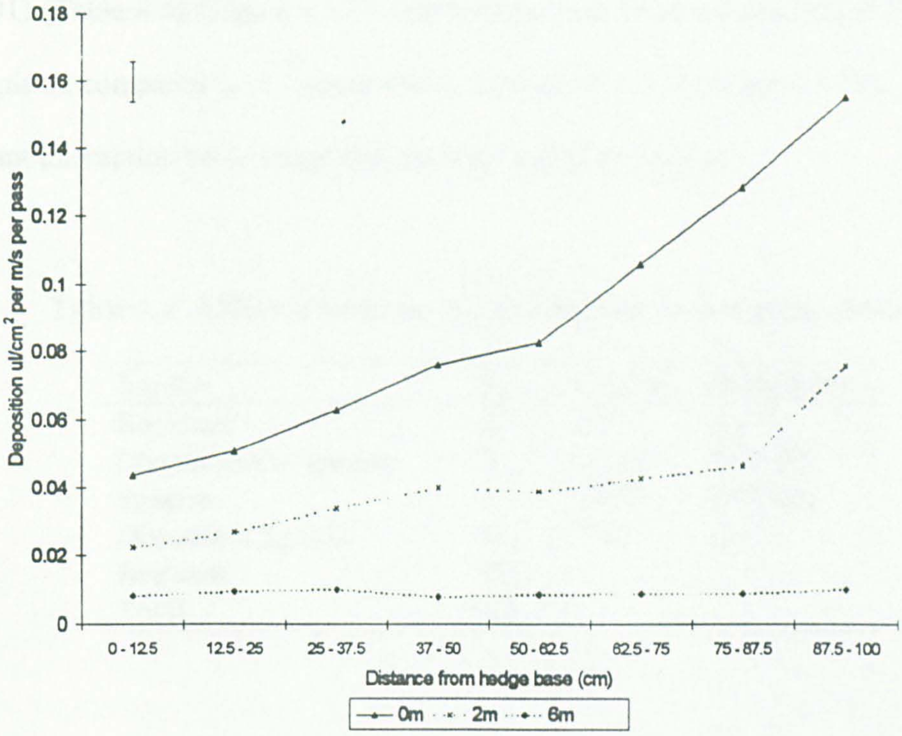


Figure 4.10 Mean displaced spray formulation ($\mu l/cm^2$) at different distances from the base of the hedge collected on filter paper strips in hedge-bottom on windward side of hedge when spray was applied 0, 2 and 6 m away from crop edge (application rate 240 l/ha). Vertical bar represents SE.

4.3.3 Deposition on plants placed in hedge-bottom

More spray was detected on test plants when the sprayer was at 0m compared to 2m or 6m (P<0.001) (Table 4.4) (Figure 4.11). More spray was detected per cm^2 of leaf area on *B. sterilis* plants compared to *A. elatius* and *R. repens* (P<0.001) (Figure 4.12). There was no significant interaction between sprayer distance and plant species.

Table 4.4 ANOVA table for spray detected on test plant species.

Source	df	F value	Probability
Replicate	2	3.57	n.s.
Distance from sprayer	2	24.56	P<0.001
Species	2	13.29	P<0.001
Distance x Species	4	2.44	n.s.
Residual	16		
Total	26		

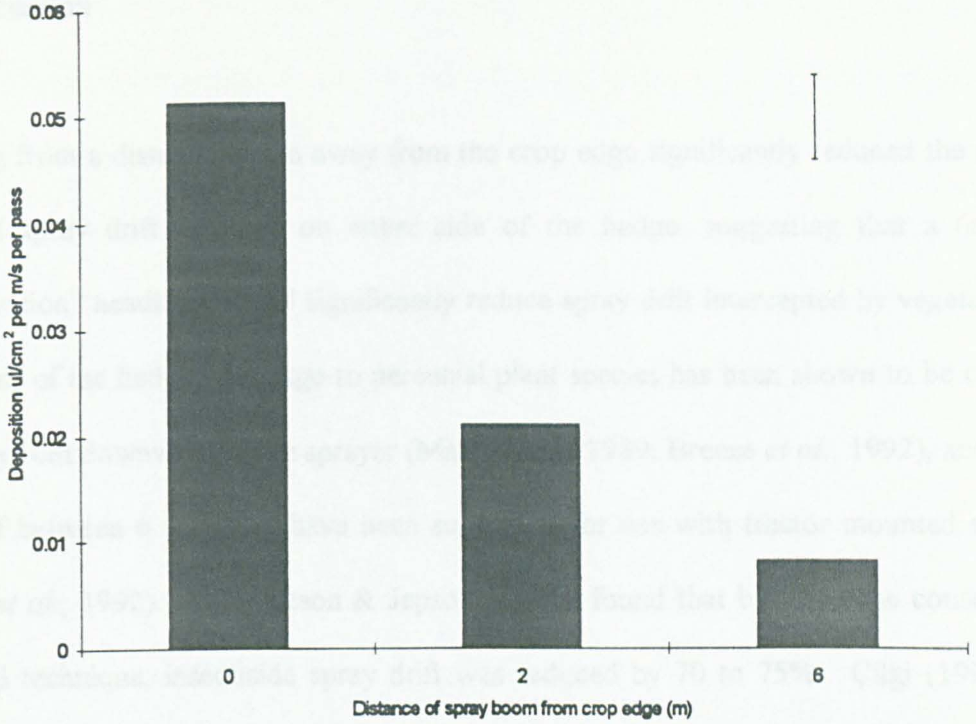


Figure 4.11 Mean deposition rate (µl/cm^2) of spray formulation on plant species in pots placed in hedge-bottom on windward side of hedge when spray was applied 0, 2 and 6 m away from crop edge (application rate 240 l/ha). Vertical bar represents SE.

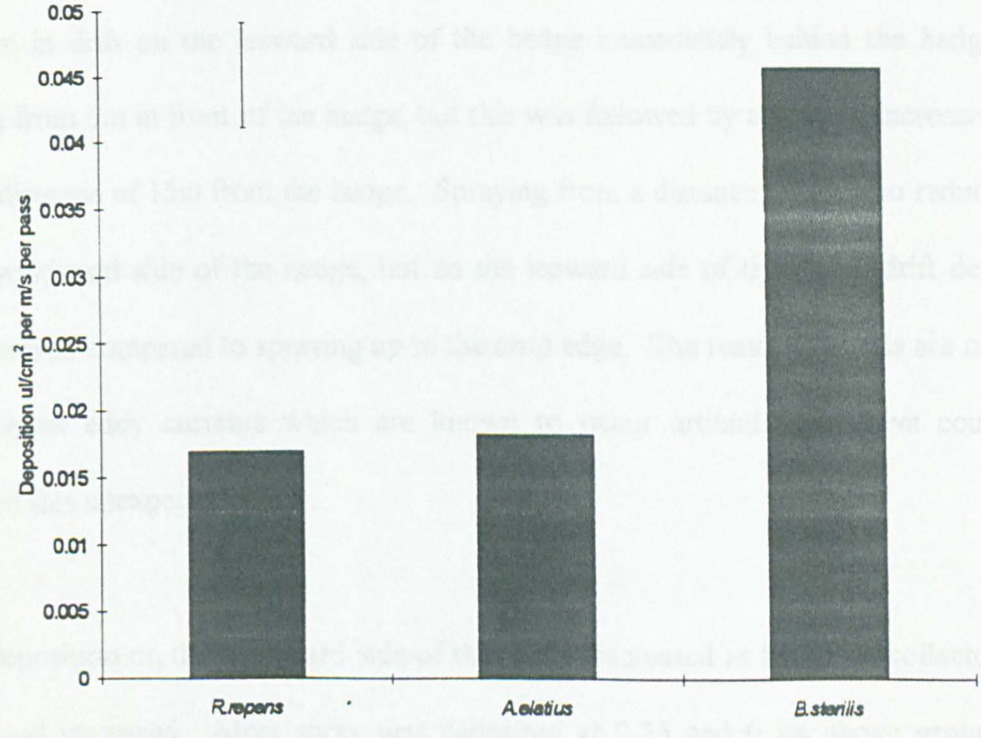


Figure 4.12 Mean deposition (µl/cm^2) on plants of *Ranunculus repens*, *Arrhenatherum elatius* and *Bromus sterilis* grown in pots and placed in the centre of the hedge-bottom on the windward side of the hedge. Means for all sprayer distances. Vertical bar represents SE.

4.4 Discussion

Spraying from a distance of 6m away from the crop edge significantly reduced the amount of aerial spray drift detected on either side of the hedge, suggesting that a 6m wide "conservation" headland would significantly reduce spray drift intercepted by vegetation on both sides of the hedge. Damage to perennial plant species has been shown to be confined to within 10m downwind of the sprayer (Marrs *et al.*, 1989; Breeze *et al.*, 1992), and buffer zones of between 6 and 10m have been suggested for use with tractor mounted sprayers (Marrs *et al.*, 1992). Cuthbertson & Jepson (1988), found that by using the conservation headland technique, insecticide spray drift was reduced by 70 to 75%. Çilgi (1993) also found that a 6m unsprayed zone between the crop edge and the field boundary to reduce the level of pesticide drift into field boundaries. In the current study, simulated herbicide drift was reduced by 39% on the windward side of the hedge, and by 24% on the leeward side, when compared to spraying up to the crop edge. Davis *et al.* (1994) found that there was a reduction in drift on the leeward side of the hedge immediately behind the hedge when spraying from 6m in front of the hedge, but this was followed by a gradual increase in drift up to a distance of 15m from the hedge. Spraying from a distance of 2m also reduced drift on the windward side of the hedge, but on the leeward side of the hedge drift deposition was increased compared to spraying up to the crop edge. The reasons for this are not clear, but complex eddy currents which are known to occur around hedgerows could have produced this unexpected result.

Spray deposition on the windward side of the hedge decreased as height of collector above the ground increased. Most spray was deposited at 0.25 and 0.5m above ground level. Longley *et al.* (1997) found that most insecticide spray drift was deposited at a height of 1m, though a taller crop was present than in the current study (at GS70-79, compared with

GS25), and this may have shielded lower receptors. Boom height used by Longley *et al.* (1997) was also slightly higher, 1.4m compared to 1m, and this may have contributed to the differences in height of maximum deposition in these two studies. The amount of drift collected on the windward side declined rapidly once above the height of the hedge (1.5m).

There was a significant interaction between the distance of the sprayer from the crop edge and the height of the collector on the windward side of the hedge. Less drift was detected at all heights when the spray boom was 6m away from the crop edge, whilst spraying from 2m away reduced drift up to the height of the hedge, but thereafter there was little difference between the 2m and 0m treatments.

On the leeward side of the hedge, most spray was deposited at 2m above ground level (0.5m above the top of the hedge). Receptors below hedge height showed a decrease in deposition. This supports the findings of Davis *et al.* (1994), who found that deposition was reduced at heights of 0.45 and 1m immediately behind a hedge. Deposition tended to decrease above 2m as on the windward side of the hedge.

Overall, significantly more spray was deposited on the windward side of the hedge than the leeward side. Therefore vegetation on the windward side would be more at risk from damage by herbicide spray drift.

Mean displaced spray at ground level showed a similar pattern to spray drift on aerial collectors, in that 6m and 2m buffer zones significantly reduced deposition compared to spraying up to the crop edge. When the spray boom was positioned at 0m from the crop edge, 4% of the field rate was deposited in the hedge-bottom, this was reduced to 2% when spraying from 2m away, and a ten-fold reduction to 0.4% of the field rate was deposited when spraying from 6m away. Nordby & Skuterud (1975) stated that under good spraying conditions, spray drift of up to 6% of the volume applied can be expected, and half of this spray drift may be deposited in a strip 10m wide extending from the end of the spray boom. Significantly more spray was detected at the front of the hedge-bottom, compared to the base of the hedge. This means that vegetation closest to the field would be most at risk from displaced spray, whilst vegetation at the back of the field margin would be less affected. This effect was more pronounced when spraying up to the crop edge, whilst when a 6m unsprayed zone was implemented, displaced spray was fairly constant through-out the hedge-bottom, and at a much lower level. A 2m unsprayed area would appear to offer some protection, but less than a 6m one. The structure of vegetation in a field boundary will affect the quantity and deposition patterns of spray drift. In this study, surrounding vegetation height was relatively short, so later on in the season it could be assumed that even less drift would reach the back of the hedge-bottom, as taller vegetation near the front would capture even more of the drift. Surrounding vegetation height has been shown to have a significant effect on mortality of seedlings placed 5m downwind of drifting herbicide sprays (Marrs *et al.*, 1991a, 1993)

More spray was deposited on plants of *B. sterilis* compared to *A. elatius* and *R. repens*. Narrow structures such as hairs are more effective at trapping spray droplets (Davis & Williams, 1993). Although all three species have surface hairs, *B. sterilis* is much more hairy than the other two, and trapped over twice as much spray formulation. The interception of pesticide drift in different vegetation types is complex, and is often included in drift deposition models as a "roughness factor", and has been shown to increase with increasing vegetation height (Elliot & Wilson, 1983). This suggests that some field margin plant species, especially those with many hairs, or fine leaves and stems, may be more prone to damage from herbicide drift. The original spray volume was 240 l/ha. The equivalent of almost 5 l/ha (2% of field dose) was deposited on the surface of *B. sterilis* plants, and almost 2 l/ha (0.8% of field dose) on *A. elatius* and *R. repens*, and had this been an actual herbicide, this could have delivered enough active ingredient to cause an effect. In the experiment reported in Chapter 3, investigating the effects of nitrogen fertiliser and sub-lethal doses of the herbicide glyphosate on selected field margin species, the lowest rate of glyphosate used was 12.5 % of the field rate, and in some cases, particularly against grasses, this was enough to reduce cover abundance compared to untreated controls. However, lower doses of herbicide were not investigated, so it is not known if an effect would still occur at rates of 2 % of the full dose and below, as deposited on the leaves of test species in this study.

The results of this investigation suggest that by spraying from a distance of 6m away from the crop edge, and to a lesser extent from a distance of 2m, herbicide spray drift into a field boundary can be reduced. However some caution should be used as the experiment was only carried out on one occasion. An attempt was made to repeat the investigation, but this had to be abandoned due to equipment failure.

Chapter 5. General Discussion

5.1 Introduction

This final chapter brings together the results of the preceding chapters which investigated the effects of field margin management practices on crop yield and weed biomass, surveyed crop yields and weed biomass from cereal headlands, examined the effects of fertiliser and herbicide misplacement on field margin plant communities, and measured spray drift into a field boundary. The results are discussed, and suggestions put forward for field margin management procedures.

5.2 Field Margin Management Treatments And Survey Of Cereal Headlands

For farming to be profitable, agricultural crops must be grown at the lowest cost per tonne. This will mean that British agriculture is competitive not only with other European countries, but also on world markets. Crops will continue to be grown using agrochemical inputs, such as pesticides and fertilisers, in order to produce adequate supplies of food of acceptable quality to the consumer. Therefore, because of the limited biodiversity on cropped fields, it is essential to optimise the conservation value of the non-cropped areas on the farm, such as hedgerows, woodlands, ponds, etc., to provide suitable habitats for farmland species.

The adoption of Integrated Crop Management (ICM) by farmers will help to bring about these changes by encouraging the minimal use of pesticides. Choice of chemicals will be made on their environmental profile, and application justified according to thresholds, decision support systems etc. ICM also requires a farmer to carry out a farm audit, identifying the habitats and their conservation value, before preparing a plan for their maintenance and improvement.

Field margins are recognised as one of the important uncropped areas of considerable wildlife potential on farms. ICM advocates a minimum of a one metre strip of perennial species adjacent to the field boundary. What is the economic consequence to the farmer of this strip in terms of crop yield? This question cannot be answered without knowledge of the crop yield adjacent to field boundaries, and the factors affecting crop growth. Results have shown that the yield of cereal crops on the headland area tended to be lower than in the centre of the field, because of increased weed competition and soil compaction. Taking a further 1m out of production, which is an option in the Countryside Stewardship Scheme could reduce overall cereal yields. However, the additional 1m field margin adjacent to the crop could be mown to impede growth of problem annual weeds, such as *G. aparine* and *B. sterilis*, preventing contamination of the crop edge. This would ensure a full yield of cereal crop right up to the field margin and allow the combining to take place without contaminating grain with weed seeds. There would also then be a 1m buffer between the crop and the 1m of uncut perennial vegetation ensuring minimum disturbance to flora and fauna.

Measurements of crop yield and weed dry matter were carried out on plots which had received different field margin management techniques over two cropping seasons. Field margin management treatment did not have any significant effect on cereal yields, and treatments which had 1m taken out of crop production to establish either a sterile, natural regeneration or sown strip, did not produce any less overall yield than those in which the 1m adjacent to the field margin was cropped. This outer 1m of the field is very low yielding, probably due to a number of contributing factors, such as soil compaction, shading from hedge vegetation and weed competition, and any crops grown on this area do not yield productively. Conservation headlands generally contained greater amounts of weed dry matter than fully sprayed headlands, but grain yields were not significantly affected during the period that was monitored, though if weed numbers continued to build up over successive seasons a reduction in yield would eventually occur. However, it is recommended that conservation headlands are rotated round the farm, and so it would be unlikely for them to be sited in the same area over a number of years. The fact that there were few differences in yield between conservation and fully sprayed headlands was probably due to there being relatively few weeds present in the conservation headlands, and those that were present (such as *Capsella bursa-pastoris*, *Myosotis arvensis*, *Polygonum aviculare* and *Tripleurospermum inodorum*) were not particularly competitive towards the crop. Percentage cover data of weed species reflected destructive weed biomass measurements, with more weeds, especially dicot species, occurring in conservation headlands. Conservation headland management did not appear to adversely affect yield in this study, and the benefits of a conservation headland, such as increased game bird chick survival, increased numbers of polyphagous predators, increased butterfly abundance and the possibility for the conservation of rare arable weeds would increase the overall wildlife value of the farm.

Soil compaction affected yield in one of the field experiments, but not the other, where soil density values were fairly uniform. It was originally anticipated that weed amounts would be the major factor affecting grain yield, but this did not appear to be the case, so some other factor, possibly soil compaction, was contributing to reduced yields across the headland. Sparkes *et al.* (1994) who measured soil compaction across headlands, found that yield was reduced in the tramlines where soil density was greatest. No relationship was found between fertiliser application and yield.

Low numbers of seedlings emerging from the seedbank samples collected made statistical analysis invalid. All species found in the seedbank study were also observed in the above ground flora. No rare species were found, and species diversity was low, suggesting that the soil seedbanks at the two sites were relatively impoverished, and typical of much arable land. Any natural regeneration strips developing from this seedbank would be likely to be dominated by a number of undesirable weedy annuals, and a sown strip of perennial wildflowers and grasses would be a better option, both in terms of weed management and wildlife value. The benefits of sterile strips have come under debate recently. Although they are favoured by many farmers as they are thought to provide a "clean edge" to the crop to facilitate combining, they may in fact provide the bare ground needed for germination of annual species such as *B. sterilis*, which can then spread into the crop. Also the distribution of many rare arable weeds is confined to the area close to the field margin (Wilson & Aebischer, 1995). The presence of a herbicide sprayed sterile strip in this area would have severe implications for the survival of endangered weed species.

The survey of cereal headlands used a multivariate approach to investigate a number of different factors which might affect crop yield from headland areas. Distance from the field boundary was the most important factor affecting yield which was measured in the survey. Where yield increased with distance, there was a strong linear relationship with log distance, which showed no sign of reaching an asymptote up to 30 m from the crop edge, suggesting that yields were reduced even this far out into the field. Several other studies have shown yields from crop margins to be lower than from the rest of the field (e.g. Boatman, 1992; Boatman & Sotherton, 1988; de Snoo, 1994), and where yields have been measured at different distances into the field there has been a general trend for yields to increase with distance (Speller *et al.*, 1992; Sparkes *et al.*, 1994). Unfortunately soil compaction was not measured in the survey, but it could also have contributed to this effect, as Sparkes *et al.* (1994) found that soil compaction was lower in the main area of the field, away from headland areas used for turning of farm machinery.

Weed dry matter was related to distance, and there was a significant relationship between weed dry matter and grain yield in the first year of the survey. Negative relationships between yield and weeds have been reported elsewhere (e.g. Boatman, 1992; Christensen, 1994). The greater prevalence of weed dry matter at crop edges may be contributing to lower cereal yields, however, other factors such as poor crop establishment caused for example by soil compaction, could encourage growth of weed seedlings.

5.3 Fertiliser And Herbicide Misplacement

Communities of herbaceous field margin species were established, and the effects of nitrogen fertiliser and sublethal glyphosate application were examined over two years.

As in a typical old-field succession pattern (Bazzaz, 1968), annuals were the dominant vegetation type during the first year of monitoring, but by the second year, perennials recorded the greatest amount of cover. Cover abundance of grass species was greater than that of dicotyledonous species throughout the experiment, but by the final sample date in August 1996, there was little difference between the two, though all species were naturally senescing by this time. In the second year of monitoring, nitrogen fertiliser application increased the cover abundance of grasses, particularly the perennial species *A. elatius* and *E.repens*. Fertiliser has been shown to increase cover of grasses at the expense of dicotyledonous species in other studies, for example in the Park Grass experiment (summarised by Tilman *et al.*, 1994), and on hay meadows (Mountford *et al.*, 1993). *B.*

sterilis was the most abundant species in 1995, but by 1996 it had been replaced by *A. elatius*. Studies of grassland communities have shown that fertiliser application can cause rapid shifts in vegetation composition (e.g. Tilman, 1988). An increase in nutrient resources can lead to an increased biomass production and subsequently an increased competition for light (Wilson & Tilman, 1993). *A. elatius*, which became the most abundantly recorded species in 1996 is efficient at competing for nitrogen (Berendse *et al.*, 1992), and being the tallest of the six sown species, was also more effective at competing for light than the other species. Fertilisation is known to lead to a decrease in species diversity in grassland ecosystems (Tilman, 1988; Mountford *et al.*, 1993). In this study, none of the sown species became extinct during the time that monitoring occurred, though it is probable that the prostrate growing *R. repens*, which was only present in low numbers throughout the experiment, would be increasingly unable to compete for resources, particularly light, with the dominant, taller grass species

Increasing levels of fertiliser generally had a negative effect on total vegetation cover in 1995, probably due to individual plants lodging. However, in the first few months of sampling in 1996, fertilised plots had a greater cover abundance than unfertilised ones. During the second year, fertiliser application increased the cover abundance of the dominant perennial species, *A. elatius*, and also to a lesser extent the annuals *B. sterilis* and *G. aparine*.

Sublethal doses of the herbicide glyphosate significantly reduced total cover abundance, mainly at the highest application rate, and appeared to have a greater effect on grasses compared to dicot species. Where the highest dose of herbicide had been applied, gaps in the perennial vegetation were created by the reduction in cover of grass species, which then allowed *G. aparine* to germinate. Glyphosate is a broad-spectrum herbicide and when applied at full rate is effective in controlling both grasses and dicotyledonous species, though at the sub-lethal dose rates used it appeared to be more effective against grass species. In a normal field boundary, plants are likely to experience drift from a range of herbicide types, which could affect different species in various ways. In this experiment, the vegetation was only exposed to herbicide drift once a year, but in many field boundaries, plants may be exposed to herbicide drift on more than one occasion. Measurement of spray drift into a field boundary showed that field margin vegetation would be at risk from spray drift, especially if no buffer zone was used between the field margin and the crop.

The field margin communities that were created were not as greatly influenced by the effects of fertiliser and herbicide as had been anticipated. This may have been because the species that were sown are commonly found in today's impoverished field margins, and have through selection pressure, become adapted to tolerate fertiliser and herbicide application. If some of the less common (more desirable) field margin species had been used, and if a greater number of species had been sown, the outcomes may have been different. The effects of mechanical disturbance and cutting were not included in this experiment, and they could also affect the species composition of field margins.

5.4 Herbicide Spray Drift

Measurement of simulated spray drift into a hedgerow showed that by positioning the end of the spray boom either 2m or 6m away from the crop edge, a significant reduction in drift into the hedge-bottom was achieved on both sides of the hedge, though this effect was greatest when spraying from 6m away. Under the Countryside Stewardship scheme (MAFF, 1996) there are options for 2m and 6m wide uncropped strips to be established alongside arable field margins. These would help to reduce the amount of spray drift reaching hedge-bottom vegetation. On sandy and calcareous soils a 6m wide conservation headland must also be used alongside the uncropped area when the field is cropped with cereals, and this would reduce the amount of drift by an even greater amount.

5.5 Conclusions

Much of the wildlife interest in arable areas is found at the field edges. Taking a small area out of production at the edge of the field would not significantly reduce yields, as this part of the field tends to be lower yielding than other areas due to factors such as soil compaction and increased weed competition. There were no significant differences on crop yield when sited next to either a sterile strip, a natural regeneration strip or a sown strip. A sterile strip would need to be maintained regularly to prevent weed ingress into the crop. This could be done either by cultivation or using a herbicide application to keep the strip weed free, and if herbicides are used there is a risk of drift occurring. Where there is already a diverse flora within the field margin, natural regeneration of the strip area may be a suitable option. However, in many cases a wildflower mixture may be the most viable option of establishing a suitable perennial flora, especially when coupled with selective herbicide use (e.g. Marshall & Nowakowski, 1995; Smith & Macdonald, 1992). If sown vegetated strips were implemented rather than sterile ones they would also attract a range of animals including invertebrates, birds and mammals. Conservation headland management did not result in significantly lower yields than fully sprayed headlands, and would also be beneficial to insects, game birds, and rare arable weeds.

Spray drift into hedge-bottom vegetation would be likely to affect some species more than others, but should be avoided as it creates gaps in the perennial vegetation which allow for the establishment of pernicious annuals such as *G. aparine* and *B. sterilis*, which have the potential to become serious field weeds. Spraying from a distance of 6m from the crop edge (e.g. as in a typical conservation headland) would significantly reduce drift into field margins.

The present study indicates that specific field margin management can offer benefits to wildlife through reducing agrochemical misapplication, and by creating a suitable habitat of perennial vegetation, without having detrimental effects on crop yields, and can be integrated into overall farm management, especially with the aid of schemes such as the Countryside Stewardship arable field margins option.

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