Pesticides Research Nr. 58 2002
Bekæmpelsesmiddelforskning fra Miljøstyrelsen

Effects of reduced pesticide use on flora and fauna in agricultural **fields**

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Preface and Acknowledgements

In 1995 the Danish Ministry of Environment and Energy called for projects, which should elucidate possible effects on flora and fauna of reducing pesticide dosages experimentally at large scale. The present project was successful in the tendering.

The project was first designed in 1995 and further elaborated after a pilot phase in 1996 by the partners below who also executed the practical part of the project. It included the three main areas, botany, entomology (arthropods), and ornithology and in a addition supporting disciplines such as yield estimation, economic aspects and statistics. The project was initiated with a pilot year on one farm in 1996 and had its main period of practical work on five farms 1997-98-99 The finalization of sampling and counting took place in late summer and autumn 1999, ending with assessments of accumulated weed problems and occurrence of birds on stubble fields. The treatment of data and statistical analyses were finalized in 2001.

The Partners and assisting partners of the project were:

Botanical aspects: Dept. of Physiological Ecology, Botanical Institute, University of Copenhagen (Anne-Mette M. Jensen and Ib Johnsen)

Entomological aspects: Zoology Section, Dept. of Ecology, Royal Veterinary and Agricultural University (Peter Esbjerg and Søren Navntoft)

Ornithological aspects: Ornis Consult A/S (Bo Svenning Petersen)

Yield effects: The Danish Agricultural Advisory Centre (Hans Kristensen and Poul Henning Petersen)

Economic aspects: Economy Section, Dept. of Economy, Forestry and Landscape, Royal Veterinary and Agricultural University (Clemen Rasmussen and Svend Rasmussen)

Statistical advice: Section of Mathematics and Statistics, Dept. of Mathematics and Physics, Royal Veterinary and Agricultural University (Ib Skovgaard et al.)

Project coordination: Center for Ecology and Environment / Dept. of Ecology, Royal veterinary and Agricultural University (Peter Esbjerg)

Further the project has been assisted in assessments of annual yield reductions and of final weed accumulation by "The foundation for Sugar Beet Research", Alstedgaard, (Jens Nyholm Thomsen), "Syd-Østsjællands Landboforening" (Jørgen Dabelsteen and Niels Skov) and "Køge-Ringsted Landboforening " (Morten Nygaard).

For the practical execution of the project it was necessary to find landowners with suitable fields and crops. Among a rather limited number suitable of

farms with suitable fields the owners and managers of the five listed below accepted the contract based collaboration.

Gjorslev Estate, Landowner Peter Tesdorf and Chief Manager J. Klith Jensen
Lekkende Estate, Landowner Andreas Hastrup
Nordfeld Estate, Landowner Jens K. Haubro
Nybøllegård, Landowner Thomas Christfort
Oremandsgård Estate, Landowner Daniel Hage and Manager Mogens Tved

The above landowners and managers are thanked for their collaboration without which the project could not have been carried out. Thanks are also due to all other assisting organizations and persons who contributed to a multifaceted project like this.

Furthermore thanks are due to the below members of the steering committee of the project:

Henning Clausen, Inge Vibeke Hansen, Jørn Kirkegaard and Kaj Juhl Madsen, Danish Environmental Protection Agency
Niels Elmegaard, National Environmental Research Institute, Silkeborg
Chris Topping, National Environmental Research Institute, Kalø
Jørgen Jakobsen and Jesper Rasmussen, Danish Institute of Agricultural Sciences, Flakkebjerg

Summary and conclusions

This report presents the results of investigations of responses of wild flora, insects and birds in arable fields to reduced dosages of pesticides. The investigation was related to the Danish Pesticide Action Plan I (1987-96) and complied with requests from the financing Ministry of Environment and Energy as regards large scale, three dosage levels and technical readiness for practical implementation. The studies were carried out in 1996 (pilot study at one farm) and 1997-99 (main study at five farms). All farms were situated on clay soils in southeastern Denmark.

Hosting was contracted with five large farms with spring barley, winter wheat and sugar beets as crop rotation. The two cereal crops differ in structure and cover the major part of Danish arable land, while sugar beet is a row crop with built-in problems due to lack of competitiveness. All study fields were sufficiently large to include three dosage plots of 6 hectares or more. In these plots, herbicides and insecticides were applied at normal, half and quarter dosages whereas fungicide dosages were not reduced. The pesticides used and the dosage level defined as normal were at each occasion decided upon by the farmer, based on his experience. From a scientific point of view this was inconvenient, but anything else would have been meaningless due to local variations of the weed problems. In this way also the request for practical implementation was met. In the pilot study, broad swath application of reduced dosages in sugar beets led to unacceptable amounts of weeds. Therefore band spraying was used to obtain the two reduction levels in the main study. As a supplementary weeding, mechanical hoeing was carried out on the farmer's decision.

The number of weed species present was determined before and after herbicide applications, and weed densities and phenology were recorded. Also the seed rain was studied. Sampling of insects was performed every 7-10 days from mid-May to mid-August using a 4WD-tractioned vacuum sampler and supplementary pitfall trapping in fenced sub-plots was carried out in wheat. Within the same period, birds were censused and their location within the fields recorded every five days. A combination of point counts and line transects was used. As a supplement to the biological investigations, crop yields were determined.

Weed densities after spraying differed significantly between dosages, with 30 plants/m^2 at normal, 48 plants/m^2 at half and 55 plants/m^2 at quarter dosage. Besides there was a considerable difference between crops: 84 plants/m^2 in barley, 32/m^2 in sugar beets and 28/m^2 in wheat. Species richness tended to increase with decreasing dosage (significant in barley only) and rare and scarce species occurred more frequently at reduced dosages. The proportion of flowering species increased with decreasing dosage, and there were indications of increased seed production at quarter dosage.

Insect abundance generally increased at reduced dosages. This was very clear in barley while the picture was slightly obscure for wheat and sugar beets if narrow taxonomic units were considered. An overall analysis of non-carnivores and carnivores in the three crops strongly supported the improvement at quarter dosage. More specifically, higher densities of beneficial insects were found at quarter. Aphids were also more numerous at this dosage level but did not occur in densities of economic importance. Combined analyses showed some correlation between plant and insect abundances. This was clear among others for selected herbivorous weevils and larvae of moths.

The bird counts revealed a change from uniform distribution early in the season towards concentration in plots with reduced treatments. Skylarks, Whitethroats and “small seed-eaters” (Yellowhammer, Linnet etc.) all responded significantly to dosage reductions. The effect was most pronounced for species that breed in hedgerows and search their food in the fields. In July the number of Whitethroat records doubled at quarter dosage while small seed-eaters increased by 50% and Skylarks by 20-25% relative to normal dosage. The effect of half dosage was less clear, but the estimates indicate that half of the improvement at quarter dosage was also obtained at half dosage. The effect of reduced dosages was independent of crop and year.

In cereals, yield was significantly reduced in 3 of 64 cases, always at quarter dosage. Sugar beet yields were reduced in 5 of 32 cases; three at quarter dosage and two at half. The average yield in sugar beet varied much more than in cereals and at one farm the revenue was impaired by 11-27%. Despite this, profitability analyses indicate that pesticide reductions as used here generally have a very limited economic impact, at least on short term. Effects not properly covered are the risk of accumulated weed problems by continuous use of reduced dosages and possible adjustment costs associated with new growing conditions.

In conclusion, both reductions to half and quarter dosages of herbicides and insecticides improve the “nature element” of the fields. The gain at quarter dosage is much more marked than the gain at half. However, use of half dosage will only create negligible, if any, agricultural problems, especially if supplementary control of particular weed patches is carried out. General use of quarter dosage may be more problematic in this respect. Only longer time series can support a more conclusive picture, and the possible side effects of increased mechanical weeding also call for more attention.

Sammenfatning og konklusioner

Rapporten beskriver resultater fra fire års undersøgelser af, hvordan reduceret anvendelse af pesticider påvirker flora og fauna i det danske agerland. Projektet har fra begyndelsen været knyttet til Pesticidhandlingsplan I (1987-1996) og de tilhørende ønsker om at dokumentere mulige effekter af denne plans reduktionsmål. Projektet har fulgt Miljøstyrelsens ønsker om forsøg i stor skala og med et indhold og en metodik, der gør resultaterne umiddelbart relevante for praktisk landbrugsdrift. Undersøgelserne er finansieret af Miljøstyrelsen og er gennemført i et samarbejde mellem Den Kongelige Veterinær- og Landbohøjskole, Københavns Universitet og Ornis Consult.

Formålet med undersøgelserne var at belyse effekterne på vilde planter, insekter og fugle – og deres økologiske samspil – i landbrugslandet, når doseringerne af herbicider og insekticider blev reduceret til halvdelen og en fjerdedel af det normale. Efter et pilotforsøg i 1996 blev undersøgelserne gennemført i 1997-1999 på fem store landbrug på Sydsjælland og Møn.

Undersøgelserne blev gennemført i vårbyg, vinterhvede og sukkerroer. De to kornafgrøder, byg og hvede, dominerer det danske agerland, men adskiller sig med hensyn til fænologi, ukrudts- og insektproblemer. Sukkerroer blev medtaget som rækkeafgrøde med dertil knyttede ukrudtsproblemer og særlige fuglefauna pga. det åbne areal mellem rækkerne.

På hvert af de fem landbrug udvalgtes tre marker på minimum 18 hektar, der indgik i ovennævnte sædskifte. Hver af de 15 marker blev ved forsøgets start opdelt i tre parceller på minimum 6 hektar. Disse blev gennem de tre forsøgsår konsekvent behandlet med henholdsvis normal, halv og kvart dosering af herbicider og insekticider, men blev herudover som grundprincip behandlet ens. De anvendte midler og den ”normale” dosering blev i hvert tilfælde valgt af den stedlige driftsleder ud fra vurdering af det konkrete behov. Dette var umiddelbart problematisk ud fra videnskabelige standardiseringshensyn. Imidlertid gav kun denne fremgangsmåde mening i praksis, da især ukrudtsproblemerne kunne variere meget fra sted til sted. I sukkerroer blev reduktionen af doseringerne gennemført ved båndsprøjtning med henholdsvis halv og kvart båndbredde. Herudover blev radrensning foretaget i det omfang, driftslederen anså for påkrævet.

Analyserne af ukrudtsfloraen omfattede registrering af arter og deres tæthed i prøvefelter før og efter pesticidbehandling. Desuden blev floraens fænologi undersøgt. Endelig foretoges undersøgelser af frøregnen fra ukrudtsfloraen i to efterår (1998 og 1999). Forekomsten af planter blev primært opgjort som antallet af vilde plantearter og deres tæthed, og kun i pilotåret blev der foretaget bestemmelse af dækningsgrad og biomasse. Frøregnen blev bestemt ved standardiseret sugning af jordoverfladen efterfulgt af frøbestemmelse under stereolup.

I insektdelen blev undersøgt, i hvilket omfang reducerede doseringer af pesticider påvirker mængden af insekter. Der blev specielt fokuseret på naturlige fjender af skadedyr og på vigtige fuglefødeemner. Insektmængden blev bestemt ved, at der i hver afgrøde indsamledes prøver med en 4WDtrukket maskine til sugeprøvetagning (figur 3.2). Der blev i hvede desuden benyttet faldgruber (plasticbægre nedgravet i niveau med jordoverfladen) til indsamling af især løbebiller på afgrænsede arealer. Herudover blev bladlusangreb optalt i marken. Efter indsamling blev insekterne identificeret, optalt og totalvægten beregnet. Antal og totalvægt blev brugt som mål på forskelle mellem doseringer.

De ornitologiske undersøgelser skulle belyse, om fuglene foretrak parceller med reducerede pesticidbehandlinger. Fuglene i forsøgsparcellerne blev i alle årene optalt ca. hver femte dag i perioden maj-juli. Ved hvert besøg gennemførtes optællinger formiddag og eftermiddag med to forskellige teknikker, rettet mod forskellige arter. Herudover blev fuglenes fordeling på de afhøstede marker undersøgt i efterårene 1998 og 1999, ligesom forekomsten blev undersøgt i vinteren 1997-98.

I byg og hvede gennemførtes standardiserede udbytteforsøg i lille skala for at belyse, i hvilket omfang reduktionen af pesticiddoseringerne påvirkede udbyttet. Med samme formål blev der i roer foretaget standardiserede prøveoptagninger med efterfølgende bestemmelse af udbytte. Efter afslutningen af det sidste forsøgsår blev samtlige forsøgsmarker gennemgået med henblik på at vurdere, i hvilket omfang der var sket en akkumulation af ukrudtsproblemer i perioden med reducerede doseringer.

Som storskala-forsøg har projektet arbejdet med meget store datamængder, men også med betydelige variationer mellem lokaliteter, marker, afgrøder og anvendte pesticider. Fordelen ved dette design er, at resultaterne må antages at have stor generaliseringsværdi. Ulempen er, at der kun i ringe omfang opnås en dybere forståelse af de processer, der ligger til grund for resultaterne. Ændringerne i forekomsten af planter, insekter og fugle samt de mulige årsager hertil er derfor behandlet på et ret overordnet plan. Dette gælder også konsekvenser for udbytter og driftsøkonomi.

De botaniske undersøgelser viste, at ukrudtstætheden efter sprøjtning ændrede sig signifikant med aftagende dosering, fra 30 planter pr. m^2 ved normal dosering til 48 planter pr. m^2 ved halv dosering og 55 planter pr. m^2 ved kvart dosering. Der fandtes store forskelle i ukrudtstæthed mellem afgrøderne, med gennemsnitligt 84 planter pr. m^2 i vårbyg mod henholdsvis 32 og 28 planter pr. m^2 i roer og vinterhvede. Ukrudtstætheden før sprøjtning over de tre år var uforandret uanset dosering, så der kunne ikke ses nogen generel, akkumuleret effekt af dosisreduktionerne. Følgende arter/slægter var de hyppigste i markerne: Ager-stedmoderblomst, Enårig Rapgræs, Ærenpris sp., Vej-pileurt og Tvetand sp. De hyppigste arter var samtidig de dominerende med hensyn til tæthed. For to tredjedele af de dominerende ukrudtsarter steg gennemsnitstætheden med aftagende dosering. Sjældnere arter som Liden Vortemælk og Nat-limurt viste også en større tæthed med aftagende dosering.

I alt 85 ukrudtsarter blev fundet i forsøgsfelterne. I så godt som alle tilfælde øgedes antallet af ukrudtsarter signifikant med aftagende dosering (figur 2.10), og sjældne og fåtallige ukrudtsarter var mere talrige ved reducerede doseringer. I gennemsnit øgedes artsantallet med 16% ved reduktion fra normal til halv dosering og med 28% ved reduktion til kvart dosering. Der skete ingen ændring i antallet af arter pr. parcel i løbet af forsøgsperioden, hverken før eller efter sprøjtning. De dominante ukrudtsarter var de samme for de enkelte marker uanset afgrøde.

Andelen af arter, der blomstrede, steg med aftagende dosering, og der var signifikant forskel på normal og kvart dosering. Også andelen af blomstrende individer af de enkelte arter tiltog med aftagende dosering i kornafgrøderne. I roer var det modsatte tilfældet, utvivlsomt pga. radrensningens supplerende effekt på ukrudtsplanterne. Studierne af frøregn i kornafgrøderne antydede en øget frøsætning ved kvart dosering, men der var ingen signifikante forskelle mellem doseringerne på antal og biomasse af de fundne ukrudtsfrø. Ligeledes sås ingen kumulativ effekt fra 1998 til 1999.

Insektlivet udviste generel fremgang som effekt af nedsatte pesticiddoseringer. Der var dog en betydelig forskel på effekten i de tre afgrøder. De største forskelle mellem doseringer fandtes i byg, hvorimod effekten i hvede og roer var væsentlig mindre. Samtidig observeredes et noget varierende udslag på specifikke insektgrupper. Imidlertid viste en sammenfattende analyse af rovlevende og ikke-rovlevende insekter meget entydig fremgang ved kvart dosering (tabel 3.11). Der blev bl.a. fundet en større mængde af nyttedyr, f.eks. mariehøns og løbebiller ved mindre sprøjtning, men samtidig blev der observeret en stigende mængde bladlus ved lavere doseringer.

Der er klare tegn på, at effekten skyldtes en kombination af nedsatte doseringer af insektgifte og en øget og mere varieret forekomst af ukrudt. Korrelerende analyser mellem planter og insekter viste en vis sammenhæng mellem de to biologiske niveauer. På trods af nogen usikkerhed fandtes flere signifikante korrelationer mellem forekomsten af ukrudt og flere planteædere, bl.a. sommerfugle og snudebiller. Den øgede ukrudtsfauna har, udover en effekt i form af en øget fødemængde, sandsynligvis også en effekt på mikroklimaet til gavn for specielt tørkefølsomme insekter.

De ornitologiske undersøgelser viste, at fuglene i maj var nogenlunde jævnt fordelt, men i løbet af sommeren koncentreredes i de parceller, der var behandlet med reducerede doseringer, især kvart dosering. Tre arter/grupper (Sanglærke, Tornsanger samt gruppen ”små frøædere”) var langt de hyppigst registrerede og de eneste, hvis forekomst blev analyseret statistisk. Alle tre viste signifikante forskelle mellem doseringer; men de klareste effekter fandtes hos de arter, der yngler i de omgivende hegn og primært udnytter markerne til fouragering.

I juli blev der registreret 20-25 % flere Sanglærker, 50% flere små frøædere og 100% flere Tornsangere i parcellerne med kvart dosering end i parcellerne med normal dosering. Effekten af halv dosering var mindre klar, men der var stadig signifikante forskelle. Estimaterne antyder, at i hvert fald halvdelen af gevinsten ved kvart dosering også opnås ved halv dosering. Analyserne af fuglenes forekomst i forhold til mængden af insekter og ukrudt gav ikke noget entydigt billede. Der var dog en klart signifikant sammenhæng mellem total-biomassen af insekter og antallet af Tornsangere i marken.

Afgrøden havde stor indflydelse på antallet af fugle, og fuglenes afgrødepræferencer ændredes i takt med afgrødernes tilvækst. Analyserne afslørede dog ingen vekselvirkning mellem afgrøde og dosering, så effekten af de reducerede doseringer på fuglene var den samme uanset afgrøden. Ligeledes var doserings-effekten den samme i alle tre forsøgsår. Analyserne af fuglenes forekomst i efterårs- og vintermånederne viste ingen signifikante forskelle mellem doseringer.

Undersøgelserne af udbytter og driftsøkonomi var sekundære i forhold til de biologiske undersøgelser, og resultaterne skal derfor tages med forbehold. I kornafgrøderne fandtes en signifikant udbyttenedgang i 3 ud af 29 markforsøg med kvart dosering, men aldrig ved halv dosering. Generelt blev udbyttenedgangene mere end opvejet af de lavere omkostninger til pesticider. I roer var udbyttet signifikant reduceret i 3 ud af 16 parceller med kvart og 2 ud af 16 parceller med halv dosering. Gennemsnitsudbyttet var kun svagt nedsat; men variationen var langt større end i kornafgrøderne, og på en enkelt bedrift reduceredes dækningsbidraget med 11-27 %.

De driftsøkonomiske beregninger viser, at de foretagne reduktioner af herbicid- og insekticiddoseringerne generelt har kunnet gennemføres uden nævneværdige økonomiske konsekvenser. Vurderingerne efter forsøgets afslutning – samt den eksisterende viden på området – indicerer imidlertid, at anvendelse af reducerede doseringer af herbicider på længere sigt kan medføre en akkumulation af problemukrudt, i hvert fald pletvis. Dette forhold, og de dertil knyttede omkostninger, har kun i begrænset omfang kunnet inddrages i beregningerne.

Sammenfattende kan det konkluderes, at en halvering af de normalt anvendte doseringer af herbicider og insekticider har en målelig, men dog begrænset, positiv effekt på det dyrkede lands vilde planter, insekter og fugle. Under forudsætning af at der suppleres med målrettet bekæmpelse af pletvist forekommende problemukrudt, vil en sådan reduktion have yderst få, om overhovedet nogen, negative konsekvenser for driftsøkonomien i landbruget. En yderligere reduktion af pesticiddoseringerne til en fjerdedel medfører mere markante forbedringer for plante- og dyrelivet, men er i den foreliggende undersøgelse ledsaget af signifikante udbyttenedgange i ca. 10% af tilfældene i korn og ca. 20% af tilfældene i roer. En endelig konklusion fordrer dog undersøgelser over længere tid, ligesom en vurdering af den økologiske betydning af alternativ mekanisk bekæmpelse af ukrudt bør foretages.

1 Introduction (Esbjerg, P. & Petersen, B.S.)

1.1 Background

The present project is a derivative of the governmental Pesticide Action Plan I of 1986. The goal of this plan was a reduction in two steps from 1987 to 1997 of pesticide use both in terms of amount of active ingredients used and in terms of treatment intensity expressed as treatment intensity index.

The ***treatment intensity index*** is the theoretical number of pesticide treatments per hectare, as calculated by dividing the amount of pesticides used on the land of current interest with the dosage indicated on the approved label of the particular products (Danmarks Statistik 1992). The Pesticide Action Plan used the treatment intensity index for all arable land in Denmark as a practical measure. Within the first five years of the plan, the first step of a 25% reduction in sold amount and in treatment intensity index should be achieved, and finally in 1997 via the second step a total of 50% reduction should be achieved. The overall aim of the reductions was to protect the groundwater against pollution and the flora and fauna against further degradation.

A few years before the end of the 10 years period of the plan, however, it became increasingly clear that the reduction in treatment intensity index was unlikely to be reached. Parallel with this it was debated which effects the reductions aimed at would have in practice. The so-called Bichel Committee was appointed with the task of evaluating the consequences of a wholly or partly phasing out of agricultural pesticide use in Denmark. Based on their report, a Pesticide Action Plan II was approved in 2000. In general terms, the goal of this action plan is to reduce the use of pesticides as much as possible without significant economic losses. As an interim goal, the treatment intensity index (summed for all pesticide classes) shall be less than 2.0 by the end of 2002.

The public debate, and later on the work within the Bichel Committee, disclosed that scientific evidence of the effects of different levels of pesticide use on flora and fauna in general was sparse. In earlier investigations of pesticide free field margins (Hald ***et al***. 1988) some positive effects on flora and fauna had been demonstrated, and Braae ***et al***. (1988) had found higher densities of birds at organic farms than at conventional farms. An experimental documentation of effects on flora and fauna by ***reducing*** the pesticide dosages in general was, however, lacking. Furthermore, there was a need for a project at such a scale that its results might be regarded of general value and immediately relevant for practical farming.

Large-scale studies had previously been carried out in the English Boxworth Project (Greig-Smith ***et al.*** 1992). In this project, running from 1982 to 1988, the effects of three different pesticide regimes (Full insurance, Supervised and Integrated) on flora, invertebrates, mammals and birds were investigated. However, the low-input regimes at Boxworth by and large correspond to normal farming practice in Denmark today, rendering the results of limited value in the present context.

1.2 Overall project design

1.2.1 Aim and conditions

In accordance with the tender documents the aim of the project has been ***to demonstrate possible effects on flora and fauna of a reduction of pesticide dosages***. The effects in this context should be and have been investigated in a broad sense with changes in occurrence of a wide range of plants and animals as the measure. It follows from this that ***the project aim has in no respect included investigations of dose-response relationships of specific organisms to specific chemicals or groups of chemicals.***

Throughout the report, the term ***"biodiversity"*** is used in a rather inexact sense, an increased biodiversity referring to an increased species richness or to increased frequencies/densities of one or more species of plants or animals. This is in line with current terminology of the Danish Environmental Protection Agency.

From the beginning of the project a series of conditions had pronounced influence on the selection of study areas, pesticides and possible technologies.
- An economical frame, which despite wide did not allow the inclusion of all groups of pesticides or the inclusion of zero treatment plots.
- A demand for large areas to enable bird observations and to demonstrate possible consequences for flora and fauna at a scale which was relevant to agricultural practice and economy.
- A request for, if possible, including a minimum of three dosage levels and observing both direct and indirect affects across trophic levels.
- A request for working with widely cultivated crops with high levels of pesticide use as well as to problems anticipated in case of reductions in pesticide use.
- A request for using current farming technologies or, if deemed necessary, to introduce only changes in farm technology which could be brought into practice almost immediately.

Besides the above points it has been an obvious desire to use methodologies which would ease comparison with earlier results of related investigations on flora and fauna of the arable land.

In order to respect the management by the farmers and to minimize interference with normal farming practice, ***the experimental fields were in all aspects, except those closely related to pesticide dosages, treated in accordance with normal practice at the site.*** Hence all the variation which would otherwise be minimized as much as possible to ensure transparency and unambiguousness of scientific results has been included. Apart from practical considerations, the advantage of this approach is that the general value of the results is probably increased.

1.2.2 Selection of pesticides

In the setting of priorities concerning pesticide types and their effects, herbicides were the first to be included. The reasons were their pronounced dominance in practice and their known and presumed effects: directly on plants (1^{st} trophic level) and indirectly on food availability and behaviour of insects (2^{nd} and higher trophic levels) and on birds (2^{nd} and higher trophic levels). Insecticides were included because of their status as the generally most toxic plant protection chemicals to animal life (Candolfi ***et al***. 1999, Samsøe-

Petersen 1993, 1995a,b) and because of their wide-ranging presumed effects: directly on target organisms, on other herbivorous insects (2nd trophic level), on predators and parasitoids (3rd and higher trophic levels), and indirectly on parasitic and predatory insects and birds (3rd and higher trophic levels).

Fungicides were left out because major pesticide effects of principal interest could be demonstrated through the use of herbicides and insecticides. Furthermore, the number of potential direct and indirect effects would be high, but also very difficult to demonstrate at field level. Interesting topics include effects on insect pathogenic fungi on both pests and beneficials as well as effects on fungal food sources of arthropods serving as a food reserve for many predatory insects. Also effects on fungi antagonistic to plant pathogens could be of interest but very difficult to demonstrate in the field. The economic burden of producing unambiguous results of this nature, however, proved prohibitive already in the planning phase.

1.2.3 Selection of crops and farms

Winter wheat and spring sown barley together account for the vast majority of the Danish cereal area (82%) and in addition for a remarkably large proportion (46%) of the total arable land in Denmark (Landboforeningerne 2001). As regards pesticide applications winter wheat is a relatively insecticide intensive cereal crop because of its sensitivity to cereal aphids. In addition to this, winter wheat is often treated with herbicides in both autumn and spring.

Sugar beets cover a relatively small area but can act as a key representative for row crops with their inherent weed problems due to a limited vegetation cover until late in the season. Furthermore, sugar beet for contract-based delivery is a row crop of significantly higher economic value than cereals, but still not with the same room for more costly operations as vegetable row crops.

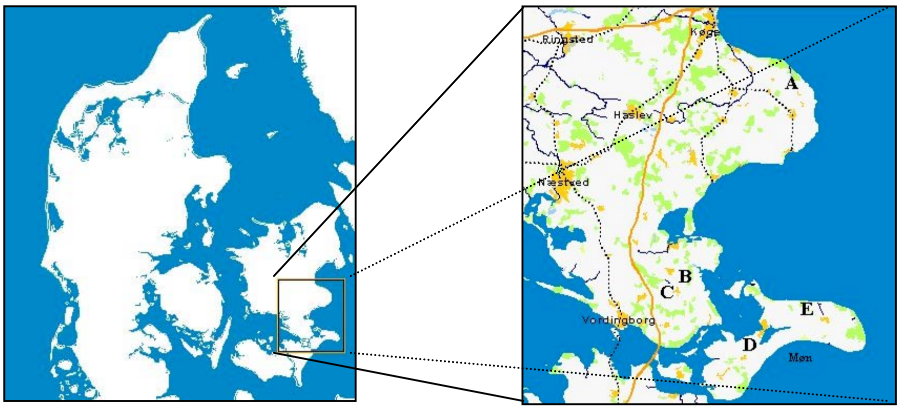

Fig. 1.1. The location of the five study sites. A: Gjorslev Estate, B: Oremandsgård Estate, C: Lekkende Estate, D: Nøbøllegård, E: Nordfeld Estate (© Kort og Matrikelstyrelsen (A. 42-02)).

In order to meet the area requirements of the ornithological studies it proved necessary to work with experimental plots of a minimum of 6 hectares. With three dosages this implied a need for fields of at least 18 hectares for every crop included at every farm. Because of the additional demand for a 3-years crop rotation of spring barley, winter wheat and sugar beet, the number of suitable farms was limited, as mentioned in the preface. Already in the planning phase it became clear that travelling time would be a major constraint because of the number of operations to be performed. Taking this into account it was decided to work on the five estates / large farms listed in the preface and shown in Fig. 1.1. Despite considerable soil variation at the local level, all study sites are placed on relatively heavy soils with a high fraction of clay.

1.2.4 Pesticide dosages

In accordance with the requests mentioned earlier it was decided to work with a defined ***normal dosage,*** and with 50% and 25% of this. Zero treatment plots, however attractive from a scientific point of view, were not included for practical and economical reasons. In terms of standardization and scientific practice it would seem desirable to use cropwise exactly the same pesticides and dosage levels at all five farms. This would, however, have been of limited sense in practice, primarily because of the occurrence of particular weed problems and accordingly special herbicide requirements at four of the five farms. Furthermore, it does not make sense to use the same insecticides if aphids are the main problem in one season but caterpillars in the next season.

With these complications and the demand for a close connection to practice, it was decided to request each farmer to make at every instance his own decision, based on local experience, about which chemical(s) to use, when to apply, and at which dosage(s). ***By definition, the farmer's choice in the particular instance was then the normal dosage,*** despite all the scientific trouble implied. The amount of liquid applied had to be the same at all dosage levels of a particular treatment, with the exception of sugar beet (cf. below).

It might appear attractive to use the politically oriented measure: the treatment intensity index, calculated separately for herbicides and insecticides, as a common yardstick for dosage levels. However, it should be noticed that because, e.g., different herbicides contain different active ingredients with different effects on plants, this measure is of limited scientific value.

All chemicals applied, and the normal dosage of each, are listed in Appendix A. It should be carefully reminded that in accordance with the above-mentioned constraints, the normal dosage of a certain chemical may differ between farms and years. In Table 1.1 the farmers' use of herbicides and insecticides during the study is summed up as treatment intensity indices. The table shows that the treatment intensity indices varied a lot from farm to farm and from year to year (field to field), reflecting the very different products and dosages chosen. For each of the three crops the farmers involved in this study had, on average, a higher treatment intensity index of both herbicides and insecticides than the average treatment intensity index in Denmark for the same crops.

Table 1.1. Summed treatment intensity index for herbicide and insecticide applications at normal dosage. Herbicides are divided in products against broad-leaved species and products against grasses (*Elymus repens* and *Avena fatua*). "Target 2002" indicates the goals set up in Pesticide Action Plan II.

Farm	Year	Herbicides against broad-leaved species			Herbicides against grasses		Insecticides		
		Spring barley	Winter wheat	Sugar beets	Spring barley	Winter wheat	Spring barley	Winter wheat	Sugar beets
Gjorslev	1996	1.25	-	1.38	-	-	0.00	0.00	3.67
	1997	0.45	0.65	1.49	1.00	1.00	0.48	0.40	2.87
	1998	0.68	1.35	1.49	-	-	0.80	0.32	2.34
	1999	0.37	0.33	1.49	-	-	0.25	0.25	0.67
Oremandsgård	1997	1.41	1.93	2.24	-	-	0.50	0.40	0.50
	1998	1.32	1.65	2.03	1.20	1.20	0.45	0.50	1.00
	1999	1.30	1.48	1.96	-	-	0.50	0.50	0.00
Lekkende	1997	0.88	1.60	1.76	0.67	0.83	0.80	1.00	2.00
	1998	2.25	1.14	2.91	0.67	-	0.40	2.00	3.49
	1999	1.17	1.00	1.74	-	-	1.00	0.50	2.00
Nøbøllegård	1997	0.88	1.65	3.10	0.63	-	0.00	0.40	0.00
	1998	0.55	0.85	2.71	1.00	-	1.90	0.65	1.35
	1999	0.37	0.65	1.67	-	-	0.40	0.25	1.00
Nordfeld	1997	1.29	2.28	1.83	-	0.80	0.50	0.50	0.40
	1998	0.67	1.85	0.97	0.67	0.83	0.50	0.50	1.80
	1999	1.01	1.50	1.28	-	1.17	0.50	0.40	0.00
Mean for all farms	1997-1999	0.95	1.48	1.91	0.39	0.39	0.60	0.57	1.29
Mean in DK[1]	1997-1999	All herbicides 0.85	1.63	1.85	Included in the former three columns		0.23	0.26	0.77
Target 2002[2]		0.70	1.20	2.40			0.30	0.25	0.50

[1] Data from Miljøstyrelsen (1998, 1999, 2000)
[2] Danish Agricultural Advisory Centre (2000)

The use of herbicides in the crops was 24% higher than the average use in Denmark, while the use of insecticides was 119% above the average. These higher treatment intensity indices may be due to the location of the farms on high quality soil, where the average treatment intensity index normally is higher than on low quality soil (Jensen 2001). This is supported by the fact that the smallest deviations are seen in sugar beets, which are grown much more often on high quality than on low quality soils. Also the location of the farms in eastern Denmark might increase the use of insecticides, since aphid attacks are more frequent in eastern than in western Denmark (Poul Henning Petersen ***pers. com.***). In addition, large farms/estates (as the experimental farms in this study) in general have a higher treatment intensity index than small farms (Jensen 2001). Due attention must be paid to these differences if the results of this study are extrapolated.

In sugar beets a further peculiarity proved necessary in order to combine the scientific project aims and the applied aspects. During the pilot phase in 1996 at Gjorslev, the sugar beet plots were treated with broad swath at all dosage levels. This practice, however, left a cover of weeds at half and quarter dosages which, irrespective of surprisingly small immediate yield effects, was unacceptable to farmers. The problem had to be solved if the project was to carry on for the subsequent three years, and again practicability influenced the solution despite some scientific shortcomings.

The method chosen was broad swath application at normal dosage, and band spraying (with normal dosage) in the half and quarter dosage plots, so that only 50% and 25-28% (minimum band width), respectively, of the area were treated in these plots. In addition to this, supplementary mechanical hoeing was carried out in all half and quarter dosage plots with sugar beets and also in the normal dosage plots depending on the desire of the individual farmer. (At Gjorslev the combination of broad swath spraying and mechanical hoeing had already been practiced for a number of years).

A table of field operations performed at each farm in each study year is enclosed as Appendix 1.5.

1.2.5 Field plots

At all farms, the fields were included in a crop rotation scheme as illustrated on Fig. 1.2. In practice, there could be some distance between the fields, and in rare cases even between dosage plots on fields that might be considerably larger than 18 hectares.

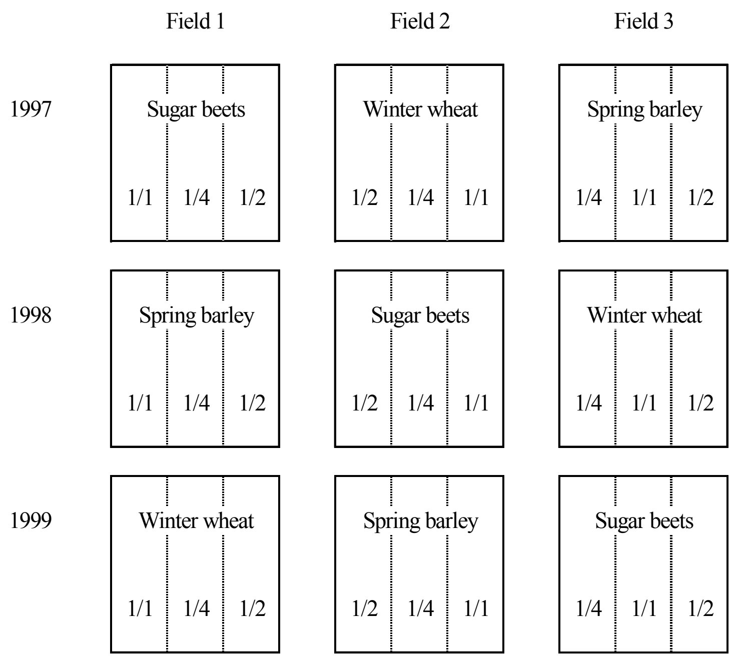

Fig. 1.2. Schematic example of crop rotation between the three experimental fields at one farm.

Each field was subdivided into three plots, preferably in a regular fashion with the longest axes along the longest side of the field. The plot size of minimum 6 hectares should ensure that a sufficient number of birds were observed, while the rectangular shape allowed cultivation operations to be performed without substantial inconvenience.

Dosages were allocated to plots in a random way with one crucial exception: ***if the field was surrounded by hedgerows, the middle plot was always used for half dosage while normal and quarter dosage were randomly allocated to the outer plots.*** The reasons for this decision were as follows: Hedgerows have profound effects on the distribution of most species of birds and some species of arthropods within the fields (cf. section 4.1.1). Thus, plots that are bordering on hedgerows are not fully comparable with plots that are not. One solution to this problem is to randomize the assignment of treatments to plots; this avoids introducing any systematic bias but increases the variation. However, because the dosage-related differences in bird and arthropod densities might well be small, it was feared that such an increase in random variation would prevent the detection of any differences. Therefore, to maximize the chance of detecting any differences at all, it was decided to give priority to a comparison of normal and quarter dosage by allocating the dosages as described. Although the interpretation of the ornithological (and to some extent also the entomological) results from half dosage might be difficult, the results of the botanical investigations (the primary production level) should still be fully valid and thus provide a basis for some general conclusions about the effect of a halving of pesticide dosages.

The selected dosage plots were fixed throughout the project period in order to allow for possible accumulative effects of the reduction of pesticide dosages.

1.2.6 Study sites

Maps of the five study sites are shown in figs. 1.3-1.7, and a short description of the field surroundings is given in each figure caption. Further field data are presented in Appendix B.

Fig. 1.3. Aerial view of the experimental fields at Gjorslev with the dosage plots indicated. All fields surrounded by dense hedges with scattered trees. A single marl-pit with reeds in Field 1 and three small marl-pits, surrounded by trees, in both Fields 2 and 3. Farm buildings and park immediately N and NW of Field 1. Fields 2 and 3 situated between the park and the lake Gjorslev Møllesø. Deciduous forest on the other side of the lake. Photo by courtesy of Kampsax.

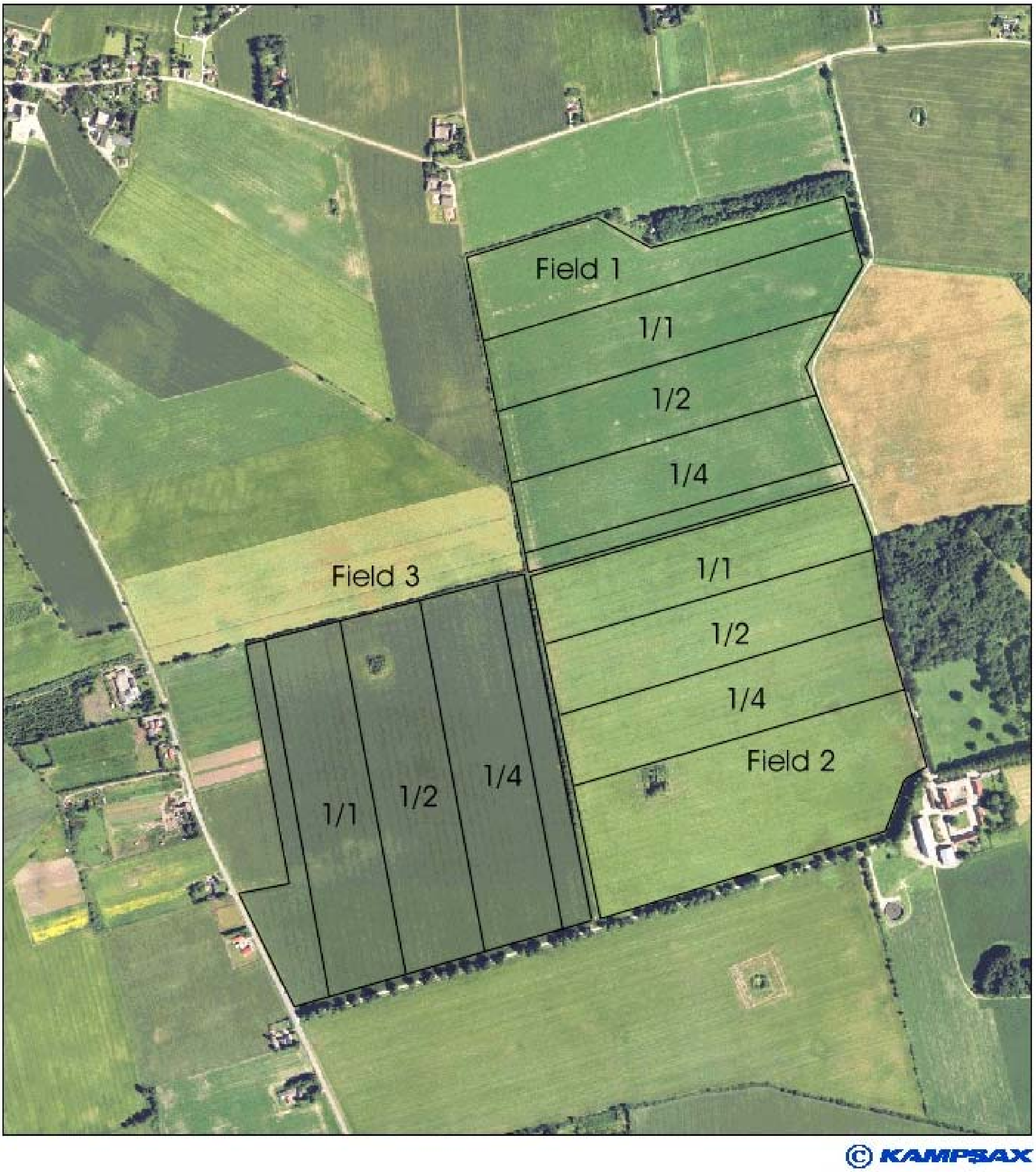

Fig. 1.4. Aerial view of the experimental fields at Oremandsgård with the dosage plots indicated. Large fields in a fairly open landscape. Single marl-pits, surrounded by trees and scrub, in Fields 2 and 3. Deciduous hedgerows, partly quite open, N and W of Field 1, between Fields 2 and 3, and N of Field 3. Alley with old, broad-leaved trees S of Fields 2 and 3. Old, deciduous wood E of Field 2 and farm buildings towards the SE. Photo by courtesy of Kampsax.

Fig. 1.5. Aerial view of the experimental fields at Lekkende with the dosage plots indicated. Fields located in an open, rolling landscape, sloping towards the SE and towards the strip of meadow and lakes to the NE. Field 1 with hedgerows along the NW and parts of the SW border and scattered trees towards the SE. Hedgerow between Fields 2 and 3 and W of Field 3. Covert with deciduous scrub in Field 1 and a small marl-pit, surrounded by trees, in Field 2. Photo by courtesy of Kampsax.

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Fig. 1.6. Aerial view of the experimental fields at Nøbøllegård with the dosage plots indicated. Fields located in an open landscape along the coastline. Field1 bordered by a fairly open hedgerow towards W and with a small village towards SE. Field 2 divided into two parts, c. 250 m apart. Reduced dosage plots with well-developed hedgerow towards the sea and less dense hedgerows towards E and W; normal dosage plot with hedgerow towards Field 3. Field 3 also bordered by hedgerow towards W and partly towards N where a fairly steep slope leads to the seashore. Single marl-pits, surrounded by trees or scrub, in Fields 1 and 3; farmsteads in Fields 2 and 3. Photo by courtesy of Kampsax.

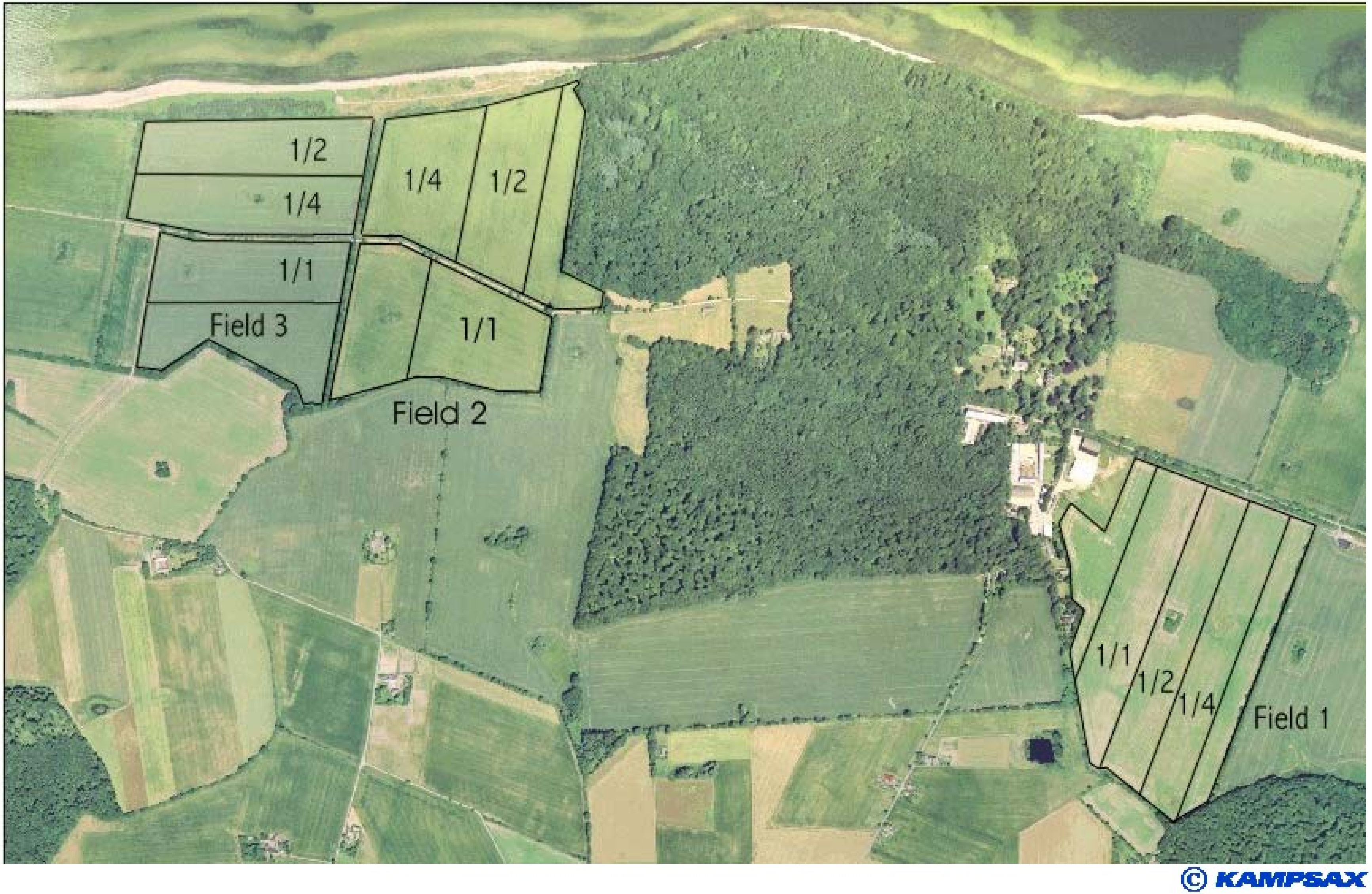

Fig. 1.7. Aerial view of the experimental fields at Nordfeld with the dosage plots indicated. Field 1 undulating, lying between two deciduous woods and surrounded by hedgerows on three sides. Farm buildings towards NW. Fields 2 and 3 situated W of the wood, close to the beach, with well-developed hedgerows on all sides. Both fields divided into two parts by gravel road bordered by scattered trees (Field 2) or hedgerows (Field 3). Single, small marl-pits, surrounded by trees and scrub, in all fields. Photo by courtesy of Kampsax.

1.2.7 Data sampling

The project has comprised a botanical part, an entomological part and an ornithological part. These parts aim at demonstrating effects at different trophic levels and thereby allow for the demonstration of indirect as well as direct effects. This is indicated by the arrows on Fig. 1.8, which also in principle illustrates why the work should focus more on some arthropods than on others. Thus a larva of a particular species which is linked to a particular weed and also is an attractive food item to birds is an insect of focus interest. The population density of such an insect may be affected by herbicide caused food limitation but may also be reduced by insecticide treatments. A further interesting element is added to this web if the herbivorous larva in focus is also prey for some ground beetles which are themselves food items for birds. Hence the entomological part of the project has been oriented as much as possible towards connections to the botanical and ornithological parts.

Very few direct effects are seen in birds, but birds may be affected indirectly by herbicide effects (via plant and arthropod food depletion) and by insecticide effects (via arthropod food depletion). Whereas plant and arthropod responses to reduced pesticide dosages were assessed by density measures, bird response could only be assessed in terms of occurrence (aggregation of birds in plots with reduced dosages). Population density studies would of course have been desirable, in particular if studies of productivity and survival in response to food availability could have been included as well. However, the appropriate scale demands for such studies would be rather different for plants, arthropods and birds. Also, detailed population studies would have to be limited to one crop and/or one site, and to one or two model species at each trophic level.

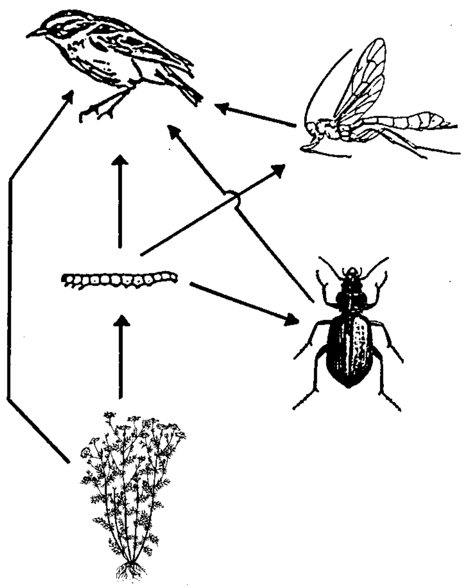

Fig. 1.8. Diagrammatic presentation of the role of the organisms included in the study. The arrows indicate which types of animals or plants are consumed by which other types.

The detailed methodologies of the three parts are described within the specific sections in chapters 2 to 4.

1.2.8 Weather conditions

The pilot season 1996 was preceded by a relatively cold winter during which January was very dry. Also March and April were much drier than normal. During the growing season, June and July were rather chill and dry while august was warm (mean 2°C above normal) (Friis ***et al.*** 1996).

In the first year of the main study, 1997, February was warm (mean 3°C in contrast to a normal of 0°C). The weather in spring was close to normal, although with a fairly cool and wet May. July was rather warm and August very warm (mean 20.2°C in contrast to normally 15.6°C). The precipitation of the growing season was fairly normal. In the post harvest period, October was rather cold and the first snowfall occurred early (Jensen ***et al.*** 1997).

1998 started with a mild winter, with February temperatures as much as 5°C above normal and with a considerable amount of precipitation. The spring was somewhat peculiar, with almost twice as much precipitation in April as normal, followed by a warm and dry May. June was very much like Danish average while July was chill and wet (mean precipitation 92 mm, 40% more than normally). The weather situation in August was quite normal, but September had the lowest number of sunshine hours and October the highest amount of precipitation (171 mm) recorded for more than 100 years. At many locations the moist conditions troubled the autumn seed drilling (Hansen ***et al.*** 1998).

The early winter part of 1999 was mild and humid, and with a high precipitation in March plants in larger patches of autumn-sown fields were drowned regionally. This agriculturally problematic situation was eased by fairly normal conditions in April-May, but in June again very high amounts of precipitation occurred (mean 120 mm, normal mean 52 mm) resulting in weed problems at many locations. During July the weather gradually changed, with high temperatures (up to 30°C) occurring towards the end of the month. In August the weather was close to normal whereas September was the warmest for years with a mean of 16.2°C (normal mean 12.7°C) (Sørensen ***et al.*** 1999).

1.2.9 Yield effects and economy

As the focus of the project has been on the biological effects, less emphasis was given to effects on yield and agro-economy. However, the need for a scale to justify possible compensations because of reduced yields was met by establishing an array of very small treatment plots of 9 or 12 m x 2.5 m in the cereal fields, according to guidelines of The Danish Agricultural Advisory Centre. For practical reasons these field trials were placed in the normal dosage plots. Because of the small size of the plots it was not possible to assign a particular dosage level to the same area of ground every year. Therefore these plots have not been able to demonstrate the possible accumulation of weeds over the three project years. To some degree, however, the final assessments of accumulated weed problems carried out after the last season compensate for this.

In sugar beet, mini-plots were also used during the pilot phase but obvious difficulties in harvesting questioned the validity of results. Therefore a manual sampling procedure was developed in consultation with "The foundation for sugar beet research" which also took care of the final yield assessment.

Despite these shortcomings of the yield estimates they were also used to obtain a minimum of evaluation of the economic effects of reducing pesticide dosages. This evaluation also leant on the final assessment of weed problems carried out by the project and the corresponding economical compensations based on qualified estimations of the costs of weed removal.

1.2.10 Statistical analyses

Fundamentally, the whole experiment may be looked upon as a fully balanced Latin Square design with five replicates (farms), and three crops rotating between three fields in three years. Due to the cultivation history at each farm, the allocation of crops to fields in the first year was not random, but it is unlikely that this has introduced any notable bias to the results. Each field was divided into three dosage plots which constituted the basic experimental units (45). As described above, the allocation of dosages to plots was not fully random. The implications of this depend on the organisms studied and are discussed in the individual chapters on the botanical, entomological and ornithological studies.

The main focus of the analyses has been on the demonstration of differences between dosages, taking possible crop effects and the (random) variation between farms, fields and years into account. In some cases tests for dosage effects could be performed across all crops, in other cases each crop had to be tested separately. In general, the statistical analyses were based upon general linear models (anovas etc.) with the dependent variable (number of plants, density of birds etc.) being transformed as appropriate to achieve an approximately normal distribution. Sometimes, however, the nature or distribution of the response variable demanded that an analysis based on a Poisson distribution (a generalized linear model) or a non-parametric test was used.

Tests of effects of differences at one trophic level on another (higher) trophic level were performed by including covariates describing density/diversity at the lower trophic level(s) in the analyses of response variables related to the higher trophic level (e.g., arthropod biomass was included in analyses of the occurrence of insectivorous bird species).

The statistical methods are described in more detail in the appropriate sections of chapters 2 to 6.

2 Wild flora (Jensen, A.-M.M. & Johnsen, I.)

2.1 Pilot studies

The purpose of the initial studies was to select, evaluate and adjust methods for the analyses of weed vegetation in a large-scale field study with different levels of pesticide application. The pilot study was used to find the right methods and a dimensioning of the main study that was adequate to make the collection of a sufficiently large amount of data possible despite large variations in weed populations and pesticides.

During 1996 – the pilot year – investigations were performed at one farm: Gjorslev. Two fields were selected for the pilot studies, one grown with spring barley and one with sugar beets. Time of sprayings and normal dosage of pesticides used on the fields appear in Appendix A.1.

2.1.1 Methods (pilot study)

Three different vegetation studies were performed during the pilot year (1996):

1) Biomass determination of selected weed species in combination with determination of plant developmental stages (phenology).
2) Observations of weed density, cover and number of weed species in permanent sites.
3) Preliminary investigations of the seed bank and the seed rain.

Biomass is a well known variable responding on herbicide use (e.g. Kudsk 1989, Salonen 1992b, Olofsdotter ***et al***. 1994). In addition, the plant biomass is positively correlated to the seed production (e.g. Thompson ***et al.*** 1991, Hald 1997). Thus a high biomass produces more seeds available for seed eating birds and insects. The development stage is determined from the numbers of leaves, presence of buds, flowers, seeds etc. on a plant. The presence of flowers and seeds are important for the fauna that eats pollen, nectar or seeds. Thus the developmental stage indicate where in the development phase from seedling to seed setting the plant is, not whether the biomass of the individual plant is high or low. Evidently, the developmental stage and the biomass are positively correlated in a population. The cover of the vegetation is positively correlated to the biomass (e.g. Smartt ***et al.*** 1974) within a more or less homogeneous vegetation community. However the growth forms of the species influence cover markedly. The density of plants is also assumed proportional with the biomass, provided each plant has the same average biomass despite the density of plants. However this is often not true as several studies have revealed that the average biomass per plant decreases at high plant densities (e.g. Watkinson 1980).

It has been shown that high weed biomass, density and cover support high faunal density (Chiverton & Sotherton 1991, Moreby 1997). The number of plant species in a vegetation community reflects the diversity of the community, and high numbers of plant species often lead to high numbers of animal species.

2.1.1.1 Determination of biomass and phenology

Only weed species with high densities were selected for this study: ***Viola arvensis*** in the spring barley field, and ***Aethusa cynapium***, ***Atriplex patula*** and ***Bilderdykia convolvulus*** in the sugar beet field. For each species, twenty plants from three to five random quadrates in each plot were sampled at four different days during the growing season (May to September). This resulted in a minimum of 60 individual plants for analysis per dosage per collection. The twenty plants were collected in the order of observation within a quadrate. The developmental stage of the collected plants was determined after the BBCH-scale (Hansen ***et al.*** 1995) immediately after collection by counting the number of true leaves, branches, buds, flowers and fruits. To measure dry biomass, plants were dried at 80^{o} C for 24 hours. Biomass data were log-transformed before means were calculated (=geometric means) and analyses of variance were performed. Means of biomass were analysed parametricly and medians of development stages were analysed non-parametricly by a Kruskal-Wallis test.

2.1.1.2 Observations of density, cover and number of weed species

In every plot, 5 permanent subplots of 25 m x 25 m were chosen at random. The distance to other plots, hedges, habitat islands etc. was always larger than 12 m to avoid impact from farming operations on the field headland, which may differ considerably from those practised on the experimental field (Fielder 1987). Vegetation in headlands and field margins often differ from the inner part of a field with respect to plant density and species composition (Marshall 1989, Wilson & Aebischer 1995).

In each of these 625 m^2 subplots a number of smaller sampling sites were selected for non-destructive vegetation observations. Hence, four random sampling sites were selected in the spring barley fields and 10 in the sugar beet field. Each sampling site measured 0.6 m x 0.4 m = 0.24 m^2 and was marked, so it could be visited several times during the season. At each visit, the weeds (seedlings, vegetative or generative plants) were identified to species according to Haas & Laursen (1994), Hanf (1990) or Hansen (1981). In addition, the cover of each species was estimated on a scale from 0 % to 100 % cover of the soil surface. The same person performed the identification of plants and the subjective estimates of cover during the whole season. Values of density, cover and number of weed species were summed up to the level of subplots. Weed density was log-transformed and cover was square root transformed to improve approximation to normal distribution before data were analysed for effect of dosage. Data from each visit were analysed separately.

2.1.1.3 Seed bank and seed rain

The viable seed bank population was studied in both fields in August by sampling five soil cores at six random places per plot, each core was 2.0 cm in diameter and 10 cm in depth. In September, samples of the seed rain were obtained from another six random places per plot. Each seed rain sample was extracted from the soil surface of five 0.1 m^2 squares using a house vacuum cleaner connected to a transformer placed in the boot of a van. The number of seeds in the seed bank and seed rain samples was estimated and identified to species by allowing the viable seeds to germinate. After approximately a month the seed samples were spread as a 5 mm layer upon a 3 cm thick sterile substrate of vermiculite and permaculite and placed in a unheated greenhouse with presumably very little influx of weed seeds. Germinating seedlings were identified to species, counted and removed. The germination trays were observed for 16 months and watered when necessary. Trays without seed sample addition were left in the greenhouse for control of sterility and any possible seed influx. This germination method has been used with satisfactory results during most of the last century to reflect the amount of viable seeds in the soil seed bank of agricultural land (e.g. Jensen 1969, Roberts 1981).

2.1.2 Results (pilot study)

2.1.2.1 Determination of biomass and phenology

Biomass of weed species in sugar beets

From the fourth collection in September (Fig. 2.1), the mean dry biomass of ***Atriplex patula*** was significantly higher in the plot sprayed with quarter dosage than in the plots sprayed with half or normal dosage (Tukey-Kramer tests, $p=0.013$ and $p<0.0001$, respectively). No significant effect of dosage was seen in biomass of ***Aethusa cynapium*** or ***Bilderdykia convolvulus*** at this collection.

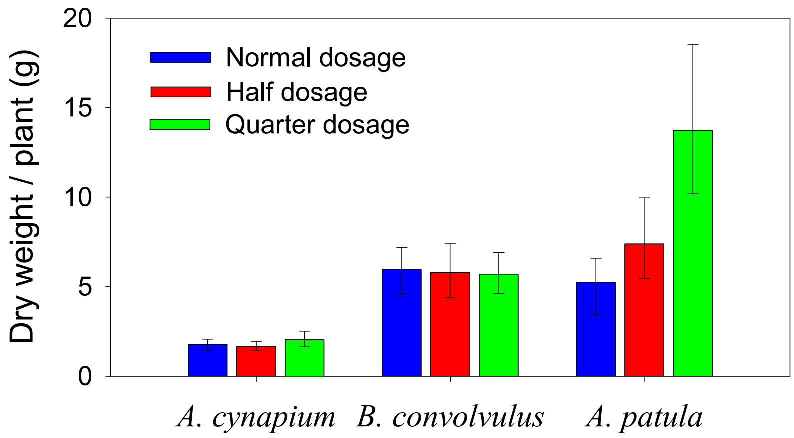

Fig. 2.1. Mean dry biomass (g) per plant for *Aethusa cynapium*, *Bilderdykia convolvulus* and *Atriplex patula* collected mid-September (fourth collection) in a sugar beet field treated with three different dosages of pesticides. Error bars represent the 95 % confidence limits.

The higher biomass of ***Atriplex patula*** at quarter and half dosages than at normal dosage was significant from second collection already.

Only at second collection in late June, plant dry weight of ***Bilderdykia convolvulus*** showed an effect of dosage. Plants at quarter dosage had a significantly higher biomass than at half dosage (Tukey-Kramer test, $p=0.005$) and the plants at half dosage had a significantly higher biomass than plants at normal dosage (Tukey-Kramer test, $p=0.001$).

At third collection in late July a significant effect of pesticide dosage was observed for dry biomass of ***Aethusa cynapium***, mean dry biomass was higher at quarter dosage than at normal dosage (Tukey-Kramer test, $p=0.002$).

Biomass of Viola arvensis ***in spring barley***

Very few ***Viola arvensis*** plants survived spraying with normal herbicide dosage in spring barley, not enough for statistical analyses, thus no observations on biomass and developmental stages were performed in the spring barley plot receiving normal dosage. Immediately before harvest of spring barley in August, significantly smaller ***V. arvensis*** plants (mean 13 mg) were found in the plot receiving half dosage in comparison with plants in the plot receiving quarter dosage (mean 23 mg) (t-test, p=0.002). No difference, however, was observed at any other time of collection.

Phenology of Aethusa cynapium
Five weeks after spraying, ***A. cynapium*** showed a significant difference in developmental stages at different herbicide dosages in the sugar beet field (Kruskal-Wallis test, p<0.001). Plants treated with quarter dosage were significantly more developed than plants treated with normal dosage (Fig. 2.2). This pattern was found at the first three collection days, while at last collection the differences in developmental stages among dosages were no longer significant (Kruskal-Wallis test, p=0.08).

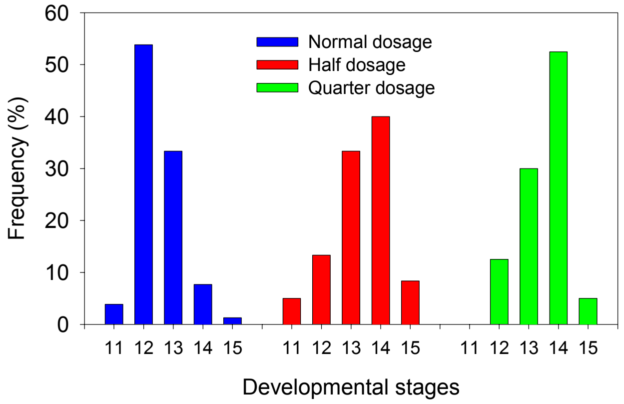

Fig. 2.2. Distribution of developmental stages for *Aethusa cynapium* in the sugar beet field mid-June. A higher figure on the x-axis corresponds to a higher plant developmental stage.

Phenology of Atriplex patula
The developmental stages for ***A. patula*** showed significant differences only at the second seasonal collection, plants sprayed with half or quarter dosage were at a higher developmental stage than plants sprayed with normal dosage (Kruskal-Wallis test, p<0.0001).

Phenology of Bilderdykia convolvulus
The developmental stages for ***B. convolvulus*** showed no differences between the three levels of pesticides at any of the seasonal collecting times.

Phenology of Viola arvensis
The developmental stages of ***V. arvensis*** were significantly higher at second and fourth collecting day for the spring barley plot receiving quarter dosage compared with the plot receiving half dosage (Wilcoxon tests, (p=0.17), p=0.02, (p=0.26) and p<0.001, respectively).

2.1.2.2 Observations of density, cover and number of weed species
Density and cover of weeds in sugar beets
Total weed density at quarter dosage rose from week 30 to week 40 (Fig. 2.3A) because of germinating seedlings originating from seed shedding plants in the field (especially ***Poa annua***). The confidence limits for weed density at quarter dosage were huge mainly because one of the subplots had a three times higher density than the other four. The total cover of weed increased

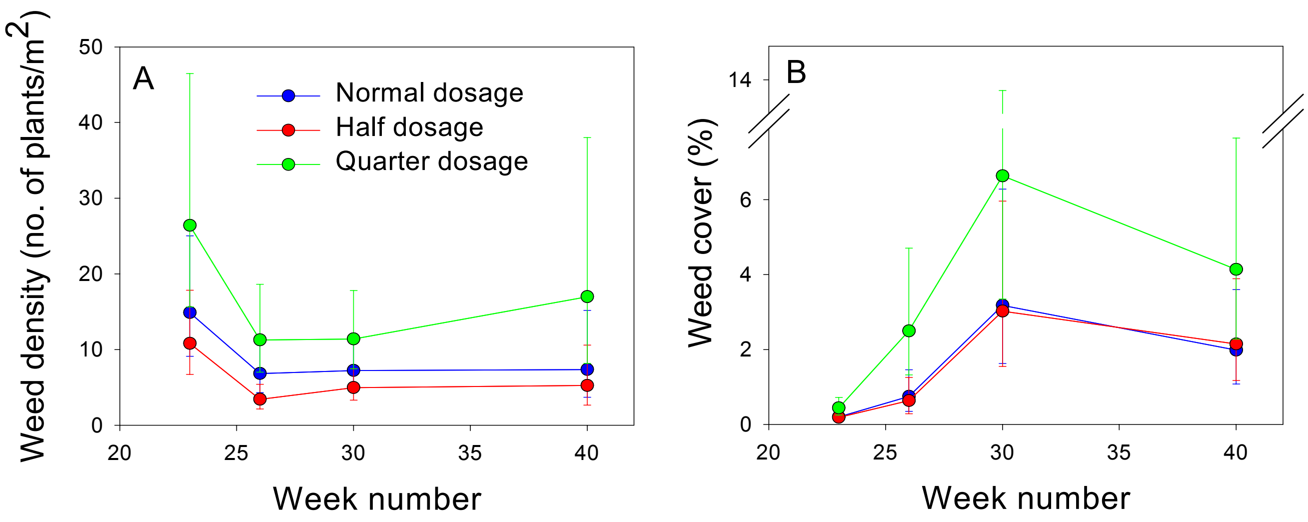

Fig. 2.3. Development in total weed density (A) and weed cover (B) during the growing season in a sugar beet field sprayed in week 19 and 20 with normal or reduced dosages of herbicides. Every dot is a geometric mean of five values. Error bars represent the 95 % confidence limits

from under 0.5 % in the beginning of the season to 4 % on average at the end of July (week 30) (Fig. 2.3B). The cover decreased to 3 % on average in week 40 because some species defoliated. During the season, changes in total cover were greater than changes in total density.

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Dosage had a significant effect on total density in week 23, 26 and 30 (anovas) giving higher plant density at quarter dosage than at half dosage. The cover was only significantly affected by dosage in week 26 ($p=0.014$) (Fig. 2.3B).

The most numerous species in the beet field was ***Aethusa cynapium***, whereas more than 50 % of the total weed cover was contributed by ***Bilderdykia convolvulus***.

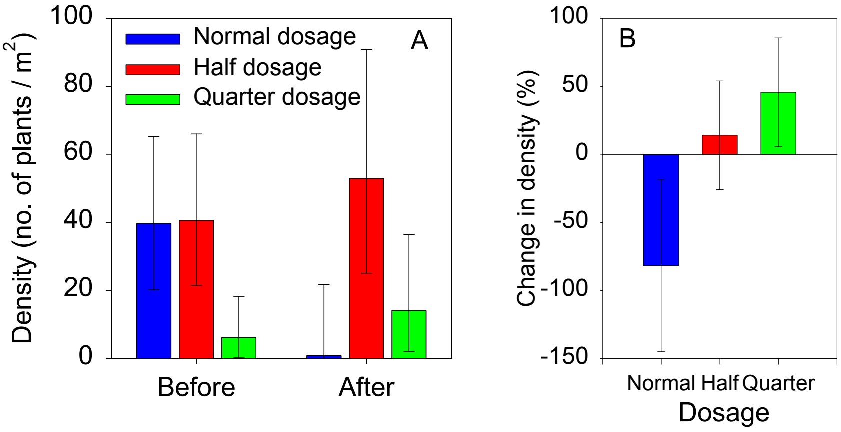


Fig. 2.4. A) Density of *Viola arvensis* in spring barley before and after spraying with normal or reduced dosages of pesticides. B) Change in density of *Viola arvensis* after spraying, where density before spraying is set to 100 %. Each column represents the mean of five values. Error bars represent the 95 % confidence limits.

Density of ***Viola arvensis*** in spring barley
Before spraying, the average density was very low in the quarter dosage plot and much higher and nearly equal in the half and normal dosage plots (Fig. 2.4A).

After spraying with normal dosage the average density of ***V. arvensis*** decreased markedly and the average densities in plots sprayed with half and quarter dosage increased (Fig. 2.4B).

Number of weed species in sugar beets
The highest number of species was present in the beginning of the growing season (Fig. 2.5). Number of species was decreasing at the same time as the total density was decreasing. No significant effects of dosages were found (anovas).

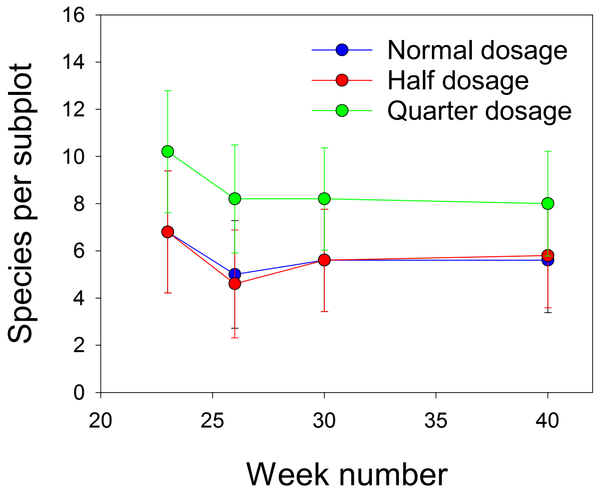


Fig. 2.5. Development in number of weed species during the growing season in a sugar beet field sprayed with normal or reduced dosages of pesticides in week 19 and 20. Error bars represent the 95 % confidence limits.

2.1.2.3 Seed bank and seed rain

In the control trays seedlings of ***Chamomilla*** sp., ***Conyza canadensis***, ***Epilobium sp.***, ***Erophila verna***, ***Poa annua***, ***Sonchus*** sp. and ***Taraxacum*** sp**. g**erminated. These seeds may have been in the substrate or more likely must have spread from the surroundings into the greenhouse. They are all wind dispersed or grew near the greenhouse. Three of the species (***Chamomilla*** sp., ***Poa annua*** and ***Taraxacum*** sp**.**) were observed in the field vegetation. Therefore, it is not possible to clarify whether the seeds of these species were in the soil samples from the field or whether they have arrived from outside the greenhouse. Fig. 2.6 shows the distribution of germinated seeds from the samples grouped according to the proportion of seeds from species also found in control trays, species from the fields, grains and unidentified seeds, respectively. In total 15,921 seedlings were identified from the seed bank and the seed rain. More than 50 % of the seedlings were of species also found in the control trays. Only 8 % of the seedlings were identified as weed species originating from the field.

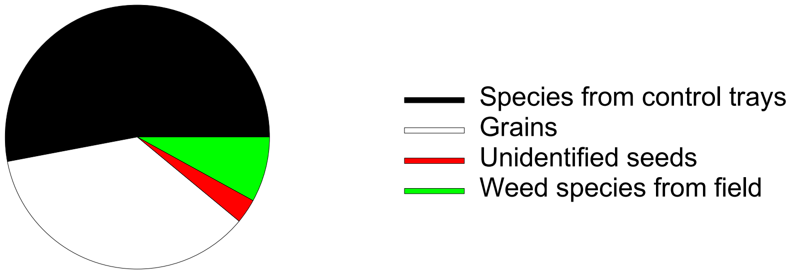


Fig. 2.6. Total number of germinating seeds in seed rain and seed bank samples distributed on species from control trays, grains, unidentified seeds and weed seeds from the field.

2.1.3 Conclusions (pilot study)

2.1.3.1 Determination of biomass and phenology

The results of the determination of biomass provided good information on weed response after spraying with reduced dosages in the fields (which have also been shown by several others (e.g. Landbrugets Rådgivningscenter 1999b)). Five of twelve analyses showed a significant effect, in all cases with a higher biomass at quarter dosage than at normal dosage. The changes in weed developmental stages among dosages (and collection days) seem to reflect well the impact of pesticide application on phenology. Six of sixteen analyses showed a significant effect, which in all cases with a higher developmental stage on average at quarter dosage than at normal dosage.

For measurements of biomass and developmental stages, many plants of the same species at each treatment are needed, because of a very large variation between plants and a small variation between dosages. In addition, the investigation demands a very even distribution of plants of the same species in the three plots in a field. In many fields, this would not be possible to achieve except for the most abundant species. Furthermore, the method is very time-consuming, and would be impossible to perform on a sufficient area within each plot in the large-scale field study. In conclusion, the determinations of biomass and developmental stages were abandoned in the main experiment 1997-1999.

2.1.3.2 Observations of density, cover and number of weed species

Density and cover were measured four times through the growing season. Density was more stable than cover after week 26, where the mortal effect of the herbicide treatments had stopped. Thus, measurements of cover vary much over the growing season, as also found by Hill ***et al.*** (1989) for several species. However, greater variation in the measurements of cover than densities results in less significant differences between treatments. In this experiment, significant effects of reduced pesticide dosages were found three times in the analysis of total density and only once in the analysis of cover. Furthermore, cover is a subjective personal estimate and differs from person to person (Kennedy & Addison 1987). Therefore, variation would be greater in the main study, where several persons would evaluate the cover, than in this one-year study, where only one person estimated the cover. If a more exact analyse of cover was performed (e.g. a pinpoint analyse) the time used would at least be trebled. However, the advantage would be that exact estimations of cover might give a better estimate of the competitiveness of the weed species

(Silvertown & Dale 1991) compared to density measurements. Densities tell nothing about the size of the plants and, hence, how well they compete with the crop for light and nutrition. Plant biomass might still be a better indicator of the food resource available than density of plants of unknown size, even though the two measurements are positively correlated. However, the density is more stable during the last half of growing season than the biomass (which may follow the same flutuations as cover) and may therefore be more useful in analyses of fauna densities, since the large-scale study only allows one registration during each season. On balance, it was decided to abandon the measurements of cover and retain the measurements of density in the main experiment 1997-1999.

Repeated observations of the vegetation through the growing season are time-consuming and contribute little additional information because data are not independent (counting the same plants several times). Figs. 2.3 and 2.5 show that density and number of species do not change after week 26 and until new seedlings germinate. Thus, one registration after June gives sufficient data to determine differences in vegetation density and richness, in relation to the use of pesticides. This agrees with Hald & Lund (1994), who measured weed densities in unsprayed fields at two periods during springtime and did not find any great difference in densities between the periods.

The development in density of ***Viola arvensis*** in spring barley (Fig. 2.4) illustrates that it is very important to know the differences between plots before spraying; else false conclusions may easily be drawn. This knowledge can be achieved by observing the vegetation before spraying and use that observation as a covariate in the analyses of the vegetation after sprayings. In the main study, the density and number of species were registered before spraying (in April-May) and once after spraying (in July-August).

No significant effect of dosages on species number was found in the sugar beet field. This might be due to the small area of investigation in the sugar beet subplots. The weed density in the sugar beet field was much lower than the density in the spring barley field, suggesting that the occurrence of different species would also be more scattered in the sugar beet field. If the recorded number of species is low compared to the maximal number of species found in that habitat, the variation between samples will be greater than if the number was close to the maximal number of species possible. Consequently, the sampling sites in sugar beet fields were doubled in size and a higher number of samplings sites were investigated in the main experiment.

2.1.3.3 Seed bank and seed rain

The germination method for seed bank samples proved unsatisfactory, because of the very high contamination of the samples with many arriving seeds from the environment germinating in the trays. Contamination under germination experiments in greenhouses is usual; Jensen (1969) found a contamination of 4 % of the total number of germinating seeds. Nevertheless, in the present experiment the amount of incoming seeds was unacceptablely high. Thus, another method for measuring the seed rain had to be used in the main experiment.

2.2 Vegetation studies

During the main phase of the study (1997-1999), two different kinds of studies were performed, a vegetation study (section 2.2) and a seed rain study (section 2.3).

The objectives of the vegetation study were to detect any effects of reduced pesticide dosages on the wild flora, measured by several vegetation parameters such as density, species richness (=weed diversity), species composition and ability to flower. Data were obtained from 15 experimental fields: five of each crop (spring barley, winter wheat and sugar beets) over a period of three years. The aim was not to study the effectiveness of the herbicides to control (kill) the weed flora and correlate this effectiveness with the individual treatments of individual herbicides, such studies have been performed in many small field trials (e.g. Landbrugets Rådgivningscenter 1999b). Rather, it was aimed to measure changes in the weed flora parameters that might have an impact on the existence of the fauna on the fields.

The objective of the seed rain study was to detect effects of reduced pesticide dosages on the number of species and density of seeds in the seed rain in early autumn. Data was obtained from 4 winter wheat and 5 spring barley stubble fields in 1998 and 4 winter wheat and 4 spring barley stubble fields in 1999.

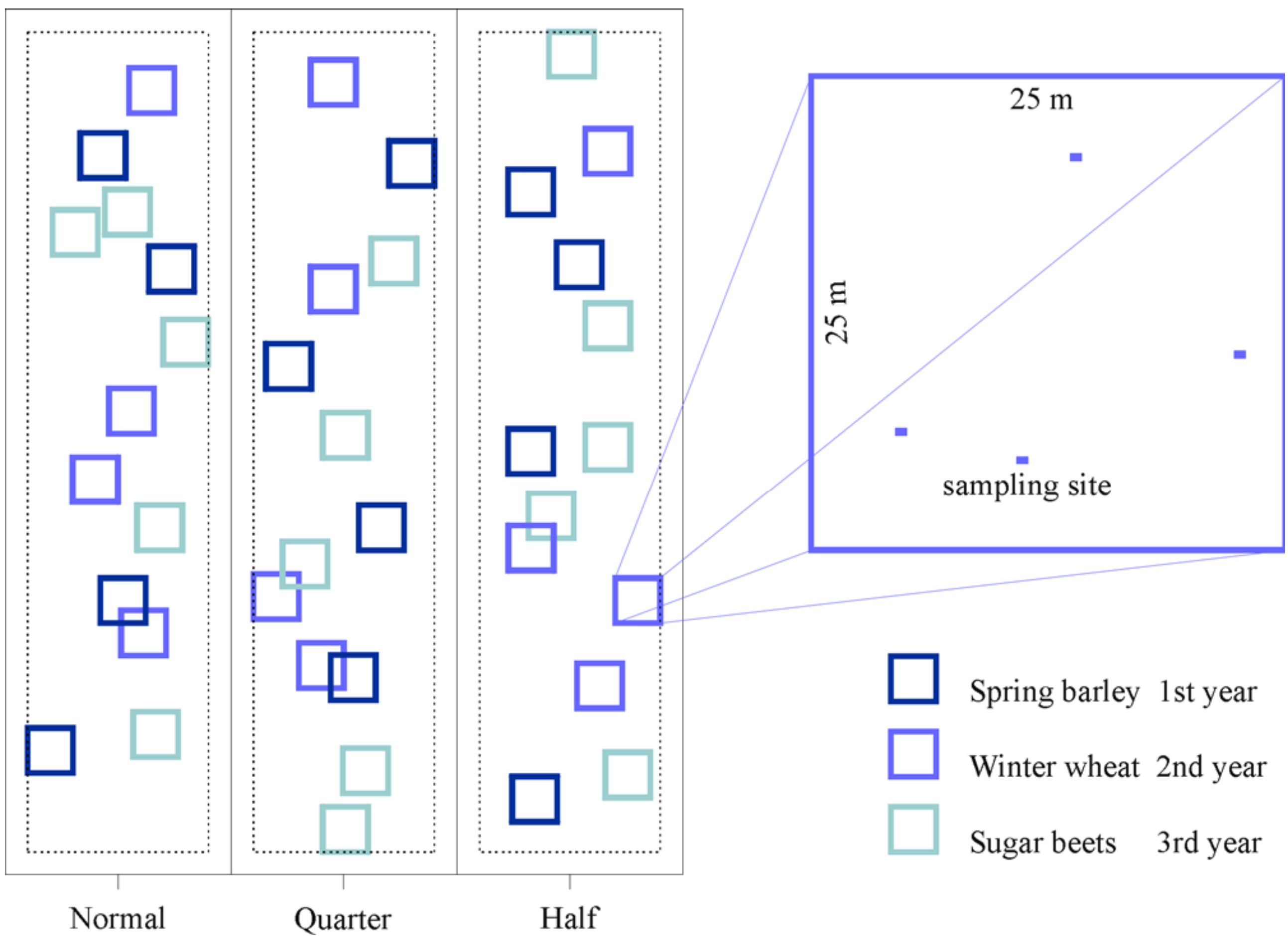


Fig. 2.7. One example of locations of plots (Normal, Quarter and Half), subplots and sampling sites (in magnified subplot) in a field grown in a three years rotation with spring barley, winter wheat and sugar beets. Punctuated lines indicate the 12 meter zone to hedges etc.

2.2.1 Methods

2.2.1.1 Sampling design

Field design is illustrated in Fig. 2.7. In each plot, subplots of 25 m x 25 m were chosen at random with at least 12 m to other plots, hedges and habitat islands such as small game plantations, ponds etc. Non sowed tramlines were avoided. 5 subplots were chosen in each sugar beet plot and 4 subplots in each cereal plot.

Location of the subplots within a plot varied from year to year. Within the sugar beet subplots ten sampling sites of 1.0 m x 0.5 m were placed at random. Within the cereal subplots, four sampling sites of 0.6 m x 0.4 m were placed at random. These sampling sites were used for the vegetation studies. The total area used for vegetation observations per subplot was thus in the sugar beet fields 5.0 m^2 (10 x 0.5 m^2), and in the cereal fields 0.96 m^2 (4 x 0.24 m^2). The different area of subplots and their numbers were chosen on background of results from the pilot study (section 2.1.3.2).

2.2.1.2 Vegetation measures

The vegetation study included identification of the weed species present as well as counting the number of individual plants per species within the sampling sites. Data from the individual sampling sites within the same subplot were summed up giving the total number of species present per subplot and the density of plants per species and in total per square meter. The reasons for selections of these parameters are given in section 2.1.3.

2.2.1.3 Number and timing of field observations

As a consequence of results found in the pilot study (section 2.1.3.2), each sampling site was examined two times during the growing season, once immediately before sprayings with herbicides in spring (April-May) and once approximately 3 months later (July-August).

Eight of the winter wheat fields were sprayed with herbicides both in autumn and in spring, four only in autumn and three only in spring. For a better comparison of effects of spring spraying with sugar beet and spring barley fields, only data from the eleven winter wheat fields sprayed in spring entered the analyses and figures. Observations of arthropods and birds were not carried out in winter wheat fields before spring, so only effects of spring sprayings were analysed in the vegetation. The weed observations before spring sprayings were used as a covariate in the analyses of weed variables after spraying in that way the effects of soil cultivation and autumn sprayings on the weed populations were included in the covariate. The exclusion of winter wheat fields only sprayed in autumn was due to an expectation of very few and only minor changes in the weed populations between spring and summer caused by dosage differences in the autumn sprayings.

2.2.1.4 Flowering status

After treatment with pesticides in 1998 and 1999, the numbers of flowering plants per species were recorded in all sampling sites. A plant was defined as flowering if it was generative, i.e. if it had developed buds, flowers, fruits or showed any sign of fruit setting (e.g. empty sepals in ***Lamiaceae***). The aim was to detect whether pesticide dosages had sublethal effects on weed plants by reducing fitness, measured as ability to flower. In addition flowering plants provide pollen and nectar for insects and later in the season seeds for both insects and birds, whereas vegetative plants provide less energy-dense food. The proportion of flowering plants was calculated as the number of flowering individuals of all species divided by the total sum of plants across all species in a plot. The proportion of flowering species was calculated as the number of species, where at least one plant did flower, divided by the total number of species in a plot.

2.2.1.5 Habitats in sugar beet fields

At reduced dosages in the sugar beet fields two different microhabitats arose for the weeds: within the row, where the weeds had to compete with the beets and tolerate/escape the herbicides to survive; and between the rows, where competition from the sugar beets was less strong but the weeds had to survive hoeing. At normal dosage only Gjorslev performed hoeing regularly between the beet rows (Appendix B). In 1998 and 1999, it was noted whether the weeds occurred within the sugar beet rows (closer than 12.5 cm to a row) or between them (more than 12.5 cm apart from a row).

2.2.1.6 Identification and counting of plants

Seedlings were identified using Hanf (1990) or Haas & Laursen (1994), the vegetative grasses using Grøntved & Sørensen (1941) and the flowering plants using Hansen (1981). Nomenclature follows Tutin ***et al.*** (1964-1980). All plant species except the grown crop were counted inclusive volunteer plants of previous crops (e.g. oil seed rape plants in a sugar beet field and winter wheat plants in a spring barley field). Determination of densities of perennial plants that either germinates from roots or from rhizomes (e.g. ***Cirsium arvense*** and ***Elymus repens***) was based on shoots more than 2 cm apart. Shoots closer than 2 cm were counted as one individual plant.

2.2.1.7 Definition of common, rare, scarce, non-target and target species

Species were divided in different groups: ***Common species*** are common or very common all over DK according to Hansen (1981) in contrast to ***rare species***, which is species mentioned as seldom or rare at least in some parts of Denmark. The rare species in this study are not rare in the Southeastern part of Denmark, but occur very seldomly if at all in the Western and Northern parts of Denmark (Mikkelsen 1989). Many of the investigated species appeared only in a few plots, although their overall abundance in Denmark was common. Species found in less than six of the 123 investigated plots were classified as ***scarce species***. ***Non-target species*** in contrast to ***target species*** are species that do not reduce the crop yield neither by competition with the crop for light, water or nutrients nor by impeding the harvesting, thus non-target species are not unwanted from the farmers point of view. It is evident that the competition from a weed species against the crop plants depends on the density of the weed species and the competitiveness of the crop. Cereals are strong competitors and row-crops as sugar beet are weak competitors. In sugar beets nearly all weed species would be target species, whereas in cereals weed species can be divided in strong or weak competitors. Species with a competitiveness from medium to very strong in winter wheat (Christensen & Rasmussen 1998) were defined as target species. In addition the top ten species with the highest weed equivalents in either autumn sown or spring sown crops were defined as target species (Jensen 1996). All other species were in this report defined as non-target species.

2.2.1.8 Statistical analyses

Response variables

The basic experimental unit in the analyses of all variables was the plot (n=123, the four wheat fields without herbicide sprayings in spring being excluded). Values from subplots within a plot were summed or averaged to one value for each plot each year. Statistical analyses were performed on the following response variables:

1) Mean density per plot for all weed plants
2) Development of mean total density per plot during the study years
3) Mean density per plot for the most common species in cereals, separately
4) Density of some rare species, separately
5) Total number of species per plot
6) Development of species number per plot during the study years
7) Abundance of rare species
8) Abundance of scarce species
9) Proportion of flowering plants per plot
10) Proportion of flowering species per plot

In the rest of this section, variable number refers to the above response variables.

Fields, where a species was not present in any of the plots after spraying was excluded in the analyses of density for that particular species (variable 3 listed above), because lack of the species was regarded as non-informative with respect to dosage dependency. A plot was omitted from the data analyses of proportion of flowering species (variable 10) if the number of species found in the plot was less than six, due to high stochastic variation in proportions based on small numbers.

Tests

The null hypothesis was that the means of the response variables were not significantly influenced by pesticide dosages (variables 1, 3, 4, 5, 7, 8, 9 and 10) or year (variables 2 and 6). For the variables 1-6 and 9-10, the hypothesis about differences between dosages or years was tested by means of analysis of variance, taking into account the effect of differences between explanatory factors such as crop, farms, fields, years and weed status before spraying (Table 2.1).

The variables were transformed in order to improve the approximation to a normal distribution and make the variance independent of the mean. The data transformations were accepted after running the model, if the plot of residuals against predicted values did not show any apparent trends.

Effects may have accumulated during the study period because the relative dosages applied to a certain plot were the same in all three years. This was taken into account in the analyses of variable 1-6 by using density or species richness before spraying as a covariate. The total density of plants might influence the number of species found, therefore the density of weed plants was used as a covariate in analyses of variable 5 and 6 and the proportion of flowering plants was used as a covariate in analyse of variable 10.

Notice that dosage was treated as a class variable, so no assumptions were made about the effects of half dosage falling in between those of quarter and normal dosages.

The explanatory factors (main factors and interactions) used in the full models are shown in Table 2.1.

Model reduction was performed using an iterative procedure to remove the variables with $p > 0.10$ until the model consisted only of variables with $p \leq 0.10$. If a significant effect of dosage was revealed, the differences among dosages were tested by a Tukey-Kramer adjustment for multiple comparisons of least-squares means. The analyses were performed using the GLM procedure in SAS (SAS Institute 1999).Because not all winter wheat fields were used in the statistical analyses, the design was unbalanced, and the F-tests had to be modified, this was done using the Random/Test statement in the GLM procedure.

The proportion of variation explained by a certain factor was calculated as the sum of squares for that factor divided with the total sum of squares.

Dosage effects on the abundance of rare and scarce species (variables 7 and 8) were analysed using chi^2-tests. Species or groups of species with very low abundance were summed before tested.

Table 2.1. Explanatory factors included in the variance analyses. An asterisk indicates that the explanatory factor is included in the full model for that particular response variable. df = degrees of freedom.

Explanatory factors	Included in the full model for variable: 1, 4, 5	3	2, 6	9, 10	Description	Max. df
Density or species number before	*	*			diff. in density or species number before spraying	1
Density or flowering proportion	*only variable 5		*only variable 6	*only variable 10	diff. in density or in proportion of flowering plants	1
Dosage	*	*	*	*	diff. between dosages	2
Crop	*	*	*	*	diff. between crops	2
Farm	*	*	*	*	diff. between farms	4
Field(Farm)	*	*	*	*	diff. between fields within farms	10
Year	*	*	*	*	diff. between years	2
Season			*		diff. between before and after spraying	1
Dosage×Crop	*	*	*	*	diff. between dosages vary between crops	4
Dosage×Farm	*	*	*	*	diff. between dosages vary between farms	8
Dosage×Year	*	*	*	*	diff. between dosages vary between years	4
Crop×Farm	*		*		diff. between crops vary between farms	8
Crop×Year	*		*		diff. between crops vary between years	4
Farm×Year	*		*		diff. between farms vary between years	8
Dosage×Season			*		diff. between dosages vary between seasons	2
Crop×Season			*		diff. between crops vary between seasons	2
Farm×Season			*		diff. between farms vary between seasons	4
Year×Season			*		diff. between years vary between seasons	1
Dosage×Crop×Farm	*		*	*	diff. between dosages vary between crops and farms	16
Dosage×Crop×Year	*		*		diff. between dosages vary between crops and years	8
Dosage×Farm×Year	*		*		diff. between dosages vary between farms and years	16
Crop×Farm×Year			*		diff. between crops vary between farms and years	16
Dosage×Season×Crop			*		diff. between dosages vary between crops and seasons	4
Dosage×Season×Farm			*		diff. between dosages vary between farms and seasons	8
Dosage×Season×Year			*		diff. between dosages vary between years and seasons	4

2.2.2 Results

2.2.2.1 Density

Total weed density

Weed densities after spraying changed markedly with dosage, so the density at normal dosage (mean 30 plants per m^2) was significantly lower than at half (mean 48 plants per m^2) and quarter dosage (mean 55 plants per m^2) (Tukey-Kramer tests, p=0.016 and p=0.008, respectively). No significant difference in densities was seen between half and quarter dosage (p=0.96).

Density differences between crops were highly significant (anova, p=0.007) and explained most of the variation in densities. Total density after spraying was on average 84 plants per m^2 in spring barley, significantly higher than in sugar beets (32 plants per m^2) and winter wheat (28 plants per m^2) (p<0.0001 for both comparisons).

Development of weed density

Densities before spring spraying averaged over three crops (mean 98 plants per m^2) were significantly higher than after spraying (mean 43 plants per m^2) (anova, $p_{season}<0.003$) (Fig. 2.8). The density before spring spraying was significantly lower in winter wheat (mean 63 plants per m^2) than in spring barley (mean 141 plants per m^2) and sugar beets (mean 110 plants per m^2), this difference was mainly due to autumn sprayings, winter mortality and a higher competitiveness in winter wheat than in spring sown crops. No significant dosage difference was found in the weed density before spring spraying, though the density at half dosage was higher than at normal dosage with quarter dosage in between.

There was no effect of year on the densities before spraying, but the densities after spraying increased with year independently of dosage (anova, $p<0.0028$ for year as a continuous explanation factor and $p=0.65$ for dosage×year). Thus, no between year differences in the effect of dosage were found, so no traceable accumulation of effects could be detected over the three years.

Densities of seedlings counted prior to implementation of treatments (1997 before) were not significantly different (anova, $p=0.72$) on plots designed to receive normal, half and quarter dosage of pesticides. Thus, the experimental basis was not biased before the beginning of the study. No effect of dosage was seen on the weed seedling densities before spring spraying in 1998 and 1999, hence after one or two years with reduced pesticide dosages.

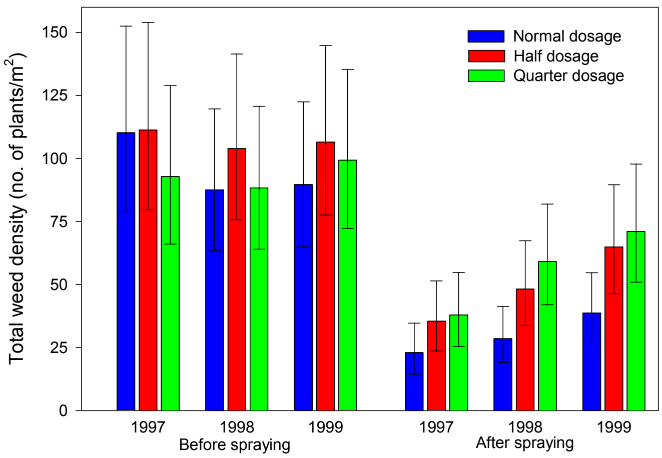


Fig. 2.8. Development of total weed densities before and after spraying over three crops during three growing seasons. Each bar represents the geometric mean of 12 to 15 values of mean density per m^2. Error bars represent the 95 % confidence limits.

Density of common species

Viola arvensis, ***Poa annua***, ***Veronica*** sp., ***Polygonum aviculare*** and ***Lamium*** sp. were the most frequent species/genera, occurring in 75-85 % of the plots after spraying. The ten species/genera that occurred in most plots were also the ten species/genera with the highest overall densities; thus, the frequent species were also the dominant species. Table 2.2 lists the twelve most frequent species/genera, and the effect of dosage on their densities in cereal fields (anovas).

Densities of four species/genera showed a significant effect of dosage. Of those, the density at quarter dosage was higher than at normal dosage in all cases, and in one case, the densities at half dosage were higher than at normal dosage (Table 2.2). The estimated mean density of more than two thirds of the species was higher at reduced dosages than at normal dosage despite the density was only significant different in one third of the species.

Table 2.2. Species/genera found in more than 50 % of the 123 plots. Effect of dosage on the density of each species/genus in cereal fields analysed by variance. Each species is defined as a target (T) or a non-target (NT) species (cf. section 2.2.1.7). Statistical significant difference from normal dosage is indicated as follows: +: *: 0.05≤p<0.10, *: 0.01≤p<0.05, **: 0.001≤p<0.01 and ***: p<0.001.

Common species/genera	Target (T) or non-target (NT)	Number of plots in the analysis (n)	Estimated mean density (plants/m^2) at		
			normal dosage	half dosage	quarter dosage
Aethusa cynapium	NT	54	2.4	4.2*	4.9**
Anagallis arvensis	NT	51	1.2	1.2	1.2
Bilderdykia convolvulus	NT	66	1.0	1.3	1.9*
Chamomilla sp./ *Matricaria perforata*	T	57	0.7	0.8	0.9
Chenopodium album	T	42	0.7	1.1	1.4
Elymus repens	T	57	1.1	0.9	1.1
Lamium amplexicaule/hybridum/purpureum	T	66	1.0	1.5	1.8*
Poa annua	NT	69	4.9	5.8	6.6
Polygonum aviculare	NT	66	2.7	3.4	3.4
Stellaria media	T	66	1.3	1.8	3.1***
Veronica agrestis/arvensis/persica	NT	66	1.9	2.5+	2.3
Viola arvensis/tricoor ssp. *tricolor*	NT	75	2.4	2.8	3.1

Density of rare species

Of the rare species (definition in section 2.2.1.7) found in this field study only ***Euphorbia exigua*** and ***Silene noctiflora*** were found in sufficient numbers for statistical analyses.

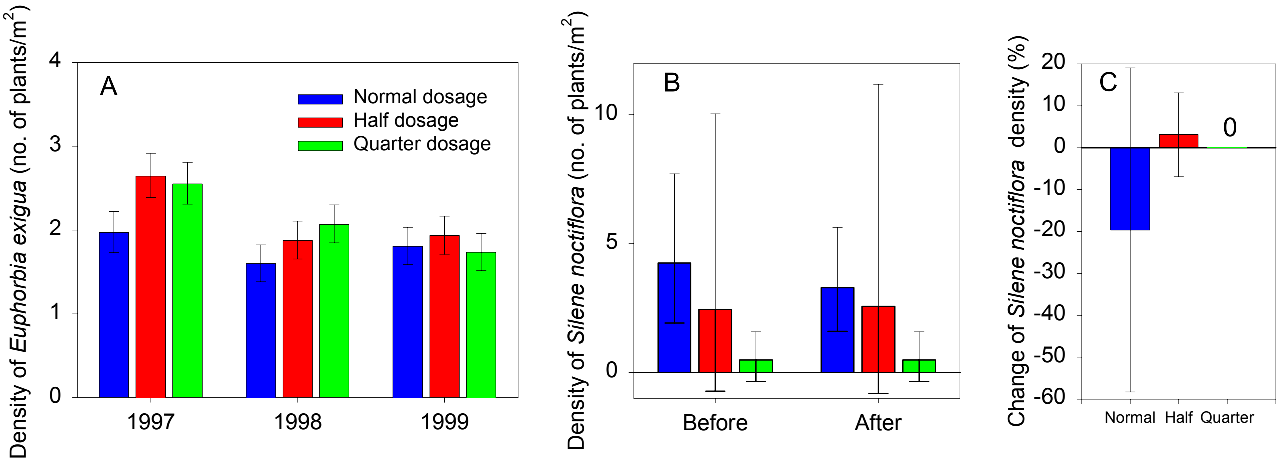


Fig. 2.9. A) Densities of *Euphorbia exigua* after spraying with different dosages of pesticides in three subsequent years. Every bar represents the geometric mean of three plot means from fields at one farm. B) Density of *Silene noctiflora* before and after spraying with different dosages of pesticides in 1998 at the spring barley field at one farm. Each bar represents the geometric mean of four values from different subplots. C) Change of *S. noctiflora* density after spraying compared to density before spraying. Error bars represent the 95 % confidence limits.

Fig. 2.9A shows the densities of ***E. exigua*** at different dosages during three years. In 1997 and 1998 there was a significant effect of dosage on density of ***E. exigua***, with a higher density at quarter dosage than at normal dosage. In 1999, no significant dosage effect was found, which might be due to chances. The density of ***S. noctiflora*** plants before and after spraying is illustrated on Fig. 2.9B. Because of a huge variation between subplots, no significant effect of dosages was found (anova, p=0.18). However, the figure illustrates that density at normal dosage was lower after spraying than before spraying in comparison to density at half and quarter dosages, which did not decrease (Fig. 2.9C).

2.2.2.2 Species richness

A total of 85 weed species were found within the study plots during the three-year study period (see Appendix C.1). Four of the species were only found before spraying. Of the 81 different species found after spraying 69 of them were broad-leaved species, 11 monocotyledons and 1 pteridophyte. The species grouping by life cycles gave; 4 trees, 18 perennials and 59 annuals of which 30 were purely summer annuals.

Number of species per plot

The dosage had a highly significant effect on the number of species present in a plot (Fig. 2.10). The variation in the covariates (species richness before spraying and total weed density) explained a significant part of the variation in number of species after spraying (Table 2.3). Crop type explained most of the variation in number of species and had a highly significant effect on the number of species present (anova, p<0.0001). The number of species can not be directly compared between the sugar beets and the cereals, because of the different sizes of the investigated areas. There was a much higher number of species in spring barley than in winter wheat.

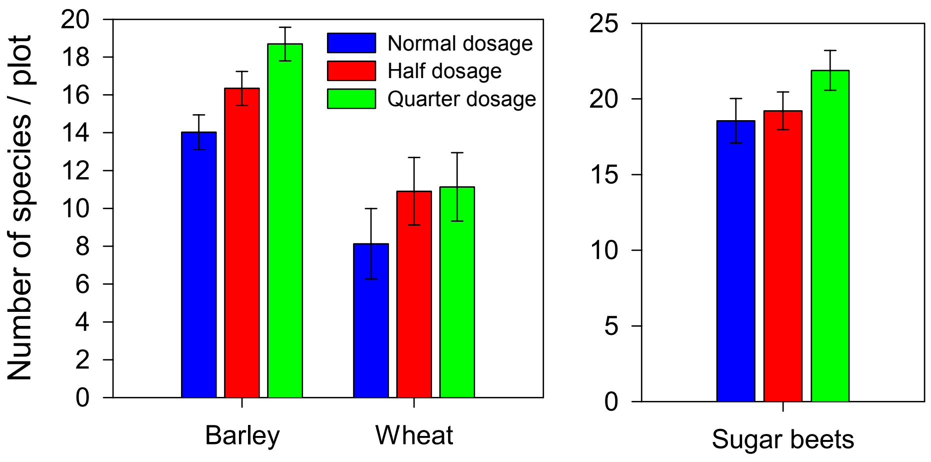


Fig. 2.10. Number of plant species after spraying with normal, half and quarter dosage of pesticides in three crops. Cereals and sugar beets are depicted individually since the areas investigated were of different sizes. Each bar represents the mean of 15 (spring barley and sugar beets) or 11 (winter wheat) values. The error bars represent the 95 % confidence limits.

In spring barley, the effect of dosage was significant and explained 17 % of the variation in species number. The number of species at quarter dosage was 14 % higher than at half dosage (p=0.002) and the number of species at half dosage was 16 % higher than at normal dosage (p=0.004). Most of the variation in number of species was explained by the farm×year interaction, probably reflecting differences between fields.

Dosage had an almost significant effect on species richness in winter wheat (anova, p=0.054), giving 36 % higher species richness at reduced dosages than at normal dosage. Most of the variation in species richness after spraying was explained by variation in total weed density.

Table 2.3. Schematic summary of the analyses of species richness. Statistical significance is indicated as follows: +: $0.05 \le p < 0.10$, *: $0.01 \le p < 0.05$, **: $0.001 \le p < 0.01$ and ***: $p < 0.001$. Grey areas indicate explanatory factors not included in the full model.

Factors	All crops (n=123)	Species richness Barley (n=45)	Wheat (n=33)	Sugar beets (n=45)
Species richness before	**	***	**	
Weed density	***	*	***	*
Dosage	***	*	+	
Crop	***			
Farm				
Field (Farm)	*			
Year				
Dosage×Crop				
Dosage×Farm				
Dosage×Year		+		***
Crop×Farm				
Crop×Year				
Farm×Year	**	***		***
Dosage×Crop×Farm				
Dosage×Crop×Year				
Dosage×Farm×Year				

An effect of dosage on species richness in sugar beets existed but varied between years (Table 2.3). No significant dosage effect was detected in 1997 and 1999, but in 1998 a significantly higher species richness was present at quarter dosage than at normal dosage (Tukey-Kramer test, p=0.032).

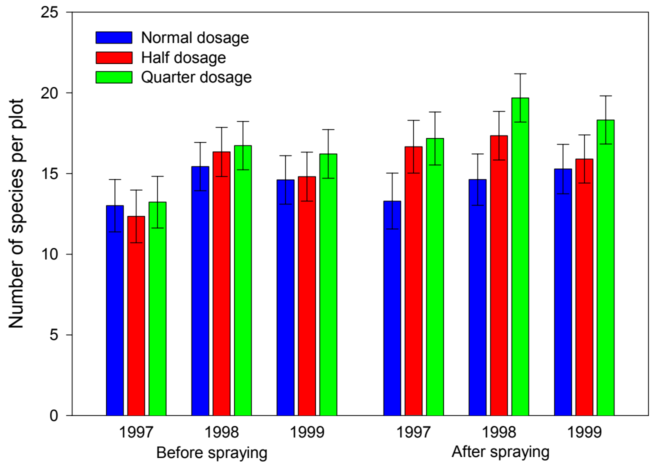


Fig. 2.11. Development of species richness before and after spraying over three crops during three growing seasons. Each bar represents the mean of 12 to 15 values. Error bars represent the 95 % confidence limits.

Development of species richness
No significant effect of year was found on species richness neither before nor after spraying (Fig. 2.11).

The species richness found prior to implementation of treatments (1997 before spraying) was not significantly different on plots intended to receive normal, half and quarter dosage of pesticides, giving the optimal base for the experiment. There was a significant difference in species richness before and after spraying (anova, $p=0.01$). The species richness after spraying was on average 12 % higher than before spraying. This is mainly due to an artefact caused by a more exact identification of plants after spraying than before spraying. Before spraying, some seedlings could be identified to genera only, whereas most plants could be identified to species after spraying.

2.2.2.3 Species composition and occurrence of rare and scarce species
The dominant weed species were the same in a particular field from year to year, despite the different crops grown on the field, but varied considerably from field to field. Appendix C.1 lists the occurrence of particular species in plots sprayed with normal, half or quarter dosage. Most species, occurring in more than a few plots, did grow at all three dosages, but often with the lowest occurrence at normal dosage. A few species were most common at one or two levels of dosages: ***Ranunculus repens*** was found seldom at half dosage compared to plots sprayed with quarter or normal dosage; and ***Atriplex patula*** was found seldom at normal dosage compared to reduced dosages. Only one of the species was found exclusively at one dosage: barley as weed was only present in half dosage plots.

Rare species
None of the species found in this experiment is mentioned in the Danish Red List (Stoltze & Pihl 1998). However, a few of the agricultural weed species found are quite rare in the Northern and the Western parts of Denmark according to Hansen (1981) and Mikkelsen (1989) viz. ***Chaenorhinum minus, Euphorbia exigua***, ***Kickxia elatine***, ***Silene noctiflora***, ***Stachys arvensis*** and ***Veronica hederifolia.*** Table 2.4 shows the number of plots where the six species were observed at least once during the three years of study. A species was only counted once in each plot to avoid dependent observations, coming from identical populations year after year.

Table 2.4. Number of plots where six rare species occurred at least once during the three years.

Species	Dosage		
	Normal	Half	Quarter
Chaenorhinum minus	0	2	0
Euphorbia exigua	4	6	7
Kickxia elatine	3	3	4
Silene noctiflora	6	7	5
Stachys arvensis	1	1	3
Veronica hederifolia	0	1	0

The occurrence of the rare species was not significantly influenced by differences in dosages (chi^2-test, df=6 (the three species with low occurrence was summed), $p>0.1$).

Scarce species

The scarce species (found in less than 6 of the 123 investigated plots) can be divided into different groups based on habitat preferences:
Woodland species: ***Acer pseudoplatanus***, ***Fraxinus excelsior***, ***Salix*** sp. and ***Sambucus nigra***.
Crop species: ***Beta vulgaris*** ssp. ***vulgaris***, ***Hordeum vulgare***, ***Medicago lupulina*** and ***Secale cereale***.
Species from roadsides and meadows: ***Achillea millefolium, Artemisia vulgaris***, ***Carduus crispus***, ***Cerastium fontanum*** ssp. ***triviale***, ***Cirsium vulgare***, ***Festuca rubra***, ***Ranunculus acris*** ssp. ***acris*** and ***Rumex crispus***.
Species growing in dry or wet soils: ***Arabidopsis thaliana***, ***Arenaria serpyllifolia***, ***Bidens tripartita***, ***Epilobium parviflorum***, ***Filaginella uliginosa*** and ***Juncus bufonius***.
Arable species: ***Alopecurus myosuroides***, ***Avena fatua***, ***Chaenorhinum minus***, ***Galeopsis tetrahit***, ***Geranium pusillum***, ***Papaver dubium***, ***Papaver rhoeas***, ***Raphanus raphanistrum***, ***Stachys arvensis***, ***Thlaspi arvense***, ***Veronica hederifolia*** and ***Viola tricolor*** ssp. ***tricolor***.

Table 2.5. Number of plots where at least one of the species in a group has appeared, at least once in three years.

Group	Dosage		
	Normal	Half	Quarter
Woodland species	4	0	3
Crop species	1	5	2
Species from roadsides and meadows	3	1	9
Species growing in dry or wet soils	1	2	4
Arable species	1	7	8

A higher number of scarce species were found at quarter dosage than at normal and half dosages. This has to be seen in connection with the general higher species richness at quarter dosage than at normal dosage. However, the relative proportion of scarce species might be higher at quarter dosage than at normal dosage.

There was a significant effect of dosage on the group occurrences (chi^2-test, df=8, $0.01<p<0.05$). A higher occurrence of woodland species than expected was found at normal dosage, moreover the occurrence of crop species was higher than expected in plots sprayed with half dosage (Table 2.5).

The occurrence of woodland species at normal and quarter dosages and not at half dosages might be explained by the experimental design, since a higher proportion of plots receiving normal and quarter dosage were located near hedges (see section 1.2.5). The dispersal of seeds from woody species is expected to be more frequent near hedges. In contrast, crop species occurred most often in the half dosage plots more distant from hedges.

2.2.2.4 Ability to flower

Proportion of flowering plants

The proportion of flowering plants was on average 44 % ranging from 5 % to 76 %. Fig. 2.12 illustrates the proportion of flowering plants in relation to crop and dosage. Table 2.6 lists the result of the variance analysis for proportion of flowering plants.

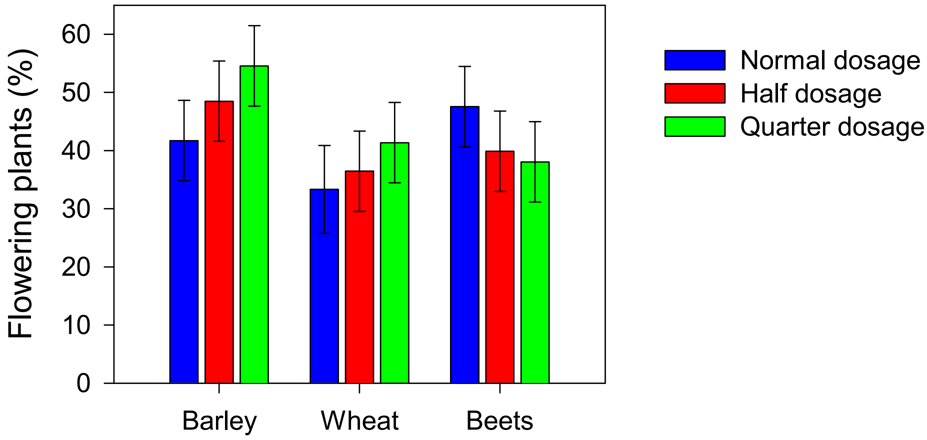


Fig. 2.12. Mean proportion of flowering plants after spraying with normal, half or quarter dosage of pesticides in three crops. Each bar represents a mean of 8-10 values. The error bars indicate the 95 % confidence limits.

A significant effect of dosage was found in the analysis of the proportion of flowering plants, but it varied between crops (Table 2.6). In the cereals, the proportion of flowering plants increased with decreasing dosage. In contrast, the proportion of flowering plants in the sugar beet fields decreased with decreasing pesticide dosage (see sections 2.2.2.5 and 2.2.3.5 for further explanation). Moreover, the proportion of flowering plants was highly affected by the variation between fields.

Proportion of flowering species

The proportion of species recorded flowering was on average 62 % but varied between 17 % and 100 %.

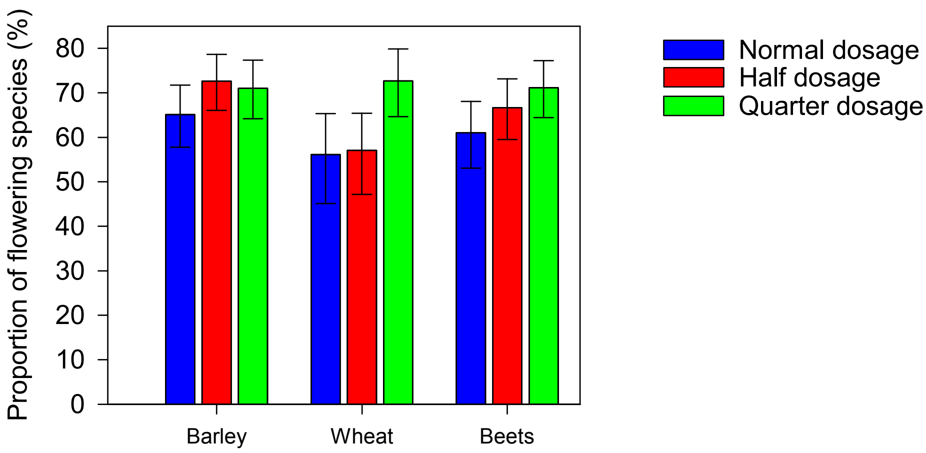


Fig. 2.13. Mean proportion of flowering species after spraying with normal, half or quarter dosages of pesticides in three crops. Each bar represents a mean of 8-10 values. The error bars indicate the 95 % confidence limits.

Dosage had a highly significant effect on the proportion of flowering species in a plot (Table 2.6 and Fig. 2.13). The proportion of flowering species was significantly higher at quarter dosage than at normal dosage (p=0.0032). Moreover, the proportion of flowering plants affected the proportion of flowering species positively. More plants in flower increased the possibility that a higher proportion of different species was represented.

Table 2.6. Schematic summary of the analyses of proportion of flowering plants and flowering species, respectively. Factors not included in any of the models have been omitted from the table. Statistical significance is indicated as follows: +: 0.05≤p<0.10, *: 0.01≤p<0.05, **: 0.001≤p<0.01 and ***: p<0.001.

Explanatory factors	Ability to flower	
	Plants (n=83)	Species (n=82)
Dosage		**
Proportion of flowering plants		**
Crop	*	+
Farm		*
Field(Farm)	***	
Dosage×Crop	*	

2.2.2.5 Habitats in sugar beets

Fig. 2.14 shows occurrence of weeds in the sugar beet fields grouped by their habitat: within the rows or between the rows.

Total weed density and species richness in sugar beets were not significantly influenced by the habitat (Fig. 2.14A and C) (anovas, p>0.1). Nevertheless, both were strongly affected by dosage (see sections 2.2.2.1 and 2.2.2.2).

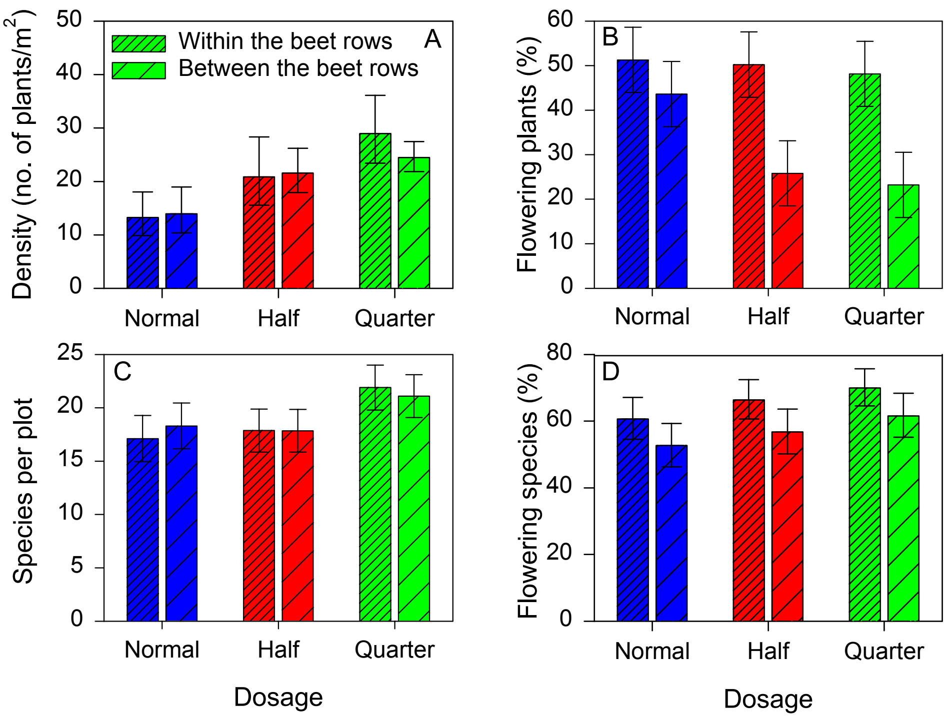


Fig. 2.14. A) Total weed density, B) proportion of flowering individuals, C) number of species per plot and D) proportion of flowering species in sugar beet fields after spraying with normal or reduced dosages of pesticides. For each dosage the weed plants are grouped by their habitat in the field: within the beet rows (dense hatching) or between the beet rows (light hatching). Each bar represents a mean of ten plots and error bars indicate the 95 % confidence limits.

The proportion of plants flowering was significantly affected by habitat, although the effect varied between dosages ($p=0.036$ for the dosage×habitat interaction). The response of habitat was strongest at the reduced dosages (Fig. 2.14B). No significant effect of dosage was found on proportion of flowering plants within the beet rows, whereas between the rows 44 % of the weed plants were flowering at normal dosage, 26 % at half dosage and only 23% at quarter dosage.

Equally, the proportion of flowering species was close to significantly affected by habitat (anova, $p=0.074$), with more species capable of flowering within rows than between rows (Fig. 2.14D).

2.2.3 Discussion

2.2.3.1 Weed density

Dosage effect

Investigation of the effect of pesticide application on weed densities showed a reduction of 45 - 70 % after spraying (Fig. 2.8), dependent on the dosage applied. This reduction can be related to the effects of the herbicides and to other natural changes in the population occurring between the time of spraying and the registration three months later. This period covers most of the growing season for annual plants, in which some seeds still germinate, seedlings become established, plants flower and set seeds, if the conditions allow it. In addition, many of the seedlings could have died as an effect of intra- or interspecific competition. The yield trials in this study have shown that the densities of weed plants in unsprayed areas of spring barley decreased with 6 % from seedlings to mature plants, whereas the densities in areas sprayed with quarter dosage decreased with 25 % (see section 5.1). Therefore, the reductions in weed densities are mainly due to the herbicide sprayings. No significant differences in weed densities between half and quarter dosages were found, whereas the density at normal dosage was significantly lower. The biomass reduction after spraying is often higher than the density reduction (Salonen 1993a) indicating that the growth of each surviving plant may be reduced too. Therefore the relationship between weed density and weed biomass is probably dosage-dependent, making density just a rough measure of biomass.

For four of the twelve most dominant species (***Aethusa cynapium, Bilderdykia convolvulus***, ***Lamium*** sp. and ***Stellaria media***), it was possible to show a significant effect of dosage, with fewer plants killed at quarter dosage than at normal dosage (Table 2.2). The responding species were both target and non-target species, indicating that densities of both categories increased at strongly reduced pesticide dosages. Thus, even though, the herbicides were chosen mainly to control the target species, densities of non-target species also decreased at spraying with normal dosage.

Elymus repens is a weed species farmers want to control, but most of the herbicides used in spring against broad-leaved species are not effective against grasses. ***E. repens*** is usually controlled by glyphosate in the autumn. Thus, ***E. repens*** and ***Poa annua*** do not show any significant dosage response to herbicides used in spring. The rare non-target species ***Silene noctiflora*** and ***Euphorbia exigua*** were negatively influenced by the dosage of herbicides used (Fig. 2.9) though only significant for ***Euphotbia exigua*** in two of three years. Many herbicides are broad-spectrum herbicides, affecting the density of target species as well as non-target species, and may result in a local or temporary loss of non-target species (McLaughlin & Mineau 1995), as was confirmed by this study. Use of reduced herbicides dosages may increase the population size and thus improve possibilities of long-term survival in the arable fields.

The different interspecific responses observed at reduced dosages might be due to different susceptibility towards the herbicides (e.g. Cashmore & Caseley 1995).

This study covers very different herbicide products and spraying situations, which increases the statistical uncertainty. However, the results include the great variations found between farms and years and may therefore be of more general value, than studies of responses to one herbicide on one farm in one year.

Many dose response trials have been performed, where plants of one weed species have been treated with many different dosages of one herbicide and the biomass measured afterwards, resulting in a mathematically described dose response curve (e.g Streibig 1992, Streibig ***et al.*** 1993, Olofsdotter ***et al.*** 1994). Despite only three points on a dose response curve were revealed in this study, it is the first time that large-scale dose response trials have been performed over different weed communities of several weed species, different herbicide products and different years, resulting in much variation. Therefore it is without much value to compare directly with known dose response trials.

Time effect
The increase in weed densities after spraying over the three years is difficult to explain but might reflect variations in growing and spraying conditions across the different years, resulting in a higher percentage of individuals surviving at all dosages in 1999 than in 1997. Populations of short-lived plant species often vary in number of individuals between years (e.g. Milberg ***et al.*** 2000). Moreover, reductions in total weed number caused by herbicide application may vary considerably. One year Derksen ***et al***. (1995) found a 90 % reduction in total weed number due to a herbicide spraying, next year the reduction was only 39 % despite the field, the product and the dosage being similar.Accumulation of dosage effects are described in section 2.3.3.1.

2.2.3.2 Species richness
Crop effect
This study has found a higher species richness in spring barley than in winter wheat (Fig. 2.10). The spring cereals in Denmark have more weed species than winter cereals (Andreasen ***et al***. 1996, Hald 1999), because the weed flora in Denmark has been selected over many years towards the ecological conditions prevailing in spring sown crops (Hald 1999). This is confirmed by the dominance of pure summer annuals in spring barley and by the fact that all except one of the winter annual species present in this study were also capable of germination in spring. Eight of the eleven winter wheat fields sprayed in spring were also sprayed in autumn. The number of species was thus reduced twice, which might be another reason for the lower species number in winter wheat than in spring barley. Furthermore, winter cereals have a higher degree of cover at springtime than spring cereals. The competition in spring from the crop against the weed species is thus stronger in winter cereals than in spring cereals.

Dosage effect
Species richness was affected by the dosage of pesticides used; the lowest dosage gave the highest species richness (Fig. 2.10). A reduction in pesticide dosage from normal to quarter dosage resulted in 28 % more species, and a reduction to half dosage resulted in 16 % more species on average over all three crops. Thus, reduced pesticide input promotes higher weed diversity as suggested by Clements ***et al.*** (1994). The increase in richness at reduced dosages was not solely an effect arising from the fact that species diversity increases with an increase in plant density (the species-area relationship). This effect was accounted for in the analyses by including weed density as a covariate (with a significant and positive effect on richness). To sum up, dosage affects richness both directly and indirectly through density. A total cease of herbicide use would presumably increase the richness even more as found by Boström & Fogelfors (1999). In this experiment, knowledge of the size of increase in weed richness with no use of herbicides would have allowed us to conclude whether a 28 % increase was high compared to the maximal possible.

It is worth noticing, that it was possible to detect an increased species richness at reduced pesticide dosages, even though the arable fields are poor in plant richness and the potential species pool has been strongly diminished the last decades (Jensen & Kjellsson 1995) and there were large variations in weed communities between fields.

Time effect
No clear tendencies towards an increase in species richness could be detected between years, even after two subsequent years with reduced dosages of herbicides (Fig. 2.11).

2.2.3.3 Species composition
This study has like others (Andreasen ***et al.*** 1991, Wilson ***et al.*** 1994) demonstrated that species abundance and species composition also vary considerably from field to field. Despite the fact that all fields are placed on clay soils in the same region in Denmark. Differences between fields may be the result of different agricultural histories before the start of the main experiment and different agricultural practices during the study years, including among other things differences in the pesticide products used and differences in the dosage chosen as normal.

It proved impossible to find indicator species in the sense, that the species exclusively occurred in fields receiving only reduced dosages of pesticides, due to the huge variation in dominant weed species from field to field. Scarce species were found more often at quarter than at normal dosage, which may be due to a higher possibility of being established in quarter dosage plots as seeds from hedges and habitat islands.

2.2.3.4 Ability to flower
No general effect of dosage was seen on the proportion of flowering plants, but dosage had different effects on the ability to flower in cereals and in sugar beets. The expected inverse relationship between proportion of flowering species and dosages was seen in cereals, whereas in sugar beets the proportion of flowering plants was higher at normal than at reduced dosages (Fig. 2.12). This was a result of the mechanical control of weeds between the beet rows (see section 2.2.3.5). A higher proportion of flowering plants at the reduced dosages in cereals is probably accompanied by a higher plant biomass on

average, since flowering annual plants has more biomass than vegetative annual plants - in general. Debaeke (1988) showed a positive relationship between dry weight per plant and number of seeds produced per plant. Therefore, it is possible that reduced pesticide dosages will result in a higher seed production per surviving plant as shown for some species (Hald 1993, Rasmussen 1993a, Rasmussen 1993b).

Dosage had a strong impact of the proportion of flowering species (Fig. 2.13), both directly and indirectly through the proportion of flowering plants, resulting in more reproductive species at quarter dosage than at normal dosage. This is to our knowledge the first time it has been demonstrated that reduced pesticide dosages increase a weed community's ability to flower. These results imply that the fitness of surviving plants is higher for plants exposed to reduced dosages than for plants exposed to normal dosage.

2.2.3.5 Habitats in sugar beets

Differences between the two habitats for weeds in the sugar beet fields had a strong impact on the proportion of flowering plants. Hoeing between the rows reduced the proportion of flowering plants with more than 50 % compared to plants exposed to spraying within the beet row. Although the density of plants was not significantly different between habitats, the ability to flower was highly affected. Hoeing operations were often performed later in the growing seasons than the sprayings, and harmed plants at a higher developmental stage. In addition, hoeing dried out the roots of weed plants between rows and promoted new weed seedlings to germinate. Most of these seedlings had not the time to reach flowering and could therefore never set seeds. Although plants are very plastic, they need time to reach a size where the plant has the energy necessary for flowering. This time is longer after spraying than after hoeing, because hoeing is performed later in the growing season than spraying. Hoeing in combination with 25 cm band spraying compared with broad spraying have not increased the weed density significantly, whereas 12.5 cm band spraying in combination with hoeing resulted in significantly higher weed density than at broad spraying (Fig. 2.14). The hoeing in contrast to the spraying gives each surviving weed plants a lower ability to flower than at broad spraying, probably resulting in a lower seed set. However, the overall proportion of species flowering was still higher in low dosage plots than at normal broad-spraying.

2.3 Seed rain study

In this study, the term seed rain refers to seeds lying on the soil surface called surface seed bank by Mortimer (1976). The aim of the study was to measure the effect of reduced pesticide dosages on the seed number per square meter soil surface, the diversity of species (richness) and the seed biomass available for bird consumption after crop harvest. The seed rain is not only eaten by birds (e.g. Christensen ***et al.*** 1996), but also insects (Van der Wolf 1992, Cromar ***et al***. 1999) and small mammals like mice (Green 1979, Angelstam ***et al.*** 1987) utilise the seeds as a food resource.

It may be assumed that all seeds constitute a potential food resource for e.g. birds and mice, but seeds of some weed species might be poisonous or be avoided for other reasons (Diaz 1990). The seed rain may also play a role as food resource after the seeds have germinated and become seedlings (e.g. Green 1980). Especially in winter, seeds on arable stubble fields constitute a major part of the food eaten by birds in the agricultural landscape (Steenfeldt ***et al.*** 1991, Donald ***et al.*** 2001). The number, composition and richness of seeds in the seed rain are very important for the structure of the vegetation in the following years. Most of the seeds enter the soil seed bank as a result of cultivation and then become a part of the potential future weed vegetation.

2.3.1 Methods

2.3.1.1 Field work

The seeds on the five winter wheat and the five spring barley stubble fields were sampled in autumn of 1998 and 1999, where bird counts were carried out (section 4.2.2). High precipitation made it impossible to collect seeds from the winter wheat stubble field at Gjorslev in 1998; therefore, no data exist from that field. Unfortunately, one farmer did not wish to continue the investigations on the stubble fields in 1999. Thus, 9 fields were investigated in 1998 and 8 fields in 1999.

The seed rain was sampled once every year, on average 12 days after harvest, depending on the weather and the time of straw collection. The samples were taken in dry and sunny weather, after the dew had evaporated, and at least five hours after rainfall. All samples from one field were taken on the same day. At each field 12 samples (4 per plot at regular intervals) from 0.18 m^2 were taken with a C-vac constructed by Navntoft ***et al.*** (see Fig. 3.2). Each sample was taken as ten 5-seconds suctions covering 0.018m^2. The samples consisted of surface soil, seeds, straw, awns and seed shells from the cereals. An average sample weighed 34 g of which less than 0.62 g were weed seeds. The samples were taken at least 12 meters from other plots, hedges etc. to avoid edge effects.

2.3.1.2 Laboratory work

In the laboratory, the samples were air dried at 20 °C, to avoid seed germination and seed predation by insects present in the samples. The dry samples were fractionated using a 2-mm and a 0.5-mm mesh sieve successively. Every organic particle over 2 mm was manually sorted into seeds or debris. Soil clumps bigger than 2 mm were manually pushed through the mesh. Particles less than 0.5 mm were dropped to reduce the bulk and thereby save time in the laboratory. This was done with two arguments: 1) The vast majority of weed seeds have a minimum diameter bigger than 0.5 mm in diameter (Holm-Nielsen 1998) and none of the dominant weed species present in this study had seeds that small. 2) Seeds smaller than 0.5 mm in diameter are only eaten by very few bird species foraging in the agricultural land (Christensen ***et al.*** 1996). Species with small seeds are, however, very important with respect to other aspects of the vegetation dynamics.

After sieving, the samples were weighed and submersed in a flotation solution of potassium carbonate (K_2CO_3) with a specific density of 1.43 g/ml. Specific densities of weed seeds varied between species from less than 0.7 to 1.42 g/ml (Jensen unpublished data). The amount of flotation solution was between 1 and 2 times the volume of the seed samples. After 24 hours, the high-density particles precipitated and the low-density particles (organic material) remained at the surface. The supernatant was carefully transferred to a filter paper over a vacuum pump, which removed the remaining flotation solution. The filter paper with all the organic material was placed in a petri dish and air-dried at 20 °C. Then the material was spread in a thin layer under a magnifying stereoscope and all seeds and seed shells were identified to species and counted. Seeds were identified by literature (Beijerinck 1947, Holm-Nielsen 1998) or by comparison with a seed reference collection made from mature plants in the fields. Some seeds were only identified to genus level, e.g. seeds from ***Lamium amplexicaule***, ***Lamium hybridum*** and ***Lamium purpureum*** were very difficult to distinguish from each other (***pers. obs.***), thus seeds from these species were all called ***Lamium*** sp. Seeds from ***Atriplex patula*** and ***Chenopodium album*** looked like each other and were treated as one species: ***Atriplex patula/Chenopodium album.*** A few seeds were impossible to identify although they were clearly different from all other seeds. Those seeds were named type A.

2.3.1.3 Data description

The seeds were divided in two groups: whole seeds and damaged seeds. Seeds resisting the pressure from a pair of tweezers were registered as whole seeds. Seeds not resisting the pressure were hollow and thus categorised as damaged seeds together with pieces of seeds and seed shells. It was attempted to estimate how many whole seeds the pieces of seeds and seed shells in the samples corresponded to, and this figure was added to the hollow seed count. The number of damaged seeds calculated in this way was a conservative measure, because small pieces of seeds and seed shells might be lost during sieving.

For comparison with bird data, seeds were divided in two groups: Spilt grains and weed seeds. For each group, the number of seeds and the biomass per square meter were calculated. The mean seed weight of most species is known from the literature (Korsmo 1926, Salisbury 1942, Gross 1990, Melander 1993) (see Appendix C.2). If there was great variation between seed weight mentioned by different authors or no seed weight could be found in the literature, seeds of those species were weighed in the laboratory. The total biomass was calculated by multiplying the seed weight of each species with the number of seeds per species and adding the biomass for all species in a sample. The same seed weight was used for whole and damaged seeds, although most of the damaged seeds weighed less than a whole seed. Number of weed species was counted as the number of taxa in a plot, excluding taxa on genus or family level in which a taxon at species level was counted.

2.3.1.4 Control of methods

26 of 204 seed samples selected at random were checked for viable seeds in the discarded sample parts. There were several discarded parts: 1) Organic material over 2 mm classified as debris. 2) Sediment from the flotation. 3) Residuals from the petri dish after visible seeds had been picked out. All discarded parts were placed in a tray on a substrate of sterilised soil and placed in a greenhouse for three months to see if any germination occurred. Seedlings were counted and identified to species. The greenhouse was different from the greenhouse used in the pilot study (section 2.1) and the seed influx was nearly zero.

2.3.1.5 Statistical analyses

The following response variables were analysed statistically:

1) Mean number of weed seeds per m^2
2) Mean biomass of weed seeds per m^2
3) Mean number of spilt grains per m^2
4) Mean biomass of spilt grains per m^2
5) Number of weed species per plot
6) Proportion of damaged spilt grains
7) Proportion of damaged weed seeds
8) Proportion of damaged seeds per species

The basic experimental unit in the analyses of all variables was the plot (n=51). In order to improve approximation to a normal distribution and make the variance independent of the mean, the mean number of seeds and seed biomass (variables 1-4) were $\log_e(y+1)$ transformed before further analyse. The proportions of damaged grains (variable 6) were square root transformed and the proportions of damaged weed seed (variable 7) were log (arcsine (y)) transformed. The data transformations were accepted, if after running the model the residuals plotted against the predicted values were without apparent trends.

The proportion of damaged seeds was calculated as the number of damaged seeds divided by the number of damaged and whole seeds per plot. Data for variables 1-5 included damaged seeds. The factors used to explain the variation in seed rain were: dosage, crop, farm, year, density of generative plants, the sample weight and the interactions dosage×crop, dosage×farm, dosage×year, crop×year, dosage×crop×year and crop×farm×year. The log-transformed sample weights were used in the analyses, to allow for possible effects of sample size on the number of seeds found.

Response variables 1-7 were analysed separately in a general linear model with the explanatory factors mentioned above. The number of explanatory factors was reduced during the full-scale model calculations using an iterative procedure removing the variables with $p > 0.1$ until the model consisted of variables with $p \leq 0.10$ only. The analyses were performed using the GLM procedure (with Random/Test statement) in SAS (SAS Institute 1999).

The proportion of damaged seeds of a given species (variable 8) was tested with a Kruskal-Wallis test with regard to differences in median values between dosages. Only plots with more than ten seeds of a given species were tested, because a rather large stochastic variation exists in proportions calculated from small populations.

2.3.2 Results

2.3.2.1 Seed number and biomass

The seed rain of the spring barley and winter wheat stubble fields consisted of spilt grains and weed seeds. On the 17 investigated fields there were on average 62 spilt grains (corresponding to 1.77 g dry weight) and 206 weed seeds (corresponding to 0.18 g dry weight) per m^2. Even though there were three times as many weed seeds than spilt grains per m^2, the weed seeds made up less than 10 % of the total seed rain biomass (Fig. 2.15). A total of 19,980 weed seeds and 7,920 spilt grains were found (Appendix C.2).

Weed seeds

The main contributors to the seed rain were ***Stellaria media***, ***Atriplex patula***/***Chenopodium album, Aethusa cynapium*** and ***Polygonum aviculare***, which together accounted for 46 % of the seeds. ***Bilderdykia convolvulus*** made up the largest proportion of the weed seed biomass (24 %) followed by ***Stellaria media*** and ***Atriplex patula***/***Chenopodium album*** each with 12 %.

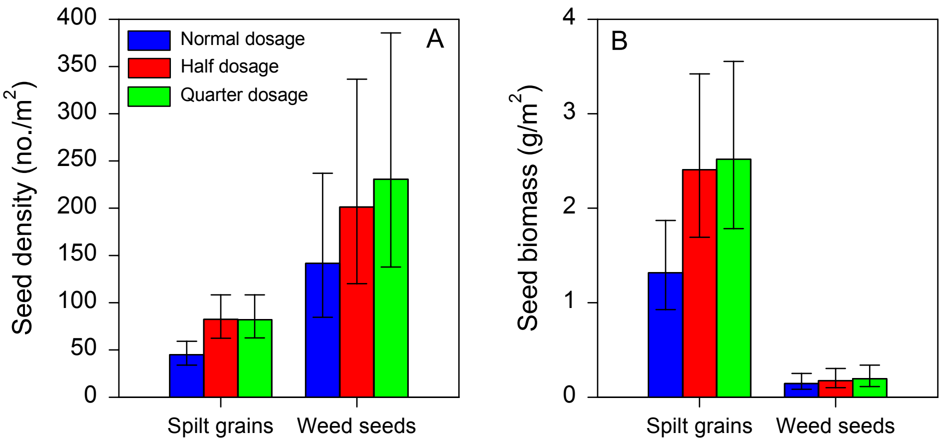


Fig. 2.15. Seed rain in 17 stubble fields at three dosages of pesticides. A) shows the geometric means of the number of spilt grains and weed seeds (per m^2), respectively. B) shows the geometric means of the biomass of spilt grains and weed seeds. Error bars represent the 95 % confidence limits. Damaged seeds were included in the estimates.

The number and biomass of weed seeds was not significantly affected by pesticide dosage (Fig. 2.15 and Table 2.7), though it appeared higher at quarter dosage than at normal dosage with half dosage in between. The number of weed seeds per m^2 ranged from 9 to 2779 across dosages, crops and years. The covariate (density of generative plants in the vegetation) was highly significant in the analysis of seed number and biomass and explained one third of the variation in both response variables. If the covariate was excluded from the model, dosage had still no significant effect on the weed seeds. The analysis showed that there were significantly more weed seeds present in winter wheat fields than in spring barley fields. The farm factor had a significant effect on the weed seed number, due to the occurrence of significantly more seeds on Nøbøllegård than on the other farms (Tukey-Kramer tests). There were especially many seeds of ***Matricaria perforata*** on Nøbøllegård. ***Matricaria perforata*** has light seeds (Appendix C.2), which may explain why the effect of farm was not as strong in the analysis of biomass (Table 2.7).

Table 2.7. Schematic summary of the analyses of the seed rain. Factors not included in any of the reduced models have been omitted from the table. Statistical significance is indicated as follows: +: 0.05≤p<0.10, *: 0.01≤p<0.05, **: 0.001≤p<0.01 and ***: p<0.001. Grey areas indicate explanatory factors not included in the full model.

	Weed seeds		Spilt grains		
	no/m^2 (n=51)	mg/m^2 (n=51)	no/m^2 (n=51)	mg/m^2 (n=51)	no/m^2 (excluded roundup sprayed fields) (n=45)
Sample weight			*	+	
Density of generative plants	***	***			
Dosage			**	*	
Crop	**	*			
Farm	***	**			
Dosage×Crop×Year					**
Crop×Farm×Year			***	***	***

Spilt grains

Reduction of pesticide dosage affected the number and biomass of spilt grains significantly (Table 2.7). There was an estimated geometric mean of 45 grains per m^2 in plots sprayed with normal dosage compared to 82 grains per m^2 in plots sprayed with half or quarter dosages (Tukey-Kramer test, p=0.009 and p=0.011, respectively).

In 1998, two of the fields were sprayed with glyphosate before harvest (Appendices A.3 and A.4). To detect if the number of spilt grains was influenced by dosage of Roundup sprayed on the fields before harvest, the analysis was run once more without data from these two fields. The dosage had no longer any general significant effect on the number of spilt grains on the remaining fields (analysis of variance, p=0.43). However, the interaction between dosage, crop and year was significant in the model indicating that there were still differences between dosages that varied between years and crops (at the remaining barley fields, the number of grains was lowest at quarter dosage in 1998, while in 1999 the highest number of grains was also found at quarter dosage).

The number and biomass of spilt grains was also affected by the interaction between crop, farm and year (Table 2.7) explaining more than 70 % of the variation in number and biomass of spilt grains. Furthermore a positive correlation between sample weight and number of spilt grains was found, but the sample weight explained less than 2 % of the variation in number of spilt grains.

2.3.2.2 *Species richness*

A total of 39 weed species were found in the seed rain (Appendix C.2). There were between 4-17 species per plot. On average 11 species were present per plot sprayed with quarter or normal dosages and 10 species per half dosage plot.

Dosage had no significant effect on the number of species per plot (Table 2.8), and the significant explanatory factors were number of generative species per plot, farm and the interaction between year and crop.

Table 2.8. Schematic summary of the analysis of weed richness in the seed rain. Factors not include in the reduced model have been omitted from the table. Statistical significance is indicated as follows:
*: 0.01≤p<0.05, **: 0.001≤p<0.01 and ***: p<0.001.

Factors	Number of weed species per plot
No. of generative species per plot	***
Farm	**
Crop×Year	*

The number of species per plot in the seed rain was positively correlated with the number of generative species in the vegetation (Fig. 2.16). The correlation explained 11 % of the total variation in number of species per plot in the seed rain.

The differences among farms in species richness were mainly caused by a significantly lower species richness per plot on Gjorslev (9.1 species) and Lekkende (8.9 species) than at Nøbøllegård (12.8 species).

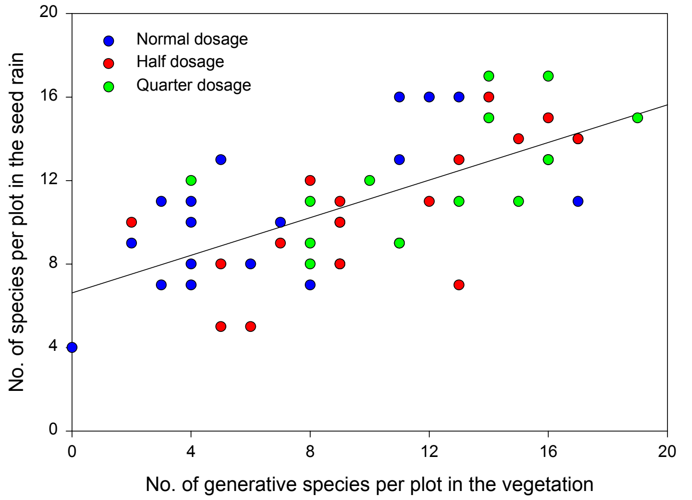


Fig. 2.16. Correlation between the number of species found in the seed rain and the number of generative species in the vegetation. The relation did not vary significantly between dosages (p=0.33 in test for homogeneity of slopes).

The effect of crop×year showed that there was a higher species richness in spring barley fields than in winter wheat fields in 1998, and a higher number in winter winter wheat than in spring barley in 1999. Because of the crop rotation, the fields with spring barley in 1998 were exactly the same fields as the fields with winter wheat in 1999.

Comparing species richness in seed rain and vegetation

A total of 61 species were found in the vegetation study on the 17 seed rain fields, whereas only 39 species were found in the seed rain study. Of this, 36 species were found in both studies. Some of the seeds could not be identified to species but only to genus, therefore the number of species present was probably higher than indicated (Table 2.9).

Table 2.9. Number of species found in the vegetation in July and / or in the seed rain in September.

Number of species	In seed rain	Included in seed rain on genus level	Not in seed rain	Total
Generative in vegetation	32	7	8	47
Vegetative in vegetation	4	1	9	14
Not in vegetation	3	0	-	3
Total number	39	8	17	64

2.3.2.3 Damaged seeds

To detect if dosage had an effect on the proportion of damaged seeds a variance analysis was performed on the proportion of damaged weed seeds and damaged spilt grains. The mean proportion of damaged seeds (22 %) and spilt grains (24 %) were almost identical (Fig. 2.17). Most damaged grains were pieces of grains, whereas most of the damaged weed seeds consisted of hollow seeds and to lesser extent of intact seeds and seed shells.

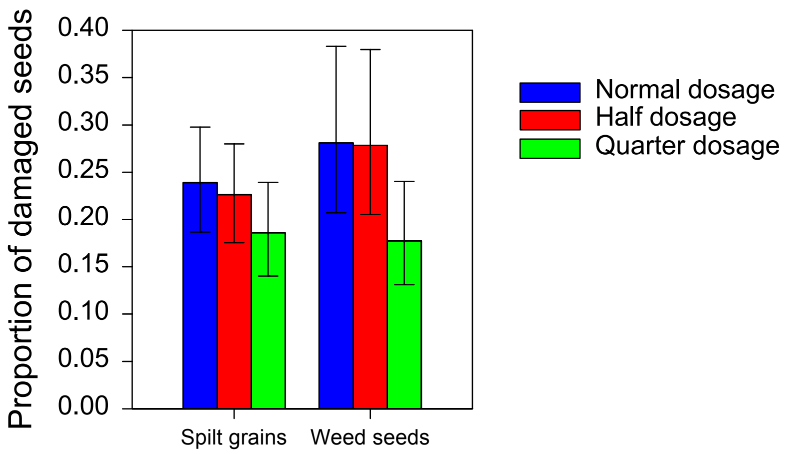


Fig. 2.17. Mean proportion of damaged seeds (hollow seeds + seed shells + pieces of seeds) at different dosages of pesticides. Error bars represent the 95 % confidence limits.

Dosage did not have any general significant effect on the proportion of damaged spilt grains. Only the interaction between farm, year and crop could explain a significant part of the variation in proportion of damaged spilt grain (Table 2.10).

The proportion of damaged seeds varied between species from zero in ***Galium aparine*** and ***Veronica agrestis/persica*** to 90 % in ***Atriplex patula***/***Chenopodium album***. When the proportion of damaged seeds was analysed no significant effect of dosage was seen in the nine most abundant species (Kruskal-Wallis and Wilcoxon tests, $7<n<28$, $p>0.10$ in all nine cases).

The effect of pesticide dosage on the proportion of damaged weed seeds varied between farms. On three farms, the proportion of damaged weed seeds was highest at normal dosage, while the remaining two farms had the highest proportions either at half dosage or quarter dosage. Furthermore, the farm factor had a significant effect on the proportion of damaged weed seeds. Two farms (Nøbøllegård and Gjorslev) had a very low proportion of damaged seeds (10 %), while the three other farms had a high proportion of damaged seeds (42 %). In this context, it is interesting that different weed species were dominant in the seed rain at different farms. By number, ***Matricaria perforata*** dominated on Nøbøllegård and ***Aethusa cynapium*** dominated on Gjorslev and both ***Matricaria perforata*** and ***Aethusa cynapium*** had a very low proportion of damaged seeds.

Table 2.10. Schematic summary of the analyses of proportion of damaged seeds in the seed rain. Factors not included in any of the reduced models have been omitted from the table. Statistical significance is indicated as follows: +: $0.05\leq p<0.10$, *: $0.01\leq p<0.05$, **: $0.001\leq p<0.01$ and ***: $p<0.001$.

	Proportion of damaged seeds	
	Spilt grains (n=51)	Weed seeds (n=51)
Farm		*
Year		+
Dosage×Farm		*
Crop×Farm×Year	***	**

2.3.2.4 Control of method

From the trays with discarded parts 78 seeds germinated. In the same 26 samples 2706 whole seeds were found under the stereoscope after flotation (Table 2.11).

Table 2.11. Total number of whole seeds in the 26 control field samples found under stereoscope or in the discarded parts by germination. - : Indicates that the material has not been investigated.

Parts	Weed seeds		Grains	
Number of whole seeds found in samples or in discarded parts	found	discarded	found	discarded
1) Discarded organic material over 2 mm from sieving before flotation	23	20	837	22
2) Discarded sediment from the flotation	-	0	-	0
3) Discarded material in petri dish after visible seeds have been picked out	1808	33	38	3
Effectiveness of methods used	97 %		97%	

The flotation method gave a success rate around 97 % for both weed seeds and spilt grains extracted from a sample. No germination occurred in the sediment from the flotation. This might be due to the fact, that there were no seeds in the sediment, but more likely, that some remaining potassium carbonate might have prevented germination (Tsuyuzaki 1993). Thus, the actual success rate may be lower than indicated.

2.3.3 Discussion

2.3.3.1 Seed number, biomass and species richness

Weeds

No direct effect of dosage was found on the number of seeds, biomass or richness. However, a highly significant correlation was found between the density of generative species in the vegetation and the biomass and number of seeds. In addition, the number of generative species in the vegetation was positively correlated with the species richness in the seed rain (Fig. 2.16). Both weed density and species richness in the vegetation were highly affected by dosage (sections 2.2.2.1 and 2.2.2.2); so reduced dosages have indirectly a positive effect on the seed rain. The great variation found between farms makes it very difficult to detect dosage differences.

No clear tendency towards an increase in germination of weeds could be detected, even in the third year with quarter dosage of herbicides (Fig. 2.8). Ploughing turns around the soil, so seed rain from the first year may not reach the soil surface before spring the third year. These findings are in accordance with Salonen (1993c), who did not find any increase in weed densities during four years without the use of herbicides. The soil seed bank may work as a buffer (Wilson & Lawson 1992), so it takes several years before a possible increase in germination can be detected. A continuous reduction of inputs of herbicides over a period of years has been found to result in an increase of seeds from weedy species accumulating in the soil seed bank, followed by an increased weed problem in subsequent crops (Hill ***et al.*** 1989). However, this study does not support those results. No significant response can be due to the low density of weeds at the beginning of the experiment and the lack of problematic grass weed species. In a longer period with use of reduced dosages the effect may be more pronounced. An experiment with low inputs of herbicides through 6 years compared to recommended inputs of herbicides revealed a significant positive effect on the number of seeds in the soil seed bank on one of two farms (Jones ***et al.*** 1997).

The higher density of seeds found on winter wheat stubble fields than on spring barley stubble fields may be due to a longer growing season in winter cereals than in spring cereals, especially for annuals germinating in autumn and winter. Thus, weed plants in winter cereals may have a higher biomass when they reach the seed setting phase and may then be capable of a higher seed set (Thompson ***et al.*** 1991).

A weed seed rain of approximately 200 seeds per m^2 right after crop harvest may seem rather low in comparison to soil seed bank estimates of 128,000 seeds per m^2 in fields in Denmark (Jensen & Kjellsson 1995). However, if seeds of ***Juncus bufonius*** are excluded from this figure the soil seed bank estimate becomes only 12.000 per m^2 (Jensen & Kjellsson 1995). The use of geometric mean (this study) compared to arithmetic mean (Jensen & Kjellsson 1995) make the difference seems larger than it is. The soil seed bank constitutes seed rain from several decades why the content of soil seed banks might be expected to be much higher than the seed rain from one year. In the same period, the farmers have intensified their use of herbicides considerably, their use of more competitive crop cultivars, their use of more "effective" ploughs etc. resulting in a general low weed density (Andreasen ***et al.*** 1996). It must be assumed that most seeds in the seed bank are very old, which the low seed viability found by Jensen & Kjellsson (1995) infers.

Grains

The dosage effect on number of spilt grains was only observed in fields sprayed with Roundup a few weeks before harvest. The number of spilt grains per m^2 was lowest in plots sprayed with normal dosage of Roundup. This could be explained by at least two factors, maybe in combination: 1) A homogenous ripening of grains at normal dosages of Roundup, but not at reduced dosages. This may result in lowest escape during harvest at normal dosage because the size and hardness of the grains will be more homogenous. 2) Reduced dosages could result in a higher green weed biomass, which could reduce the effectiveness of the combine harvester and result in a higher amount of spilt grains. Sheppard ***et al.*** (1984) showed that pre-harvest spraying with Roundup compared to no spraying resulted in lower moisture content of the grains and lower grain loss from the combine harvester. This might be the case with reduced dosages too, however more experiments are needed before clear conclusions can be drawn.

2.3.3.2 Damaged seeds

This study has shown that a least 24 % of the weed seeds shed in a particular year are hollow or so badly damaged that they are not viable. Investigations of the soil seed bank in Western Denmark (Jensen 1969, Jensen & Kjellsson 1995) have also revealed a very high proportion of non-viable seeds (73 % and 79 %). The pool of dead seeds in the soil seed bank consist of both hollow seeds and whole seeds not capable of germinating, in comparison to the 24 % damaged seeds in this study, that mostly consisted of hollow seeds. The whole seeds found in this study have not been tested for viability, and many might be non-viable. In addition, some seed shells are very robust and might persist for years in the soil seed bank before decomposition although the embryo is dead (Roberts & Ricketts 1979).

On three of five farms, the ratio of damaged seeds was highest at normal dosage. This result might arise by chance or be due to the reduction in herbicide dosages. Surviving plants at normal dosage might be more stressed and more delayed in development than at quarter dosage thus having less energy resources to complete seed formation and a degeneration of the embryo and the endosperm takes place. The existence of huge differences in ratios of damaged seeds between weed species is interesting - a high production of hollow seeds (empty seed shells) seems a waste of energy. Abortion of seeds was expected to happen when seeds were immature and before the seed shells were totally developed and looked 100 % like mature seeds. A plausible explanation for a high percent of empty seeds could be that some annual plants with high seed setting capacity was able to produce a lot of seed shells early in the season and, if the resources are provided, fill them later in the season. Each seed may not represent very much energy for annual plants with high seed setting capacity. This hypothesis is supported by findings of Ogunremi (1986) who found that the percent of empty seeds in ***Helianthus annua*** was highest at early harvest time. The phenomenon with intact but empty seeds has been observed but not explained in some other dicotyledonous plant species (Ebadi ***et al.*** 1996, M. Philipp ***pers. com.***), but to the authors knowledge the percent of empty seeds has never been recorded as high as in this study, where 90 % of the ***Chenopodium album*** seeds were empty. More knowledge is necessary to understand the biological mechanisms behind these results.

2.3.3.3 Species composition

Seed from four weed species made up 46 % of the number of weed seeds in the seed rain: ***Atriplex patula/Chenopodium album***, ***Stellaria media***, ***Aethusa cynapium*** and ***Polygonum aviculare***. Leguizamon and Roberts (1982) investigated the topsoil of fields without crops in England and found four species accounting for 87 % of the seeds. This difference could be explained by the different calculations of means: Geometric means are used in this study, decreasing the influence of extremely high values, whereas Leguizamon and Roberts (1982) used arithmetic means. Using the arithmetic mean, the four species with most seeds in this study would account for 72 % of the total amount of seeds.

The species composition of generative plants was different from the species composition in the seed rain. Species like ***Stellaria media*** and ***Chenopodium album*** (very frequent in the seed rain) had a very high seed set per plant compared to species like ***Viola arvensis/tricolor*** ssp. ***tricolor*** and ***Aethusa cynapium*** (frequent in the vegetation). This is in accordance with previous findings of seed setting capacity of those species (Korsmo 1926) and can explain the differences in species composition between the vegetation and the seed rain. Also the time a weed plant requires from germination to seed set may varies between species, which influence the amount of seeds produced at harvest time.

Seeds from three weed species made up nearly 50 % of the wild seed biomass: ***Bilderdykia convolvulus, Stellaria media*** and ***Atriplex patula/Chenopodium album.*** Seeds from these species are known as food items for birds (Christensen ***et al.*** 1996). It is worth noting that more than 90 % of the total seed biomass on stubble fields consisted of spilt grains. Therefore, grains are the main sources of food available for birds foraging on stubble fields in autumn. In addition, many birds prefer eating grains rather than weed seeds (Christensen ***et al.*** 1996, Berthelsen ***et al.*** 1997).

Comparing species in seed rain and vegetation

This study showed a good qualitative accordance between the species found in the vegetation in July and in the seed rain in September. The lower total richness found in the seed rain compared to the vegetation has many explanations: 1) Some of the seeds can not be identified to species but only to genus, therefore the number of species present is possible higher than indicated (Table 2.9). 2) Some of the species found in the vegetation do not reproduce by seeds or have not reached the reproductive age (e.g. ***Equisetum*** sp., ***Sambucus nigra*** or ***Salix*** sp.). 3) Vegetation was studied on 3.6 m^2 per plot, whereas the seed rain was just collected from 0.72 m^2 per plot. The species-area relationship implies that more species would be found in the vegetation than in the seed rain samples. This is supported by the fact that most of the generative species had a scattered distribution and were only found few times in the vegetation study. 4) It is possible that one or two species in the seed rain have been overlooked (e.g. seeds from ***Kickxia elatine***, which looks like a placenta from ***Anagallis arvensis***). 5) Moreover, seeds less than 0.5 mm were excluded from the identification (e.g**. *Epilobium montanum*** or ***Juncus bufonius***).

2.3.3.4 Evaluation of methods

The methods used in this study were suitable to reveal the qualitative and quantitative characteristics of the seed rain on stubble fields with high efficiency. The methods were also suitable to determine low seed densities over large areas. However, the methods had some disadvantages.

Random errors

The weight of a sample had a positive significant effect on the number of spilt grain in the sample. This suggests that the sampling method had an impact on the results. The weight of a sample depends among other things on the soil structure, the amounts of straw on the fields and the humidity of the soil at the time of suction. These factors varied a lot from field to field but they did not vary much between plots within a field.

Systematic errors

The estimate of the size of the seed rain was certainly an underestimation, because not all seeds have been sampled by the C-vac method. Firstly, numerous seeds might have germinated after rainfall. Genera like ***Lamium***, ***Veronica*** and ***Viola*** spread seeds many weeks before harvest of the crop, and some of these seeds might have entered the soil seed bank as a result of earthworms or rainwash (Hurka & Haase 1982). Secondly, some species like ***Aethusa cynapium*** set seeds several weeks after crop harvest and the seeds are therefore not shed at the time of sampling. Finally, not all seeds lying on the soil surface will end up in the C-vac, since the effectiveness of the sampling by suction lies around 80 % (Jensen unpublished data) and varies from species to species. Another, systematic error happens during the identification and counting under a magnifier on a white background, where it is common to miss small and light seeds (Gross 1990). This might also had happened in this study.

All these random and systematic errors implies, that the results found in this study should not be considered an exact measure of the seed rain on stubble fields after harvest. However, the results reveal the proportional distribution of seeds between dosages.

2.4 Summary of dosage effects

In Table 2.12 the dosage effects on all dependent vegetation and seed rain variables are summarised.

Table 2.12. Summary of dosage effects on the weed vegetation and the seed rain. Percentage increases (+) and decreases (-) in response variable at reduced dosages compared to estimated mean values at normal dosage. Significance is indicated as follows: +: 0.05≤p<0.10, *: 0.01≤p<0.05, **: 0.001≤p<0.01 and ***: p<0.001.

Response variable	Crop	Dosage: Normal	Half	Quarter	Positively correlated with
Weed density	Spring barley	66 plants/m^2	+30 %	+47 % *	
	Winter wheat	18 plants/m^2	+ 23 %	+ 85 % *	
	Sugar beets	15 plants/m^2	+127 % ***	191 % ***	
Species richness	Spring barley	14 species/plot	+ 16 % **	+ 33 % ***	Weed density
	Winter wheat	8 species/plot	+ 34 % +	+ 37 % +	Weed density
	Sugar beets	19 species/plot	+ 3.5 %	+ 18 %	Weed density
Proportion of flowering plants	Spring barley	42 %	+ 16 %	+ 31 %	
	Winter wheat	32 %	+ 26 %	+ 38 %	
	Sugar beets	48 %	- 16 %	- 20 %	
Proportion of flowering species	Spring barley	64 %	+ 14 % +	+ 14 % +	Proportion of flowering plants
	Winter wheat	47 %	+ 12 %	+ 56 % **	Proportion of flowering plants
	Sugar beets	61 %	+ 6.9 %	+ 13 % +	Proportion of flowering plants
Density of weed seeds	Cereals	142 seeds/m^2	+ 42 %	+ 63 %	Density of generative weed plants
Density of spilt grains	Cereals	45 grains/m^2	+ 83 % *	+ 82 % **	
Biomass of weed seeds	Cereals	0.15 g/m^2	+ 21 %	+ 35 %	Density of generative weed plants
Biomass of spilt grains	Cereals	1.3 g/m^2	+ 83 % +	+ 93 % *	
Species richness in seed rain	Cereals	11 species/plot	- 10 %	-0.4 %	Number of generative species
Proportion of damaged weed seeds	Cereals	27 %	- 0.9 %	- 36 % +	
Proportion of damaged spilt grains	Cereals	24 %	- 5 %	- 22 %	

This large-scale field study has illustrated that reduced pesticide dosage affects the weed vegetation in many ways and with profound impacts. A reduction in dosage, from normal to quarter dosage is followed by a considerably higher species richness and a higher density of weed plants. Furthermore, species have a higher probability to flower and set seeds at quarter dosages, so the fitness of surviving species is higher than at normal dosage. All these effects of reduced pesticide dosages on the vegetation may affect the fauna by improving the living conditions at low dosages.

3 Arthropods (Navntoft, S. & Esbjerg, P.)

Farmland crop pests like ***Aphididae*** (aphids) and ***Oulema melanops*** (Cereal leaf beetles) as well as their natural enemies, often referred to as beneficials, have received much attention in pesticide research. The term "beneficial" when applied to crop-dwelling arthropods is usually associated with the predatory species of crop pests or with pollinators. There are however many other groups of species whose role within the crops may be termed beneficial. These include the so-called chick-food group; several orders or guilds of insects that are important components in the diet of other farmland species, especially birds (Sotherton & Moreby 1992). In this chapter attention will be paid to this group as well as on the traditional target species.

3.1 Pilot studies

Pilot experiments were conducted primarily to evaluate the time consumption and suitability of different sampling methods under the actual conditions and also to get an overview of the arthropod composition in general and in relation to reduced pesticide dosages.

Sampling of arthropods on plant foliage and on the ground below is an ongoing challenge to entomologists and each method has advantages and shortcomings. No single method of density or abundance estimation is suitable for all circumstances and different sampling methods are therefore relevant in order to obtain a reasonably efficient sampling depending on the target species.

3.1.1 Methods (pilot study)

The pilot experiments were carried out on the farm "Gjorslev" in 1996. Four sampling methods were evaluated in all three crops:

1. ***Coloured water traps***, consisting of circular plastic bowls (diam. 200 mm, height 85 mm). A set of three traps in different colours was placed together on the ground and in each 1 litre of trapping fluid (water added 70% alcohol and ethylene glycol (3:1:1) with one drop of non-perfumed dish soap) to ensure drowning and preservation. In each plot five sets of traps were randomly placed avoiding the outer 20 metres of the plots to limit interference from boarder zones. The traps were serviced once a week from 9 May to 1 August in the cereals and 9 May to 10 October in beets. All catches were preserved in 70% alcohol until further treatment. The target arthropod groups were primarily flying insects and insects living in the canopy.

2. ***Pitfalls*** (plastic cups, diam. 110 mm, depth 135 mm) were buried pairwise in the ground 1 meter apart, connected by a 150 mm high steel barrier to improve the efficiency of the traps. The traps were partly filled with trapping fluid (see above). The number, distribution as well as sampling of the traps was performed as described above. The target group was epigaeic arthropods, in particular the adult carabids, a predominant and important arthropod family in the arable land.

3. ***Suction sampling.*** Different machinery has been used to sample by suction arthropods living on plant stems, in canopy and on the soil surface. The most widely used is the D-vac (Dietrick ***et al***. 1959, Dietrick 1961). The advantages of vac-sampling is that it provides density estimates in contrast to water traps and pitfalls, which provide relative estimates since their sampling area is not defined. For the pilot experiments a modified hand carried vac-sampler was used. A few samples were taken in spring, but the machinery was not sufficiently powerful for this purpose and the sampling was cancelled.

4. ***Direct countings*** were conducted in all crops primarily to estimate ***Aphididae*** populations, but in beets also to monitor a severe attack of ***Autographa gamma*** (Silver Y's). Sampling comprised mainly the ***Aphididae Rhopalosiphum padi*** (Bird-cherry oat aphid) and ***Sitobion avenae*** (English grain aphid) in the cereals and ***Aphis fabae*** (Black bean aphid) in beets. On each assessment day and in each plot, 100 randomly selected wheat and barley ears on a diagonal transect (Danielsen 1992) were inspected and the number of cereal ears with ***Aphididae*** was counted. In beets, sampling was done on weekly intervals in the period early July to late August. 50 plants per plot were inspected following in principle the same methodology as in the cereals. Four times during the season 21 randomly selected sugar beets plants were inspected for larvae of ***A. gamma*** (this was an ad hoc methodology).

All arthropods collected were identified to at least order. ***Coleoptera*** (beetles) were all identified at least to family with most emphasis on the pitfall collected ***Carabidae*** (ground beetles) among which imagines of larger species were identified to species. In the water traps the most abundant larger ***Diptera*** (two-winged) were identified to family. ***Lepidoptera*** (butterflies and moths) and ***Symphyta*** (sawflies) were not identified further with ***A. gamma*** as an exception. The water trap catches could be huge which automatically restricted the sorting to the higher level taxi.

3.1.2 Statistical analyses (pilot study)

Water traps and pitfalls

Data for all common groups of arthropods, depending on taxonomic level of identification, were analysed for possible dosage effects on the populations. Each crop was analysed separately since each type of crop was considered unique. Also, the data from water traps and pitfalls were analysed separately because of their different mode of action and their different target species, but the statistical method used was the same. The data on each relevant arthropod group from each set of traps on each sampling date were $\log_e(x+1)$ transformed to normalise variance. Subsequently the data from the various sampling dates from each trap set were pooled to avoid that repeated measurements on the same spots provided dependent data (Stryhn 1996). The dependent variable (total number per trap group) was assumed to follow a Poisson distribution and was analysed by the GENMOD procedure in SAS/STAT using Likelihood ratio tests (SAS Institute 1990). The variable was analysed in relation to the class variable dosage only and corrections for over-dispersion were made. The replicates (sets of traps) were all from the same plot due to the experimental design, and this lack of "true" replications weakens the reliability of the test results.

Suction sampling

The sampling was insufficient for statistical analyses.

Direct counting
No statistical analyses were conducted. Percent infested plants on a given sampling date are presented.

3.1.3 Results (pilot study)

Water traps
The results from the water traps were unsatisfactory, variation in catch was very high and no results will be presented.

Pitfalls
It should be stated that pesticide effects on ***Carabidae*** and ***Staphylinidae*** (rove beetles) populations might be a result of treatments the previous year, during which some of the adult individuals, caught the current year, were at the larval stage. This, of course, weakens the possibility of obtaining significant results in a one-year pilot experiment. Only results of barley and beets are presented (Table 3.1), since no experimental sprayings were carried out in wheat. Significantly different numbers are found within a limited range of families and species of ***Carabidae*** and ***Staphylinidae***. The strength of the results, however, in spite of the limitations of the method and statistical analysis, is a consistent picture. The significant differences found, all confirm the trend of higher catches in quarter dosage followed by half and normal dosages.

Table 3.1. The estimated number of specific *Carabidae* (ground beetles) and *Staphylinidae* (rove beetles) per pitfall group on Gjorslev. Numbers are total catches from 9 May – 1 August 1996 in the barley, and 9 May – 10 October in beets. Estimates given are least squares means. Significant differences between dosages ($p<0.05$, paired t-tests) are indicated by different letters. P-values of the variable dosage are given (*: $p<0.0.5$, **: $p<0.01$, ***: $p<0.001$).

Crop	Family	Order / species	Estimated number			P-value
			Normal	Half	Quarter	
Barley	*Carabidae*	*Loricera pilicornis*	9.0 a	8.4 a	16.2 b	0.0162 *
	Staphylinidae	*Philonthus spp.*	150.6 a	152.4 a	264.2 b	0.0003 ***
		Larvae spp.	18.8 a	20.4 a	49.8 b	0.0186 *
Beets	*Carabidae*	*Harpalus rufipes*	14.0 ab	6.0 a	29.6 b	0.0117 *
		Loricera pilicornis	3.1 a	6.6 ab	12.7 b	0.0213 *
		Carabus nemoralis	0.2 a	0.6 a	3.4 b	0.0162 *

Direct countings
The number of ***A. gamma*** larvae per 21 plants per plot was counted 4 times during the season, and results are presented in Fig. 3.1. The counting on 16 July was carried out right before the application of dimethoate (see Appendix A for pesticide treatments). This application was not very effective and another application with Lambda-cyhalothrin was conducted 22 July. The latter application seemingly knocked down the population, and apparently even quarter dosage was enough to strongly diminish the population.

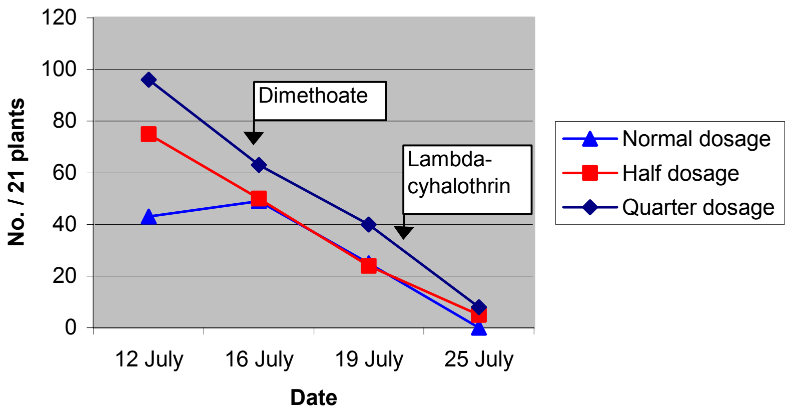


Fig. 3.1. Estimated population densities of *Autographa gamma* larvae at the three different dosage levels in sugar beets at Gjorslev 1996. The two relevant insecticide treatments are marked with arrows.

In Table 3.2 results of the aphid countings in beets are given. Only the pirimicarb spraying had an effect, which was obviously dosage related. No insecticide sprayings were conducted in the cereal fields and only slightly differences were found in the ***Aphididae*** populations between the different dosage plots.

Tabel 3.2. Mean percentages of sugar beets plants (Gjorslev, 1996) infested by the aphid *Aphis fabae*. Dates of relevant insecticide applications are given.

Date	Percentage of plants with *Aphis fabae*		
	Normal dosage	Half dosage	Quarter dosage
3 July	14	8	16
9 July	8	14	16
16 July	Dimethoate		
22 July	Karate		
23 July	100	96	92
31 July	100	100	92
4 August	Pirimicarb		
8 August	20	36	44
15 August	12	24	76
22 August	10	10	16
29 August	0	4	6

3.1.4 Discussion (pilot study)

3.1.4.1 Evaluation of sampling methods

Water traps are easy to handle but suffered from the well-known problem of lacking density estimation. Besides insects blown into the traps only animals attracted by the colours and/or humidity may be caught, including species not related to the crop. The results obtained with this method are inconsistent.

Pitfall trapping. Pitfall trapping provided some interesting results. It is, however, very laborious to trap intensively at a large scale, and the subsequent sorting in the laboratory is often very demanding since catches may be high.

Especially in beets there may be problems because of repeated weed hoeing. The lack of density estimates can be overcome by fencing the pitfalls thereby sampling a specific area only. This is, however, costly.

Suction sampling. Little experience was obtained due to the insufficient equipment. The method is however, widely used and accepted. The D-vac has proved to be a practical sampling device under a wide range of conditions. It is very effective at sampling most arthropod taxa, diurnally active in the vegetation layer and on the soil surface (Thomas & Marshall 1999). Suction machines may, however, not efficiently sample some life stages, e.g. juvenile stages of beneficials. Examples are larvae of ***Syrphidae*** (hooverflies) and ***Coccinellidae*** (ladybirds) (Sunderland ***et al.*** 1995). Furthermore the efficiency of suction samplers is likely to be influenced by vegetation structures and density. A significant limitation to the use of techniques involving suction samplers is that the habitat to be sampled must be dry (Sunderland ***et al***. 1995), not only to avoid invertebrates getting stuck before reaching the collecting container, but also to ease the following sample treatment. Sampling is also often limited to daylight hours, and may therefore underestimate nocturnal species, which include most of the carabids found in agricultural habitats (Thiele 1977). The method, however, is rather independent of the activity of the sampled organism, and is therefore generally less prone to error (Thomas & Marshall 1999).

Field counting of ears with/without insects is a well-established binomial technique providing useful results for ***Aphididae and O. melanops***. For easily recognisable ***A. gamma*** occurring in high numbers, counting the number per plant is a very useful method.

Generally, both pitfall trapping and direct counting proved useful, and it was decided to use both methods in the main phase of the study. The weakness of the pitfall sampling method in relation to obtaining absolute density estimates led, however, to the decision of downgrading the method and to use it in wheat only due to resource limitations.

Instead of pitfalls it was decided to focus on suction sampling as it provides the density estimates, which are relevant in population studies, and also enable comparisons with somehow similar investigations carried out in Denmark earlier. Based on the literature but taking the difficulties during the pilot phase into account, it was decided to develop a more powerful suction sampler than the well-known types. For practical reasons it was also decided to use suction sampling as the “back bone” sampling method throughout the investigations (see 3.2.1.1).

3.1.4.2 Discussion of results

The pitfall-sampled carabids as well as the Pirimor-sprayed ***Aphididae*** in beets showed a tendency towards higher densities at reduced pesticide dosages. The extent of the sampling combined with the lack of true replicates, however, obstruct the possibility to make any straightforward conclusions.

Regarding ***A. gamma*** there did not seem to be a pronounced dosage effect, due to the common slopes of the curves. It is, however, possible that the higher number of larvae recorded on beets plants at reduced dosages is caused by a higher weed density which may have imposed the pregnant females to lay their eggs there. The actual concentration of larvae especially in the plots half and quarter is higher than illustrated in Fig. 3.1, since larvae found on weed (not counted) contribute significant to the population.

3.2 Main studies 1997-1999

3.2.1 Methods

3.2.1.1 Suction sampling

In order to achieve comparable samples from a total area of at least 270 ha, it was decided to use a 4WD vehicle to transport the suction sampler between the sampling sites. The size of the suction sampler was therefore less important, opening possibilities to construct a more efficient suction sampler than the one used in the pilot studies and other commercially available models. Based on experiences from 1996 a new suction sampler was designed to extract insects from the crops at a higher level of efficiency (Fig. 3.2). Test of sampling efficiency was done with larger carabids known as difficult to extract by suction (Hald & Reddersen 1990). The test showed an 80% recapture efficiency of carabids, which was a higher rate than that of the vac-samplers (incl. the D-vac®) with which it was compared. Further information will be published.

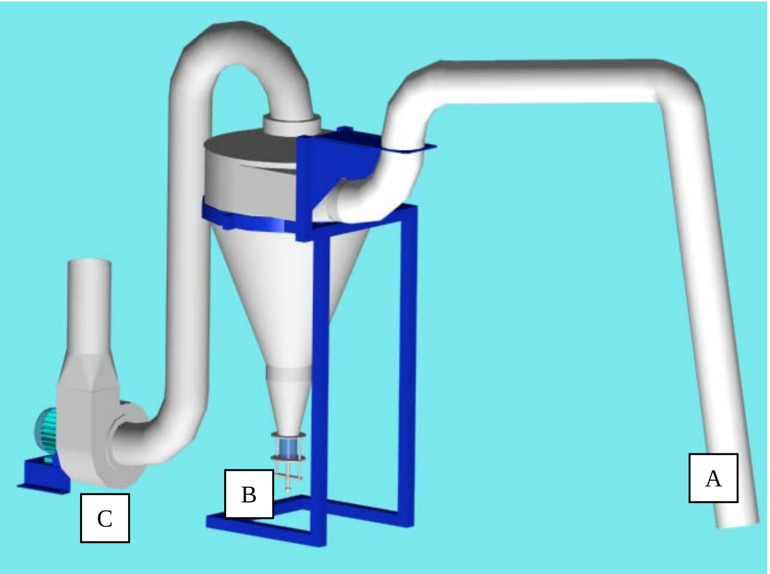


Fig. 3.2. The suction sampler. A. Suction hose/pipe. B Collection jar. C. Fan providing high speed air flow. The construction was mounted on a trailer with a 4WD as traction.

Many replicates are necessary to obtain useful density estimates. Within each plot, 15 sub-plots (sub-plot: ±10 m from a marker stick) were selected. Sampling was restricted to the main crop area and plot margins were therefore excluded (minimum 20 m). Thereby interference between plots and effects from field edges was minimised.

The 15 sub-plots were evenly distributed along 3 tramlines in order to minimise crop damage. The length of the suction tubes limited sampling to within 1.5 meters from the tracks. The sampling of one field was always finished within 1 - 1.5 hour. If the sampling of a field had to be cancelled, e.g.

because of rain, samples already collected were removed and a new set collected as soon as possible. All samples were collected between 10.00h and 21.00h under dry conditions. Each sample comprised 10 sub-samples of 10 seconds application of the vac-nozzle (total area 0.2 m^2) in cereals. In sugar beets it was necessary to reduce the number of sub-samples to 5 (total area 0.1 m^2) because large amounts of soil accumulated in the collecting jars due to the lesser plant cover compared to the cereals. Sampling in beets was only done within the rows since hardly any arthropods were observed at the almost bare field between the rows. The samples were labelled and placed directly into cooling bags. Later, the same day, they were frozen until further treatments.

Sampling was carried out 5-7 times during each season from mid May to mid August (Table 3.3). The first samples were taken in wheat at mid May, whereas sampling in barley and beets began by early June. The last samples were collected in sugar beets at mid August whereas sampling ended in early August in the cereals. If possible a sampling was conducted just before insecticide application and no samples were taken until about one week after spraying to make sure that killed arthropods were decomposed. The sampling order of the farms varied, as did the order of the fields sampled within the farms, whereas sampling within the fields always followed the same order.

Table 3.3. Statistical information about the sampling in the experimental fields. For each combination of crop and year, the number of sample visits is shown (average and range). Also, the period during which the sample collections were performed is shown together with the median date.

	1997			1998			1999		
	No. of sample visits	Period	Median date	No. of sample visits	Period	Median date	No. of sample visits	Period	Median date
Barley	5.0 (5-5)	06.06 - 06.08	04.07	6.0 (6-6)	02.06 - 03.08	01.07	5.0 (5-5)	31.05 - 29.07	02.07
Wheat	5.0 (5-5)	06.06 - 05.08	03.07	5.8 (5-6)	15.05 - 02.08	01.07	6.0 (6-6)	21.05 - 29.07	25.06
Beets	5.2 (5-6)	12.06 - 20.08	17.07	5.4 (5-6)	13.06 - 11.08	16.07	7.0 (7-7)	16.06 - 24.08	16.07

After defrosting the samples were sieved through 3 grids (2.0, 1.4 and 1.0 mm laboratory test sieves, Endecotts Ltd. London) to extract animals from soil and debris. The arthropods were hand-picked from the grids and transferred to 70% alcohol. All arthropods, except ***Aphididae*** and ***Collembola*** (spring-tails) found within the 3 grids, were collected but animals passing through all grids were ignored. The sample content was subsequently identified under binocular microscopes at 5 - 40 x magnification.

Araneae (spiders), ***Chilopoda*** (centripedes), ***Dermaptera*** (earwigs), ***Diplopoda*** (millipeds), ***Ephemeroptera*** (mayflies), ***Isopoda*** (woodlice), ***Orthoptera*** (grasshoppers) ***Opiliones*** (harvestmen), ***Plecoptera*** (stone flies), ***Psocoptera*** (booklice) and ***Thricoptera*** (caddis flies) were not identified further. ***Hemiptera*** were identified to at least family. ***Lepidoptera*** were identified to at least superfamily. ***Diptera*** were divided into 6 groups: 1. ***Asilidae*** (Robber flies) ***& Empidoidea***, 2. ***Bibionidae*** (bibionid flies), 3. ***Syrphidae*** (Hoover flies), 4. ***Tipulidae*** (Crane flies), 5. Other ***Brachycera/Cyclorrhapha*** and 6. Other ***Nematocera***. ***Neuroptera*** (lacewings) were identified to family whereas for ***Hymenoptera***, parasitic wasps were identified as a group and the rest identified to family. ***Coleoptera*** were all identified at least to family but ***Carabidae*** imagines were identified to genus or species. All arthropods were separated into developmental stages except ***Aranae***, ***Chilopoda***, ***Dermaptera***, ***Diplopoda*** and ***Opiliones*** for which life stage is not easily identified.

Collembola, an important detritivorous group of prey was not included because they require a comprehensive soil-sampling program in order to obtain reliable population estimates. Such a program was beyond the frame of this project.

Statistical analyses

Two variables were used to describe the data: 1. dry mass and 2. number of individuals. The dry mass is mainly important for arthropod – bird relations, and the numbers are mainly important when evaluating populations and predator – prey relations. Each type of data was analysed separately.

Dry mass was used as a measure of the available amount of arthropod food for birds. It is a variable relatively easy to measure making it widely used. Dry mass, however, does not take into account that the actual food quality may vary between the different arthropods. E.g., the food quality of carabids may be smaller than that of butterfly larvae due to their relatively higher cuticle content, which is of minor nutritious value.

Arthropod dry mass was estimated from the formula $W = 0.0305 \times L^{2.62}$ mg, where L is the length of the arthropod in mm (Rogers ***et al***. 1977). When the arthropods were identified to species the length of adults used for the calculations was obtained from the literature (Fauna Entomologica Scandinavica) using the mean of the length intervals given. For the remaining arthropods, including juvenile stages, the length of the arthropods was obtained by measuring between 50 and 100 individuals of each relevant group (but sometimes less if occurrence was rare). Because the data were reasonable symmetrically distributed, simple arithmetic mean lengths were calculated. The individuals measured were selected randomly from all farms, crops, sampling dates and dosages. A restriction was that a maximum of 5 individuals from each relevant arthropod group was taken from one field at a certain sampling date, to ensure a representative length estimate, especially for juvenile life stages, which change in size over time. Changes in the mass of a given species because of change in life stage during a season were consequently not included in the analyses.

All arthropods are not equally important as food items for all bird species. Some species may be characterised as "important food items" because of the selective food choice of farmland birds. Their preferences are probably based on the abundance, size, availability, nutritious value and (lack of) defence/escape mechanisms of the arthropods. Skylark was the most common bird throughout the study period (Chapter 4) and several studies on its diet have been conducted, e.g. Elmegaard ***et al***. (1994 , 1999). The food choice of this species was therefore selected as reference bird prey. The diet of Skylarks listed by Cramp & Simmons (1977-94) comprise almost all arthropods found, including even very small species like ***Collembola*** and small ***Ichneumonoidea*** (ichneumonid wasps). Such small species were not found to be relevant in a comprehensive study in Denmark of Skylark food references, because of their limited overall energy contribution (Elmegaard ***et al***. 1999). They found that ***Carabidae*** dominated, accounting for 42% of the estimated food dry mass in faecal pellets. ***Lepidoptera*** imagines and larvae contributed with 19% and ***Heteroptera*** (bugs) 7%. The rest of the groups contributed less than 5% to the total food dry mass including ***Diptera***, which represented < 3% in Elmegaard

et al*.’s** results. No findings of ***Collembola or smaller ***Hymenoptera*** were reported although some may have been included in the < 2% “rest” group.

There is apparently no distinct line between “preferred” and “non-preferred” arthropods, making the “important food items” variable rather arbitrary. Focus, however, was put on Danish research with experiments by Elmegaard ***et al***. (1999) as the main reference. The list of relevant arthropod food items selected in this experiment comprised ***Araneae*** and ***Coleoptera*** except ***Coccinellidae*** and ***Cantharidae***. Others taxa included were ***Chilopoda, Dermaptera*** and ***Diplopoda.*** Among ***Diptera*** only ***Bibionidae*** and ***Tipulidae*** were relevant. Also ***Ephemeroptera*** and ***Hemiptera*** were included but among ***Hymenoptera*** only ***Symphyta*** were relevant. Finally, ***Lepidoptera, Orthoptera***, ***Opiliones, Plecoptera*** and ***Trichoptera***, were all on the list. ***Neuroptera*** were never identified in faecal pellets by Elmegaard and was therefore not included.

The experimental unit was a dosage plot (see chapter 1), each of which was represented by 15 samples per sampling date. These 15 samples were summarised to form the dependent variables “mg food item dry mass / 3 m^2” or “mg total dry mass / 3m^2” in the cereals (3 m^2 equals 15 samples of 0.2 m^2). In beets the sample area per plot was 1.5 m^2 only. After summation, the data were $\log_e(x+1)$ transformed to stabilise the variation. As described in 4.2.1.2., repeated sampling in the same plots may violate the required independence of data. To avoid this, a geometric mean of the data collected during the actual period (entire season, before/after insecticide spraying or other relevant periods within the sampling seasons) was used, leaving only one figure per combination of the variables ***period***, ***farm***, ***crop*** and ***dosage***.

General Linear Models (GLM) (SAS Institute 1990) were used for the analyses of dry mass (***mg food item dry mass*** or ***total dry mass / 3 m^2***) (1.5 m^2 in beets), in order to determine a possible general effect of reduced dosages of pesticides on arthropods as a food resource. The dry mass was analysed in relation to the three class variables: ***year***, ***farm***, ***dosage*** as well as the interactions ***dosage×farm*** and ***dosage×year*** and the two numerical variables comprising the normal dose treatment intensity indices for insecticides (***I-index***) and herbicides (***H-index***). The model was extended with H-index and I-index (see Appendices A.2-A.4) to take into account that normal, half and quarter dosages were not reflecting uniform dosages between years and farms. Contradictory to the birds, arthropods may be directly affected by the actual dosage. By adding the treatment intensity indices the models were generally improved, as reflected by generally lower p-values of the models. Since sampling was restricted to the main crop area, it was not necessary to consider possible edge effects in the analyses.

In ***the population studies,*** data were separated into carnivore and non-carnivore groups, which were again separated into more specific taxonomic levels. If the juvenile stage was carnivorous, imagines were also recorded as carnivores e.g. ***Syrphidae.*** Overall the data sets were constructed as described above under dry mass analyses. The dependent variables in this case, however, were ***numbers of individuals / 3 m^2***. Data of many insect populations follow a Poisson distribution. To analyse such data, Generalised Linear Models (GENMOD) (SAS Institute 1990) with Likelihood ratio tests on $\log_e(x+1)$ transformed data were used for the population analyses. The procedure can also be used for those arthropod groups not following a Poisson distribution since the difference between a Normal distribution and a Poisson distribution after $\log_e(x+1)$ transformation with adjustment for over dispersion is limited.

Therefore this procedure was used throughout the population analyses to make them comparable. For each analysis least squares means were estimated. When a significant dosage effect was found, t-tests were used to interpret pairwise dosage-differences.

A non-parametric test was performed to reveal if there were a significantly higher number of the most abundant arthropod groups improving under a reduced pesticide regime. The arthropod groups were divided into the six superior groups: ***Barley carnivores*** (n = 18), ***Barley non-carnivores*** (n = 17), ***Wheat carnivores*** (n = 18), ***Wheat non-carnivores*** (n = 18), ***Beets carnivores*** (n = 19) and ***Beets non-carnivores*** (n = 17)) (see Table 3.8-10). A Friedman test based on ranked data was conducted for each the superior groups using the FREQ procedure in SAS/STAT (SAS Institute 1990).

3.2.1.2 Pitfall sampling

Carabids contribute significantly to the arthropod fauna. They are important both as beneficials (Lövei & Sunderland 1996) and as food items for birds (Elmegaard ***et al***. 1999) making it important to estimate their density and therefore to sample them efficiently. Especially larger species, however, are not easy to sample by suction since they may be nocturnal and concealed in refugia during the day. Furthermore they may occur at very low densities at the soil surface (Lövei & Sunderland 1996).

Pitfalls where chosen because they are very suitable for catching carabids. Due to resource aspects, sampling was limited to winter wheat on three farms: Gjorslev, Oremandsgård and Lekkende.

In 1998 and 1999 enclosed plots were established by surrounding 10 x 10 m areas with 60 cm high metal plates buried 20 cm into the ground. The barriers made it possible to obtain estimates of the actual density of carabids in the sampling period by catching nearly all carabids within the enclosures, which at the same time secured that no ground beetles from outside of barriers could reach the traps. 4 enclosures per plot were established at least 25 m from the plot edges in normal and quarter dosages treatments. The enclosures were equally spaced along a longitudinal gradient in an attempt to minimise variation. Also the barriers were placed at the same distance from field margins if possible to maximise comparability. The establishment in normal and quarter dosages only was due to resource limitations. The enclosures were established 18 – 26 May 1998 and 12 – 20 May 1999. At this time of year it was assumed that field invasion from the wintering sites was completed.

Nine pitfalls were placed within each enclosure in a way that aimed at ensuring maximum catches. Five were placed in the middle in the same pattern as number 5 on a dice separated by four 100 cm x 15 cm metal plates positioned between each peripheral trap and the central trap, a method that increase trapping efficiency. Furthermore one pitfall was placed in each corner of the enclosures since carabids are known to follow vertical edges. In 1998 the weekly samplings were carried out in the periods 1 July to 7 August at Gjorslev and Oremandsgård and 17 June to 7 August at Lekkende. In 1999 the period was 23 June to 3 August at all 3 farms. Furthermore a pre-insecticide sampling was conducted in both years in mid June.
After the five-day pre-insecticide sampling period, the pitfalls were closed with lids to temporary stop further sampling within the enclosures. One week after insecticide spraying the lids were removed again and sampling continued non-stop to the end of the season.

Catches were stored in glass containers with 70% alcohol until further treatment. In the laboratory adult carabids were counted and identified at least to genus.

Statistical analyses
The pre-insecticide catches were generally low and scattered, which weakened the possibility of making a reliable analysis on the pre-insecticide application data considering the low number of replicates. These data were therefore pooled with the post-insecticide spraying samples. Two variables were used to describe the data: 1. total dry mass and 2. number per genus. Due to competition among species of the carabid-family it seemed of less value to analyse the total number of carabids caught per barrier.

As described for the suction samples (see 3.2.1.1) the dry mass was estimated using the length of the beetles. Most lengths were obtained from the literature (Lindroth 1985 & 1986) but some beetle groups (***Bembidion, Trechus and Amara***) were identified to genus only**.** For those groups an arithmetic mean of the length of at least 50 randomly selected individuals per group were used for the dry mass estimations.

The experimental unit was the enclosure in which catches were collected 5-7 times during each season. These 7 samples were summarised to form the dependent variables "mg dry mass / 100 m^2" and "number per genus / 100 m^2" to avoid dependent data. Summation was followed by a $\log_e(x+1)$ transformation to stabilise the variance.

General Linear Models (GLM, SAS/STAT) (SAS Institute 1990) were used for both the dry mass analyses and the population analyses in order to determine a possible general effect of reduced dosages of pesticides since the log-transformed data were assumed following a normal distribution. The dependent variables were analysed in relation to the 3 class variables: ***year***, ***farm*** and ***dosage*** as well as the interactions ***dosage×farm*** and ***dosage×year***. Stepwise model reduction was used. For each analysis least squares means for dry mass and population size were estimated.

G. polygoni (knotgrass beetles) is of particular interest because it is important for farmland birds, e.g. partridge (***Perdix perdix***) and it is a potential control agent for its host plants ***Polygonum convolvulus*** and ***Polygonum aviculare*** (Sotherton & Moreby 1992).

At Gjorslev a high numbers of ***G. polygoni*** - adults and larvae - were caught in the fenced pitfalls in 1999. The number of adults within each enclosure was counted in order to reveal a dosage effect on the beetles. The statistical analysis was conducted as described above, but the dependent variable "no. / 100 m^2" was analysed in relation to the class variable ***dosage*** only.

3.2.1.3 Direct counts
The aphid counting was conducted as described in section 3.1.1, with the exception that 100 beets plants were inspected instead of 50 on each assessment day. If possible the first inspection was carried out immediately before insecticide application and the following about one week after application to get the full effect of the application. The overall aim was ***not*** to estimate crop damage, but to reveal possible effects on the populations.

Statistical analysis

Statistical analyses were not conducted on these data. Percent infested cereal ears / beets plants are presented in Appendix D.

3.2.1.4 Sweep net sampling of Miridae

In 1997 a severe attack of ***Miridae*** (mirid bugs) occurred in sugar beets on Gjorslev. The attack was restricted to the border zone. Two days after insecticide application 40 samples per plot were taken to evaluate the effects of reduced dosages. A sample comprised 10 standardised sweeps with a butterfly net (diam. 36 cm) with one sweep pr. row in the 10 outermost rows.

Statistical analysis

The basic sampling unit was considered to be one sample. The data followed a Poisson distribution and a log-linear model was fitted, using the GENMOD procedure. Log Likelihood ratio tests were used to estimate the difference in numbers per sample between treatments. Since sampling was carried out in one field and one year only, the replicates (n = 40) were all taken from the same dosage plot and should therefore be considered as pseudo-replicates, weakening the possibility to generalise the result.

3.2.2 Results

3.2.2.1 Suction samples

Dry mass

The results of the analyses of variance are summarised in Table 3.4. The factors ***year*** and ***farm*** always had significant effects and were consequently included in all the models. The factors ***dosage*** and ***I-***index were significant in barley. In wheat and beets no significant effects of dosage was found, and the treatment intensity indices for insecticides and herbicides only occasionally proved significant which seemed incidental. With none of the tested models significant interactions were found.

The factors ***year*** and ***farm*** constituted, not surprisingly, an absolutely dominating part of the variation, leaving only a minor part to be explained by the factor ***dosage***. Especially in the cereals ***year*** was dominating.

Table 3.4. Schematic summary of the dry mass analyses based on dry mass means of the entire sampling season. I-index / H-index. (treatment intensity indices for insecticides / herbicides, for definition see section 1.1). Statistical significance is indicated as follows: */+/–: 0.01<p<0.05, **/++/– –: 0.001<p<0.01, ***/+++/– – –: p<0.001. A +/÷ indicates if the correlation is positive/negative.

	Barley		Wheat		Beets	
	Bird prey d.w.	Total d.w.	Bird prey d.w.	Total d.w.	Bird prey d.w.	Total d.w.
Dosage	**	**				
Year	***	***	***	***	*	***
Farm	***	***	**	***	***	***
Dosage×year						
Dosage×farm						
I-index	– –	–		–		
H-index			+			

The estimated mean dry masses are presented in Table 3.5. The estimates are means over the entire season.

Significant differences of the estimated mean dry masses between dosages were found only in ***barley*** with higher dry mass at quarter dosage than in normal and half dosages that mutually were not significant different. A 30% higher dry mass of food items was found at quarter dosage than in normal dosage. A corresponding 28% difference was found for the total dry mass.

Table 3.5. The estimated mean dry masses of relevant bird prey (based on known skylark prey (Elmegaard *et al.* 1999) and the estimated mean dry masses of all arthropods collected in the three different crops. The numbers given are least squares estimates of the mean dry mass, of 5-7 samples per year in the period late May - mid August. In cereals the estimates are "mg/3 m^2" and in beets "mg/1.5 m^2 plants". The estimates are followed by 95% confidence intervals. P-values for test of significance of the factor "dosage" are given (**: p<0.01). Significant differences (p<0.05) between the different dosages are found by paired t-tests and are indicated by different letters.

Crop		Normal dosage	Half dosage	Quarter dosage	p-value
Barley mg/3 m^2	Food items	293.3 a [261.3; 329.3]	296.5 a [264.0; 332.8]	381.7 b [340.0; 428.5]	0.0031**
	Total	508.0 a [451.4; 571.7]	528.1 a [469.3; 594.3]	652.4 b [579.7; 734.2]	0.0093**
Wheat mg/3 m^2	Food items	356.8 [299.7; 424.8]	408.2 [342.8; 485.9]	404.1 [339.4; 481.0]	0.4678 ns
	Total	699.8 [591.7; 827.7]	785.8 [664.4; 929.3]	821.9 [695.0; 972.0]	0.3754 ns
Beets mg/1.5 m^2	Food items	117.2 [98.0; 141.3]	112.5 [93.6; 135.0]	125.4 [104.4; 150.5]	0.6971 ns
	Total	251.1 [210.0; 300.2]	264.7 [221.4; 316.5]	291.6 [243.9; 348.6]	0.4839 ns

Even though no significant differences between dosages were found in wheat and beets, there was a tendency towards higher dry masses at reduced dosages. In beets there was a 13% higher estimated food item dry mass at quarter dosage than in normal dosage. In wheat a correspondingly 7% higher dry mass was indicated. Similarly in wheat a 17% higher total biomass was revealed at quarter dosage than in normal dosage and in beets a 16% higher total dry mass. In barley and beets the estimated dry masses at half dosage were closer to the normal dosage estimates than to quarter dosage but in wheat the estimated dry mass at half dosage was closer to the dry mass at quarter dosage.

To reveal possible dosage effects limited to the post insecticide treatment period, statistical tests on the ***wheat*** data were conducted on the biomass data limited to the whole period ***after*** insecticide applications. The ***farm*** and ***year*** proved significant and no significant interactions were found. A test for a dosage effect on the bird prey biomass did not show a significant effect (p = 0.4973) (estimated means and 95% confidence intervals: Normal = 410.0 [339.4; 495.3] mg/3 m^2, half = 459.7 [380.6; 555.3] mg/3 m^2, quarter = 475.6 [393.7; 574.5] mg/3 m^2). A similar test on the total biomass did neither reveal significant differences (p = 0.2354) (normal = 929.6 [790.4; 1093.2] mg/3 m^2, half = 1047.7 [890.9; 1232.2] mg/3 m^2, quarter = 1129.1 [960.1; 1327.9] mg/3 m^2). Statistical tests for the 14 days period after insecticide applications did not show significant dosage effects on bird prey biomass (p = 0.5649) (normal = 458.7 [363.2; 579.3] mg/3 m^2, half = 514.0 [407.0; 649.1] mg/3 m^2, quarter = 543.8 [430.6; 686.6] mg/3 m^2) or on total biomass (p = 0.6953) (normal = 1118.0 [933.3; 1339.4] mg/3 m^2, half = 1179.3 [984.4; 1412.7] mg/3 m^2, quarter = 1243.7 [1038.2; 1489.9] mg/3 m^2).

In beets, tests for the corresponding periods after insecticide spraying were performed but only comprising data from farms which carried out a mid-summer insecticide application. Due to the lower number of replicates the treatment intensity indices for herbicides and insecticides were not included in the model. In all the models tested, the ***farm*** and ***year*** had a significant impact but no significant interactions were found. For the ***entire post-insecticide*** period, a nearly significant ***dosage*** effect (p = 0.0755) was found on the bird prey dry mass (estimated means and 95% confidence intervals: Normal = 220.9 [181.7; 268.7] mg/3 m^2, half = 239.0 [196.5; 290.7] mg/3 m^2, quarter = 288.5 [237.2; 350.8] mg/3 m^2). The test for a dosage effect of the total biomass showed significance (p = 0.0273^*) (normal = 378.5 [298.2; 480.4] mg/3 m^2, half = 406.0 [319.9; 515.4] mg/3 m^2, quarter = 555.5 [437.6; 723.5] mg/3 m^2). Pairwise t-tests showed significant differences between normal and quarter dosage and between normal and half dosage. Tests for the ***14-day period only*** after insecticide spraying did not reveal a significant dosage effect on bird prey biomass (p = 0.2445) (normal = 158.7 [123.5; 203.9] mg/3 m^2, half = 175.6 [136.7; 225.5] mg / 3 m^2, quarter = 203.2 [158.2; 261.0] mg/3 m^2) but a significant effect was found on the total biomass (p = 0.0130^*) (normal = 209.1 [157.6; 277.5] mg/3 m^2, half = 237.3 [178.8; 314.9] mg/3 m^2, quarter = 353.1 [266.1; 468.5] mg/3 m^2). Pairwise t-tests showed significantly higher dry masses at quarter and half than at normal dosage.

The generally significant effect of the dominating factor ***year*** (table 3.4) may to a large extent be explained by climatic factors, which are important for arthropod population sizes. Also different spraying intensity between years and a possible accumulating pesticide effect through the experimental years, may have contributed to the significant effect. Estimates of the parameter differences of the factor ***year*** are presented in table 3.6.

Table 3.6. Parameter estimates of the *year*-differences of the bird prey dry mass analyses.

	Bird prey dry mass		
	Barley	Wheat	Beets
β_{1997} - β_{1998}	-1.2283	-1.4326	-0.2271
β_{1997} - β_{1999}	-1.0739	-1.5250	0.1250
β_{1998} - β_{1999}	0.1544	-0.0924	0.3521

From table 3.6 it appears clearly that the estimated arthropod dry mass in the cereals in 1997 was overall low. This fact may be the main reason behind the significant effect of ***year*** in the analyses of cereals mentioned above the table. In beets the highest estimated arthropod dry mass was in 1998 followed by 1997 and 1999.

To evaluate the development in the amount of available important bird prey and the total arthropod dry mass during the sampling season, the relevant dry masses were estimated in period intervals for each of the three crops. Results are presented in Fig. 3.3 and 3.4. In barley and wheat the amount of important food items remained stable with a tendency to increase during the sampling season and peaking in July. In beets, however, there was a substantial and steady increase in the amount of available prey during the season. In barley there was a tendency towards higher bird prey biomass in quarter pesticide dosage throughout the season. After the period of insecticide treatments there was a higher dry mass at half than at normal dosage. In wheat there was a higher bird prey dry mass at half dosage in the first period, mid May to mid June, before insecticide spraying. During the rest of the season more biomass was found in quarter dosage followed by half and normal dosage. In beets there were only indications of a difference in the last period, 1 - 20 August, with more bird prey biomass found at quarter than at half and normal dosage.

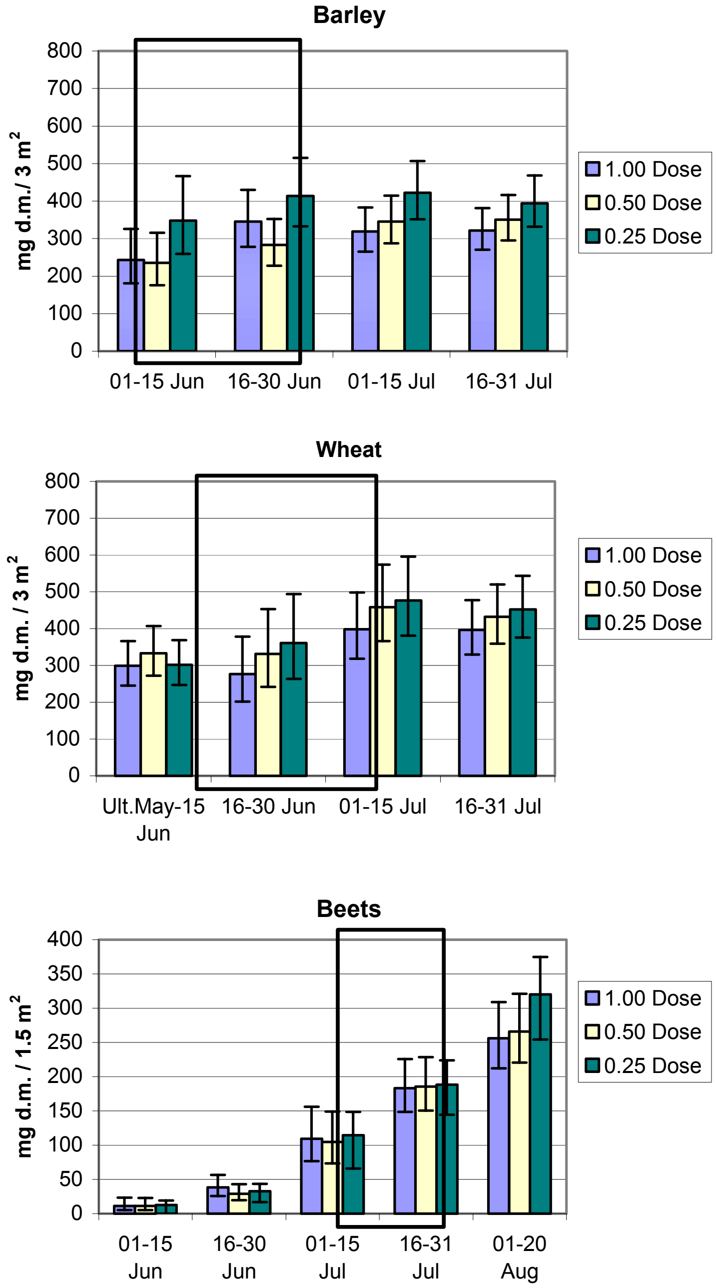


Fig. 3.3. The development in the amount of important arthropod food for birds in the three different crops. The shaded areas indicate periods of insecticide treatments. Notice that data in barley and wheat are per 3 m², whereas data in beets are per 1.5 m² (75 plants). The error bars indicate 95% confidence intervals.

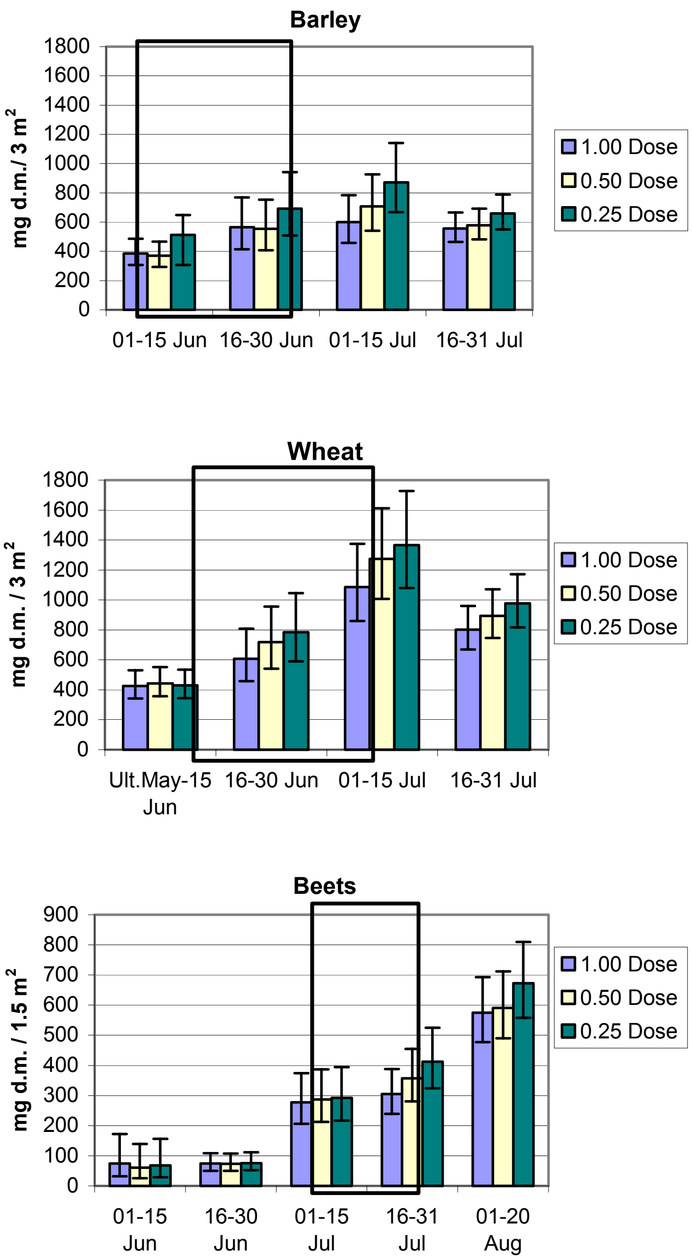


Fig. 3.4. The development in the total arthropod dry mass in the three different crops. The shaded areas indicate periods of insecticide treatments. Notice that data in barley and wheat are per 3 m^2, whereas data in beets are per 1.5 m^2 (75 plants) The error bars indicate 95% confidence intervals.

Overall the total dry mass of arthropods was roughly about twice the amount of the bird prey dry mass. Generally, the development during the season of the total dry mass was similar to bird prey dry mass with two exceptions: 1. The increase during the season in the total dry mass in wheat was much steeper compared to the bird prey dry mass. 2. Contrary to the bird prey dry mass in beets, there seemed to be a higher total dry mass at reduced dosages for the period 16 – 31 July.

The composition of the biomass, including estimates and statistical tests for dosage effects on the most dominant orders is presented in Table 3.7. In the cereals the dominant order across dosages were ***Coleoptera*** (about 50%)

followed by ***Diptera*** (30-40%) whereas the rest of the abundant orders were more evenly distributed. In beets ***Diptera*** dominated with about 50% of the dry mass and ***Coleoptera*** with 20%. ***Lepidoptera*** contributed here 10%, which was remarkably higher than in the cereals. Significant differences between dosages were found in barley for the predominant taxa ***Coleoptera*** and the undefined rest group "others". There was, however, in all crops and for all orders except ***Araneae*** a general trend towards higher biomass in quarter dosage compared to normal dosage. The dry mass estimates of half dosage did not reveal a uniform trend.

Table 3.7. Estimated dry masses of arthropods separated into the most important orders. The numbers given are least squares estimates of the mean dry mass of 5-7 samples per year in the period late May - mid August. In cereals the estimates are "mg/3 m^2" and in beets "mg/1.5 m^2". The estimates are followed by 95% confidence intervals in square brackets. P-values for test of significance of the factor "dosage" are given (*: p<0.0.5, **: p<0.01, ***: p<0.001). Significant differences (p<0.05) between the different dosages are found by paired t-tests and are indicated by different letters.

Crop	Order	Normal dosage	Half dosage	Quarter dosage	p-value
	Araneae	6.3 [5.6; 7.0]	6.4 [5.7; 7.2]	6.3 [5.7; 7.1]	0.9680 ns
	Coleoptera	176.2 a [161.0; 192.7]	175.6 a [160.5; 192.0]	212.0 b [193.8; 231.9]	0.0059 **
	Diptera	114.2 [91.2; 142.9]	111.9 [89.4; 140.1]	135.6 [108.3; 169.7]	0.4121 ns
Barley	*Hemiptera*[1]	10.7 [8.9; 12.9]	12.8 [10.6; 15.3]	13.9 [11.5; 16.7]	0.1417 na
	Hymenoptera	22.1 [16.1; 30.3]	24.2 [17.6; 33.2]	33.1 [24.1; 45.2]	0.1730 ns
	Lepidoptera	4.6 [3.1; 6.6]	3.8 [2.5; 5.5]	6.9 [4.8; 9.8]	0.0763 ns
	Others	21.5 a [16.3; 28.3]	23.5 a [17.8; 30.9]	35.9 b [27.3; 46.9]	0.0243 *
	Araneae	8.3 [7.1; 9.8]	9.3 [7.9; 10.9]	8.1 [6.8; 9.5]	0.4388 ns
	Coleoptera	232.5 [191.1; 282.8]	261.9 [215.3; 318.5]	262.5 [215.8; 319.3]	0.5932 ns
	Diptera	195.1 [155.3; 244.9]	208.5 [166.0; 261.7]	225.1 [179.3; 282.7]	0.6672 ns
Wheat	*Hemiptera*[1]	6.6 [5.4; 8.1]	9.3 [7.9; 10.9]	8.1 [6.8; 9.5]	0.1052 ns
	Hymenoptera	24.8 [19.3; 31.8]	31.3 [24.5; 40.0]	29.4 [22.9; 37.5]	0.3800 ns
	Lepidoptera	3.4 [2.4; 4.7]	3.1 [2.2; 4.3]	3.4 [2.4; 4.6]	0.9082 ns
	Others	40.1 [27.0; 59.1]	42.1 [28.4; 62.1]	49.8 [33.7; 73.4]	0.7067 ns
	Araneae	3.8 [3.2; 4.5]	4.1 [3.4; 4.8]	4.1 [3.5; 4.8]	0.7807 ns
	Coleoptera	31.9 [27.6; 36.9]	34.7 [30.1; 40.1]	39.2 [34.0; 45.3]	0.1357 ns
	Diptera	78.2 [61.3; 99.5]	89.0 [69.8; 113.2]	93.4 [73.3; 118.8]	0.5571 ns
Beets	*Hemiptera*[1]	6.6 [5.6; 7.9]	8.4 [7.0; 9.9]	8.5 [7.2; 10.1]	0.0845 ns
	Hymenoptera	4.3 [3.4; 5.4]	4.9 [3.8; 6.1]	6.0 [4.8; 7.5]	0.1322 ns
	Lepidoptera	15.7 [11.1; 22.1]	17.1 [12.1; 23.9]	19.3 [13.7; 26.9]	0.6931 ns
	Others	19.2 [13.7; 26.7]	17.1 [12.2; 23.8]	21.2 [15.2; 29.5]	0.6443 ns

[1]The dry mass estimates do not include *Aphididae*.

Population estimates

In Tables 3.8 – 3.10 density estimates of the most common arthropod groups are presented. The results of the analyses of variance of each factor for each arthropod group except ***dosage*** are excluded, since it would be too comprehensive to present. Other arthropod groups than those listed were found but their relevance to this study were considered minor, or their abundance was too low to be relevant. ***Aphididae*** are considered the most important insect pest and special emphasis will be put on their predators. Polyphagous predators like ***Carabidae***, ***Staphylinidae*** and ***Araneae*** have often been considered of special importance because they are abundant throughout the season. Emphasis will also be put on the specialised aphid predators ***Syrphidae***, ***Chrysopidae*** and ***Coccinellidae***, as well as on species considered of special importance as food items. Regarding the non-carnivores, focus will be on the potential pests as well as on groups considered important food items for birds.

Table 3.8. Barley. Mean densities of the most common carnivore and non-carnivore groups (no./3 m^2). Estimates given are least squares means with 95% confidence limits in square brackets per sampling. Significant differences between dosages (p<0.05, paired t-tests) are indicated by different letters. P-values for test of the factor dosage are given (ns: P>0.05, *: p<0.05, **: p<0.01, ***: p<0.001). Abbreviations: Col.= *Coleoptera*, Dip.= *Diptera,* Hem.= *Hemiptera*, Hym.= *Hymenoptera*, Neu.= *Neuoptera,* Img.= Imagines, Lar.= Larvae, Nym.= Nymphs, Pup.= Pupae.

Carnivores	Normal dosage		Half dosage		Quarter dosage		p-value
Araneae	46.1	[41.3; 51.5]	46.5	[41.6; 51.9]	46.9	[42.0; 52.4]	0.9703 ns
Chilopoda	1.3	[1.0; 1.8]	1.2	[0.9; 1.6]	1.5	[1.2; 2.0]	0.4165 ns
Col: *Cantharidae*	2.3	[1.6; 3.4]	1.9	[1.3; 2.9]	2.2	[1.5; 3.3]	0.7874 ns
Col: *Carabidae* img.	37.4	[32.3; 43.4]	40.7	[35.3; 46.9]	42.8	[37.2; 49.1]	0.4003 ns
Col: *Carabidae* lar.	1.5	[1.0; 2.1]	1.8	[1.3; 2.5]	1.8	[1.3; 2.4]	0.5242 ns
Col: *Coccinellidae* img.	1.0	[0.6; 1.5]	0.8	[0.5; 1.4]	1.2	[0.8; 1.8]	0.5560 ns
Col: *Coccinellidae* lar.	0.4 a	[0.2; 0.9]	0.6 a	[0.3; 1.2]	1.1 b	[0.6; 2.1]	0.0038 **
Col: *Staphylinidae* img.	98.1	[88.7; 108.5]	96.5	[87.3; 106.8]	99.0	[89.5; 109.4]	0.9328 ns
Col: *Staphylinidae* lar.	15.4 a	[12.0; 19.8]	17.2 a	[13.5; 21.9]	22.9 b	[18.4; 28.6]	0.0095 **
Dermaptera	0.3 ab	[0.2; 0.7]	0.3 a	[0.1; 0.6]	0.4 b	[0.2; 0.9]	0.0136 *
Dip: *Asilidae* & *Empidoidea* img.	1.5	[0.4; 5.3]	0.8	[0.2; 3.0]	0.9	[0.2; 3.2]	0.1625 ns
Dip: *Syrphidae* img.	0.7	[0.2; 2.2]	1.9	[0.9; 3.9]	1.4	[0.6; 3.2]	0.2553 ns
Dip: *Syrphidae* lar.	3.8 a	[2.7; 5.3]	3.6 a	[2.6; 5.1]	5.6 b	[4.1; 7.5]	0.0338 *
Hem: *Nabidae* img.	0.8	[0.5; 1.2]	1.0	[0.7; 1.4]	0.7	[0.4; 1.0]	0.3105 ns
Hem: *Nabidae* nym.	0.7	[0.4; 1.2]	0.9	[0.6; 1.6]	1.2	[0.8; 1.9]	0.1861 ns
Hym: Parasitic wasps img.	69.7	[56.2; 86.4]	69.1	[55.7; 85.7]	80.1	[65.1; 98.6]	0.3380 ns
Neu: *Chrysopidae* img.	0.4	[0.3; 0.7]	0.5	[0.3; 0.7]	0.5	[0.5; 0.7]	0.9234 ns
Neu: *Chrysopidae* lar.	1.5 a	[1.1; 1.9]	1.8 ab	[1.5; 2.3]	2.1 b	[1.7; 2.6]	0.0378 *
Non-carnivores	**Normal dosage**		**Half dosage**		**Quarter dosage**		**p-value**
Col: *Chrysomelidae* img.	6.5	[5.0; 8.3]	5.4	[4.1; 7.1]	6.8	[5.3; 8.7]	0.3933 ns
Col: *Chrysomelidae* lar.	0.5 a	[0.3; 1.0]	0.4 a	[0.2; 0.8]	0.9 b	[0.5; 1.7]	0.0013 **
Col: *Cuculionidae* img.	1.9	[1.2; 2.9]	1.9	[1.3; 3.0]	2.2	[1.4; 3.2]	0.8838 ns
Col: *Elateridae* img.	0.2	[0.1; 0.4]	0.3	[0.2; 0.6]	0.2	[0.1; 0.4]	0.1458 ns
Col: *Lathridiidae* img.	3.4	[2.2; 5.5]	2.8	[1.7; 4.7]	2.7	[1.6; 4.6]	0.7313 ns
Col: *Meligethes* img.	1.3	[0.5; 3.8]	1.4	[0.5; 3.9]	1.8	[0.7; 4.7]	0.8129 ns
Diplopoda	0.8	[0.4; 1.5]	0.8	[0.4; 1.5]	1.0	[0.5; 1.9]	0.7141 ns
Dip: *Tipulidae* img.	0.6	[0.4; 1.1]	1.0	[0.6; 1.5]	1.0	[0.6; 1.5]	0.3403 ns
Dip: Others img.	101.9 a	[80.3; 147.6]	252.7 b	[182.4; 350.1]	158.0 c	[112.0; 223.1]	<.0001 ***
Dip: lar./pup.	2.2	[1.7; 3.0]	2.3	[1.8; 3.1]	2.8	[2.2; 3.7]	0.1976 ns
Hem: *Auchenorrhyncha* img.	17.2	[13.0; 22.7]	19.0	[14.5; 24.8]	17.6	[13.4; 23.2]	0.8353 ns
Hem: *Auchenorrhyncha* nym.	6.3	[4.8; 8.2]	5.9	[4.5; 7.7]	6.3	[4.8; 8.2]	0.8279 ns
Hem: *Miridae* img.	0.8	[0.5; 1.1]	0.8	[0.5; 1.1]	1.3	[0.9; 1.7]	0.0533 ns
Hem: *Miridae* nym.	0.4	[0.2; 0.8]	0.6	[0.3; 1.1]	0.4	[0.2; 0.8]	0.4208 ns
Hym: *Symphyta* lar.	0.6 a	[0.3; 1.1]	0.7 a	[0.4; 1.4]	1.3 b	[0.7; 2.4]	0.0026 **
Lepidoptera img.	0.3	[0.2; 0.5]	0.3	[0.1; 0.4]	0.4	[0.3; 0.7]	0.1992 ns
Lepidoptera lar.	0.5 a	[0.4; 0.7]	0.6 ab	[0.4; 0.8]	0.8 b	[0.6; 1.1]	0.0455 *

Results of the population analyses in ***barley*** are presented in Table 3.8. Dosage had a significant effect on nine groups, of which seven were juvenile groups. ***Dermaptera***, which was significantly affected by ***dosage,*** was not divided into ***imagines*** and ***juveniles*** and the only group purely of ***imagines***, which responded significantly to ***dosage,*** was "other dipterans". The groups showing significant responses were almost evenly divided between carnivores and non-carnivores. It is noticeable that all aphid-specific juvenile predator groups ***Coccinellidae, Syrphidae*** and ***Chrysopidae*** were significantly affected by dosage with the highest densities at quarter dosage.

The population analyses of carnivores in ***wheat*** (Table 3.9) revealed results quite similar to those found in barley. The two aphid specific predators ***Coccinellidae*** and ***Syrphidae*** responded significantly to dosage but in contrast to barley the significant effect was for adult ***Coccinellidae***. The estimates for the larvae, however, also indicated an effect with twice as high estimates at quarter than in normal dosage. Also for ***Dermaptera*** there was an effect in wheat whereas contra to barley a dosage effect was found for ***Carabidae*** instead of ***Staphylinidae***.

Table 3.9. Wheat. Mean densities of the most common carnivore and non-carnivore groups (no./3 m^2). Estimates given are least squares means with 95% confidence limits in square brackets per sampling. Significant differences between dosages (p<0.05, paired t-tests) are indicated by different letters. P-values for test of the factor dosage are given (ns: p>0.05, *: p<0.05, **: p<0.01, ***: p<0.001). Abbreviations: Col.= *Coleoptera*, Dip.= *Diptera,* Hem.= *Hemiptera*, Hym.= *Hymenoptera*, Neu.= *Neuoptera,* Img.= Imagines, Lar.= Larvae, Nym.= Nymphs, Pup.= Pupae.

Carnivores	Normal dosage	Half dosage	Quarter dosage	p-value
Araneae	50.6 [43.1; 59.4]	53.7 [45.9; 62.8]	49.2 [41.8; 57.8]	0.6968 ns
Chilopoda	0.7 [0.5; 1.1]	0.9 [0.6; 1.4]	1.1 [0.7; 1.6]	0.3439 ns
Col: *Cantharidae* img.	3.8 [2.4; 6.0]	5.3 [3.5; 7.9]	4.1 [2.7; 6.4]	0.4256 ns
Col: *Carabidae* img.	93.7 [78.0; 112.6]	99.4 [83.2; 118.9]	92.7 [77.1; 111.5]	0.8344 ns
Col: *Carabidae* lar.	4.4 a [3.4; 5.6]	5.5 ab [4.4; 7.0]	6.4 b [5.1; 8.0]	0.0461 *
Col: *Coccinellidae* img.	0.2 a [0.2; 0.4]	0.3 ab [0.2; 0.5]	0.5 b [0.3; 0.7]	0.0220 *
Col: *Coccinellidae* lar.	0.3 [0.2; 0.6]	0.5 [0.3; 0.9]	0.6 [0.3; 1.0]	0.2257 ns
Col: *Staphylinidae* img.	84.9 [69.2; 104.1]	95.4 [78.6; 115.8]	93.1 [76.5; 113.3]	0.6613 ns
Col: *Staphylinidae* lar.	23.0 [18.5; 28.7]	27.5 [22.4; 33.9]	25.4 [20.5; 31.4]	0.3533 ns
Dermaptera	0.5 ab [0.2; 1.1]	0.3 a [0.1; 0.8]	0.8 b [0.4; 1.7]	0.0255 *
Dip: *Asilidae* & *Empidoidea* img.	0.2 [0.0; 1.2]	0.2 [0.0; 1.5]	0.2 [0.0; 1.4]	0.5349 ns
Dip: *Syrphidae* img.	0.2 [0.1; 0.4]	0.2 [0.1; 0.4]	0.3 [0.2; 0.5]	0.3388 ns
Dip: *Syrphidae* lar.	4.0 a [2.5; 6.4]	7.0 b [4.7; 10.6]	7.5 b [5.0; 11.3]	0.0115 *
Hem: *Nabidae* img.	0. [0.2; 0.5]	0.3 [0.2; 0.5]	0.6 [0.4; 0.9]	0.0609 ns
Hem: *Nabidae* nym.	0.2 [0.0; 1.2]	0.2 [0.0; 1.4]	0.2 [0.0; 1.0]	0.8076 ns
Hym: Parasitic wasps img.	67.6 [57.1; 80.1]	70.7 [59.9; 83.5]	78.6 [66.9; 92.3]	0.2821 ns
Neu: *Chrysopidae* adults	0.8 [0.5; 1.2]	0.7 [0.5; 1.1]	0.8 [0.5; 1.2]	0.9243 ns
Neu: *Chrysopidae* larvae	3.9 [2.9; 5.1]	4.3 [3.3; 5.6]	4.2 [3.2; 5.5]	0.8117 ns
Non-carnivores	**Normal dosage**	**Half dosage**	**Quarter dosage**	**p-value**
Col: *Chrysomelidae* img.	1.3 [0.9; 1.8]	1.3 [1.0; 1.8]	1.6 [1.2; 2.2]	0.4145 ns
Col: *Chrysomelidae* larvae	0.6 [0.2; 1.8]	0.4 [0.1; 1.4]	0.4 [0.1; 1.3]	0.7202 ns
Col: *Cuculionidae* img.	1.3 [0.9; 1.9]	1.9 [1.4; 2.7]	1.9 [1.4; 2.6]	0.1458 ns
Col: *Elateridae* img.	0.2 [0.0; 0.7]	0.3 [0.1; 1.0]	0.2 [0.0; 0.7]	0.5590 ns
Col: *Lathridiidae* img.	2.8 [2.1; 3.6]	2.6 [2.0; 3.4]	2.4 [1.8; 3.2]	0.7814 ns
Col: *Meligethes* img.	0.2 [0.1; 0.4]	0.3 [0.2; 0.4]	0.3 [0.2; 0.5]	0.7068 ns
Diplopoda	1.7 [1.0; 3.1]	2.5 [1.5; 4.3]	2.2 [1.3; 3.8]	0.3392 ns
Dip: *Bibionidae* img.	0.1 [0.0; 2.9]	0.3 [0.0; 7.4]	0.1 [0.0; 3.4]	0.1673 ns
Dip: *Tipulidae* img.	1.0 [0.7; 1.4]	0.6 [0.4; 0.9]	0.9a [0.7; 1.3]	0.0902 ns
Dip: Others img.	544.2 [422.6; 700.9]	389.4 [294.7; 514.6]	449.8 [344.4; 593.2]	0.0681 ns
Dip: Lar./pup.	3.0 a [2.1; 4.1]	4.6 b [3.4; 6.2]	4.1 ab [3.0; 5.6]	0.0301 *
Hem: *Auchenorrhyncha* img.	6.7 a [5.7; 7.9]	8.4 b [7.2; 9.7]	8.2 b [7.1; 9.6]	0.0317 *
Hem: *Auchenorrhyncha* nym.	0.8 [0.4; 1.3]	1.0 [0.6; 1.7]	0.8 [0.5; 1.4]	0.5604 ns
Hem: *Miridae* img.	0,3 a [0,2; 1,8]	0,7 b [0,5; 1,2]	0,8 b [0,5; 1,2]	0,0041 *
Hem: *Miridae* nym.	0.1 a [0.1; 0.3]	0.1 a [0.1; 0.2]	0.3 b [0.2; 0.5]	0.0050 **
Hym: *Symphyta* lar.	0.9 [0.6; 1.6]	1.2 [0.7; 1.9]	1.3 [0.8; 2.1]	0.3176 ns
Lepidoptera img.	0.1 [0.1; 0.3]	0.1 [0.1; 0.3]	0.2 [0.1; 0.5]	0.0891 ns
Lepidoptera lar.	0.6 [0.4; 0.8]	0.6 [0.4; 0.8]	0.6 [0.5; 0.9]	0.8574 ns

An equal number of carnivore and non-carnivore groups revealed a significant dosage effect. The dosage effects on non-carnivores in wheat were on other groups than in barley. In wheat significant dosage effect were found for larvae/pupae of ***Diptera***, ***Auchenorrhyncha*** and adults and nymphs of ***Miridae***, the last one considered important bird prey.

Table 3.10. Beets. Mean densities of the most common carnivore and non-carnivore groups (no./1.5 m^2). Estimates given are least squares means with 95% confidence limits in square brackets per sampling. Significant differences between dosages (p<0.05, paired t-tests) are indicated by different letters. P-values for test of the factor dosage are given (ns: p>0.05, *: p<0.05, **: p<0.01, ***: p<0.001). Abbreviations: Col.= *Coleoptera*, Dip.= *Diptera,* Hem.= *Hemiptera*, Hym.= *Hymenoptera*, Neu.= *Neuoptera,* Img.= Imagines, Lar.= Larvae, Nym.= Nymphs, Pup.= Pupae.

Carnivores	Normal dosage	Half dosage	Quarter dosage	p-value
Araneae	28.2 [24.6; 32.4]	26.5 [23.1; 30.5]	24.7 [21.4; 28.6]	0.4031 ns
Chilopoda	0,4 [0,3; 0,7]	0,3 [0,2; 0,5]	0,4 [0,3; 0,7]	0.6586 ns
Col: *Cantharidae* img.	0.6 [0.5; 0.9]	0.9 [0.7; 1.3]	0.9 [0.7; 1.2]	0.0947 ns
Col: *Carabidae* img.	18.8 [15.9; 22.1]	18.2 [15.5; 21.5]	19.5 [16.6; 22.8]	0.8425 ns
Col: *Carabidae* lar.	0.2 [0.1; 0.4]	0.2 [0.1; 0.4]	0.3 [0.2; 0.5]	0.6648 ns
Col: *Coccinellidae* img.	0.5 [0.3; 0.8]	0.4 [0.3; 0.8]	0.5 [0.3; 0.9]	0.8089 ns
Col: *Coccinellidae* lar.	0.1 a [0.0; 0.2]	0.1 b [0.1; 0.3]	0.2 b [0.1; 0.4]	0.0013 **
Col: *Staphylinidae* img.	11.5 a [10.0; 13.2]	11.9 ab [10.4; 13.7]	14.2 b [12.5; 16.2]	0.0432 *
Col: *Staphylinidae* lar.	0.3 ab [0.2; 0.5]	0.2 a [0.1; 0.4]	0.5 b [0.3; 0.8]	0.0224 *
Dermaptera	0.3 ab [0.1; 1.0]	0.2 b [0.1; 0.7]	0.5 a [0.2; 1.4]	0.0220 *
Dip: *Asilidae* & *Empidoidea* img.	0.1 a [0.0; 0.3]	0.1 a [0.0; 0.3]	0.2 b [0.1; 0.6]	0.0022 **
Dip: *Syrphidae* img.	0.5 [0.3; 0.9]	0.3 [0.2; 0.7]	0.6 [0.3; 1.0]	0.2124 ns
Dip: *Syrphidae* lar.	0.4 [0.3; 0.7]	0.4 [0.2; 0.6]	0.5 [0.3; 0.7]	0.7242 ns
Hem: *Nabidae* img.	0,6 [0,4; 0,8]	0,5 [0,4; 0,7]	0,5 [0,3; 0,7]	0,4921 ns
Hem: *Nabidae* nym.	0,1 [0,0; 0,2]	0,2 [0,1; 0,3]	0,2 [0,1; 0,4]	0,3861 ns
Hym: Parasitic wasps img.	20.5 a [16.9; 24.9]	24.1 a [20.1; 28.9]	30.6 b [26.0; 36.1]	0.0029 **
Neu: *Chrysopidae* img.	1.2 [0.8; 0.2]	1.0 [0.6; 1.6]	1.1 [0.7; 1.8]	0.7624 ns
Neu: *Chrysopidae* lar.	1.3 [1.0; 1.8]	1.5 [1.1; 2.0]	1.7 [1.3; 2.3]	0.3260 ns
Opiliones	0.2 [0.1; 0.3]	0.2 [0.1; 0.4]	0.3 [0.2; 0.5]	0.4802 ns
Non-carnivores	Normal dosage	Half dosage	Quarter dosage	p-value
Col: *Chrysomelidae* img.	1.5 [0.9; 2.6]	1.9 [1.2; 3.1]	2.6 [1.7; 4.0]	0.2043 ns
Col: *Chrysomelidae* lar.	0.1 [0.0; 0.2]	0.1 [0.0; 0.3]	0.2 [0.0; 0.5]	0.3005 ns
Col: *Cuculionidae* img.	1.1 a [0.7; 1.7]	1.7 ab [1.1; 2.5]	2.2 b [1.5; 3.2]	0.0136 *
Col: *Lathridiidae* img.	1.2 [0.9; 1.7]	1.2 [0.8; 1.7]	1.3 [0.9; 1.9]	0.8374 ns
Col: *Meligethes* img.	0.3 a [0.1; 0.7]	0.8 a [0.4; 1.4]	1.6 b [1.0; 2.7]	<.0001 ***
Diplopoda	0.3 [0.1; 0.5]	0.2 [0.1; 0.5]	0.4 [0.2; 0.7]	0.1836 ns
Dip: *Bibionidae* img.	0.4 [0.1; 1.8]	0.9 [0.3; 2.9]	1.0 [0.3; 2.9]	0.4244 ns
Dip: *Tipulidae* img.	0.4 [0.2; 0.7]	0.4 [0.3; 0.7]	0.6 [0.4; 0.9]	0.3890 ns
Dip: Others img.	242.4 [187.4; 313.4]	227.6 [175.2; 295.8]	252.6 [196.0; 325.5]	0.7725 ns
Dip: Lar./pup.	0.4 [0.2; 0.7]	0.5 [0.3; 0.8]	0.4 [0.2; 0.6]	0.6814 ns
Hem: *Auchenorrhyncha* img.	17.0 a [14.2; 20.4]	13.2 b [10.9; 16.0]	11.7 b [9.6; 14.3]	0.0002 ***
Hem: *Auchenorrhyncha* nym.	2.1 [1.3; 3.5]	2.3 [1.4; 3.7]	1.6 [1.0; 2.7]	0.0864 ns
Hem: *Miridae* img.	1.6 a [1.3; 1.9]	2.3 b [2.0; 2.7]	2.1 b [1.8; 2.5]	0.0006 ***
Hem: *Miridae* nym.	1.3 [0.7; 2.3]	1.5 [0.8; 2.6]	1.5 [0.8; 2.6]	0.9118 ns
Hym: *Symphyta* lar.	0.1 [0.0; 0.3]	0.2 [0.1; 0.4]	0.3 [0.1; 0.5]	0.1097 ns
Lepidoptera img.	1.3 [0.9; 1.9]	1.5 [1.1; 2.2]	1.5 [1.1; 2.1]	0.7361 ns
Lepidoptera lar.	3.3 [2.7; 4.1]	3.3 [2.6; 4.1]	3.7 [3.0; 4.5]	0.6814 ns

In ***beets*** (Table 3.10) the number of groups significantly affected was about evenly distributed between carnivores (5) and non-carnivores (4). The carnivore group comprised the generalists ***Staphylinidae*** and ***Dermaptera*** as well as the aphid specific specialists, ***Coccinellidae*** and parasitoid wasps, which were a broad ranged group comprising a lot of specialists. The non-carnivores affected significantly by ***dosage*** were all true herbivores: Adult ***Curculionidae***, ***Meligethes*** (pollen beetles), ***Miridae*** and ***Auchenorrhyncha***, all considered relevant bird prey.

A non-parametric Friedman test confirmed that a significantly higher number of the most common carnivore groups did improve at quarter dosage in all three crops (Table 3.11). Regarding the non-carnivores, significantly more groups benefited from quarter dosages in barley and beets, but significant differences were not found in wheat. Half dosage did not show any uniform pattern. For the groups “barley non-carnivores”, “wheat carnivores” and “beets non-carnivores” the effect of half dosage was in between quarter and full dosage without being significantly different. For “barley carnivores” and “beet carnivores” the effect of half was nearer normal dosage.

Table 3.11. Results of a non-parametric test performed on the data in Tables 3.8 - 10 to elucidate if a significant number of arthropod groups benefited from reduced dosages of pesticide applications. P-values for test of the factor dosage are given (ns: P>0.05, *: P<0.05, **: P<0.01, ***: P<0.001). Pairwise tests were used to reveal significant differences (p<0.05) between dosages.

Crop	Food preference	No. of groups	p-value dosage	Difference
Barley	Carnivores	18	0.0017**	1/4 > 1/2, 1/1
	Non-carnivores	17	0.006**	1/4 > 1/1
Wheat	Carnivores	18	0.0032**	1/4 > 1/1
	Non-carnivores	18	0.1603ns	-
Beets	Carnivores	19	0.0005***	1/4 > 1/2, 1/1
	Non-carnivores	17	0.0027**	1/4 > 1/1

3.2.2.2 Pit-falls

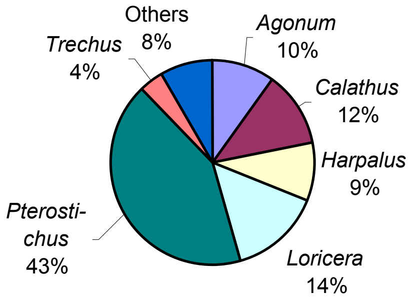
The estimated total carabid dry mass differed significantly between quarter and normal dosages (Table 3.12). The difference in dry mass was about 25%. As for the suction samples the factors ***farm*** and especially ***year*** constituted a dominating par of the variation. A significantly higher carabid dry mass was found in 1999 accordingly to the parameter estimates (not presented).

Table 3.12. Estimated total dry mass of adult carabids caught in 100 m^2 enclosures in winter wheat in the periods 1/7- 7/8 1998 and 31/5-3/8 1999. Estimates given are least squares means with 95% confidence limits in square brackets per sampling. P-value for test of the factor dosage is given (*: p<0.05).

	Normal dosage	Quarter dosage	p-value
Mg dry mass / 100 m^2	7738.7 [6642.3; 9015.9]	9648.0 [8281.2; 11240.3]	0.0456 *

The genus ***Pterostichus*** dominated across dosages, contributing about 40% to the total dry mass of adult carabids (Fig. 3.5). Also ***Loricera, Calathus, Agonum*** and ***Harpalus*** contributed significantly to the carabid biomass.

Fig. 3.5. The composition (by dry mass) of the carabid beetle fauna caught in fenced pitfalls 1998-99.



In table 3.13 the results of statistical analyses of possible dosage effects on the most abundant genera are presented. The results of the analyses of variance of each factor for each group except ***dosage*** are excluded, since it would be to too comprehensive to present. The population of the larger carabid ***Pterostichus*** increased significantly at reduced pesticide applications but the two genera ***Bembidion*** and ***Synuchus*** were significantly more abundant at normal dosage. Two other genera, ***Loricera*** and ***Demetrias***, also seemed affected by dosage. The populations of both seemed to increase at reduced dosages. The conclusion of these two genera, however, was complicated by the significant interaction farm×dosage, which revealed that a dosage effect was not found on all farms.

Juvenile stages may be more sensitive than the adult individuals. It was, however, not possible to count all larvae caught in the pit-falls but a pesticide effect on the larva, whether direct (lethal) or indirect (sublethal, changed microclimate or altered food supply), was fund by suction sampling in wheat (Table 3.9).

Table 3.13. Mean numbers of carabids caught in pit-falls within 100 m^2 enclosures in wheat in the periods 16/6-5/8 1998 and 31/5-3/8 1999. Estimates given are least squares means with 95% confidence limits in square brackets per sampling. P-values for test of dosage are given (ns: p>0.05, *: p<0.05, **: p<0.01, ***: p<0.001).

Genus	Normal dosage		Quarter dosage		p-value
Agonum	140.3	[118.9; 165.5]	123.5	[104.6; 145.8]	0.2787 ns
Amara	25.1	[20.9; 30.0]	22.4	[18.7; 26.9]	0.3961 ns
Bembidion	56.8	[44.3; 72.7]	39.4	[30.7; 50.5]	0.0416 *
Calathus	51.4	[38.7; 68.2]	76.5	[57.7; 101.4]	0.0507 ns
Carabus	0.4	[0.1; 0.8]	0.8	[0.5; 1.3]	0.0919 ns
Clivina	13.2	[8.2; 20.8]	16.3	[10.2; 25.5]	0.5235 ns
Demetrias	5.2	[3.9; 6.9]	8.7	[6.6; 11.3]	0.2924 ns
Harpalus	36.6	[30.0; 44.7]	33.2	[27.1; 40.5]	0.4833 ns
Loricera	139.7	[123.1; 158.5]	218.1	[192.2; 247.4]	0.1149 ns
Nebria	0.5	[0.2; 0.9]	0.5	[0.2; 0.9]	0.9578 ns
Notiophilus	9.0	[6.6; 12.0]	8.9	[6.5; 11.9]	0.9848 ns
Pterostichus	62.1	[44.4; 86.6]	100.7	[72.2; 140.3]	0.0444 *
Stomis	7.3	[5.1; 10.3]	8.9	[6.3; 12.5]	0.4074 ns
Synuchus	17.9	[13.2; 24.3]	9.8	[7.1; 13.5]	0.0085 **
Trechus	273.5	[217.9; 343.3]	214.5	[170.8; 269.3]	0.1349 ns
Others	0.9	[0.5; 1.3]	0,9	[0.6; 1.4]	0.8562 ns

Gastrophysa

A significant dosage effect was found on the number of ***Gastrophysa polygoni*** (chrysomelid beetles) caught in pitfalls (Table 3.14). Least squares estimates revealed much higher catches at quarter dosage than at normal dosage. It is unclear whether the effect was due to reduced insecticide spraying or to higher occurrence of its host plants ***Polygonum convolvus*** or ***P. aviculare*** or to a combination of various factors.

Table 3.14. Estimated numbers of *Gastrophysa polygoni* adults (total no./100m^2) in wheat on Gjorslev 1999. Estimates given are least squares means with 95% confidence limits in square brackets per sampling. P-value for test of the factor dosage is given (*: p<0.05).

	Normal dosage	Quarter dosage	p-value
Number/100m^2	35.4 [8.0; 138.6]	588.2 [148.3; 2324.1]	0.0121*

3.2.2.3 Direct counts

Generally a dosage effect on ***Aphididae*** was found in all three crops. The aphid specific insecticide Pirimor (pirimicarb) proved more effective than pyrethoids and Dimethoate. The efficiency of the insecticide applications, however, was highly variable. A table with results is presented in Appendix D.

3.2.2.4 Sweep net sampling

The results are presented in Table 3.15, which shows a significantly higher occurrence of ***Miridae*** in quarter dosage. Since the estimates are not absolute due to the sweep net sampling method, it may be more relevant to look at the ratios between the estimated numbers. The results showed that it could be expected to find between 3 – 17 times more ***Miridae*** at quarter dosage compared to normal dosage, and between 2 - 8 times more in half compared to normal dosage.

Table 3.15. The estimated number of *Miridae* (Mirid-bugs) per sample (10 standardised sweeps in the outer 10 rows) after insecticide application in beets, Gjorslev 11 July 1997. Estimates given are least squares means with 95% confidence limits in square brackets per sampling. Significant differences between dosages (p<0.05, paired t-tests) are indicated by different letters. The p-value for test of the factor dosage is given (***: p< 0.001).

Normal dosage	Half dosage	Quarter dosage	p-value
0.15 a [0.84; 1.51]	0.28 a [0.15; 0.50]	1.13 b [0.84; 1.51]	<0.0001***

3.2.3 Discussion

In a tri-trophic context the insect part had a dual aim. One was to research if, and to what extent, reduced dosages of pesticides, insecticides and herbicides, affected the amount of available arthropod food for the farmland birds. The other was to explore if and how much pesticides affected the populations of specific taxa of arthropods. Of special importance were populations of "beneficials", especially predators of crop pests also being important food items for birds. Dosage effects on the most important crop pests, ***Aphididae*** (aphids), were roughly estimated by counting tillers/plants with aphids. The overall aim was not to estimate crop damage, but only to reveal effects on the populations.

Possible pesticides effects could be either direct (lethal) or indirect (sublethal, changed microclimate or altered food supply). Due to the complexity of this experiment and the complexity in general it is complicated (if at all possible) to reveal the relative importance of the actual mechanism(s) causing significant findings. However, the most likely causes for effects found will briefly be discussed here and more deeply in chapter 7 and further analyses of correlation between arthropods and weed are presented and discussed in chapter 6 and 7.

Overall there was a general tendency towards more arthropod biomass at reduced dosages of pesticides (Table 3.5). There was considerable difference between the findings in the three experimental crops. In barley, a significantly higher dry mass was revealed at quarter dosage than at half and normal dosages. In wheat and beet no overall significant differences between dosages were found, but in beets a higher total arthropod dry mass was revealed at the reduced dosages after insecticide application. In barley a 30% higher total dry mass and food item dry mass was estimated between quarter and normal dosages. In wheat and beet the corresponding differences indicated were never more than about the half of that in barley. The dry mass estimates for half dosage was mostly in between the two other dosages but sometimes the estimate was nearer quarter and other times it was closer to normal dosage.

Possible reasons for the pronounced dosage effects found in barley were, that the insecticides were applied earlier and barley was a more open crop compared to wheat, allowing pesticides to penetrate deeper into the canopy thereby improving their effects (see also 7.2). Furthermore insecticides were applied more often in barley than in beets and broader ranged products were used in barley. In beets, weed hoeing was always conducted at half and quarter dosage. At Oremandsgård and Gjorslev weed hoeing in normal dosage plots was carried out once per season irrespective of the number of herbicide applications. Nordfeld had done similarly at one instance (1998), while the farms Lekkende and Nøbøllegård have never used weed hoeing in normal dosage plots (see Appendix B). Generally it may be assumed that soil-tilling has a negative impact on arthropods (Holm ***et al***. unpubl.). Reasons for this could be disturbance and altered micro-climate, maybe shading the effects of reduced pesticide dosages.

Wheat had the highest arthropod biomass followed by that of barley and beets. A possible reason could be, that winter wheat is an early established, higher and denser crop probably providing a more favourable environment throughout the season. Furthermore, in wheat no soil tilling was conducted in the spring probably in favour of especially soil-dwelling arthropods. In beets the arthropod dry masses were always lower during the season when comparing with the corresponding periods in the cereals; especially at the beginning of the season. This is most likely due to the canopy development, which affects the microclimate. In beets, the long period of bare soil in early half of the season creates a rather harsh microclimate, which however changes with ongoing crop development towards being shadowy and humid. As mentioned for wheat, in winter cereals, the less extreme conditions already established in early spring creates more favourable conditions for most relevant arthropods. It should be noticed, that the arthropod estimates for beets, which had the lowest dry mass estimates until the end of the season, actually would be lower if sampling had covered not only the crop plants but also the almost bare field between the rows.

When comparing the dry mass fluctuation between years in beets with the climatic data presented in section 1.2.8 it seems likely that the relatively high precipitation in July 1998 had benefited the arthropod populations. In the cereals, in which arthropod populations are established earlier due to the crop phenology, the relatively cold May in 1997 may have suppressed the populations permanently that year. It is also possible that the relatively higher catches in the cereals in 1998 and 1999 are due to an accumulated effect of reduced pesticide dosages. It is, however, not possible to analyse such an effect isolated. Between-year differences of the amount of pesticides applied are limited and do apparently not explain the fluctuations (Table 1.1, Appendix A.2-A.4).

A non-parametric test (Friedman test) confirmed that numbers of the most common arthropod groups did increase under a reduced pesticide regime, but with the group "wheat non-carnivores" as an exception. There was a clear effect of quarter dosage, whereas there was no general effect of half dosage.

There was a tendency towards, that most affected arthropod carnivores in all three crops were aphid specific, often at juvenile stages. The populations of ***Dermaptera*** (earwigs) were higher at quarter dosage in all three crops, and they are also known as important aphid predators (Sunderland & Vickerman 1980). It is possible that this was due to prey removal, rather than a direct lethal effect on the predators. On the other hand the specific aphid predators are very exposed to insecticides due to their location high in the canopy. Furthermore the juvenile stages have limited mobility making them good indicators of pesticide effects compared to the often highly mobile adults having the ability to re-colonise quickly. The increase of the aphid specific predators responding significantly to the reduced dosages of pesticides was in the range of 20% - 175%, most pronounced for ***Coccinellidae*** larvae in barley. The populations, however, were probably still too low to have a significant impact on the aphid populations. Among the non-carnivores, it was generally not the same non-carnivore groups, which were significantly affected by dosage in the three crops, however the number of groups significantly affected was the same (4).

A dosage effect on ***Aphididae*** was found in al three crops. Aphids are considered the most important crop pests and they are the main targets of a majority of the insecticide applications. The aphid specific insecticide Pirimicarb, which is considered less harmful to most arthropod predators, proved more effective than pyrethoids and Dimethoate in all three crops. The absolutely lowest damage threshold in barley and wheat is a 30% ear infestation at the most vulnerable growth stages (Nielsen ***et al***. 2000). Therefore, the insecticide applications in both cereals in 1997 and in wheat in 1998 could probably have been omitted. The other insecticide sprayings in the cereals seemed justified. Despite a high variation in the efficiency of the applications, which blurs the overall picture, quarter dosage seemed close to the required minimum. In beets all the Pirimicarb applications proved efficient, even at quarter dosage, contrary to the other insecticides.

With fenced pitfalls a significantly higher estimated dry mass (25%) of the important carabids was found at quarter dosage in wheat. The results obtained on carabids using fenced pitfalls are not reflected in the suction samples probably because carabids are poorly extracted by suction. It was not possible to conduct corresponding experiments in barley and beets due to resource limitations (and the ongoing weed hoeing in beets). It is, however, most possible that the results obtained in wheat could be found in barley and beets too. This is an interesting hypothesis since ***Carabidae*** is a very dominating family within ***Coleoptera***, which already constitute a significant part of the dry mass of the suctions samples. A significant effect for carabids in barley and beets could therefore turn the overall tendency even more towards a clear dosage effect. The most abundant genus ***Pterostichus*** responded positively to reduced dosages with 62% higher density at quarter dosage. The most abundant ***Pterostichus*** species was ***P. malanarius*** which is a medium to large sized species. It is a widely studied species, known as an important predator of many crop pests.

Because the pre-insecticide catches were insufficient for statistical analysis, it was not possible to distinguish between insecticide or herbicide effects on the adult populations. Furthermore the life cycle of carabids, with larval stages in the soil having different emergence periods and consequently population fluctuations difficult to access, complicates the conclusions. However, since larger carabids generally are not very sensitive to insecticides at the applied dosages, weed cover may play a key role in the differences found between dosages. ***P. melanarius*** is nocturnal and prefers probably a dense plant cover as found at quarter dosage, whereas e.g. the most abundant ***Bembidion*** species are diurnal and may therefore prefer the less dense plant cover found at normal dosage (see 7.2). The pesticide effects found on the adult beetles may also be due to lethal effects on the larvae, especially on those with a pronounced epigaeic activity. A species, which apparently was affected by a differentiated spraying regime, was ***Loricera pilicornis***, which has epigaeic activity during the period of insecticide spraying (Traugott 1998). It is possible that the significantly higher catches in 1999 were due to an accumulated effect of reduced dosages, but it cannot be documented statistically.

The significantly higher numbers of ***Gastrophysa polygoni*** (knotgrass beetle) at quarter dosage (estimated number 15 – 16 times higher, but with high variation) on Gjorslev 1999 is in line with the results of Kjær & Jepson (1995) who found increased populations at reduced field rates of dimethoate. ***G. polygoni*** is found on the aerial parts of its host plants and is therefore directly exposed to the spraying droplets. This probably makes it very sensitive to the pyrethoid spraying (Tau-fluvalinat) conducted. It may also be because of an increased host plant resource although this was not verified. Also when herbicides do not kill the host plants, but only limit their growth and quality, the abundance of ***G. polygoni*** may be severely reduced (Sotherton 1982, Kjær & Elmegaard 1996).

Even isolated it is a very interesting case since earlier research have documented ***G. polygonum*** (as well as its host plants) as a key factor for the partridge ***Perdix perdix*** (Sotherton 1982).

4 Birds (Petersen, B.S.)

The ornithological studies were aimed at describing the number of birds of different species utilizing the fields at different pesticide dosages. Although many factors may affect the distribution of birds in the agricultural landscape, it is believed that the number of birds occurring in a certain field, or dosage plot, is to a significant degree related to the amount of available food. The occurrence of birds in relation to the amount of animal and vegetable food resources is analysed and discussed in chapters 6 and 7.

The scale of the study and the resources available did not allow investigations of population size and dynamics – i.e., no attempts of measuring the absolute number of territories, production or survival rate were made. On the other hand, with three different crops, fifteen fields of >18 hectares, and three study years it is believed that the results are of considerable general value.

4.1 Pilot studies

The aim of the pilot studies was twofold: (1) to test and adjust the census methods in the field; (2) to collect data on the occurrence of birds on the study fields. The purpose of this initial collection of data was to check if the planned dimensioning of the study (number of fields, field size, sampling period, sampling frequency) was adequate to make the collection of a sufficiently large amount of data possible.

Two separate pilot studies were carried out. Firstly, a study was performed during the breeding season of 1996 on six fields at Gjorslev. Secondly, the occurrence of birds during the winter months was studied in the winter of 1996-97 on one field at each farm. The results of these investigations are briefly dealt with in the following. They do not contribute significantly to the elucidation of the main problem, but they provide documentation for the expedience of the methods used.

4.1.1 Breeding season 1996

During the breeding season, two investigations were conducted at Gjorslev. (1) On the three fields that were to be used in the main study (1997-1999), censuses were carried out with the purpose of providing data on the distribution of birds on the fields when these were homogeneously sprayed. This information could be important for the laying out of dosage plots as well as for the choice of census technique. (2) On the experimentally sprayed pilot test fields, a series of counts was carried out with the dual purpose of optimizing the census method and providing initial data on the possible differences in bird densities between dosage plots.

4.1.1.1 Field methods

The three main study fields were sown with winter wheat, spring barley and maize, respectively, in the harvest year 1995-96. All three fields are surrounded by hedges (cf. Fig. 1.3), and the study was primarily designed to reveal the effect of these hedges on the distribution of birds on the fields. Using marker sticks, each field was divided into four zones: 0-12 m, 12-50 m, 50-100 m and > 100 m from nearest hedge; a 0-12 m zone was also marked around any habitat islands within the fields. Each field was then divided into 12 census plots of approximately equal size (1.5-2 ha). Point counts of 10 minutes duration were carried out from the edge of each census plot. All birds seen or heard within or immediately above the census plot were recorded and assigned to one or more zones. Two censuses of each field (one between 8 and 11 a.m., one between 12 and 15) were carried out on five dates between 22 May and 17 June 1996, yielding a total of 10 (not independent) counts per field. For analysis, the number of individuals of each species recorded within each zone was calculated for each of the 10 counts separately, by adding up the counts from the 12 census plots.

In the pilot test fields, four 1.5 ha subplots (census plots) were delimited within each dosage plot. This subplot size roughly corresponds to the area of a field which can be surveyed from one point. Ten minutes point counts were carried out from the edge of each subplot. All birds seen or heard within or immediately above the subplot were recorded and assigned to one or more of the following four zones: hedge/habitat island; field 0-12 m (from hedge/habitat island); field > 12 m; air. Two censuses of each field (one between 8 and 11, one between 12 and 15) were carried out on 14 dates between 1 May and 11 July 1996. At the latter date, the number of birds in the cereal fields had clearly peaked, and the censuses were stopped. In the beet field, however, numbers were still high, and four additional censuses were carried out between 18 July and 12 August.

The counts revealed that some birds were not recorded when the observer was stationary at the census points, but were flushed or became vocal when the observer moved between the points. Therefore, the point counts were supplemented by transect counts from 21 June onwards. Each route through a subplot (from one census point to the next) formed a transect, and transect time was standardized at 5 minutes. Only birds within the subplot were recorded. In the analyses only registrations from the census points (not from the transects) were included. For each dosage plot, the counts from the four subplots were added up separately for the morning and afternoon counts, and the maximum of the two counts was used.

4.1.1.2 Analyses and results

The distribution of the seven most frequently recorded bird species on the homogeneously sprayed fields is shown in Table 4.1. There were no big differences between fields, so results from the three fields have been pooled in the presentation. It is clear from the table that all of the species are affected by the presence of hedgerows, either negatively (Skylark) or positively (the

Table 4.1. The distribution of selected bird species on homogeneously sprayed fields, classified according to distance to nearest hedge. The mean number of individuals per count is given. Percentages indicate the proportion of total field area belonging to each distance zone or (for the first three bird species) proportion of total number recorded within each of these zones.

Species	Hedge & habitat island	Field 0-12 m (13%)	Field 12-50 m (30%)	Field 50-100 m (31%)	Field > 100 m (26%)
Skylark		1.13 (8%)	3.20 (23%)	5.37 (39%)	4.23 (30%)
Barn Swallow	0.07	2.97 (32%)	2.73 (29%)	2.57 (27%)	1.07 (11%)
Sand Martin		2.17 (37%)	2.20 (38%)	1.10 (19%)	0.33 (6%)
Blackbird	2.80	0.23			
Whitethroat	8.80	0.33			
Linnet	5.80	0.70	0.30		
Yellowhammer	13.17	0.93	0.17	0.07	

others). Because the census points were located along the hedges, the detection chance decreased (to an unknown degree) towards the mid-field. Thus, the Skylarks' avoidance of areas close to hedges is more pronounced than indicated by the data.

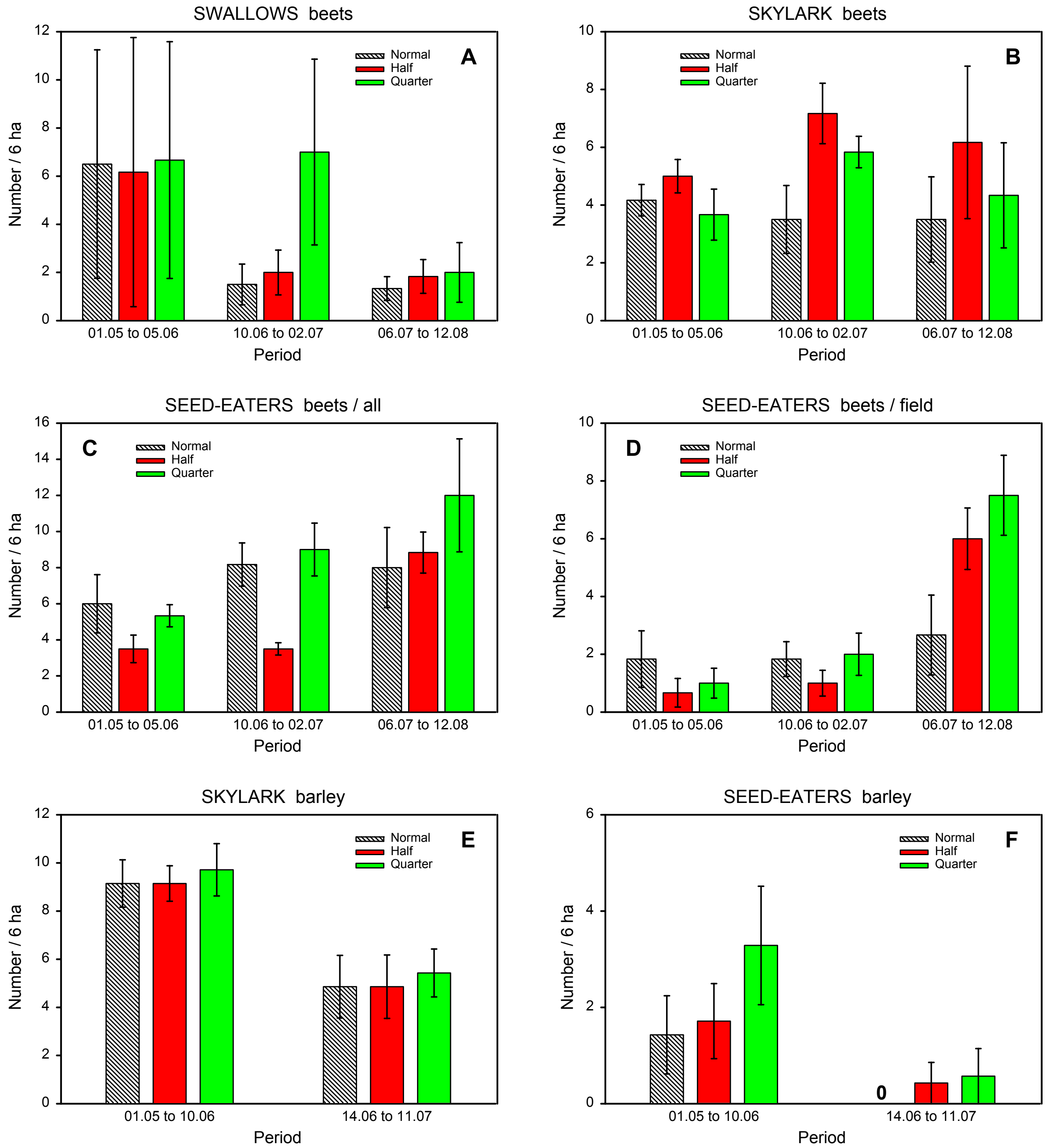


Fig. 4.1. Examples of results0 from the bird counts on the pilot test fields, summer 1996. The mean number of individuals (+/– standard error) per count is shown for plots with normal, half and quarter dosage. A: Beets; swallows and martins. B: Beets; Skylark. C: Beets; seed-eaters (all records). D: Beets; seed-eaters (only birds on the field). E: Barley; Skylark. F: Barley; seed-eaters (only birds on the field).

Some results of the counts on the experimentally sprayed pilot test fields are visualized in Fig. 4.1. The census period was divided into three parts for the beet field (1 May - 5 June; 10 June - 2 July; 6 July - 12 August) and two parts for the barley field (1 May - 10 June; 14 June - 11 July); in the wheat field no experimental sprayings were carried out. Results are shown for swallows, Skylark, and small seed-eaters (sparrows, finches and buntings).

The small seed-eaters occurring in farmland mainly feed in the fields but nest and seek cover in hedges and coverts. They are thus recorded on the field as well as in the surrounding hedges. For these species, analyses were carried out on all records as well as on the smaller sample of records from the field proper.

A formal test of differences between dosage plots is hampered by the lack of true replications; the observations on different dates within the breeding season are not strictly independent. However, to give at least some indication about the significance of the apparent differences, a log-linear model was fitted for each field and species (group), assuming the number of individuals recorded on a certain plot and date to follow a Poisson distribution. Likelihood ratio tests were used to test for differences between plots with respect to mean numbers and development in numbers between census periods. To be conservative, tests were adjusted for over-dispersion (variance greater than would be expected from a Poisson distribution), whereas under-dispersion (variance smaller than expected, indicating non-independence between observations) was not allowed. The analyses were performed using the GENMOD procedure in SAS/STAT software.

The following differences were found:
Beets, swallows: Significant differences between plots (p = 0.045*); pairwise contrasts reveal more birds at quarter dosage than at normal and half dosages (p = 0.025* and 0.047*, respectively). A closer look at the data shows that this difference did only occur in mid- and late June.
Beets, Skylark: Significant differences between plots (p = 0.0045**); more birds at half dosage than at normal (and maybe quarter) dosages (p = 0.0012** and 0.052, respectively).
Beets, seed-eaters (all): Significant differences between plots (p = 0.0092**); fewer birds at half dosage than at quarter (and maybe normal) dosages (p = 0.0024** and 0.054, respectively).
Beets, seed-eaters (field): Significant differences in development in numbers between plots (p = 0.019*); less positive development during the season at normal dosage than at half and quarter dosages (p = 0.0099** and 0.020*, respectively). No differences in overall mean numbers, but significant differences between plots in the last period (p = 0.029*); fewer birds at normal dosage than at quarter (and maybe half) dosages (p = 0.0090** and 0.053, respectively).
Barley, seed-eaters: Significant differences between plots (p = 0.014*); more birds at quarter dosage than at normal dosage (p = 0.0044**).

4.1.1.3 Discussion
The effects of hedgerows are clear from Table 4.1 as well as from the results presented in Fig. 4.1. In the beet field, the plots which received normal and quarter dosages were situated along the hedges surrounding the field whereas the half-dosage plot just bordered on hedges at its ends. Thus the Skylarks' avoidance of areas close to hedgerows is also the reason for their preference of the half-dosage plot. Conversely, the apparent avoidance of the half-dosage

plot by the small seed-eaters, which include Linnet and Yellowhammer, (Fig. 4.1 C) is caused by their preference for hedgerows. Hedgerows may also affect the distribution of airborne species like swallows: swallows were fairly evenly distributed over the test field except on two observation days in mid- and late June, when quite strong westerly winds dominated and the swallows were almost exclusively foraging sheltered by the hedgerow bordering the quarter dosage plot (Fig. 4.1 A).

If only records of seed-eaters from the field proper are considered (Fig. 4.1 D), the balance between half and normal dosage is shifted in favour of the half-dosage plot. It is notable that there was a pronounced increase in numbers during the season in the plots with half and quarter dosage but not in the normal-dosage plot. This might well reflect that towards the end of the season, more birds' food items were available in the half- and quarter-dosage plots than in the normal-dosage plot. Despite the name, the small "seed-eaters" during the breeding season to a large extent feed on arthropods, especially when feeding young (Christensen ***et al.*** 1996).

In the barley field, which was not bordered by hedgerows, a similar difference was found: significantly more small seed-eaters were recorded in the quarter-dosage plot than in the normal-dosage plot (Fig. 4.1 F). There were no differences in the distribution of Skylarks between plots.

Thus, from the ornithological pilot studies during the breeding season, two important conclusions emerged: (1) On the experimentally sprayed fields, some differences in the distribution of birds between dosage plots occurred. Dosage plots of 6 hectares and a sampling program with counts every fifth day during a three month period seemed sufficient to detect the differences. (2) The occurrence of hedgerows affects the distribution of all common farmland species to such an extent that even sizable treatment-related differences between plots may be masked.

Methodologically, it appeared that the point counts should be supplemented with line transects in order to increase the detection chance for stationary birds in the field. Further, it was clear that proper registration of swallows and martins demanded so much of the observer's attention that the registration of other, more important species suffered. So, as their distribution seemed to be very much affected by the meteorological conditions, it was decided that swallows, martins and swifts should not be recorded.

4.1.2 Winter studies

As part of the pilot studies, censuses were carried out during the winter of 1996-97 on four fields with autumn-sown wheat (the experimental wheat fields at Gjorslev, Lekkende, Oremandsgård and Nordfeld). Three counts per field were conducted between November and March. It was not clear from these pilot censuses whether the density of birds on the fields in winter was sufficient to allow statistical testing. Therefore, a full-scale winter study was carried out after the first project year (1997) on all 15 experimental fields.

4.1.2.1 Field methods

The winter counts were performed as line transects. Following a set pattern, the observer scoured each dosage plot, using a constant effort of 5 minutes per ha. All birds seen or heard on the field, above the field, or in hedgerows or habitat islands adjacent to the field were recorded. Before moving into the field, the observer scanned all three plots with a binocular, with the purpose of counting any birds of shy species that might be flushed when the transects were started. The number of birds recorded in each plot was converted to a standard plot size of 6 ha before analysis. Censuses were carried out between 1 November 1997 and 15 March 1998. Each of the 15 fields was visited twice a month, yielding a total of 9 counts per field.

4.1.2.2 Analyses and results

During the censuses 1996-97, a total of 168 birds of 21 species, or 4.7 birds per plot and count, were recorded (excluding a flock of 140 Common Gulls). No attempts to carry out any statistical analyses on this small sample were made.

In the winter of 1997-98, 4506 individuals of 49 species were recorded. Six species (groups) were selected for statistical analysis: Skylark, Crow, tits, Blackbird, Yellowhammer and small seed-eaters. Two analyses of the occurrence of Crow, Yellowhammer and seed-eaters were carried out: one using all records, one with records from hedgerows and habitat islands being excluded. Each of the three types of fields, winter wheat, "after wheat" (to be sown with beets) and "after beets" (to be sown with barley) was dealt with separately, so the total number of analyses performed was 27. Analysis of variance was used to test for differences between dosages treating the different farms as blocks. Because the repeated censuses of each plot were not strictly independent, the geometric mean of the 9 counts, calculated separately for each species (group), was used as the dependent variable. In the calculation of the geometric mean, the densities from the individual counts (which might contain zeros) were $x+1$ transformed.

Only one of the 27 tests for differences between dosages was significant at the 5% level: Blackbird on fields after wheat ($p = 0.011$*, more birds at quarter dosage than at half and normal dosages). A further two tests, both relating to the "after beets" fields, were significant at the 10% level, with the highest number of birds being found at normal dosage (Crow) and quarter dosage (Yellowhammer).

4.1.2.3 Discussion

The number of significant tests is equal to the number that would be expected by chance, if no true differences between dosage plots exist. The inevitable conclusion is that after one year of experimental treatments, no differences between dosages could be detected with respect to the occurrence of birds on the plots in winter. This is not very surprising, considering that the seed production of the year with experimental dosages was ploughed in during autumn.

Of greater importance is the fact that bird densities during winter proved quite low. Although a total of 4506 birds may sound impressive, the geometric mean number of individuals per count per plot (6 ha) did not exceed one in any of the species analysed. At such low densities, chance events become of considerable importance, and it was considered unlikely that any reliable differences between dosage plots could be detected. Therefore, winter counts were not performed during the remainder of the study period.

4.2 Methods

During the main phase of the study (1997-99), two kinds of ornithological investigations were carried out. Firstly, counts were performed on all 15 fields in all three study years from shortly after the germination of the spring crops until a few weeks before the harvest of barley and wheat. This census period coincides with the main breeding period of most bird species. Secondly, counts were carried out on the stubble fields in early autumn, from immediately after harvest until the fields were ploughed. These counts, coinciding with the dispersal and migration period, were performed in 1998 and 1999, i.e. after the winter counts were dropped.

4.2.1 Breeding season counts

4.2.1.1 Field methods

Each observation day, two kinds of censuses were carried out: morning counts (between 8 and 11 a.m.) and afternoon counts (between 12 and 15). Different methods were used for the two kinds of censuses. The morning counts were mainly based on point counts, and birds on the field as well as in the surrounding vegetation were censused. The afternoon counts were performed as line transects, and only birds on the field were censused. In all censuses, all species except swallows/martins and swifts were recorded.

In the morning, the sampling unit was the subplot. Before the counts began in early May, 12 subplots of about equal size were demarcated in each field. The number of subplots within each dosage plot was four or six, depending on the presence of hedgerows at the field borders and thus the comparability of plots (cf. section 4.1.1). If there were no hedges around a field, or if all three plots bordered on an equal amount of hedgerow and thus were directly comparable, four subplots of 1.5 ha were delimited within each plot (Fig. 4.2 A). In 7 of the 15 fields, however, the presence of hedgerows made it impossible to lay out three fully comparable dosage plots (Fig. 4.2 B). In these cases, six subplots of 1.0 ha were delimited within each of the two similar plots (always the normal- and quarter-dosage plots, cf. section 1.2.5), and the half-dosage plot was not censused during the morning counts.

The birds within each subplot were counted by means of a combination of point and transect counts. Firstly, a 10 minutes point count was carried out while the observer was stationary at the edge of the subplot. Then the observer spent 5 minutes walking through the subplot to the border of the next, adding to his list of records any birds within the subplot that had not been recorded from the census point. During the 15 minutes spent in each subplot, all birds seen or heard within or immediately above the subplot were recorded and assigned to one or more of the following four zones: hedge/habitat island; field 0-12 m (from hedge/habitat island); field > 12 m; air. Care was taken not to count an individual more than once. If a bird was recorded in more than one subplot, the observer assigned it to one, and just one of these. The chosen subplot should be the one where the bird did most of its feeding, not necessarily the one in which the nest was assumed to be located.

On the afternoon counts, the sampling unit was the plot, and all three plots were censused in all fields. Line transects were used. Following a set pattern, the observer walked through each plot, using a constant effort of 6 minutes per ha. All birds seen or heard within or immediately above the plot were recorded and assigned to one or more of the following three zones: field 0-12 m (from hedge/habitat island); field > 12 m; air. Because these counts primarily aimed at recording birds foraging in the fields, birds in hedgerows and habitat islands were not censused. Like at the morning counts, a bird recorded in more than one plot was assigned to one of these by the observer.

Fig. 4.2. Two examples of the delimitation of subplots within plots. A: Four subplots of 1.5 ha within each plot (Nøbøllegård). B: Six subplots of 1.0 ha within the normal- and quarter-dosage plots (Gjorslev). Aerial photos by courtesy of Kampsax.

A total of 17 or 18 counts (each consisting of a morning count and an afternoon count) were performed at each field per year. In 1997, 17 counts per field were carried out between 6 May and 31 July. In 1998, the census period was 11 May to 5 August, and 17 counts per field were performed. Finally, in 1999 18 counts were performed between 6 May and 5 August. To avoid systematic biases from changes in the birds' activity during the day, the starting plot varied from count to count according to a rotating scheme.

4.2.1.2 Statistical analysis

The basic experimental unit was the plot, and the standard plot size was 6 ha. Consequently, for each bird species, field and year, the dependent variable was the number of individuals per 6 ha plot per count. The results of the morning and afternoon counts were analysed separately. For the morning counts, the number of individuals recorded in each subplot within a plot were summed up to yield a 6 ha plot total for each species. For the afternoon counts, the number of birds recorded within each plot was converted to the standard plot size of 6 ha by division. In order to improve approximation to a normal distribution, and make the variance independent of the mean, all standard plot totals were $\log_e(x+1)$ transformed before further analysis.
The repeated censuses of a certain plot during the season are not statistically independent. Therefore, some kind of repeated-measures analysis is needed to test for differences between dosage plots (e.g., Stryhn 1996). Described graphically, a suitable method is as follows: The dependent variable is depicted as a function of the census date; for each species and type of count, this creates 135 curves (3 plots in 15 fields in 3 years). The 135 curves are then tested against each other for differences between dosages. This can be done by fitting a 16th or 17th degree polynomial (depending on the number of census dates) to each curve, whereupon the parameters (zero degree terms, 1st degree terms etc.) are tested against each other by means of analysis of variance. If a parameterization which yields orthogonal polynomials is used, the different parameters may be tested and (to some extent) interpreted independently of each other. In practice, the high-order coefficients are difficult to interpret, for which reason analyses of this kind are often limited to tests of zero, 1st and 2nd degree terms.

In the present case, the basic hypothesis is as follows: At the beginning of the breeding season, before any notable effects of pesticide sprayings occur, no systematic differences between dosage plots exist. As the season progresses, and the effects of the herbicide and insecticide sprayings manifest themselves, differences in the amounts of insects and other birds' food items develop between plots. Consequently, the quarter-dosage plots during the breeding season become relatively more attractive to the birds as feeding sites and the normal-dosage plots become relatively less attractive, with the half-dosage plots placed somewhere in between. This should be reflected in the seasonal development in the number of birds foraging in each of the three plots within a field.

The crucial check of this hypothesis is to test whether the first-order coefficient of the polynomial, i.e. the slope of the curve, is significantly greater in the quarter- (or half-) dosage plots than in the normal-dosage plots. Differences in mean number (the zero-order term) between plots may be a corollary of the differences in development, or they may reflect more permanent differences between plots. Because the relative dosage applied to a certain plot was the same in all three years, effects may have accumulated during the study. Accordingly, towards the end of the study period, dosage-related differences between plots might be present from the start of the breeding season.

To deal with this approach in practice, the mean and slope of the number-of-birds vs. date curve were calculated for each species, plot and year, using the REG procedure in SAS/STAT. The means and slopes were then analysed for differences between dosages by means of analysis of variance, taking into account the effect of differences between crops, years, farms and fields. It should be noticed that dosage was treated as a class variable, so no assumptions about the effect of half dosage falling in between those of quarter and normal dosage were made. The anova design applied is shown in Table 4.2; starting with the full model, stepwise model reduction was used. If a significant effect of dosage was revealed, least-squares means were calculated, and t-tests were used to test for pairwise differences. The analyses were performed using the GLM procedure in SAS/STAT.

Table 4.2. The factors included in the anova of the occurrence of birds during the breeding season, the nature of each factor (fixed/random), and the denominator (error term) used in the test of significance of each factor in a balanced design (see text).

Source of variation	Fixed / random	Denominator in F test (if balanced)
Dosage	Fixed	MS(Dosage×Year) + MS(Dosage×Farm) – MS(Residual)
Crop	Fixed	MS(Crop×Farm)
Year	Random	MS(Dosage×Year)
Farm	Random	MS(Field(Farm)) + MS(Crop×Farm) + MS(Dosage×Farm) – MS(Dosage×Crop×Farm) – MS(Residual)
Field (Farm)	Random	MS(Residual)
Crop × Farm	Random	MS(Dosage×Crop×Farm)
Dosage × Crop	Fixed	MS(Dosage×Crop×Farm)
Dosage × Year	Random	MS(Residual)
Dosage × Farm	Random	MS(Dosage×Crop×Farm)
Dosage × Crop × Farm	Random	MS(Residual)
Residual	Random	

The error terms given in Table 4.2 are only fully valid in a balanced experimental design. In the present case, however, only the afternoon counts represent such a design. Because not all of the half-dosage plots were censused at the morning counts (cf. section 4.2.1.1), the experiment in this case is unbalanced and the F-tests must be modified, causing the tests to be only approximate. The modifications applied involve a weighting of the different terms in the denominator of the F-tests and an adjustment of the degrees of freedom, as called by the RANDOM/TEST statement in the GLM procedure in SAS/STAT (SAS Institute 1990).

While the test procedures thus were based on a model with just mean and slope - in order to make the interpretation of the tests as plain as possible - 2nd degree models were calculated for illustrative purposes and to provide more information about the seasonal development in bird numbers.

Two species and one species group were selected for analysis: Skylark, Whitethroat and small seed-eaters (sparrows, finches and buntings). These species were the only ones occurring in sufficient numbers in the fields to make a reliable analysis possible. As previously mentioned, morning and afternoon counts were analysed separately. Furthermore, the analyses of morning counts of Whitethroat and seed-eaters were performed on the total sample as well as on the smaller sample from the field proper. Thus, a total of eight different (but not mutually independent) series of curves were analysed. Table 4.3 summarizes the dependent variables selected and the size of the material.

Table 4.3. The species selected for analysis and the census variables used. The number of individuals recorded is given for each of the eight variables.

	Morning counts (incl. hedgerows etc.)	Morning counts (field only)	Afternoon counts (always field only)
Skylark	–	10,317	10,609
Whitethroat	4,676	802	605
Small seed-eaters	7,960	1,690	1,782

4.2.2 Autumn counts

4.2.2.1 Field methods

The autumn counts on harvested fields were basically carried out in the same way as the winter counts (section 4.1.2.1), but with a census effort corresponding to that of the afternoon counts during the breeding season. Thus, the sampling unit was the plot, all three plots were censused in all fields, and the census method was line transects. Before the transects were started, the observer scanned all three plots with a binocular, and any birds of shy species (geese, plovers etc.) that might be flushed when he moved into the field were counted. Then the observer walked through each plot following a set pattern, using a constant effort of 6 minutes per ha. All birds (except swallows/martins and swifts) that were seen or heard within or immediately above the plot, or in the adjacent vegetation, were recorded and assigned to one or more of the following four zones: hedge/habitat island, field 0-12 m (from hedge/habitat island); field > 12 m; air. Like on the other censuses, care was taken not to count any individual more than once, and if a bird was recorded in more than one plot, it was assigned to one of these by the observer. The starting plot varied from count to count according to a rotating scheme.

Only the ten cereal fields were censused. The counts were started as soon as possible after harvest, i.e. between 22 August and 8 September. Each field was censused once a week until it was ploughed, although with a maximum of 9 counts per field in 1998 and 7 counts in 1999. In 1998 the farmers were allowed to follow their normal routines and plough the fields as soon as they pleased; this led to great differences in counting periods and number of counts per field. Therefore, in 1999 the farmers were compensated for postponing the ploughing of the study fields until 7 counts had been performed. Unfortunately, one farm did not want to participate, so only 8 fields were censused in autumn 1999. A total of 64 and 56 counts were carried out in 1998 and 1999, respectively. The average number of counts per field, the period during which the counts were performed, and the median counting date are shown in Table 4.4.

Table 4.4. Statistical information about the censuses on stubble fields in 1998 and 1999. For each combination of crop and year, the number of counts is shown (average and range). Also, the period during which the censuses were performed is shown together with the median counting date.

	1998			1999		
	No. of counts	Period	Median date	No. of counts	Period	Median date
Barley stubble	4.2 (2-6)	25.08 - 04.10	09.09	7 (7-7)	26.08 - 06.10	15.09
Wheat stubble	8.6 (8-9)	22.08 - 06.11	26.09	7 (7-7)	26.08 - 06.10	15.09

4.2.2.2 *Statistical analysis*

For each plot and census, the density of each species recorded was expressed as the number of birds per 6 ha, and the densities were $\log_e(x+1)$ transformed before further analysis. Because the repeated censuses of each plot within a year are not strictly independent, the mean of the log-transformed densities (equivalent to the geometric mean) were used as the dependent variable in the analyses. Contrary to the situation in the breeding season, any dosage-related differences in food abundance between plots were expected to be manifest from the beginning of the census period, so tests of trends were not performed.

The geometric means of selected species were analysed for differences between dosages by means of analysis of variance. The experimental design is incomplete in this case. Basically, the whole experiment is a well balanced multiple Latin Square design: 3 crops, 3 fields, 3 years and 5 replicates (farms). The autumn counts, however, concern just a subset of the Latin Square: two crops and two years, but still 3 fields per farm (due to the rotation of crops). Therefore, the effects of crop, year and field cannot be estimated simultaneously; this led to a modification of the anova design (Table 4.5).

Table 4.5. The factors included in the anova of the occurrence of birds on stubble fields, the nature of each factor, and the denominator (error term) used in the test of significance of each factor in a balanced design (see text).

Source of variation	Fixed / Random	Denominator in F test (if balanced)
Dosage	Fixed	MS(Dosage×Year) + MS(Dosage×Farm) – MS(Residual)
Crop	Fixed	MS(Crop×Year)
Year	Random	MS(Crop×Year) + MS(Dosage×Year) – MS(Dosage×Crop×Year)
Farm	Random	MS(Crop×Year×Farm) + MS(Dosage×Farm) – MS(Residual)
Crop × Year	Random	MS(Crop×Year×Farm) + MS(Dosage×Crop×Year) – MS(Residual)
Crop × Year × Farm	Random	MS(Residual)
Dosage × Crop	Fixed	MS(Dosage×Crop×Year)
Dosage × Year	Random	MS(Dosage×Crop×Year)
Dosage × Farm	Random	MS(Residual)
Dosage × Crop × Year	Random	MS(Residual)
Residual	Random	

In this anova, the interaction term crop×year contains variation arising from differences in counting periods (cf. Table 4.4) as well as variation from year-dependent crop effects. The 2nd order interaction term crop×year×farm allows these effects to vary between farms, but includes as well some variation stemming from differences between fields.

As previously mentioned, there were 5 replicates in 1998 but just 4 in 1999, so the experimental design is unbalanced and the tests only approximate. The approximate F-tests were constructed in the same way as for the morning counts in the breeding season (section 4.2.1.2). Starting with the full model shown in Table 4.5, stepwise model reduction was used. All analyses were performed using the GLM procedure (with RANDOM/TEST statement) in SAS/STAT.

Two species and one species group occurred in numbers that were sufficient for analysis: Skylark (3,434 individuals recorded), Meadow Pipit (722) and small seed-eaters (3,415). Whereas Skylarks and Meadow Pipits chiefly occur on the fields, Yellowhammers and other small seed-eaters are also frequently recorded in the adjacent hedgerows and habitat islands. The analysis of the occurrence of these species was therefore carried out on the sample of birds from the field proper (1,861 individuals) as well as on the total sample.

4.3 Results

4.3.1 Breeding season counts

The results of the analyses of variance are summarized in Tables 4.6 - 4.8. It is clear from the tables that all main factors have significant effects on the distribution of all three species. The partitioning of the sums of squares (not shown) indicates that the quantitatively most important factors affecting the mean numbers of birds are farm and field (i.e. block factors), while crop plays a minor, but still important role. Crop, farm and field also account for the majority of the variation in slope (i.e. development in numbers), but farm and field are less dominant, and effects of dosage become apparent. So, while there are great differences between farms, and also between single fields, with respect to the ***mean number*** of birds present, the variation between blocks is less pronounced with respect to the ***changes*** in bird numbers that occur during

Table 4.6. Schematic summary of the analyses of the occurrence of Skylarks on the experimental fields during the breeding season. Statistical significance is indicated as follows: *: 0.01<p<0.05, **: 0.001<p<0.01, ***: p<0.001.

	Morning counts		Afternoon counts	
	Mean	Slope	Mean	Slope
Dosage				*
Crop	***	**	***	**
Year	**	**		
Farm	**		**	
Field(Farm)	***		***	
Crop×Farm		*		***
Dosage×Crop				
Dosage×Year				
Dosage×Farm			*	
Dosage×Crop×Farm				

Table 4.7. Schematic summary of the analyses of the occurrence of Whitethroats on the experimental fields during the breeding season. Statistical significance is indicated as follows: *: 0.01<p<0.05, **: 0.001<p<0.01, ***: p<0.001.

	Morning (all obs.)		Morning (field)		Afternoon	
	Mean	Slope	Mean	Slope	Mean	Slope
Dosage	*	**	***	***		***
Crop				***		**
Year	*		***	**	***	*
Farm			*			
Field(Farm)	***		***	***	***	***
Crop×Farm	**		***		*	
Dosage×Crop						
Dosage×Year						
Dosage×Farm	*				*	
Dos.×Crop×Farm						

Table 4.8. Schematic summary of the analyses of the occurrence of small seed-eaters on the experimental fields during the breeding season. Statistical significance is indicated as follows: *: 0.01<p<0.05, **: 0.001<p<0.01, ***: p<0.001.

	Morning (all obs.)		Morning (field)		Afternoon	
	Mean	Slope	Mean	Slope	Mean	Slope
Dosage	*	*	*	**		
Crop		*	***			
Year			*	**	***	**
Farm	*		**			
Field(Farm)	***	***	***	*	***	**
Crop×Farm	*			**	***	***
Dosage×Crop						
Dosage×Year						
Dosage×Farm					**	
Dos.×Crop×Farm						

the season, exposing the effects of the experimental factors crop and dosage. Variation between years, although often significant, never accounts for more that 10% of the total variation.

In all three species analysed, the occurrence differs between crops, although the effect of crop often varies between farms (as evidenced by a significant crop×farm interaction). Concerning the effects of dosage, an important result is the lack of significant dosage×crop interactions, implying that the effect of dosage can be analysed independently of any crop effects. In some cases the dosage×farm interaction is significant (although not highly so), indicating that the effect of dosage varies between farms. Finally, the lack of any significant dosage×year interaction indicates that the effect of dosage has been the same in all three study years.

In the ***Skylark,*** the pattern of occurrence is mainly determined by the crop, while the dosage effects are barely significant (Table 4.6, Fig. 4.3). The concordance between the models based on the morning and afternoon counts is good, considering that they use data from two independent series of counts, with different census methods. In the interpretation of the results, due attention should be paid to the fact that the number of birds recorded is a function of the number of birds present in the field and their activity. The number of Skylarks seems to peak in June, but numbers are surely still high in July when they are increased by the newly fledged young. However, the territorial activity is much higher in May and June than in July.

In the beginning of the season, before the germination of the spring crops, the highest Skylark densities occur in winter cereals. But when the growth of the spring cereals makes the barley fields attractive to Skylarks around 1 May, numbers increase here, reaching a culmination in June. In the beet fields, the number of Skylarks increases throughout the breeding season, and from mid-July onwards the highest densities are found in this crop.

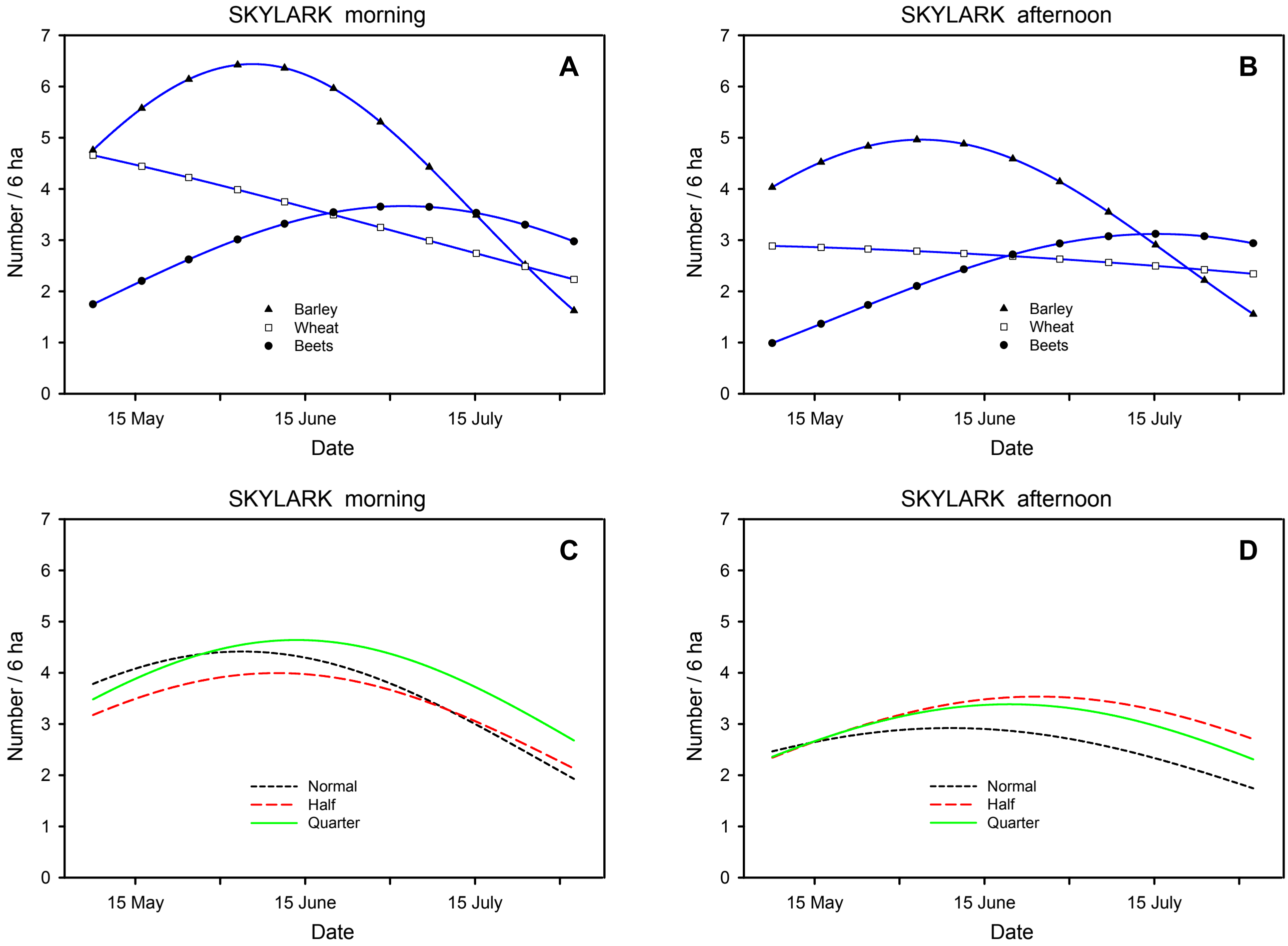


Fig. 4.3. Models of the development in Skylark numbers on the experimental fields from early May to early August in relation to crop (A, B) and dosage (C, D). A & C are based on the morning counts, B & D on the afternoon counts. All models are based on log-transformed data, so the densities indicated are not comparable with normal arithmetic mean densities.

Compared with the crop effects, the effects of differences in dosage on the distribution of Skylarks are small (Fig. 4.3 C-D). On the afternoon counts, the between-dosages differences in development (slope) are significant (p = 0.021*); pairwise t-tests indicate a significant difference between half and normal dosage (p = 0.0061**), but not between quarter and normal (p = 0.085). On the morning counts, the dosage effects are not significant (p = 0.053), but the picture is the same as on the afternoon counts: the decrease in Skylark numbers begins earlier in the season in normal-dosage plots than in plots treated with half or quarter dosage. Actually, pairwise t-tests reveal a significantly "better" (i.e. less negative) development in quarter-dosage plots than in plots treated with normal dosage (p = 0.047*, Tukey-Kramer adjustment for multiple comparisons).

The first ***Whitethroats*** occur in the first week of May, and four weeks later almost all of the population has arrived from its African winter quarters. Territorial activity is high in the first half of June, and from around 20 June onwards the number of Whitethroats is increased by the first fledglings. During July, territorial activity decreases and the birds become less visible (Fig. 4.4 A).

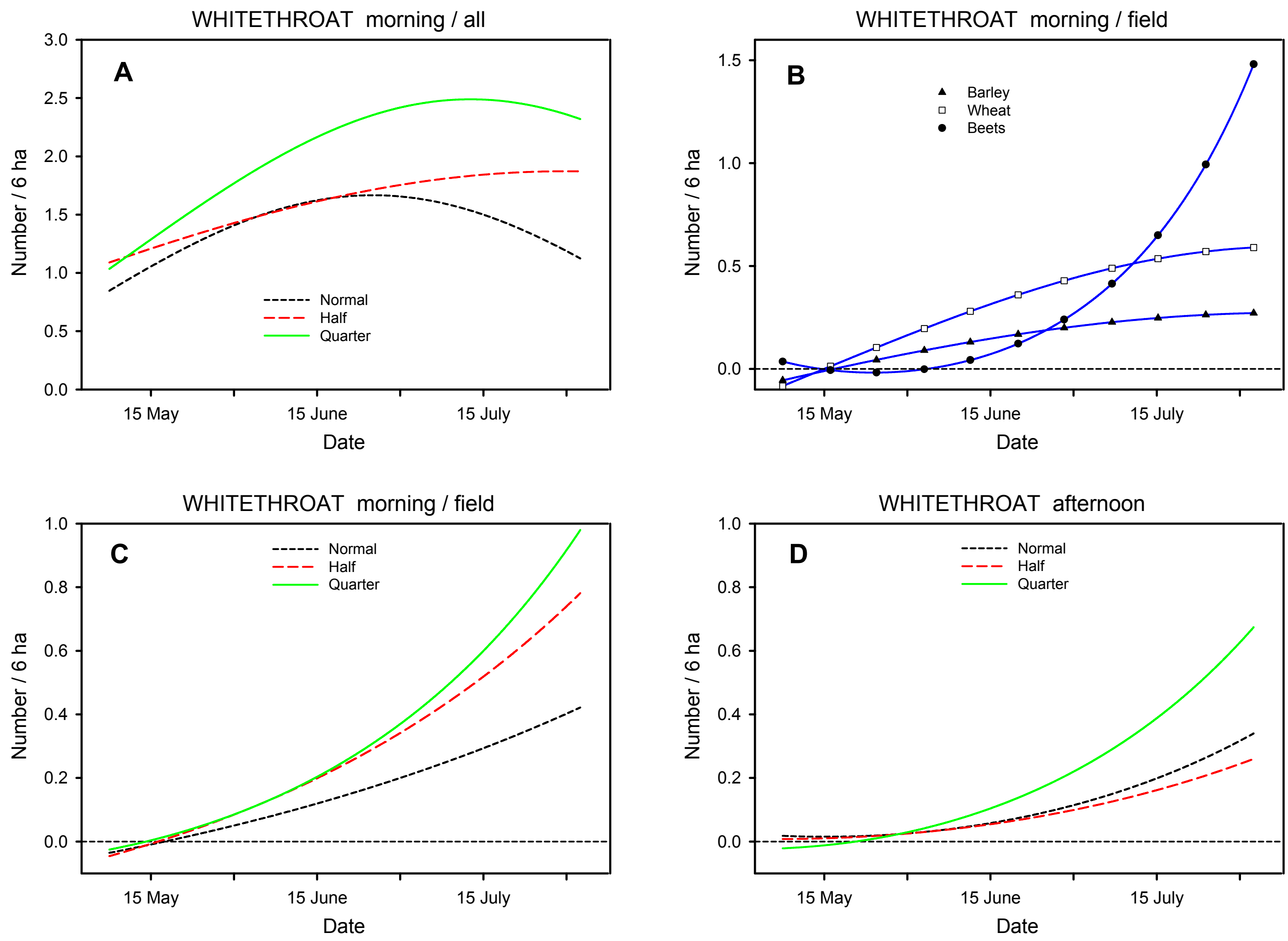


Fig. 4.4. Models of the development in Whitethroat numbers on the experimental fields from early May to early August in relation to dosage (A, C, D) and crop (B). A-C are based on the morning counts, D on the afternoon counts. A concerns all records (including the border vegetation), B-D only records inside the field. All models are based on log-transformed data, so the densities indicated are not comparable with normal arithmetic mean densities.

Although they frequently feed in the fields, Whitethroats need trees and bushes, or at least tall herbs, at the field borders for song-posts and nesting. Because the border vegetation varies strongly between the study fields, block factors farm and field account for the majority of the variation in Whitethroat numbers. Nonetheless, dosage effects are prominent, even when all records (including those in the border vegetation) are considered (Table 4.7). There are clearly significant differences in slope between dosages ($p = 0.0021$**); pairwise t-tests indicate that the overall increase in numbers during the season is significantly stronger in quarter-dosage plots than in normal-dosage plots ($p = 0.0005$***), with the development in half-dosage plots falling somewhere in between (Fig. 4.4 A).

About 17% of the morning records of Whitethroats are from the fields proper. The Whitethroats' use of the fields is crop-dependent, but generally the proportion of birds recorded in the fields increases during the season, accompanying the growth of the crops. Barley fields are used very little while wheat fields are more frequently used. The beet fields are initially not used at all, but become important feeding sites from around 10 July onwards (Fig. 4.4 B).

The dosage has a pronounced effect on the Whitethroats' distribution within the fields (Fig. 4.4 C-D). On the morning counts, the differences in development (slope) between dosages are highly significant ($p = 0.0002$***); pairwise t-tests indicate significant differences between quarter and normal dosage ($p < 0.0001$***) as well as between half and normal ($p = 0.018$*). The differences in mean numbers follow the same pattern. On the afternoon counts, the between-dosages differences in slope are also highly significant ($p < 0.0001$***), and pairwise t-tests indicate a highly significant difference between quarter and normal dosage ($p = 0.0002$***). However, the development in Whitethroat numbers in half-dosage plots is significantly different from that in quarter-dosage plots ($p < 0.0001$***) but does not differ from the development in plots treated with normal dosage. A probable reason for this difference between the morning and afternoon counts is that on the morning counts, only half-dosage plots surrounded by the same amount of hedgerows as the normal- and quarter-dosage plots were censused (cf. section 4.2.1.1), whereas all plots were censused on the afternoon counts, including those half-dosage plots that abut on a smaller amount of hedgerow than the normal- and quarter-dosage plots and thus are less likely to be visited by Whitethroats.

The ***small seed-eaters*** (sparrows, finches and buntings) nest in hedgerows, coverts and around farmsteads, whereas a major part of their foraging takes place in the fields. The number of individuals occurring in and along the fields rises steadily during the breeding season, partly because the population sizes are increased by fledglings, partly because the birds (especially sparrows) move from the farmstead surroundings to the fields when the young have fledged. Farm and field differences account for the majority of the variation in numbers because of great between-fields variation in border vegetation and distance to farm buildings.

Even when all records are considered, effects of dosage can be distinguished (Table 4.8, Fig. 4.5 A). There are significant differences between dosages in the development in seed-eater numbers during the breeding season ($p = 0.020$*); pairwise t-tests indicate slope differences between quarter and normal dosage ($p = 0.037$*) and between half and normal ($p = 0.011$*). There are similar differences in mean numbers although the difference between half and normal dosage is not significant ($p = 0.096$).

About 21% of the morning records of small seed-eaters concern birds inside the fields. The birds' use of the fields for feeding differs between crops (Fig. 4.5 B). In winter wheat there is a slow but steady increase in the number of birds during the season. The spring crops are used during a short period in May, but later on barley is the least preferred crop. Conversely, beets are used throughout the season, and beet fields are very important feeding sites from the beginning of July onwards.

Besides the crop effects, the distribution of small seed-eaters in the fields is affected by dosage effects. On the morning counts (Fig. 4.5 C), there are significant differences in seasonal development between dosages ($p = 0.0081$**); pairwise t-tests indicate significant slope differences between quarter and normal dosage ($p = 0.013$*) as well as between half and normal ($p = 0.0069$**). The differences in mean numbers follow the same pattern. On the afternoon counts, the differences in development (slope) between dosages are not significant ($p = 0.17$), and the effects of dosage on mean

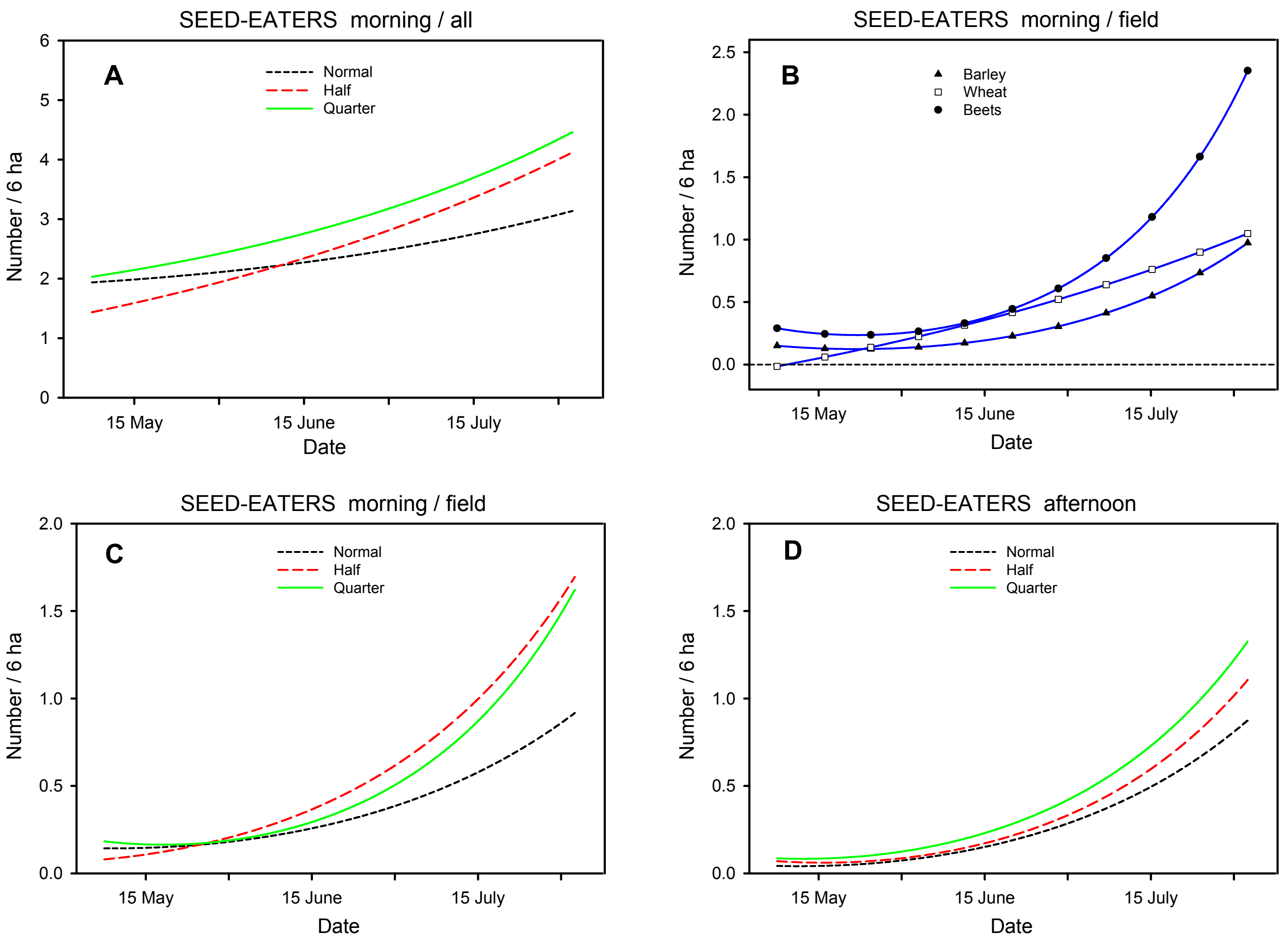


Fig. 4.5. Models of the development in the numbers of small seed-eaters on the experimental fields from early May to early August in relation to dosage (A, C, D) and crop (B). A-C are based on the morning counts, D on the afternoon counts. A concerns all records (including the border vegetation), B-D only records inside the field. All models are based on log-transformed data, so the densities indicated are not comparable with normal arithmetic mean densities.

numbers vary between farms. However, the models for quarter, half and normal dosage (Fig. 4.5 D) follow a pattern which is quite similar to that seen on the morning counts.

4.3.2 Autumn counts

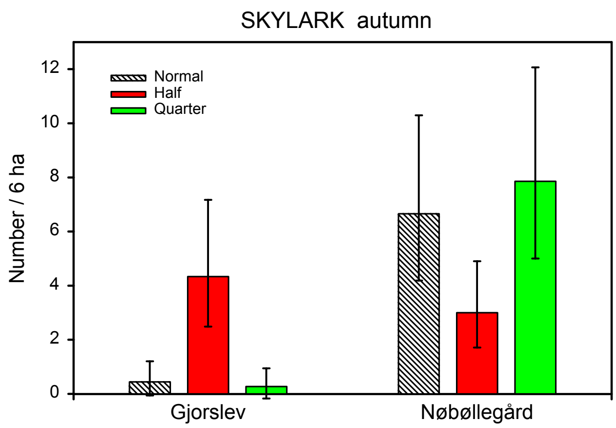
The results of the analyses of variance are summarized in Table 4.9. There are great differences between the analysed species and very few, if any, general conclusions can be drawn. The partitioning of the sums of squares (not shown) indicates that the dominating sources of variation are farm differences and/or the crop×year×farm interaction (which includes between-fields differences, cf. section 4.2.2.2). Effects of differences between years and between crops are less pronounced. No general effect of dosage is indicated, but in the Skylark and the seed-eaters, the dosage×farm interaction accounts for 17% and 11%, respectively, of the total variation.

Table 4.9. Schematic summary of the analyses of the occurrence of selected bird species on the experimental fields in autumn. Statistical significance is indicated as follows: *: 0.01<p<0.05, **: 0.001<p<0.01, ***: p<0.001.

	Skylark	Meadow Pipit	Small seed-eaters	
			All obs.	Field only
Dosage				
Crop			*	
Year			**	*
Farm	*		***	***
Crop × Year				
Crop × Year × Farm	**	***		
Dosage × Crop				
Dosage × Year				
Dosage × Farm	**			
Dosage × Crop × Year				

In the ***Skylark,*** the major sources of variation are farm and field differences. There is a clearly significant dosage×farm interaction, indicating that some differences between dosages exist, but vary between farms. Testing each farm separately reveals significant (or almost significant) dosage effects in two farms only: Gjorslev (p = 0.0056**) and Nøbøllegård (p = 0.058). At Gjorslev, Skylark numbers are clearly higher in half-dosage plots than in normal- and quarter-dosage plots (pairwise t-tests: p = 0.0048** and 0.0031**, respectively). At Nøbøllegård, numbers tend to be lower in half-dosage plots than in normal- and quarter-dosage plots (p = 0.056 and 0.028*, respectively) (Fig. 4.6).

Fig. 4.6. The occurrence of Skylarks on the experimental stubble fields at Gjorslev and Nøbøllegård in autumn. The geometric mean numbers (+/– 2*standard error) are shown for plots sprayed with normal, half and quarter dosage.



In both cases, the differences in Skylark numbers are probably due to structural differences, rather than to differences in pesticide use. At Gjorslev, all fields are surrounded by hedges, making the outer plots (always normal and quarter dosage) less attractive to Skylarks than the central (half dosage) plots (cf. section 4.1.1). At Nøbøllegård the reverse is true: the field that was censused in both years (and thus contributed 50% of the data) is bordered by a hedgerow along the half-dosage plot, making the quarter- and normal-dosage plots the most attractive to Skylarks.

In the ***Meadow Pipit,*** the crop×year×farm interaction is the dominant source of variation. In addition, the factors farm and crop×year each account for 15-20% of the total variation. There are no indications of dosage effects. The Meadow Pipits occurring on the stubble fields are almost exclusively resting migrants, with numbers peaking from late September to mid-October. In 1998, when the number and timing of the counts varied between fields (Table 4.4), the censuses on almost all of the barley fields stopped before the peak of the migration, whereas the censuses on wheat fields continued until late October and thus included the main migration period. This is probably the main reason for the dominance of the crop×year and crop×year×farm interactions.

The occurrence of ***small seed-eaters***, contrary to the other species, is to a large extent dependent on the existence of hedgerows or other suitable vegetation along the field borders. The farms and fields vary in this respect, which is probably the reason why farm differences is the dominant source of variation in the numbers of small seed-eaters. There are significant differences between years; for unknown reasons more birds were recorded in 1999 than in 1998 (no such difference was apparent during the breeding season). A significant difference between crops is evident when all records are included, but disappears when only records from the field are considered and is therefore of little interest. There are no significant dosage effects.

4.4 Discussion

The bird species analysed represent different phenologies and strategies in their exploitation of the farmland environment and may thus be considered representative for the bird community associated with arable fields. The Skylark is the only species occurring in large numbers that both breeds and forages in agricultural fields, where it is dominant and numerous from March until November. During the breeding season, its diet mainly consists of arthropods, but in autumn cereal grains and other seeds become important, and in winter and spring green plant material is frequently eaten as well (Christensen ***et al.*** 1996). Probably as part of their anti-predator strategy, Skylarks avoid areas close to hedgerows and other vertical structures (cf. Petersen 1996, Chamberlain & Gregory 1999).

Contrary to the Skylark, the small seed-eaters (Yellowhammer, Linnet, Chaffinch, Greenfinch, Tree Sparrow etc.) take advantage of the existence of suitable vegetation bordering the fields, or habitat islands within the fields, for cover and breeding. However, most of their foraging takes place inside the fields. The species occur in Danish farmland year round, often forming flocks outside the breeding season. Over the year, plant seeds (including cereal grains) make up the bulk of their diet, but during the breeding season, insects are an important part of the diet in most species.

Whitethroats are strongly associated with hedgerows and tall herbaceous vegetation along the field borders but make frequent foraging trips into the fields. Being tropical migrants, they arrive in Danish farmland in May and leave in August-September. Whitethroats are chiefly insectivorous, but fruits and berries are of some importance in late summer and autumn.

Like the Whitethroat, the Meadow Pipit is mainly insectivorous, but in early autumn seeds may constitute 15% of the diet and even more later in the year (Cramp & Simmons 1977-94). The species breeds on permanent grassland and is rarely found on arable fields during the breeding season, but during autumn and spring migration (September-October and April) large numbers rest on suitable fields. Meadow Pipits show neither preference nor avoidance of hedgerows.

Put together, the selected species utilize a broad spectrum of the animal and vegetable resources available all over the fields. The major limitations follow from their relatively small size (max. Skylark 40 g) and the fact that none of the species use their bills to probe the soil (like Starling). No larger species occurred in numbers allowing reliable statistical analyses of their distribution.

Optimal use of the available resources by the birds involves changes of crop preferences during the breeding season. The Skylark's shift in preferences is visualized in Fig. 4.3. Skylarks seemingly prefer not too dense crops of 15-45 cm height, which is probably the reason for their gradual shift from winter cereals to spring cereals in May and general leaving of the cereal fields during July (cf. Schläpfer 1988, Jenny 1990b, Wilson ***et al.*** 1997, Chamberlain ***et al.*** 1999, Toepfer & Stubbe 2001). In dense crops Skylarks often concentrate their foraging activities around tramlines and other unsown areas where locomotion is unhindered and prey items are more easily seen (Odderskær ***et al.*** 1997b). Row crops like beets, by contrast, allow the birds to walk about unrestricted all over the field, and beet fields become useful for Skylarks when the crop biomass (and hence the structural diversity) starts to increase rapidly from mid-June onwards.

The numbers of Whitethroats and seed-eaters (and several other bird species breeding in the border vegetation) that occur in the fields generally increase as the season progresses, accompanying the growth of the crops. This is especially pronounced in beet fields where the number of birds rises tremendously during July (Figs. 4.4 B & 4.5 B). A strong increase in Yellowhammers' utilization of beet fields after 10 July was also found by Biber (1993). Beet fields offer good cover and easy access and also hold good numbers of preferred birds' food items from mid-July onwards (Fig. 3.4). In cereal fields there is a slow but steady increase in the number of foraging birds of these species throughout the breeding season, most pronounced in wheat; two British studies show a quite similar picture for both Yellowhammer (Stoate ***et al.*** 1998) and Whitethroat (Cracknell 1986). Yellowhammers and other small seed-eaters also show some preference for spring crops during a short period after sowing, when the loose soil and low vegetation suit their feeding behaviour.

Contrary to the situation in the breeding season, no crop preferences were found on the autumn counts. None of the analysed bird species show any signs of preferring wheat stubble to barley stubble or vice versa. In Britain, Donald ***et al.*** (2001) found that wintering Skylarks preferred barley stubbles to wheat stubbles. Generally, stubble fields are preferred habitats during autumn and winter, compared to fields with autumn-sown crops, grass ley or bare till (Petersen & Nøhr 1992, Wilson ***et al.*** 1996, Robinson & Sutherland 1999, Donald ***et al.*** 2001).

Despite clear differences in the birds' use of the crops during the breeding season, the effects of dosage do not in any case interact significantly with the effects of crop. In other words, the effect of dosage on the occurrence of the analysed bird species is principally the same in all three crops studied.

In some cases, the dosage×farm interaction term is significant, indicating that the effect of dosage varies between farms. However, a significant interaction is almost exclusively found on the afternoon counts, where all plots were censused, including those half-dosage plots that are not fully comparable with the normal- and quarter-dosage plots (cf. section 4.2.1.1). Therefore, a

significant dosage×farm interaction is probably chiefly due to the lack of true comparability of plots, rather than to real between-farms differences in the effects of dosage. The implications of the lack of full comparability of plots for the estimations of dosage effects are further discussed in section 4.4.1.
As explained in section 4.2.1.2, the basic hypothesis is that no systematic differences between dosage plots exist at the beginning of the breeding season, but that differences develop as the season progresses and the effects of the pesticide sprayings come to the fore. If dosage effects accumulate over the years, differences between dosage plots might exist from the outset in years 2 or 3. This would show in the analyses as a significant dosage×year interaction term, as would also be the case if the effect of dosage varies between years. In all analyses, however, the dosage×year interaction is far from significant, indicating that there have been no between-years differences in the effect of dosage and no traceable accumulation of effects over the three year study period.

Clear dosage-related differences are found in the breeding season counts of Whitethroats and small seed-eaters; the most pronounced differences occur in the former. In all tests, the number of Whitethroats increases significantly more rapidly in quarter-dosage plots than in normal-dosage plots. Similar significant differences are found in the morning counts of small seed-eaters, while the afternoon counts follow the same pattern without the differences being significant.

It is probably safe to conclude that the development in the numbers of Whitethroats and small seed-eaters occurring in the fields from May to August is in full accordance with the basic hypothesis: towards the end of the season, the birds clearly prefer plots treated with quarter dosage to plots treated with normal dosage of herbicides and insecticides. All these species make foraging trips into the fields from the surrounding vegetation, but do not establish territories inside the fields. Consequently, each individual is free to choose an optimal foraging site within a certain field.

In the Skylark, the differences between dosages are much less clear than in the species discussed above. However, numbers seem to decline earlier in the season in normal-dosage plots than in half- and quarter-dosage plots, both on the morning and on the afternoon counts (Fig. 4.3 C-D). On the morning counts, there is a significant difference in development between quarter- and normal-dosage plots, whereas on the afternoon counts it is the difference between half- and normal-dosage plots that is significant at the 5% level.

Although slight, the shift from plots treated with normal dosage to half- and quarter-dosage plots is in accordance with the basic hypothesis. The shift may reflect that, as the season progresses, the birds prefer to forage in plots with reduced dosages. Another explanation may be that fewer pairs carry through a second breeding attempt in normal-dosage plots than in half- and quarter-dosage plots (cf. Odderskær ***et al.*** 1997a).

The Skylarks perform almost all of their feeding inside the fields. So, on the face of it, it may be surprising that the most numerous and specialised field species among those studied is the one that shows the weakest response to differences in pesticide treatments. One obvious explanation may be that the graded dosages do not lead to appreciable changes in the distribution of the Skylarks' food resources (but see chapter 3). Another reason may be that vegetation structure (which may or may not be dosage-related), rather than food abundance, is the most important distributing factor (Odderskær ***et al.*** 1997b, Chamberlain ***et al.*** 1999). Also, the territorial system of Skylarks may seriously restrain the individual birds' choice of feeding sites within a field, so that only a limited response to changes in the availability of food is possible during the breeding season. Finally, the methodological uncertainties are notable: the number of Skylarks within a plot is rather difficult to establish accurately, due to their numerousness and their habit of flying around above the field, chasing each other.

Territoriality is not assumed to affect the distribution of Skylarks on the stubble fields in autumn. However, the autumn counts did not reveal any differences in the distribution of Skylarks on the experimental fields that may be ascribed to differences in pesticide treatments. Likewise, no dosage-related differences in abundance were found in Meadow Pipits or small seed-eaters. There are two possible explanations: (1) The incomplete, unbalanced design does not allow sufficiently accurate estimations and powerful tests. (2) The differences in pesticide dosage do not result in differences in the amount of birds' food items on the stubble fields that significantly affect the distribution of birds (cf. section 2.3).

4.4.1 How many more birds at reduced dosages?

From an administrative, as well as from a scientific point of view, this is an essential question. However, it is impossible to give a definite answer to it, among others because no measurements of breeding population densities or production of fledglings were made in this study. Even if this had been the case, though, it would not have been possible to assess the effect on the following year's population size, because this depends on the post-fledging survival, return rate, density-dependent population regulation etc.

A simple answer to the question may be given by simply comparing the mean numbers occurring in the plots over the whole breeding season. However, because it was shown that the differences between dosages do not exist from the outset, but develop during the season, it may be more appropriate just to use data from the second half of the census period, i.e. from 21 June onwards. Such a reduced data set was used to calculate the estimates in Table 4.10.

Table 4.10. Least-squares estimates of the increase in bird densities on the experimental fields achieved by reducing the amounts of insecticides and herbicides to one-quarter or one-half of normal dosage. Point estimates and 95% confidence intervals are given. Only data from counts performed between 21 June and 5 August (incl.) were used in the calculations.

Species	Dosage comparison	Morning counts (field only)	Afternoon counts	Morning & afternoon counts averaged
Skylark	Quarter vs. normal	+22.7% [0%; +49%]	+24.1% [+1%; +51%]	+23.3% [0%; +50%]
	Half vs. normal	+1.6% [–23%; +32%]	+38.2% [+13%; +68%]	+18.2% [–7%; +48%]
Whitethroat	Quarter vs. normal	+104.1% [+56%; 157%]	+99.8% [+42%; 163%]	+101.7% [+50%; 158%]
	Half vs. normal	+77.0% [+19%; 142%]	16.6% [–65%; +36%]	+35.4% [–18%; +94%]
Small seed-eaters	Quarter vs. normal	+50.7% [+13%; +93%]	+48.1% [–10%; 118%]	+49.4% [+2%; +105%]
	Half vs. normal	+68.4% [+18%; 127%]	+18.3% [–35%; +82%]	+43.5% [–8%; +105%]

The choice of cutoff date is quite arbitrary; other dates might equally well have been chosen and would have resulted in a different set of estimates. The effect of changes in cutoff date may be judged from Figs. 4.3 - 4.5.

The figures presented in Table 4.10 should not be misinterpreted. They are estimates of differences in (or rather, ratios between) the number of birds occurring in different dosage plots, i.e. they show to which extent birds of different species prefer to stay (and probably feed) in plots with reduced dosages of pesticides compared to plots with normal dosage. ***They are not estimates of differences in population size.***

It appears from a consideration of the 95% confidence limits that the increases in bird densities are estimated with a sizable degree of uncertainty. This is an inherent problem in the estimation of differences and ratios (because the variance of a difference between two variables is the sum of the two variances), but the interval widths also reflect the great variation among the farms and fields included in the study.

As to the quarter vs. normal dosage comparison, there is nonetheless a remarkable concordance between the estimates based on the morning counts and those based on the afternoon counts. In other words, the point estimates may in this case not be as unreliable estimators of the true values as might be expected from a consideration of the confidence intervals. A quick conclusion goes that a 75% reduction of the dosages of herbicides and insecticides results in a 20-25% increase in the number of Skylarks, a 50% increase in the numbers of small seed-eaters and a doubling of the number of Whitethroats visiting the field.

The effect of a halving of pesticide dosages is more difficult to evaluate. This is largely a result of the experimental design, as it was decided to give priority to a comparison of quarter and normal dosage at the expense of half dosage in those cases where it was impossible to lay out more than two fully comparable plots within a field (cf. section 1.2.5). This was the case in 7 of the 15 experimental fields. Only truly comparable plots were censused on the morning counts (cf. section 4.2.1.1), so these counts should give the more reliable estimates. However, because just 8 half-dosage plots were censused at the morning counts (as opposed to 15 plots with quarter dosage), the half vs. normal comparison is subject to greater uncertainty than the quarter vs. normal comparison.

On the afternoon counts all plots were censused, so the sample sizes used for the half vs. normal and quarter vs. normal comparisons are identical. However, even if only birds occurring in the field proper were recorded, the results are biased due to the lack of full comparability between plots. In the vast majority of "incomparable" cases, the normal- and quarter-dosage plots were bordered by hedgerows but the half-dosage plot was not (Fig. 4.2 B), implying that the half-dosage plot was more favourable for Skylarks but less favourable for small seed-eaters and (especially) for Whitethroats than the two other plots (cf. Table 4.1). Consequently, the afternoon counts overestimates the positive effect of a halving of the pesticide dosages on Skylark numbers but underestimates the gain for Whitethroats and (to a lesser extent) for small seed-eaters.

Despite these uncertainties, and even if the averaged confidence intervals for the half vs. normal comparisons in Table 4.10 in all cases include zero, it must be emphasized that a significant, positive effect of a 50% reduction of herbicide and insecticide dosages has been established for all three species (groups) (cf. section 4.3.1). The true value of the gain in numbers is probably closer to the point estimates derived from the morning counts than to those from the afternoon counts.

5 Yield and economy

(Jensen, A.-M.M., Rasmussen, C., Rasmussen, S. & Esbjerg, P.)

This chapter is dealing with the yield and economy aspects of reduced pesticide use. Firstly, the relation between the weed vegetation and the yield is described for cereals (section 5.1). Secondly, the yield in sugar beets is described (section 5.2). Thirdly, weed problems and clean-up decisions after three years with use of reduced pesticide dosages (section 5.3) are reviewed. Finally, the profitability of use of reduced dosages is considered (section 5.4).

The main aim of the yield trials (sections 5.1 and 5.2) was to provide a measure for compensating the involved farmers for a possible yield reduction each year, not to measure an accumulated decrease in yields. The aim of the clean-up study (section 5.3) was to reveal weed problems arising after three years with reduced use of herbicides and insecticides seen from the agronomical point of view. However, three years are not enough to reveal long-term consequences for the growing practices.

5.1 Yield and vegetation in cereal fields (Jensen, A.-M.M.)

5.1.1 Purpose

The aim of this study was to analyse the yield responses of spring barley and winter wheat to reduced use of herbicides and insecticides. The reductions performed were 50 % (half dosage), 75 % (quarter dosage) and in some years a 100 % (non-sprayed) reduction of the normal dosage used in each field and crop. Weed plants compete with crop plants for water, nutrients and light in particularity. Therefore, it is expected that a high density of weeds at reduced dosages is correlated to a decrease in yield. In this study the weed vegetation measured as weed density and species richness was related to the yield and yield quality at reduced pesticide use. A higher density of insects at reduced dosages might also affect the yield, but the occurrence of insects was not measured in this study, so yield changes could not be correlated to the presence of insects, unfortunately.

5.1.2 Methods

5.1.2.1 Field design

Thirty field trials were performed, one in each field of spring barley and winter wheat in each of the three study years in the main study. One field trial in winter wheat was omitted because no differentiation in application of herbicide dosage was made. Each field trial (size: 10m x 40m) was situated in a corner of the field within the plot sprayed with normal dosage at least 30 meters from other plots, hedges, habitat islands etc. and surrounded by a 2.5 m wide buffer zone.

All field trial areas were treated exactly as the surrounding field - sown the same day, sprayed with same dosages and products on the same day etc. (Appendices A.2-A.4). Each field trial consisted of four blocks (replicates) and each block consisted of 3 plots in 1997 and 4 plots in 1998 and 1999. Each plot measured at least 10 m x 2.5 m but they were sometimes longer.

The plots within a block were sprayed with different dosages of herbicides and insecticides (Fig. 5.1). The dosages were 1/1: Sprayed with normal dosage of herbicides and insecticides, 1/2: Sprayed with half dosage, 1/4: Sprayed with quarter dosage, 0: Not sprayed. Non-sprayed plots were not included in 1997.

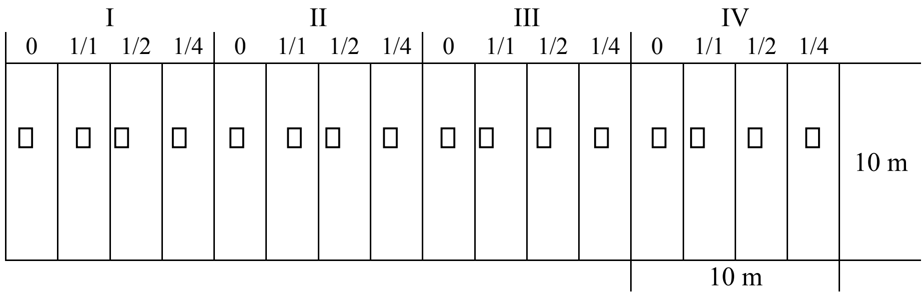


Fig. 5.1. Design of one field trial. In 1998 and 1999 each field trial contained 16 plots. In 1997, the design consisted of 12 plots, because non-sprayed plots were not present. I to IV are the blocks, 0, 1/1, 1/2 and 1/4 the dosages. The squares in the middle of the plots illustrate the weed investigation areas.

Products and dosages chosen by the farmer as normal dosage were very different from field trial to field trial and not equal recommended dosages (chapter 1 and Appendices A.2-A.4). The farmers chose products and dosages after their experiences and individual needs. The location of a field trial within a field was not totally fixed, so the same plot did not necessarily receive the same level of herbicides and insecticides throughout the three years. Therefore, cumulative effects of reduced dosages could not be expected.

5.1.2.2 Weed observations

In each plot, the weed flora was registered in an area of 0.6 m x 0.4 m (Fig. 5.1). All plants were identified as described in section 2.2.1.6 and counted, giving number of plants per square meter (density) and number of species per 0.24 square meter (species richness). The areas were fixed within a season and were visited in spring (early May) and in summer (late July) (before and after spring sprayings). Care was taken to avoid damaging the weed and crop plants under the investigations.

5.1.2.3 Yield and yield quality measurements

Each plot in each field trial was harvested separately and the yields were measured by the local advisory services. Yield was adjusted to 15 % moisture content and given as tons per hectare. Moreover, the following yield components and quality parameters were measured by the local advisory services: thousand kernel weight, moisture content, content of protein, content of starch, pureness and sorting. Samples from plots sprayed with same dosage within a field trial were pooled before measuring the quality parameters.

5.1.2.4 Treatment intensity index and efficiency

In order to compare dosages of different pesticides, two treatment intensity indexes were calculated: an index for herbicides alone and an accumulated index for herbicides and insecticides together. Herbicides applied to control broad-leaved species were included in the treatment intensity index for herbicides, so products mainly applied to control ***Elymus repens*** and ***Avena fatua*** were not included. Treatment intensity indexes were calculated for normal dosage in each field trial (Table 1.1) according to Danmarks Jordbrugsforskning & Landbrugets Rådgivningscenter (1997, 1998 and 1999).

Efficiency of a treatment is in this chapter defined as the herbicide treatment's ability to reduce the weed density and is calculated as $(n_0-n_1)/n_0$, where n_0 is the total density of weed plants in spring (before spring spraying) and n_1 is the total weed density 2-3 months after spring spraying.

5.1.2.5 Statistical tests

The following response variables were tested for dosage effects, separately: weed density, species richness, efficiency, yield and the yield quality parameters. Data from spring barley and winter wheat were tested separately, because the crop has a profound effect on weed density and species richness (see sections 2.2.2.1 and 2.2.2.2). The basic experimental unit in the analyses of these variables was the plot (n=220 for spring barley and n=208 for winter wheat).

Before running the analyses, weed density was transformed with the natural logarithm ($\log_e(y+1)$) to achieve a normal distribution and homogeneity of variances. Similarly, the species richness, efficiency, yield and quality parameters were square root, exponential or arc sinus transformed to approach a normal distribution, if necessary.

The statistical test used was analysis of variance with farm, year, dosage and interactions between these as explanatory factors in addition to the block within a field trial. Moreover, in the analysis of weed density after spraying, the weed density before spring spraying was used as a covariate. Similarly, the species richness before spring spraying and the weed density after spraying were used as covariates in the analyses of species richness after spraying. In the analysis of yield, weed density, species richness and efficiency were used as covariates.
In addition, the six yield quality parameters were tested for effects of pesticide dosage using mean weed density after spraying, mean species richness after spraying and mean yield per dosage per field trial as covariates and farm, year, dosage and first order interactions between those as explanatory factors.
At last, the yield in each field trial was analysed separately. In these analyses the explanatory factors were: dosage, block, weed density after spraying and species richness after spraying.

The number of explanatory factors was reduced during full-scale model calculations using an iterative procedure to remove the variables with $p > 0.10$ until the model consisted only of variables with $p \leq 0.10$.

Each analyse was run three times; first with the interaction between farm and year and afterwards with the two treatment intensity indexes replacing the farm×year interaction in the reduced model. This was done to clarify if the variations between field trials could be explained by variations in the treatment intensity indexes.

All analyses were performed using the general linear model (GLM) procedure in SAS (SAS Institute 1999). If a significant effect of dosage was revealed, the differences among dosages were tested by a Tukey-Kramer test for a-posteriori comparisons of least-squares means. Because non-sprayed plots were not present in 1997, the design was unbalanced and thus required modifications in the F-tests by using the Random/Test statement in the GLM procedure.

The proportion of variation explained by a certain factor was calculated as the sum of squares for that particular factor divided with the total sum of squares.

5.1.3 Results

5.1.3.1 Dosage effects on overall weed density, species richness, efficiency and yield

Table 5.1. Results of tests of effects of reduced dosages on the weed density, species richness, efficiency and yield in spring barley and winter wheat. Grey areas indicate factors not included in the full model. Statistical significance is indicated as follows: +: $0.05 \le p < 0.10$, *: $0.01 \le p < 0.05$, **: $0.001 \le p < 0.01$ and ***: $p < 0.001$.

	Spring barley				Winter wheat			
Explanatory factors	Weed density	Species richness	Efficiency	Yield	Weed density	Species richness	Efficiency	Yield
Weed density before	***				***			
Weed density after		***				***		
Species richness before		***				***		
Species richness after								
Efficiency								+
Dosage	***		***	***	***		***	+
Farm					**	+	***	
Year	+							
Dosage×Farm		**				***		+
Dosage×Year		+						*
Farm×Year	***	***	***	***	***	***	***	**
Dosage×Farm×Year	***		***	***	**			***
Block×Farm×Year	***		*	***				***

Weed density

Weed density was strongly affected by dosage, where a decrease in dosage resulted in an increase in density of weed plants in both spring barley and winter wheat (Table 5.1 and Fig. 5.2A). The estimated mean weed density in non-sprayed spring barley plots was 177 plants/m^2, which was 33 % higher than in plots sprayed with quarter dosage (p=0.0001). In winter wheat, the estimated mean weed density in non-sprayed plots was 96 plants/m^2, which was significantly higher than in plots sprayed with quarter dosage (p=0.020).

Species richness

In both crops, species richness was influenced by dosage, but the effect varied between farms (Table 5.1 and Fig. 5.2B). The species richness was highest in non-sprayed plots; 6.2 species per 0.24 m^2 in spring barley and 3.3 species per 0.24 m^2 in winter wheat.

Efficiency

As expected, the efficiency of the treatments was highly affected by dosage (Table 5.1 and Fig. 5.2C). In spring barley the efficiency was 25 % at quarter dosage, which was significantly lower than the 35 % at half dosage and the 40 % at normal dosage (p=0.043 and p=0.0003, respectively). No significant differences were found between normal and half dosages in spring barley (p=0.46). In winter wheat normal dosage was almost significantly more effective in weed control (46 %) than quarter dosage (28 %) (p=0.053), no significant differences in efficiencies were found between normal and half dosage (31 %) (p=0.16).

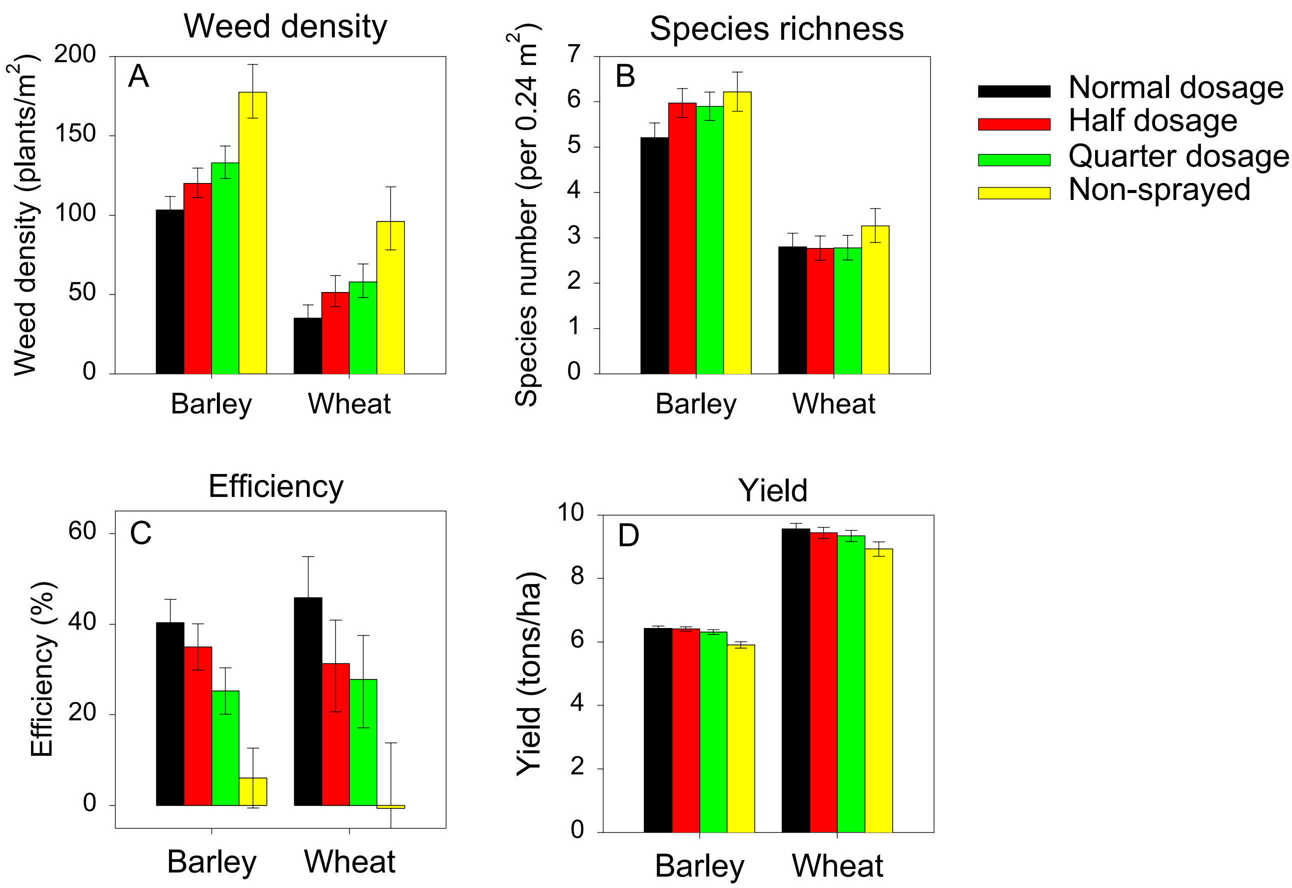


Fig. 5.2. Weed density, species richness, efficiency and yield of spring barley and winter wheat at normal and reduced dosages of pesticides. Each bar represents a mean of 40-60 values. Error bars indicate the 95 % confidence limits.

Yield

As usual in Denmark, the yield per hectare was much higher in winter wheat than in spring barley (Fig. 5.2D). There was a significant effect of dosage on yield of spring barley (Table 5.1). Non-sprayed spring barley plots had on average 8 % lower yields compared to sprayed plots ($p<0.0001$ in all pairwise comparisons). The mean yield at quarter dosage was significantly lower than at half dosage ($p=0.043$) and normal dosage ($p=0.015$). No differences in yields were found between plots sprayed with normal and half dosage

Table 5.2. Percentage increases (+) and decreases (-) in weed density, species richness, efficiency and yield at reduced or zero dosages compared to mean values at normal dosage. Significant difference from normal dosage is indicated as follows: +: $0.05 \leq p<0.10$, *: $0.01 \leq p<0.05$, **: $0.001 \leq p<0.01$ and ***: $p<0.001$.

		Dosage			
Response variable	Crop	Normal	Half	Quarter	Zero
Weed density	Spring barley	103 plants/m^2	+ 16 % **	+ 29 % ***	+ 72 % ***
	Winter wheat	35 plants/m^2	+ 47 % *	+ 65 % **	+ 174 % ***
Species richness	Spring barley	5.2	+ 15 % **	+ 13 % **	+ 19 % **
	Winter wheat	2.8	- 0.9 %	- 1.2 %	+ 16 %
Efficiency	Spring barley	40 %	- 13 %	- 37 % ***	- 85 % ***
	Winter wheat	46 %	- 32 %	- 39 % +	- 101 % ***
Yield	Spring barley	6.4 t/ha	- 0.2 %	- 1.8 % *	- 8.1 % ***
	Winter wheat	9.6 t/ha	- 1.3 %	- 2.3 %	- 6.6 % ***

(p=0.92). The yield in winter wheat was significantly affected by the dosage, but the effect varied between years and farms (Table 5.1). Yields in non-sprayed plots were on average 7 % lower than in plots sprayed with normal dosage (p=0.0002), whereas yield did not vary significantly between normal, half and quarter dosage (p>0.31 in all pairwise comparisons).

The effects of reduced dosage on weed density, species richness, efficiency and yield are summarised in Table 5.2.

5.1.3.2 Effects of variation between field trials and treatment intensity index on overall weed density, species richness, efficiency and yield

Effect of variation between field trials

All response variables showed a highly significant effect of the interaction between farm and year (Table 5.1), which corresponds to the variation between individual field trials (included among other things variations in location of the field trial and the treatment intensity index). This interaction explained most of the total variation in most response variables. Furthermore, the dosage effect varied considerably between field trials (Table 5.1).

Effects of treatment intensity index

When the treatment intensity index for herbicides replaced the interaction farm×year in the reduced models in spring barley, the models were not improved (they showed a higher p-value). Despite this, the treatment intensity index for herbicides had a significant negative effect on weed density and species richness and a positive effect on the efficiency. The yield in spring barley was not significantly affected by the treatment intensity index. In winter wheat models the p-values decreased, when the treatment intensity index for herbicides replaced the farm×year interaction. Thus, the differences in treatment intensity index for herbicides could explain the variations between field trials. The treatment intensity index for herbicides had a significant negative effect on weed density, species richness and yield and a positive effect on the efficiency. In the case of winter wheat, the result thereby indicates that the higher the treatment intensity index for herbicides the lower the yield at harvest, which is in contrast to the expected results. The yields at normal dosage in both spring barley and winter wheat are illustrated in Fig. 5.3 as a function of the treatment intensity index for herbicides. The figure indicates that no meaningful relationship exists between yield and treatment

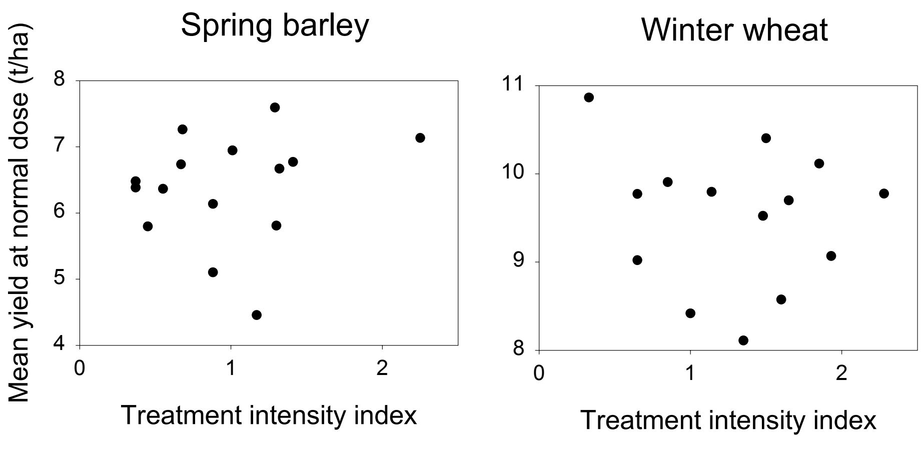


Fig. 5.3. Relationship between treatment intensity index for herbicides and mean yield at normal dosage. Each dot represents data from one field trial.

intensity index. For both crops, all models showed a higher p-value if the accumulated treatment intensity index for herbicides and insecticides replaced the farm×year interaction.

5.1.3.3 *Yield quality parameters*

Of the six yield quality parameters only moisture content in spring barley grains was significantly affected by dosage (p=0.042): The moisture content was significantly lower at quarter dosage, than at half and normal dosages (Tukey-Kramer tests, p=0.0006 and p=0.003, respectively), and no significant differences in moisture content were found between non-sprayed and sprayed plots (p=0.98, p=0.10 and p=0.20 for pairwise comparisons with quarter, half and normal dosage, respectively). No significant effect of dosage was found in any of the other five quality parameters in neither spring barley nor winter wheat.

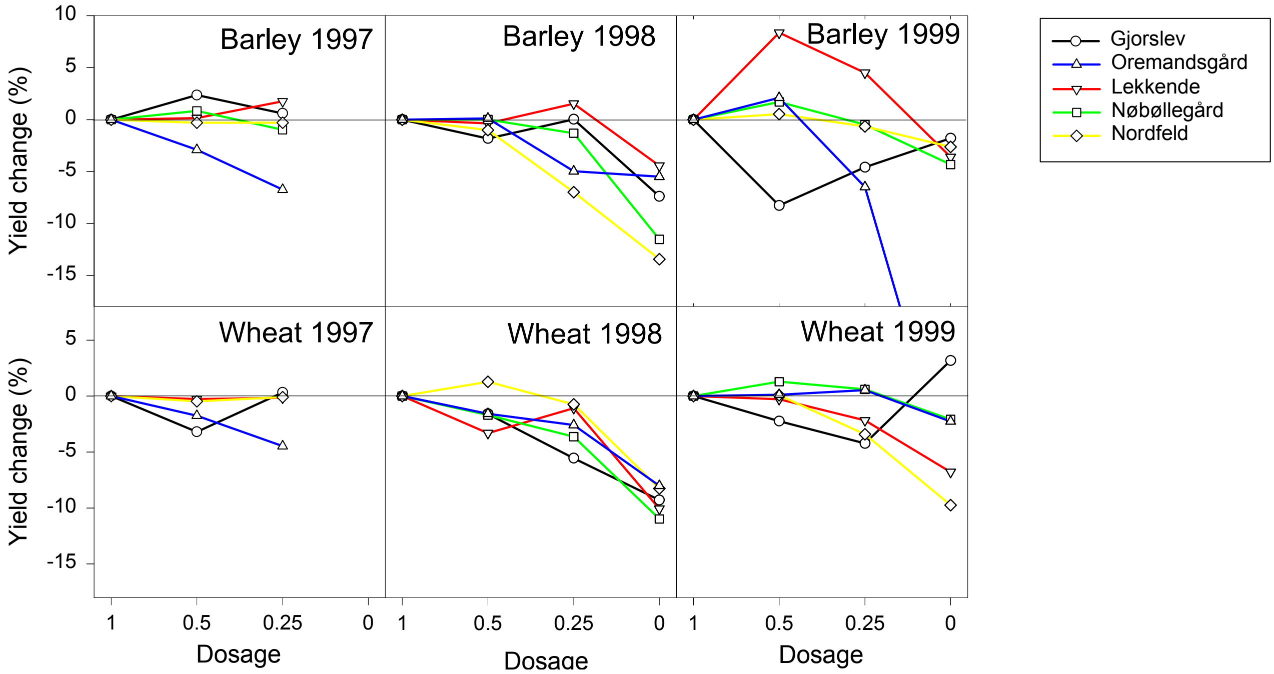


Fig. 5.4. Yield changes at reduced dosages (0.5, 0.25 and 0) in percent compared to normal dosage (1) shown for all field trials. 0 on the y-axes corresponds to yield at normal dosage.

5.1.3.4 *Yield in individual field trials*

The total weed densities before and after spring spraying and the dominant weed species varied considerably from field trial to field trial (Appendix E). Yield changes at reduced dosages of pesticides compared to yield at normal dosages are shown in Fig. 5.4 for all field trials in winter wheat and spring barley.

When each field trial was analysed separately, yield was significantly affected by the dosage in only 8 of 29 field trials (Appendix E.2). In six cases, the yield was significantly lower in non-sprayed plots than in sprayed plots. In three field trials, the yield at quarter dosage was significantly lower than at normal dosage. No field trial showed a significantly lower yield at half dosage compared to normal dosage. The simple model explained at least 75 % of the variation in yield in 86 % of the field trials (Appendix E.2).

5.1.4 Discussion

5.1.4.1 Dosage effects on yield

These field trials cover a wide range of weed species and densities (Appendices E.1A and B) and in the majority of cases a yield decrease (Fig. 5.4) at reduced dosages was found. However, the decreases were often small and only statistically significant in 28 % of the field trials. These results are in accordance with Davies ***et al***. (1989) and Salonen (1993b), who found it difficult to show yield response to reduced broad-leaved weed control in winter wheat and spring barley in Scotland and spring barley in Finland, respectively. Also Pallutt (1999) showed that application of quarter of recommended herbicide dosage was enough to prevent yield losses in strong competitive cereal stands in Germany.

It was generally not possible to show significant differences in the yield between plots sprayed with normal, half or quarter dosages, whereas the yield at unsprayed plots decreased with 8 % in spring barley and 7 % in winter wheat. Davies ***et al.*** (1989) showed that 1/8 of recommended dosage in some cases gave a yield reduction although it was not significant when a mean of five experiments was considered (Davies & Whiting 1990). In some experiments on clay soil Salonen (1992b) reported a higher yield at reduced herbicide dosage than at recommended dosage. This is also found at both half and quarter dosage in some field trials in this study (Fig. 5.4). Jensen (1986) suggested that recommended dosages of some herbicides could harm the crop, however other herbicides are applied today than in the early eighties, so this might not be the case today, although also modern herbicides in some field trials result in a higher yield at reduced dosages than at recommended dosages (Landbrugets Rådgivningscenter 1999b). Yield decrease in response to no chemical control is lower on clay soils than on sandy and organic soils (Jensen 1985). This could be one of the reasons why only small decreases in yield are found in these field trials on clay soils. From this study, it is clear that dosage can be halved without notable yield decreases within one season.

The yield decrease recorded in non-sprayed plots of spring barley (8 %) and winter wheat (7 %) was almost the same size although winter wheat has a higher competitiveness than spring barley (Rasmussen ***et al***. 1997). Therefore, it was expected that winter wheat would have shown a smaller decrease in yield at reduced dosages. On the other hand experiments performed in winter wheat have shown a yield decrease at 12 % (Davies ***et al.*** 1989) or 15 % (Wilson 1986) whereas experiments in spring barley have shown a decrease of 0 %-7 % (Courtney & Johnston 1986, Davies ***et al.*** 1989, Salonen 1992b, Salonen 1993a). Therefore, no consistent relation between crop competitiveness and yield response seems to exist. In addition, the competitiveness of crop cultivars is very variable (Valenti & Wicks 1992, Grundy ***et al.*** 1993) and confuses the picture even more.

Yield responses to reduced dosages varied from farm to farm and from year to year (Table 5.1 and Fig. 5.4), indicating that there may be differences in the effectiveness of weed or insect control between farms and between years within a farm.

From this study, it must be concluded that no meaningful relationship exists between treatment intensity index and the yield (Fig. 5.3).

5.1.4.2 Weed density and yield

Large yield reductions might be associated with high densities of weeds. However, these field trials showed no significant effect of weed density after spraying on the yields of spring barley and winter wheat.

In the separate analyses, only 14 % of the field trials showed a significant effect of weed density and richness on yield (Appendix E.2), half showing a negative relationship and half a positive relationship. These field trials (showing yield decrease above 4.5 %) were not the ones with the highest weed densities after spraying (Appendix E). One field trial (spring barley at Oremandsgård 1997) had a mean density over all treatments of less than 10 weed plants after spraying, and still showed a significant yield decrease at reduced dosages. In that field trial, the yield reduction might reflect a higher level of herbivorous insects at reduced dosages, although the occurrence of aphids was rather low in the surrounding field (Appendix D).

Many studies, like this, have made it clear that there is a poor correlation between total weed density and yield (Jensen 1991, Salonen 1992b), weed biomass and yield (Salonen 1993a) and weed cover and yield (Fischer ***et al.*** 1993). This might be the reason why it has been difficult to show yield response to reduced broad-leaved weed control in winter wheat and spring barley (Davies ***et al.*** 1989, Salonen 1993a).

Not all weed species are strong competitors with cereals. Some species have a higher competitive ability than others, measured as the ability to suppress the crop biomass (Wilson 1986, Wilson & Wright 1990, Jensen 1991, Jensen 1996). As suggested by Wilson (1986), yield responses could be influenced more by weed species than by weed densities. Today's weed control strategy is therefore based on both species and their density (Rasmussen ***et al***. 1997).

In spring barley but not in winter wheat, weed biomass was better correlated to yield loss than the weed density (Jensen 1996). Therefore, a possible difference in responses of density and biomass might not alone explain the reason why no clear correlation between yield and weed density was found in this study (Table 5.1).
It can be seen from Appendices E.1A and B that barley field trials with high densities of ***Brassica napus*/*Sinapis arvensis***, ***Polygonum aviculare*** and ***Trifolium*** sp. had a large decrease in yield at low dosages. Especially ***Sinapis arvensis*** is known as a strong competitor (Scragg 1980). No such species, accounting for major decreases in yield, can easily be found in winter wheat. Among the weed species found in this study, ***Galium aparine*** is the most competitive (Wilson & Wright 1987) but the highest yield decreases did not coincide with the presence of ***Galium aparine***. In conclusion, it must be said that in field trials with high densities of weed species with a high competitiveness reduced dosages might have the greatest potential for affecting the yield negatively. In none of these field trials populations of strong competitive grasses as ***Apera spica-venti, Avena fatua, Bromus*** sp. or ***Elymus repens*** were observed. These species might even in low densities be able to reduce the yield.

In both spring barley and winter wheat, significantly higher weed densities were found not only in non-sprayed plots but also in plots sprayed with quarter dosage than in plots sprayed with norma1 dosage (Fig. 5.2A). Thus, strongly reduced herbicide dosages did not keep the weed densities at the same level as the normal dosages did as reported from Finland (Salonen 1993a).

After spraying with reduced dosages the surviving weed plants might be weakened and are therefore not able to compete with the crop. This might explain that the yield did not decrease remarkably even when the weed density increased highly at reduced dosage of pesticides.

5.1.4.3 Dosage effects on efficiency

In many short-term experiments with cereals, reduced herbicide dosages have provided adequate control of broad-leaved weeds (e.g. Davies ***et al.*** 1989, Davies ***et al.*** 1993, Salonen 1993a) without notable yield decreases. The efficiency was as expected increasing with increasing dosage. At normal dosage, the efficiency was on average 49 % in winter wheat and 41 % in spring barley. This is a low efficiency compared to efficiency of recommended dosages, which reach 70 % in 78-91 % of the field trials performed by Salonen (1993a). The yearly variation in herbicide efficiency may be very large. One year Derksen ***et al***. (1995) found a 90 % reduction in weed number, next year the reduction was only 39 % despite the field, the product and the dosage being equal.

The biomass reduction is even higher than the density reduction mentioned here (Salonen 1993a). This means that weed plants have a lower average biomass in sprayed plots than in unsprayed plots. Furthermore, figure 2.12 indicates that the average biomass per plant was higher at reduced dosages than at normal dosages because a plant weighs more in the generative than in the vegetative phase. The long time (2-3 months) between spring sprayings and registration of the weed density after spraying may have influenced the efficiency both negatively and positively. If new plants have germinated within that period, it would be reflected in a lower efficiency, whereas competition through most of the growing season from the cereals might have resulted in dead weed plants reflected in a higher efficiency. Not many seedlings were observed in cereals in July, so the latter might be more likely than the first.

Many other factors might affect the efficiency of the herbicides (e.g. weed composition, the size of the weed, technique used for spraying, the climate around the time of spraying, the competitiveness of the crop (Kudsk & Mathiassen 1991) and water stress (De Ruiter & Meinen 1998)).

5.1.4.4 Dosage effects on yield quality parameters

Statistically significant differences in yield parameters between dosages were only detected in one case. It must be concluded that dosage has little, if any, effect on yield parameters as content of moisture, starch, protein, thousand kernel weight, pureness and sorting. However, Davies and Whiting (1990) have shown that the higher the cover of ***Stellaria media,*** the higher the moisture content in the grains at harvest. The effects of weeds on yield quality are proportionately much smaller and can not occur independent of the effects on yield (Whiting ***et al.*** 1991), so it might not be very important to focus on yield quality. Other factors varying between farms and years had a much greater influence on the yield quality parameters than dosage.

5.2 Yield in sugar beets (Esbjerg, P.)

In contrast to the preceding section concerning yields in cereals which also comprise botanical elements, which are a trade off of having mini-plots, this section solely comprises establishment of a background for the landowners yield situations. This is in essence the basis for the payment in a few cases of compensation for losses causes by the lowered dosages.

After the problems with harvesting within mini-plots of sugar beet at Gjorslev estate in the pilot phase (cf. section 1.2.9) the work on yield estimates was changed to a sampling procedure following principles for sampling aiming at estimating effects of variety, fertilization etc. The procedure was selected on the basis of recommendation from "The Foundation for Sugar Beet Research". In the present case the aim was to reveal if the effect of reduced dosages was reflected in the yield levels.

5.2.1 Sampling

In each of the three dosage plots per farm a total of 20 random selected samples were dug up manually.

Each sample consisted of 4 metres of the row at a particular position determined by the random selection procedure. The beet tops were removed in the field by standardized cutting in accordance with instructions from "The Foundation for Sugar Beet Research". This research body also took care of washing, weighing and labelling of samples for subsequent analysis of sugar content. The last part was carried out at the sugar factory in Maribo. The sugar content was only determined as safety measure but it proved to be much less meaningful than the weight due to the in-field type of variation. In addition the prices were estimated according to the type of contract with the sugar factory and the amount and quality of the harvest of the whole field. Therefore the estimated weight yields formed the best background for evaluating whether or not the landowners had losses to be compensated.

5.2.2 Yields estimated

The results are presented in Table 5.3. It appears that significant yield losses are very few and with one exception only occur at quarter dosage. In summary in 1997 Nordfeld lost 12 % of the yields at half and 14 % at quarter dosage but part of this loss may have been caused by troubles with the new equipment for mechanical hoeing under slippery conditions at sloping

Table 5.3. Yields estimated in sugar beets. It is important to notice that during the pilot phase at Gjorslev 1996 the dosage plots were all treated with the particular dosage applied as broad swath. In addition the yields at different dosages were estimated by producing mini-plots: During the subsequent years the dosage reductions were obtained by treating only bands over the rows and for yield estimations random samples were used. Every yield marked * is significantly lower than the corresponding yield of the normal dosage plot shown in the same line (the same farm and the same year).

Year	Farm	Normal dosage Tonnes / ha.	Half dosage Tonnes / ha.	Quarter dosage Tonnes / ha.
1996	Gjorslev	50.9	49.2	47.4*
1997	Gjorslev	65.3	68.2	63.9
	Oremandsgård	68.8	63.3	65.9
	Lekkende	71.6	69.9	63.7
	Nøbøllegård	59.3	61.2	59.9
	Nordfeld	68.0	59.5*	58.7*
1998	Gjorslev	66.4	73.8	66.9
	Oremandsgård	59.1	61.0	57.5
	Lekkende	69.4	59.8	52.2*
	Nøbøllegård	58.0	59.0	61.0
	Nordfeld	65.5	66.0	60.7
1999	Gjorslev	77.4	75.5	75.3
	Oremandsgård	70.3	66.3	68.5
	Lekkende	75.5	62.1	65.0
	Nøbøllegård	70.1	59.0*	64.7
	Nordfeld	71.5	68.7	74.3

terrain. (During the two next seasons this problem was counteracted by computerised steering). In 1998 Lekkende lost 25 % at quarter dosage and in 1999 no significant losses were found, except in quarter dosage at Nøbøllegård where spots of weeds, mainly common couch ***Elymus repens***, were known as problematic at that particular area. However, it would have been disturbing for the project to permit the solving of the problem by use of full dosage of Glyphosate in stubble before growing beets.

5.3 Clean-up decisions (Jensen, A.-M.M.)

5.3.1 Purpose

In this study, effects on the weed vegetation by use of reduced dosages of herbicides and insecticides during three years were emphasised.

The objective was threefold: 1) To spot major weed problems after three years with reduced pesticide use. 2) To estimate economic compensations, so the farmers could bring the areas sprayed with reduced dosages in the same state as areas sprayed with normal dosage with regard to weed populations. 3) To estimate compensations for future yield decrease as a result of accumulated weed populations.

5.3.2 Method

In July 1999, observations during field walks were made by an agricultural adviser from the local advisory service, a botanical investigator and the farmer in each of the three fields used in the main study on each of the five farms. Each of the 15 fields was observed for about an hour. Weed species with a higher density or abundance in plots sprayed with reduced dosages compared to plots sprayed with normal dosage were spotted and the area in which they were present was estimated. Most species occurred in spots within the estimated area of the plot. The possibilities for reduction of these populations as well as a price estimated for the future control strategy were discussed. In addition, economic compensations for presumable yield decrease in 1999 and 2000 were estimated.

5.3.3 Results

5.3.3.1 Weed species that may cause yield with reduced dosages over a period of more than three years

Different weed species were observed in the different fields (Table 5.4). In total, 19 weed species increased in densities in plots sprayed with reduced dosages, 12 of these species were spotted in more than one of the 15 fields. Of these species, eleven were broad-leaved and one was a grass: quackgrass (***Elymus repens***). The perennial ***Cirsium arvense*** was the species observed in most fields, although it was present in small areas compared to annual species as ***Galium aparine*** and ***Sinapis arvensis.***

No clear differences in species with increased density and the area they covered were observed between half dosage and quarter dosage.

Table 5.4. Weed species with increased abundance or density within plots sprayed with reduced dosages. The estimated area of the 6 ha-plot(s), where the species was present, is given in percentage. Prices estimated for cleaning the fields from these weed species are given in Table 5.8.

Farm	Crop 1999	Plot	Weed species with increased abundance or density	Present in estimated area of the plot(s)
Gjorslev	Spring barley	Half and quarter	*Galium aparine.*	25%
	Winter wheat	Half	*Aethusa cynapium, Galium aparine.*	75%, 25%
		Quarter	*Aethusa cynapium, Galium aparine, Artemisia vulgaris, Cirsium arvense.*	75%, 25%, 10%, 10%
	Sugar beets	Half and quarter	*Galium aparine, Chenopodium album, Polygonum aviculare, Bilderdykia convolvulus, Stellaria media, Cirsium arvense.*	75%, 50%, 50%, 25%, 25%, 10%
Oremandsgård	Spring barley	Half	*Viola arvensis, Cirsium arvense.*	50%, 10%
		Quarter	*Viola arvensis, Sonchus asper, Cirsium arvense.*	50%, 20%, 10%
	Winter wheat	Half and quarter	*Aethusa cynapium, Cirsium arvense.*	40%, 10%
	Sugar beets	Half and quarter	*Brassica napus ssp. napus, Sinapis arvensis, Chenopodium album.*	75%, 75%, 50%
Lekkende	Spring barley	Half	*Polygonum aviculare, Elymus repens, Cirsium arvense.*	60%, 40%, 10%
		Quarter	*Equisetum arvense, Matricaria perforata, Elymus repens, Cirsium arvense.*	50%, 30%, 20%, 10%
	Winter wheat	Half and quarter	*Viola arvensis, Galium aparine, Cirsium arvense, Apera spica-venti.*	100%, 75%, 10%, 2%
	Sugar beets	Half	*Elymus repens, Galium aparine, Poa annua, Polygonum persicaria, Chenopodium album.*	90%, 80%, 25%, 10%, 10%,
		Quarter	*Elymus repens, Galium aparine, Polygonum persicaria, Chenopodium album.*	100%, 80%, 20%, 10%
Nøbøllegård	Spring barley	Half and quarter	*Matricaria perforata, Elymus repens, Cirsium arvense, Artemisia vulgaris.*	30%, 15%, 10%, 5%
	Winter wheat	Half and quarter	*Matricaria perforata, Stellaria media, Galium aparine.*	50%, 50%, 10%
	Sugar beets	Half and quarter	*Bilderdykia convolvulus, Chenopodium album, Sinapis arvensis, Elymus repens, Artemisia vulgaris, Cirsium arvense.*	75%, 40%, 30%, 10%, 5%, 5%
Nordfeld	Spring barley	Half and quarter	*Chenopodium album, Cirsium arvense, Elymus repens.*	30%, 10%, 5%
	Winter wheat	Half and quarter	*Aethusa cynapium, Sinapis arvensis, Galium aparine, Matricaria perforata, Cirsium arvense.*	50%, 50%, 30%, 30%, 10%
	Sugar beets	Half and quarter	*Sinapis arvensis, Polygonum aviculare, Cirsium arvense, Capsella bursa-pastoris.*	80%, 75%, 15%, 10%

5.3.3.2 Weed species that caused heavy yield decrease in 1999 and 2000

Elymus repens was the only species that caused heavy yield decreases after three years with reduced dosages (Table 5.5).

Table 5.5. Estimated yield decrease in 1999 and 2000.

Farm	Crop 1999	Weed species	Area	Year	Estimated yield decrease
Lekkende	Sugar beets	*Elymus repens*	3.5 ha	2000	33%
Nøbøllegård	Spring barley	*Elymus repens*	1.3 ha	1999	50%

5.3.4 Discussion

5.3.4.1 Yield reductions at reduced dosages caused by weed species

Many weed species appeared in increased densities, but only the high density of ***Elymus repens*** caused heavy yield reductions in some areas. Therefore, in this study, reduced dosages of glyphosate (compound used to control ***Elymus***

repens) have economic consequences already after few years. Most broad-leaved weed species increased in densities without causing remarkable yield decrease after three years with reduced use of pesticides. The reason why broad-leaved species did not cause major yield reductions might be that the weed infestation at the beginning of the main study was very low, which are also found in other experiments running more than two years (Erviö ***et al.*** 1991). Thus, the accumulation of the broad-leaved weed population during three years has probably not yet reached a level, where it reduces the yield remarkably. Further increased densities of the broad-leaved species mentioned in Table 5.4 may result in yield decreases at reduced dosages over a period longer than three years.

Three other studies controlling broad-leaved weed species with reduced dosages of herbicides during some years have shown that: 1) Recommended dosage applied one year out of three was as effective in controlling broad-leaved species as half dosage in three years (Skorda ***et al.*** 1995). 2) Half of recommended dosage each year or recommended dosage two of three years maintain the weed density at a stable level (Jensen 1991). 3) No difference in the broad-leaved weed density or the yield was found between the following three treatments with reduced pesticide application over three years in three places: spraying in year three, spraying in years two and three or spraying in all three years (Courtney & Johnston 1986). Thus in regard to the yield and the control of the weed species, use of reduced dosages of herbicides might be performed as reduced dosages every year as well as no spraying one year followed by spraying with normal dosage the next year. However, this might not be the case, where weed plants with high competitiveness are present in high densities, then half dosage might be preferred each year to keep the yield decrease low over the years (Landbrugets Rådgivningscenter 2000b). No experiments have studied the effects on the weed and animal diversity of the latter senario, which is very important before an evaluation of the different strategies can be made.

5.3.4.2 Long-term aspects of use of reduced dosages

The yield decrease at reduced dosages is in a short term of minor economic and quantitative importance whereas the demand for a harvest without problems and the long-term aspects are very important. Especially, a build-up of seed reserves in the soil is a strong concern to farmers. No significant differences between pesticide dosages were found in the seed rain after three years (section 2.3) or in the germinating weed density after two years (Fig. 2.8). Also Salonen (1992a) could not detect statistically increases in the number of weed seeds in the soil seed bank after continuous use of on third of recommended herbicide dosages for three years. This indicates that dosage differences in the soil seed bank and the seed rain are small in comparison with the differences caused by farms, crops, land-use history, the great weed community variations within fields etc. However this qualitative clean-up study seems to indicate that an increased density of weeds may cause more seeds in the seed bank. Three years study is not enough to detect severe consequences of use of reduced dosages from the agronomical point of view - more years are needed. The extent of changes in weed population dynamics as a result of low pesticide dosages usually shows only after three to ten years, and can therefore be safely determined only in long-term trials (Pallutt 1999). Few long-term trials with reduced herbicide dosages have been performed yet (Jones ***et al.*** 1997, Pallutt 1999) both showing increased weed densities at reduced dosages either as weed seeds in the topsoil (Jones ***et al***. 1997) or as infestations of weed species with strong competitiveness (Pallutt 1999).

5.3.4.3 Reservations for the method used

The results are not based on a scientific documentation of increase in density but reflect species that mainly were spotted due to their height or the farmers' worries. These species are, anyway, weed species with a high competitiveness and therefore species that may cause economic problems over a longer period with reduced dosages of herbicides. Because this study was mainly qualitative, it could not detect the quantitative differences in weed density between half and quarter dosages as found in the main study (chapter 2).

It is a problem that the field walks did not take place during the late summers of 1996, 1997 and 1998. It is thus not possible to conclude whether or not the weed densities have accumulated over the three years. The differences in weed vegetation between normal dosage and reduced dosages might have been noticeable after one year only, as the main study indicates (Fig. 2.8), even though the total weed density has increased in all dosages during the three years.

5.4 Profitability analysis (Rasmussen, C. & Rasmussen, S.)

5.4.1 Purpose

This section presents and discusses the results of the profitability analysis of reducing dosages of herbicides and insecticides. The aim of the study was to estimate the profitability consequences in crop production when dosages of herbicides and insecticides are reduced. The objective was: 1) to estimate the impact on short-term profitability and 2) to give an example of long-term profitability effects of a dosage reduction.

5.4.2 Method

5.4.2.1 Profitability modelling

A spreadsheet budgeting model was developed for the three crops: winter wheat, spring barley and sugar beet, calculating profit for each of the three crops in three different pesticide scenarios. It is assumed that farmers are interested in maximizing net returns or profitability per hectare. Profit is the total value of the product less the total factor cost, given fixed product and factor prices. Profit is calculated by aggregating the net returns for each season, and one season is defined as one year.

Total value of the product includes for wheat and barley both grain and straw value, but for sugar beet the total value includes only beet value, which depends on the sugar content (%). It is assumed that reduced pesticide dosages do not affect the straw production. Sugar beet prices depend on sugar content meaning that a varying content of sugar may contribute to differences in the profits calculated in the three scenarios (see section 5.4.3 for results).

Total factor costs are divided into two separate measures categorised as costs I and costs II. The costs I category includes costs of seeds, NPK fertilisers, additives and all pesticides. The costs II category includes the costs of labour and machinery, both of which are calculated using machine pool standard prices. All product and factor prices are standard prices stated by Landbrugets Rådgivningscenter (1998, 1999a and 2000a) and Danmarks Jordbrugsforskning & Landbrugets Rådgivningscenter (1998, 1999 and 2000). Developments in product and factor prices are important causes of differences in profit from one year to another. Price developments are stated in the literature above.

5.4.2.2 Input factors

The model accounts for the following input factors: NPK fertilisers, herbicides, insecticides, fungicides, additives and growth regulating additives. Theoretically the output produced varies with the dosage of these input factors. Please note that only the dosages of herbicides and insecticides vary between the three scenarios. Furthermore it is important to note that the other input factors are not necessarily added in the same dosages on each farm. Apart from the variation in input factors, the treatments of the crops also varies between the five farms. Because of the variation in input factors, dosages and treatments the reference scenarios (labelled scenario A) are not identical for the five farms. Even though the reference scenarios are not identical, it seems probable that the change in profit is related to the reduction in the dosages of herbicides and insecticides. All other input factors are kept constant on each farm with the exception of sugar beet production where mechanical weed control also varies between the scenarios.

5.4.3 Results

5.4.3.1 Scenarios

Three scenarios differentiated by the dosage of insecticides and herbicides are considered in the model. Scenario A corresponds to normal dosage. Scenario A is not necessarily the optimal dosage that maximizes profit but serves as a reference scenario.

Compared to the dosage used in the reference scenario (A), scenario ½ is characterised by a 50 % and scenario ¼ by a 75 % percent reduction in the dosage of herbicides and insecticides.

5.4.3.2 Short-term impacts

Results of the economic analysis are presented in Table 5.6. In scenario A, the average profit for the five farms is calculated for each of the crops winter wheat, spring barley and sugar beet. Note that results for scenario ½ and ¼ are shown as both the absolute and the relative change in profit compared to the reference scenario.

More detailed results are presented in Table 5.7 showing the figures from Table 5.6 broken into product value, costs I and costs II. Detailed results for each farm are presented in Appendices F.1-F.5.

Table 5.6. Calculated profit in current prices (*DKK per Hectare*) and changes in relation to A at scenarios ½ and ¼.

Crop/Scenario	A	Change in proportion to A			
		½	½ (%)	¼	¼ (%)
96/97					
Winter wheat	4,460	108	2.4%	246	5.5%
Spring barley	2,419	138	5.7%	90	3.7%
Sugar beets	17,700	-342	-1.9%	72	0.4%
97/98					
Winter wheat	4,437	204	4.6%	143	3.2%
Spring barley	2,797	89	3.2%	56	2.0%
Sugar beets	16,450	316	1.9%	-646	-3.9%
98/99					
Winter wheat	4,375	198	4.5%	95	2.2%
Spring barley	2,113	83	3.9%	-28	-1.3%
Sugar beets	20,467	-1,874	-9.2%	-335	-1.6%

Table 5.7. Change in product value, costs I, costs II and profit with a ½ and ¼ dosage of insecticides and herbicides in the period 1997-1999. Results are presented in DKK per hectare in current prices.
Average for all five farms.

Crop	Winter wheat			Spring barley			Sugar beets		
Dosage	1	0.5	0.25	1	0.5	0.25	1	0.5	0.25
96/97									
Product value	9,167	-118	-93	6,214	24	-80	24,912	-728	-664
- Costs I	2,049	-226	-339	1,373	-114	-170	3,713	-698	-1,048
= Profit before costs II	7,118	108	246	4,841	138	90	21,200	-30	384
- Costs II	2,658	0	0	2,422	0	0	3,500	312	312
= Profit	4,460	108	246	2,419	138	90	17,700	-342	72
97/98									
Product value	9,528	-46	-221	6,789	-41	-139	23,930	-70	-1,437
- Costs I	2,327	-250	-364	1,367	-130	-195	3,779	-810	-1,214
= Profit before costs II	7,201	204	143	5,422	89	56	20,151	740	-222
- Costs II	2,764	0	0	2,625	0	0	3,701	424	424
= Profit	4,437	204	143	2,797	89	56	16,450	316	-646
98/99									
Product value	9,355	-14	-145	5,817	-10	-168	27,430	-1,902	-656
- Costs I	2,244	-211	-239	1,182	-94	-140	3,431	-586	-879
= Profit before costs II	7,111	198	95	4,635	83	-28	23,999	-1,315	223
- Costs II	2,736	0	0	2,522	0	0	3,532	559	559
= Profit	4,375	198	95	2,113	83	-28	20,467	-1,874	-335

For winter wheat table 5.6 shows a marginal positive change in the calculated profit in both scenario ½ and ¼. From table 5.7 it appears that the reduction in costs I due to reduced dosage of herbicides and insecticides is greater than the loss in product value causing profits to increase.

Table 5.6 also shows a marginal positive change in the calculated profit for spring barley in both scenario ½ and ¼. However, an exception appears in the scenario ¼ 98/99 where the change in profit is negative due to a decreased product value caused by a decreased yield (see Table 5.2 for estimated yields).

It is difficult to derive a clear trend in the change of sugar beet profit from the tables. As explained earlier there are several factors contributing to the change in profit for sugar beets. First of all the sugar content significantly affects beet prices and secondly additional mechanical weed control is required in scenario ½ and ¼ thus increasing costs (costs II). The varying sugar content in the three scenarios results in varying prices which seems to be the main reason for the absence of a clear trend.

In general it appears from the above results that a 50% or a 75% reduction of the herbicide- and insecticide dosages has a very limited effect on the profitability at farm level primarily because the reduced costs of pesticides compensate for the decrease in product value (if any occurs). It is, however, uncertain whether this result can be maintained on a long-term basis. This question is considered in section 5.4.4 along with the questions of increased production risk, long-term weed accumulation (see section 5.3 for discussion) and possible adjustment capacity costs. These adverse effects of a reduction in pesticide dosages have not been taken into account in the present section.

5.4.4 Discussion

5.4.4.1 Long-term effects

After the 1999 production season the clean-up costs were estimated (see section 5.3). Clean-up costs refer to the costs of returning the given plot of land to the pre-experiment state. Thus, these costs provide no indication of the development in profit the following years if production is continued using reduced pesticide dosage. However, it is probable that a long-term reduction in pesticide dosages will lead to an accumulation of weed seeds on the given plot of land. Given limitations in chemical weed- and insect-control, variation in production yield is likely to increase thereby increasing the production risk. Furthermore it may be necessary to adjust the capacity in terms of new weed control machinery or perhaps adjust the treatment of the crops to the new conditions. Consequently, adjustment costs would arise.

Even though the clean-up costs do not correspond perfectly with the costs arising from increased production risk and adjustment costs, we can interpret the clean-up costs as an example of the present value of these unpredictable long-term costs. The clean-up costs are estimated after three seasons of experimental production using reduced dosages of pesticide. It cannot be excluded that clean-up costs will increase in the future if production with a reduced pesticide dosage is continued. As an example, the clean-up costs after three years are shown in Table 5.8. The clean-up costs are stated for the land farmed with a seventy-five-percentage reduction in pesticide dosages.

Using a real interest rate of four percent the average cost per hectare per year in an infinite time horizon is also calculated in Table 5.8. This example shows that if long-term effects are taken into consideration they would probably account for an average extra cost between 50 and 78 DKK per hectare per year. Taking the average long-term costs per year per hectare into account when calculating the short-term profit it appears that the positive effect in the ½ and ¼ scenarios is markedly reduced.

Table 5.8 Clean-up costs interpreted as long run effects of a reduction in pesticide uses (DKK per hectare).

Crop	Winter wheat	Spring barley	Sugar beets
Present value of long term costs			
Gjorslev Gods	1,200	300	1,500
Nordfeld Gods	2,000	1,600	2,000
Nøbøllegård	2,000	2,093	2,000
Oremandsgård	750	1,050	1,150
Lekkende Gods	1,000	1,200	3,122
All five farms	1,390	1,249	1,954
Average cost per year in an infinite time horizon (4% real interest)			
Gjorslev Gods	48	12	60
Nordfeld Gods	80	64	80
Nøbøllegård	80	84	80
Oremandsgård Gods	30	42	46
Lekkende Gods	40	48	125
All five farms	56	50	78

In an overall assessment of the profitability consequences of reduced pesticide dosages this example is meant to illustrate that long-term effects could influence the final result significantly. Furthermore the example illustrates that the results presented in Tables 5.6 and 5.7 should ***not*** be considered as final results and therefore should ***not*** be used as basis for long-term conclusions.

5.4.5 Conclusion

The economic analysis has shown that a reduction in pesticide dosages does ***not*** have any critical short-term effect on the profit which farmers can obtain growing winter wheat, spring barley and sugar beet, nor does a reduction in pesticide dosages calls for immediate choice of alternative crops. A pesticide dosage reduction may require that farmers have to adjust for new growing conditions. These adjustments combined with the increased production risk are important long-term effects that have ***not*** been taken into consideration in the short-term assessment. Long-term effects may contribute extra costs thus being a cause of decreasing annual profits.

6 Combined analyses

(Petersen, B.S. & Navntoft, S.)

A major objective of the study was to investigate whether differences in abundance at one trophic level can be related to differences at another trophic level. Therefore, the amounts of arthropods and birds were analysed in relation to the luxuriance of the wild flora, and the occurrence of birds was analysed in relation to the abundance of insects and other arthropods. This chapter presents the results of the analyses. The results are discussed and put into a wider context in chapter 7.

6.1 Methods

6.1.1 Analysis of the occurrence of arthropods in relation to vegetation

In chapter 3 some dosage effects on the arthropod biomass and arthropod populations were revealed, especially in barley. Generally estimated dry masses and populations increased at reduced dosages of pesticides. In order to elucidate whether such effects were (partly) a result of an improved weed plant community at reduced dosages of herbicides, the analyses conducted in chapter 3 were extended with the inclusion of covariates describing the weed community in the fields.

The three dependent variables: 1. ***bird prey dry mass***, 2. ***total arthropod dry mass*** (both "mg dry mass / unit area") and 3. ***population*** (no./ unit area) consisted of the geometric mean of the $\log_e(x+1)$ transformed plot totals from ***all*** sampling dates. These variables were analysed in relation to the following 6 factors: 1. dosage, 2. year, 3. farm, 4. treatment-index of insecticides, 5. weed species richness and 6. weed density, as well as relevant interactions. The two "new" covariates ***weed species richness*** (S_Weeds: Number of weed species per plot) and ***weed density*** (Weeddens: Number of weed individuals/m^2) describing the weed community, were both based on the data collected ***after*** herbicide spraying. Weed data from ***all*** fields were included. For more information see chapter 2, 3 and 6.1.2. Some herbicides are lethal to arthropods and may thereby affect the arthropod populations directly (Candolfi ***et al***. 1999). The most dominant herbivore and many predatory insect groups, however, are not very active in the field during the periods of herbicide spraying. It is therefore most likely that the measured effects on arthropod biomass and most arthropod populations are effects of insecticide applications or effects, directly or indirectly, of an altered weed community.

The three crops were analysed separately and the analyses comprising effects on arthropod biomass were conducted using PROC GLM (SAS/STAT). PROC GENMOD (SAS/STAT) was used for the arthropod population studies due to the Poisson distribution of data (see chapter 3.2.1.1) (SAS Institute 1990). Stepwise model reduction was used with the critical value being p=0.05. Because ***species richness*** and ***weed density*** were mutually correlated, there effects were analysed separately. Vegetation data from beet fields were from within beet rows only, since arthropods have been collected in the beet rows. Since the dosage plots were fully comparable in cereals, common slopes models were analysed here (one common regression coefficient for the three dosages). In beets separate slopes models were analysed (one regression coefficient for each dosage) since treatments here were diverse with band-spraying versus broad application, and weed hoeing versus no weed hoeing. The most abundant arthropod groups were selected for the population analyses with emphasis on the herbivores, since they were assumed to be most correlated with the weed flora. Finally analyses of the impact of grass weed and flowering weed on specific insect groups will be presented.

6.1.2 Analysis of breeding season bird counts in relation to the abundance of weeds and arthropods

As demonstrated in chapter 3, the amount of animal food items for the birds within the fields generally increases during the breeding season. The insect biomass rises steadily from May/June to August in beet fields whereas in cereal fields the increase levels off around 1 July. It is obvious from a comparison of Figs. 3.3 - 3.4 and 4.4 - 4.5 (B) that the seasonal increase in the amount of animal birds' food items is accompanied by an increase in the number of Whitethroats and small seed-eaters visiting the fields.

It is not clear, however, whether the differences in bird numbers between dosages (and between fields and years) may be explained by differences in the amount of birds' food items. The luxuriance of the weed flora may also affect the distribution of birds on the fields. To investigate these issues, the average number of birds recorded in each plot during the second half of the breeding season was analysed in relation to the average insect biomass sampled during the same period and in relation to the density and diversity of the wild flora after herbicide sprayings.

In the analyses, the dependent (bird) variable for each plot was the mean of the $\log_e(x+1)$ transformed plot totals (converted to a standard plot size of 6 ha where relevant) from all counts between 16 June and 5 August (inclusive), i.e. the geometric mean of 9 or 10 counts. These mean plot totals were calculated for Skylark, Whitethroat and small seed-eaters. Morning and afternoon counts were dealt with separately, and only records of birds within (or right above) the fields were included. The data set used was identical with the set used for calculating the estimates presented in Table 4.10, with the sole exception that the cutoff date was chosen as 16 June instead of 21 June (because the earlier cutoff date gave a better fit with the arthropod sampling dates.)

A measure of arthropod abundance was derived in a similar way. For each sampling date, a plot total was calculated by summing up the arthropod biomasses (dry mass) from all samples within a plot (cf. section 3.2.1.1). Besides total arthropod biomass (Totaldrw), the biomass of a subset of arthropod taxa supposed to be preferred birds' food items was calculated as well (Fooddrw). The plot totals from the different dates were then $\log_e(x+1)$ transformed and the mean calculated, using only samples taken between 16 June and 6 August (beet fields) or between 13 June and 6 August (cereal fields). The use of these cutoff dates implies that a minimum of 4 and a maximum of 6 sampling dates were included in the calculation of each geometric mean.

The weed flora of each dosage plot after herbicide sprayings was described by two measures (cf. section 2.2.1.2). The species richness within a plot (S_Weeds) was measured as the arithmetic mean of the number of weed species recorded within each subplot. A measure of weed density was obtained by counting the number of individual plants per m^2 within each subplot and taking the arithmetic mean of these subplot densities. The plot means were then $\log_e(x+1)$ transformed (Weeddens).

In the botanical investigations, the size of the area analysed within each subplot differed between beet fields and cereal fields. Also, the arthropod sampling technique used in the beet fields was not exactly the same as the one used in the cereal fields. Consequently, the data on weed diversity and arthropod biomasses from beet fields are not fully comparable with the data from cereal fields.

The weed and arthropod variables were included as covariates in the analyses of bird numbers. Due to the lack of full comparability between crops, separate-slopes models (with different regression coefficients for each crop) were used. Furthermore, the weed/arthropod variables are mutually correlated, so in order to avoid problems with multicollinearity, only one weed and one arthropod covariate were entered into the analyses at a time.

Using the geometric mean of the bird counts conducted between 16 June and 5 August as the dependent variable (cf. above), the anova design shown in Table 4.2 was applied. Stepwise model reduction was used, with $p > 0.05$ as removal criterion. After model reduction the four covariates were entered, one or two at a time, to see if their addition lead to any improvement of the model (in terms of a reduction of the model p value). If more than one covariate (or pair of covariates) caused an improvement of the model, the covariate (or pair) which gave the "best" model (the model with the lowest p value) was selected. If the addition of covariates caused another factor to be insignificant, model reduction was resumed. When the model selection procedure was completed, estimations and tests were performed. It is important to notice that the F test in a separate-slopes model does not test for differences in slope (this is assumed ***a priori***), but tests the hypothesis that all regression coefficients (one for each crop in this case) are zero. All analyses were carried out using the GLM procedure in SAS/STAT.

6.1.3 Analysis of autumn bird counts in relation to the abundance of seeds

In chapter 4, it was concluded that no dosage-related differences in bird densities could be detected on the stubble fields in autumn. However, bird abundance may still be related to differences in the amount of seeds present. Seeds of various sizes make up the bulk of the diet of most farmland birds outside the breeding season (e.g., Christensen ***et al.*** 1996).

Seed abundance (biomass) on the stubble fields was measured as described in section 2.3.1. The seeds were divided in two groups: cereal grains and weed seeds. The weed seeds were further divided into various classes, mainly according to size, to match the feeding preferences of different bird species. For each group or size class of seeds, the mean biomass (mg/m^2) within each dosage plot was used in the analyses of bird densities. Mean seed biomasses per plot were calculated as geometric means, using $\log_e(x+1)$ transformation, and the means were not transformed back before they were entered into the analyses of bird numbers as covariates. Seed data from barley and wheat stubble are fully comparable, so a common-slopes model was used.

For Skylark, Meadow Pipit and small seed-eaters, mean densities per 6 ha plot were calculated and analysed as described in section 4.2.2.2, applying the anova design shown in Table 4.5. Stepwise model reduction was used, with p

> 0.05 as removal criterion. The analyses of the occurrence of small seed-eaters were supplemented with analyses of Yellowhammer densities, this species being the only seed-eater sufficiently widespread to allow separate analysis.

After model reduction, covariates describing seed abundance were entered, as relevant for the bird species in question (Table 6.1). The abundance of (spilt) cereal grains is independent of the abundance of weed seeds, but only one measure of weed seed biomass was included at a time, in order to avoid problems with multicollinearity. The models were then compared and the "best" model (with or without covariates) selected, following the principles described in section 6.1.2. If the addition of covariates caused another factor to be insignificant, model reduction was resumed. All analyses were carried out using the GLM procedure in SAS/STAT.

Table 6.1. Measures of seed abundance (mg/m^2) included as covariates in the analyses of the occurrence of each bird species (see text for a description of the model selection procedure). Choice of weed seeds based upon Cramp & Simmons (1977-94) and Christensen *et al.* (1996).

	Skylark	Meadow Pipit	Small seed-eaters	Yellowhammer
Cereal grains	√	√	√	√
Weed seeds (all)	√	√	√	√
Weed seeds > 0.5 mg	√			
Weed seeds ≤ 0.5 mg		√		
Non-Brassicaceae weed seeds				√

6.2 Results and discussion

6.2.1 Arthropods

The analyses did not reveal positive correlations between the estimated arthropod dry mass and the weed data (Table 6.2). In barley, a negative significant correlation (p=0.0014**) between the ***total arthropod dry mass*** and ***species richness*** (S_weeds) was found, without any immediate explanation for such a connection. The estimated coefficient of S_Weeds was – 0.0487. This indicates a drop in the total dry mass of less than 1 mg/3 m^2 if weed species richness increased with 1 species/plot; a marginal impact. The factors ***year*** and ***farm*** explained the major part of the variation in most of the models. The factor ***dosage*** was only significant in barley in line with the significant effects of the covariate ***treatment-intensity index of insecticides***, which revealed a negative correlation between a higher treatment intensity index and both measures of

Table 6.2. Schematic summary of the combined analysis of arthropod biomass. Covariates describing the abundance of weeds and differences in insecticide spraying intensity were included in the analyses. Factors not included in any of the models have been omitted from the table. S-Weeds: Weed diversity; Weeddens: Weed density. Statistical significance is indicated as follows: */+/–: 0.01<p<0.05, **/++/– –: 0.001<p<0.01, ***/+++/– – – p<0.001. A +/– indicates if the correlation is positive/negative.

	Barley		Wheat		Beets	
	Bird-prey dry mass	Total dry mass	Bird-prey dry mass	Total dry mass	Bird-prey dry mass	Total dry mass
Dosage	**	**				
Year	***	***	***	***	*	***
Farm	***	***	**	***	***	***
Treatment-index of insecticides	– –	–		–		
S_Weeds		– –				

estimated arthropod dry mass. A negative correlation between ***treatment-index of insecticides*** and ***total arthropod dry mass*** was also found in wheat, indicating an effect of diversified dosages, although the class factor ***dosage*** was insignificant.

The arthropod populations selected for the combined analyses were all true herbivores : 1. ***Chrysomelidae***. 2. ***Curculionidae***. 3. ***Miridae***. 4. ***Auchenorrhyncha***. 5. ***Lepidoptera*** and 6. ***Symphyta***. Many species of these groups are known to feed on both broad-leaved weed and on wild and cultivated grasses, and superior analyses were therefore carried out on the population sizes in relation to the general covariates describing the weed community: weed density and weed diversity.

The highest number of significant correlations between populations of abundant arthropod groups and the two covariates describing the weed community were found in barley (Table 6.3). Significant positive correlations were here found for five of the six families/orders of arthropods analysed either for adult or juvenile stages (a total of nine groups). Negative correlation, however, was found for one of the nine groups. That was for adult ***Auchenorrhyncha*** (cicada) (p=0.0194*) in relation to weed diversity. There is no immediate explanation for that contrary result, but since it is only one of 18 analyses, it may have happened by coincidence. An example on a positive correlation between an important bird food item ***Symphyta*** (sawfly) larvae and weed density is illustrated in Fig. 6.1. This and the following figures should not be interpreted too strictly; they are just models and do not show the often sizable variation between farms, years etc. demonstrated in the study.

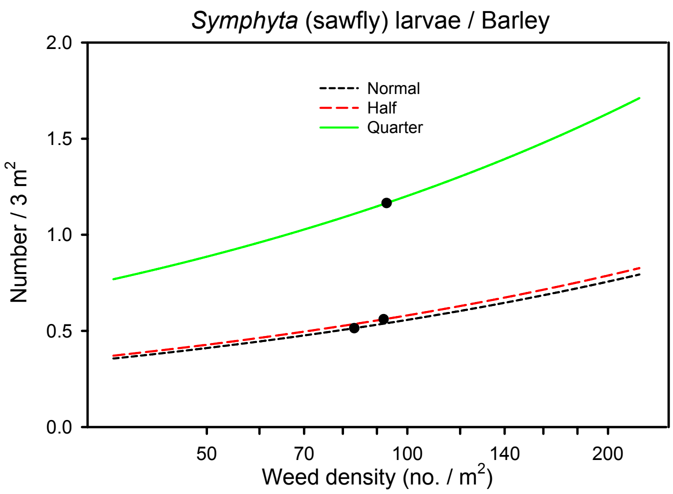


Fig. 6.1. Model of the relationship between *Symphyta* larvae and *weed density*. The centroid of the curve, corresponding to the mean weed density, is indicated (•). Notice that the model graphs do not show the range of variation and that the log-based densities are not comparable with normal arithmetic mean densities.

In wheat five of nine groups were positive correlated with increasing weed diversity/density. In beets, separate slopes models were analysed, but significant results were obtained only for one group. A correlation was found between ***Chrysomelidae*** (leaf beetle) adults and weed density, for which a positive connection was found at normal dosage (p=0.0363*), but a negative correlation was revealed in quarter dosage (p=0.0002***) (Table 6.3). A possible explanation could be that weed hoeing influenced the beetles negatively. Weed hoeing is a kind of unknown factor, which through disturbance and altered microclimate may have a negative impact on the arthropods in the plots that received reduced dosages of pesticides.

Table 6.3. Schematic summary of the combined analysis of arthropod densities. Covariates describing the abundance of weeds and differences in insecticide spraying intensity were included in the analyses. Factors not included in any of the models have been omitted from the table. S-Weeds: Weed diversity; Weeddens: Weed density. Statistical significance is indicated as follows: */+/–: 0.01<p<0.05, **/++/– –: 0.001<p<0.01, ***/+++/– – –: p<0.001. +/– indicates if the correlation is positive/negative. Abbreviations: Img.= *Imagines* Lar.= Larvae, Nym.= Nymphs.

Crop		*Chrysomelidae*		*Curculionidae*	*Miridae*		*Auchenorrhyncha*		*Lepidoptera*	*Symphyta*
		img.	lar.	img.	img.	nym.	img.	nym.	lar.	lar.
Barley	Dosage		**		**					***
	Year	***	***		**	**	***	***	***	***
	Farm	***	***	**	***	**	*	**	***	***
	Treatment-index insec.	–	– – –		–	– –	– –	–		– – –
	S_Weeds			+		++	–		+++	
	Weeddens			++	+++	+++		++		++
Wheat	Dosage					*	*			
	Year	***	***		***		***	***	***	***
	Farm	***	***	***		***	***	*		***
	Treatment-index insec.			–		– – –	+++			+
	S_Weeds				++	+			+	
	Weeddens		++	+	+					
Beets	Dosage	**		***	**		***			***
	Year	***	*	***	***	*	***	***	***	*
	Farm	***	*	***	***		***	***	**	
	Treatment-index insec.							++		
	Weeddens(dosage)	1/1: + 1/2: 1/4: – – –								

In some cases the covariates ***weed species richness*** and ***weed density*** (Table 6.3) eliminated the effect of the class factor dosage found in the analyses described in Table 3.5 – 3.7, indicating that the dosage effect found in chapter 3 may have been caused by an altered weed diversity/density. In barley, this was the case for ***Lepidoptera*** (p=0.0008***), which was positively correlated with ***species richness*** (Fig. 6.2). Since ***weed species richness*** and ***weed density*** are significantly correlated it may be random which of those that appears significant. The highly significant correlation, however, between ***Lepidoptera*** larvae and weed diversity without any correlation to weed density, is a major indication that the larvae mainly benefited from of a complex weed plant community created by reduced herbicide spraying.

The inclusion of the covariate ***weed density*** (significant at p=0.0002***) in the analysis of ***Miridae*** adults in ***barley*** (Fig. 6.3) resulted in a significant effect of dosage in contrast to the analysis in chapter 3. This indicated an improved model revealing an effect of both the weed community as well as a direct effect of pesticide application, the latter supported by a significant negative correlation with the parameter ***treatment intensity index of insecticides***. In wheat, the addition of the significant covariate ***weed density*** made the class variable dosage become ***in***significant for ***Miridae*** imagines (Fig. 6.3), indicating that the dosage effect found in chapter 3 probably was caused by an altered weed vegetation.

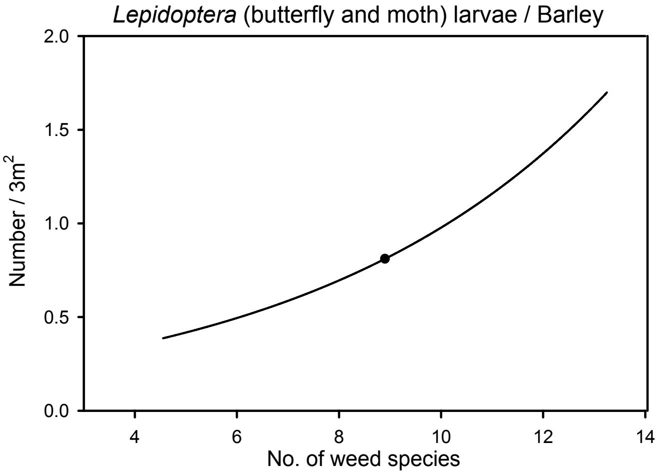


Fig. 6.2. Models of the relationship between *Lepidoptera* and *weed diversity*. The weed covariate replaced dosage (see Tables 3.8 and 6.2) as significant factor in the analyses of the occurrence of arthropods in relation to vegetation. The centroid of the curves, corresponding to the mean weed density, is indicated (•). Notice that the model graph does not show the range of variation and that the log-based densities are not comparable with normal arithmetic mean densities.

Another interesting result was that numbers of ***Curculionidae*** (weevils) both in barley and wheat were positive correlated with ***weed density*** (Fig 6.4). Neither in barley or wheat there were significant effect of ***dosage***, but in wheat there was a negative correlation to the ***treatment intensity index of insecticides*** indicating some sensitivity to the insecticides.

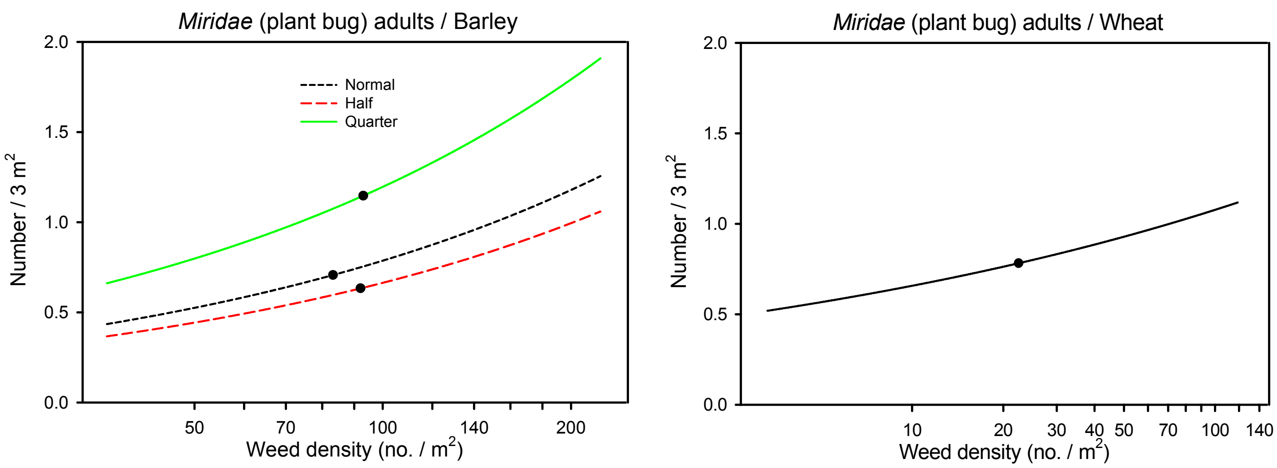


Fig. 6.3. Models of the relationship between *Miridae* adults and *weed density* in barley and wheat. The centroid of the curves, corresponding to the mean weed density, is indicated (•). Notice that the model graphs do not show the range of variation and that the log-based densities are not comparable with normal arithmetic mean densities.

Overall, specific arthropods seemed to benefit from a more complex weed vegetation in the cereals, especially in barley. In beets, no general trend could be revealed. The sometimes contradictory results, however, indicate that the findings should to be treated with caution.

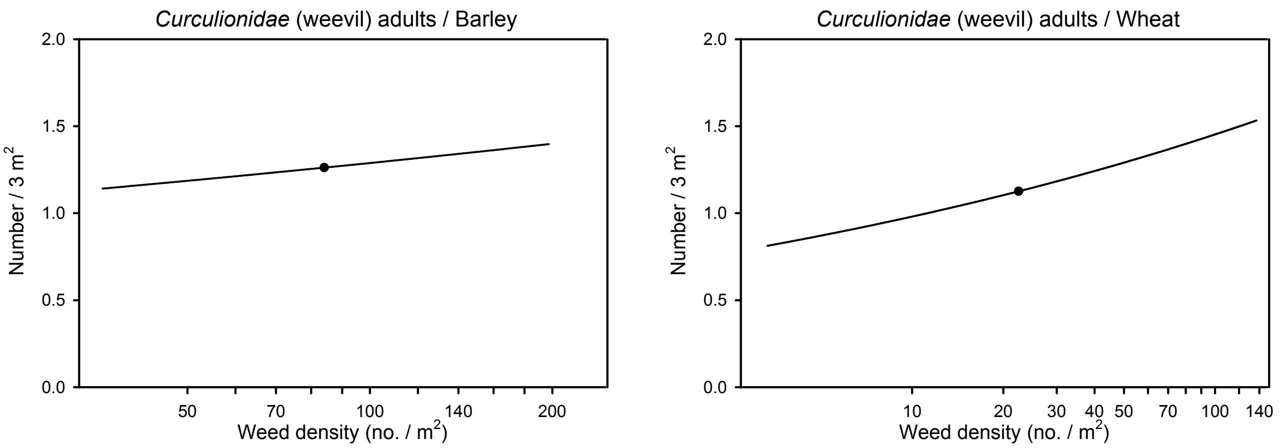


Fig. 6.4. Models of the relationship of *Curculionidae* adults versus weed density in barley and wheat. The centroid of the curves, corresponding to the mean weed density, is indicated (•). Notice that the model graphs do not show the range of variation and that the log-based densities are not comparable with normal arithmetic mean densities.

According to Potts (1986) there exists an association between the ***Miridae*** and the density of grass weed in the cereal crop. The situation is similar for some ***Cicadellidae*** and ***Delphacidae***. These arthropods are common in the suction samples in all three crops in this experiment, but grass weed was not common and corresponding correlations were not obtained when analysed (not presented).

Hymenoptera, Syrphidae and Lepidoptera adults are known to collect nectar and pollen from flowering broad-leaved plants. The density of flowering species is known to be a limiting factor for these insects (Altieri & Whitcomb 1979). The number of flowering plants and species, which are mutually correlated, did improve in the cereals under a reduced pesticide regime (section 2.2.2.4), which again may have benefited the insect populations. In order to elucidate and quantify such an inter-trophic effect, the number of adults of ***Hymenoptera***, ***Syrphidae*** and ***Lepidoptera*** were analysed in respect of the density of flowering plants and no. of flowering species per plot (1998 and 1999 only). No significant findings, however, were found for hymenopterans as a group (dominated by a range of ichneumonid wasps). A reason could be that the heterogeneity of the group made it difficult to detect specific trophic interactions. Looking at ***hymenoptera*** sub-groups, a significant positive correlation was found between adult ***Symphyta*** and the density of flowering plants in barley, but the estimated sawfly population was probably too low for a reliable analysis (not presented). No significant correlations were found for ***Syrphidae***, but a significant positive correlation was found between ***Lepidoptera*** and the number of flowering broad-leaved plants in beets (p=0.014*) (Fig 6.5) and the number of flowering species (p=0.006**) (not illustrated). There was a tendency towards a corresponding correlation in barley ($0.05<p<0.10$) but not in wheat.

The highest density of adult ***Lepidoptera*** was observed in beets followed by barley and wheat and the strength of the correlations found followed the same pattern. The densities obtained of the flying species were probably underestimated due to their ability to escape during sampling and the elatively low estimated densities of the target species have most likely affected the results obtained.

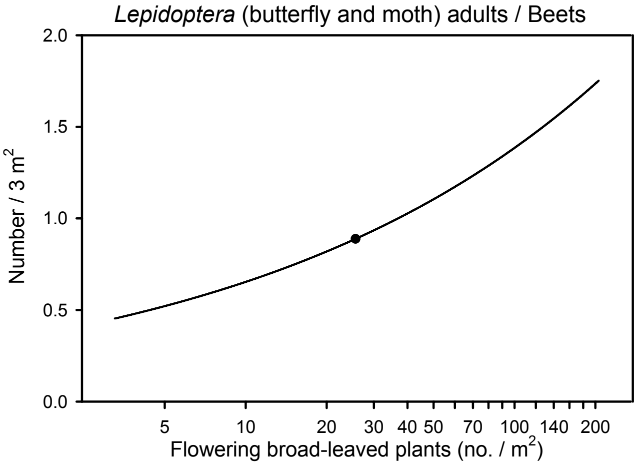


Fig. 6.5. Model of the relationship of *Lepidoptera* adults versus the density of flowering weed plants in beets. The centroid of the curve, corresponding to the mean weed density, is indicated (•). Notice that the model graph does not show the range of variation and that the log-based densities are not comparable with normal arithmetic mean densities.

6.2.2 Breeding season bird counts

The results of significance testing in the analyses of covariance are summarized in Table 6.4. The explanatory power of all models is good, with 69 to 76 percent of the total variation being explained. All main factors have significant effects on the distribution of at least two of the species tested, although the effects of dosage and crop may vary between farms. Block factors farm and field account for the major part of the variation (although the effect of farm may appear non-significant because it is tested against MS(Field(Farm))). In all models except one, the inclusion of a covariate increases the significance of the model; the covariate concerned is consistent within each species but differs between species.

Table 6.4. Schematic summary of the analyses of mean numbers of Skylarks, Whitethroats and small seed-eaters recorded on the fields 16 June - 5 August. Covariates describing the abundance of weeds and arthropods were included in the analyses. Factors not included in any of the models have been omitted from the table. Statistical significance is indicated as follows: *: 0.01<p<0.05, **: 0.001<p<0.01, ***: p<0.001.

	Skylark		Whitethroat (field)		Small seed-eaters (field)	
	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon
Dosage		(*)1)	***	(*)2)	***	
Crop	*	**				
Year	**				***	***
Farm	**	**	*		**	
Field(Farm)	***	***	***	***	***	***
Crop×Farm			***	**		***
Dosage×Farm				*		*
Totaldrw(Crop)			***	***		
S_Weeds(Crop)	**	***				
Weeddens(Crop)					***	

1) Eliminated at p=0.051

2) F=4.35, p=0.052 when tested against MS(Dosage×Farm)

In the ***Skylark***, numbers during the second half of the breeding season differ between crops, with the highest densities occurring in barley fields and the lowest densities in wheat (cf. Fig. 4.3). Before inclusion of covariates, these crop differences are significant on the morning counts (p = 0.037*), but not on the afternoon counts. Significant differences between dosages exist on the afternoon counts (p = 0.015*), but not on the morning counts, with higher densities being recorded in half- and quarter-dosage plots than in plots treated with normal dosage.

The analyses of covariance show that the significance of the Skylark models may be improved by including weed species richness in the models. The effect of weed diversity on Skylark numbers is only significant in barley fields (p = 0.0004*** and p < 0.0001*** on morning and afternoon counts, respectively) where Skylark densities increase with increasing weed species richness (Fig. 6.6 A). For the morning counts, a partitioning of the sums of squares before and after the inclusion of the covariate shows that the proportion of variance explained by the farm factor is reduced when the covariate is added to the model, indicating that it is mainly (part of) the variation between farms which is explained by the inclusion of weed diversity in the model.

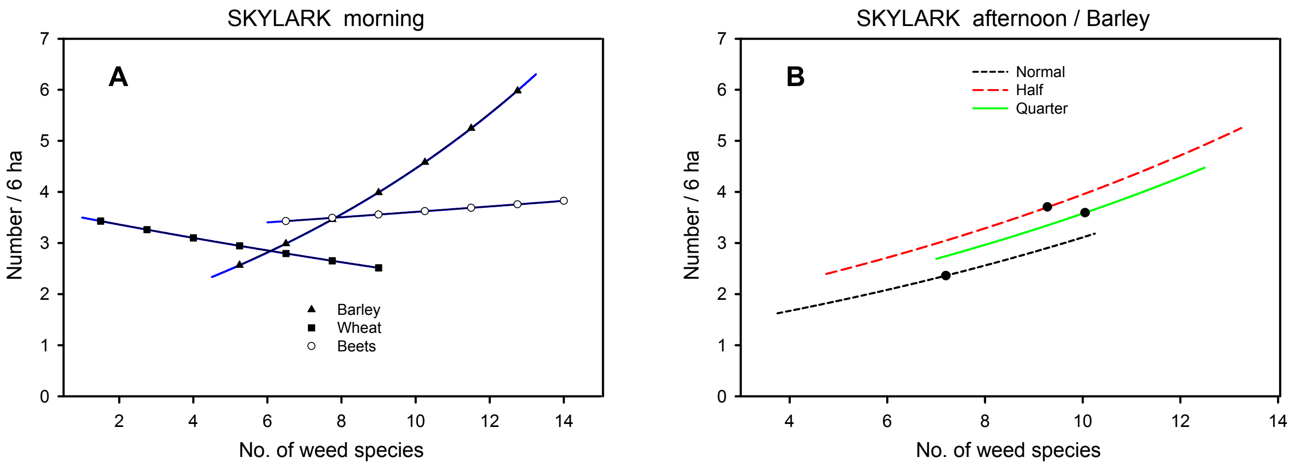


Fig. 6.6. Models of the relationship between Skylark densities and weed species richness for different crops (A) and dosages (B). A is based on the morning counts, B on the afternoon counts. In A, notice that the slope of the curve is not significantly different from zero in wheat and beets and that values for weed species richness in beets are not directly comparable with those in cereals. In B, the relationship is shown for barley fields only; the centroid of each curve, corresponding to mean weed species richness at each dosage, is indicated (•). Notice that the model graphs do not show the range of variation and that the log-based densities are not comparable with normal arithmetic mean densities.

A similar partitioning of the sums of squares for the afternoon counts indicates that not only the relative importance of the farm factor, but also the importance of differences in dosage is reduced when weed diversity is added to the model. Thus, part of the between-dosages variation in Skylark numbers may be ascribable to differences in weed species richness. Skylark densities and weed diversity are positively correlated (Fig. 6.6 B); the regression coefficients describing the shape of the relationship do not differ significantly between dosages (p > 0.10 in all pairwise comparisons). As indicated in the figure, weed diversity in barley fields decreases with increasing dosage (cf. section 2.2.2.2); consequently, the estimated mean densities of Skylarks are higher at quarter and half dosage than at normal dosage. On the afternoon counts, the highest Skylark densities are found in half-dosage plots; the reason for this is discussed in chapter 4.

The number of ***Whitethroats*** occurring in the fields differs between years, crops and dosages. After 15 June more birds are recorded in wheat and beet fields that in barley fields (cf. Fig. 4.4), although the crop differences are barely significant due to large variation between farms ($p = 0.085$ and 0.049* on morning and afternoon counts, respectively). Dosage effects are highly significant on the morning counts ($p < 0.0001$***), with higher numbers occurring at quarter and half dosage than at normal dosage, whereas the effect is less clear on the afternoon counts ($p = 0.030$*) due to large between-farms variation. Year-to-year differences are highly significant ($p = 0.0005$*** and 0.0020** on morning and afternoon counts, respectively) with higher Whitethroat densities occurring in the fields in 1998 and 1999 than in 1997.

The models for the morning and afternoon counts may both be improved by adding total arthropod dry mass (Totaldrw) as a covariate (Table 6.4). Whitethroat densities in all crops rise with increasing arthropod biomass (Fig. 6.7 A), although the effect is only significant in wheat ($p = 0.072$ and 0.017* on morning and afternoon counts, respectively) and beets ($p = 0.0003$*** and 0.0056**). In both models, a partitioning of the sums of squares before and

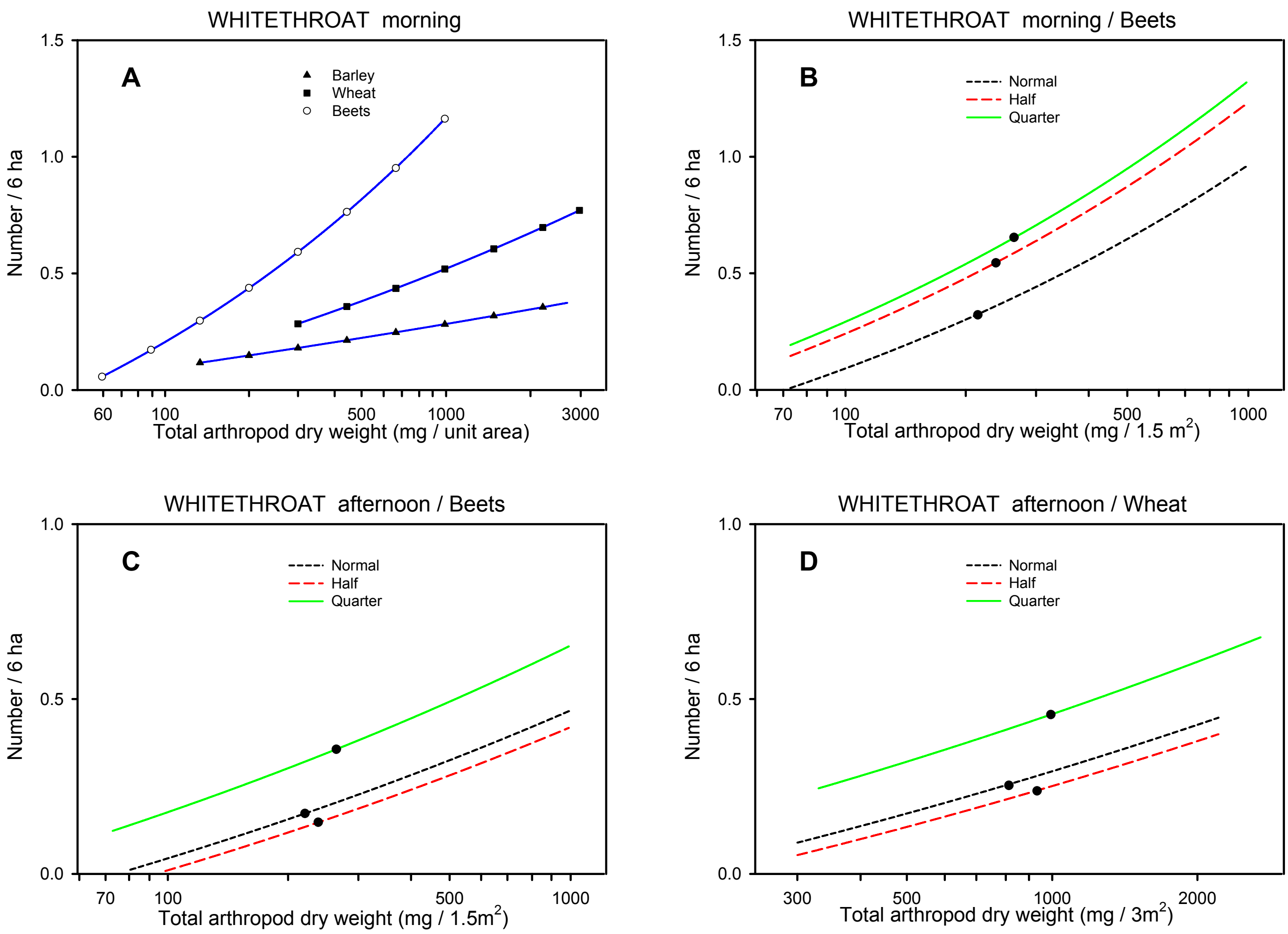


Fig. 6.7. Models of the relationship between Whitethroat densities and total dry weight of arthropods. A & B are based on the morning counts, C & D on the afternoon counts. In A, the relationship is shown for different crops; the slope of the curve is not significantly different from zero in barley and barely significant in wheat. Notice that the values for arthropod dry weight in beets are not directly comparable with those in cereals. B-D shows the relationship for different dosages in beets (B & C) and wheat (D); the centroid of each curve, corresponding to mean total arthropod dry weight at each dosage, is indicated (•). In B, the curves for half and quarter dosage are not significantly different; in C & D, the curves for normal and half dosage are not significantly different. Notice that the model graphs do not show the range of variation and that the log-based densities are not comparable with normal arithmetic mean densities.

after the inclusion of the covariate shows that the effect of the year factor is almost eliminated when Totaldrw is added to the model, indicating that year-to-year differences in Whitethroat densities in the fields may be caused by variations in the amount of arthropods available there. This interpretation is corroborated by an analysis of variance of Whitethroat densities in the border vegetation outside the fields which shows no clear between-years differences in Whitethroat numbers ($p = 0.16$).

Further consideration of the sums of squares shows that the addition of Totaldrw to the models also reduces the relative importance of field and dosage differences, although not strongly so. Significant differences between dosages still exist after the inclusion of the covariate ($p = 0.0003$*** and 0.052 for morning and afternoon counts, respectively), indicating that just a minor part of the between-dosages variation in Whitethroat numbers may be explained by differences in arthropod availability. In all crops, the shape of the curve describing the relationship between Whitethroat densities and Totaldrw (Fig. 6.7 B-D) does not differ significantly between dosages ($p > 0.40$ in all pairwise comparisons of regression coefficients). As to the estimated densities of Whitethroats in half-dosage plots, the difference between morning and afternoon counts is complementary to the difference found in Skylarks and is discussed in chapter 4.

In the model without covariates, the numbers of ***small seed-eaters*** recorded on the morning counts differ significantly between crops ($p < 0.0001$***), dosages ($p = 0.0073$**), and years ($p = 0.0031$**). After mid-June, the highest seed-eater densities occur in beets and the lowest in barley, and densities are higher in plots treated with half and quarter dosage than in normal-dosage plots (cf. Fig. 4.5). On the afternoon counts, similar crop and dosage differences are indicated but are non-significant, partly due to large variation between farms.

The analyses of covariance show that the model for the morning counts may be improved by including weed density as a covariate. In all crops, seed-eater densities prove negatively related to weed density; the effect of weed density is significant in wheat ($p = 0.0002$***) and beets ($p = 0.041$*). In the model for the afternoon counts, no covariates are significant at the 5% level; S_Weeds (number of weed species) comes closest ($p = 0.069$).

The negative correlation between weed density and seed-eater numbers on the morning counts is inexplicable and, at least on the face of it, illogical. A partitioning of the sums of squares before and after the inclusion of the covariate shows that the proportion of variance explained by the field factor is reduced when the covariate is added to the model, whereas the proportion of variance explained by the dosage (and year) factors is increased. Thus, the variation in seed-eater numbers between dosages and years is not in any way related to differences in weed densities. Probably, the small seed-eaters accidentally occur at their highest densities in fields with low weed densities, without any causal connection. The lack of obvious concordance between the models for the morning and afternoon counts supports this conclusion.

Although treated as a group here, the different species of small seed-eaters vary in their habitat requirements and feeding behaviour. They are in various degrees associated with farm buildings and gardens, and the distance to these structures may be an important distributing factor. Also, the proportion of diet made up by animal food items varies between species. Whereas the cardueline finches are granivorous throughout the year, arthropods constitute an important part of the summer diet in species like Yellowhammer and Chaffinch, and the young of these species are almost exclusively fed animal food items (Cramp & Simmons 1977-94). These differences may be another reason why the analyses of covariance do not reveal any "sensible" relationships. Unfortunately, data on the individual species are too sparse and their distribution too far from normal to allow separate analyses.

As discussed above, the analysis and interpretation of the distribution of small seed-eaters imply some particular problems, but the appearance of a rather improbable result as highly significant in the analyses nonetheless calls for circumspection. Multiple regression and related techniques are powerful tools, and whenever ***a posteriori*** variable selection is involved (like here), the hypotheses tested are to some extent created by the data, and the risk of spurious correlations emerging as significant always exists. Therefore, even if the ancova results for Skylark and Whitethroat seem more credible than those for seed-eaters, they should be treated with caution as well.

6.2.3 Autumn bird counts

The addition of covariates to the models of the distribution of birds on the stubble fields did not in any case improve the models (in terms of a reduction of the model p value). When included, no variables describing cereal grain or weed seed abundance had any significant effect on the occurrence of any of the analysed species ($p > 0.10$ in all tests for $\beta_{cov} = 0$). Only the factors indicated in Table 4.9 appeared as significant in the analyses, implying that neither differences in pesticide dosage nor differences in seed abundance (within the range found in this study) affect the autumn distribution of Skylarks, Meadow Pipits and small seed-eaters significantly. The separate analysis of Yellowhammer occurrence did not reveal any new information.

7 General discussion

(Petersen, B.S., Jensen, A.-M.M., Navntoft, S. & Esbjerg, P.)

7.1 Wild flora

The aim of the botanical investigations was to analyse whether the reductions in dosages of herbicides and insecticides caused changes in performance and diversity at the primary production level, not to evaluate the activity and efficiency of the herbicides.

Weed density expressed as total number of plants per m^2, and as number of plants per species per m^2, was highly dosage dependent. The total weed density was significantly higher at quarter and half dosage than at normal dosage, whereas no statistically significant difference was found between quarter and half dosage.
No between years differences in the effect of dosage were found, so no traceable accumulation in weed density could be detected at reduced dosages over the three years. Both target weed species and non-target species (weak competitors) increased in density at reduced dosages. The total weed density is a measure of the potential non-crop plant food supply for herbivores, and increased weed densities may thus improve living conditions for these.

The relation between total weed density and weed diversity is obvious; the weed diversity (species richness) increases with an increase in total weed density, as was also found in this study. In addition, it was found that weed species richness expressed as number of species per plot was negatively correlated with dosage, especially in spring barley fields. This was, e.g., reflected in the fact that several non-target weed species occurring at low frequencies in the experimental fields were found more often at quarter dosage than at normal dosage. This increased richness was found though the species pool in the arable fields has diminished strongly during the last decades (e.g. Jensen & Kjellsson 1995). The potential herbivore non-crop food supply thus became not only more abundant, but also more diverse as the pesticide dosages were reduced. This effect was most pronounced at quarter dosage.

The numbers of flowering species and plants were recorded, and only at quarter dosage a significant increase in the number of flowering species was observed. The future weed population is directly related to the success of the flowering plants, and they provide nectar and pollen for pollinating insects.

In the analyses of the composition of the seed rain, only 2/3 of the species observed in the vegetation were found as seeds. This infers, methodological difficulties excepted, that many species do not reproduce by seeds, either because they reproduce vegetatively or because they never reach reproductive age. Furthermore, the diversity in the soil seed bank (which is composed of seed rain from many years) is higher than in the seed rain from any single year.

The conclusion of the seed rain study is not straightforward, and possible consequences of dosage-dependent changes in weed seed production for seed-eating birds must also be related to the waste of grain in the fields, considering that the grain biomass is tenfold the weed seed biomass. When available, grains may be preferred to weed seeds by several bird species (e.g. Berthelsen ***et al***. 1997).

7.2 Arthropods

The general trend was that arthropod biomass (mg dry weight/unit area) was increased at reduced pesticide dosages. There was a noticeable difference between the three crops. In barley, a significant difference of the estimated dry weight between dosages was revealed, with estimates at quarter dosages being significantly higher than at half and normal dosages. In wheat and beets there were no significant differences, but there was a clear tendency towards more arthropod biomass at reduced dosages. Possible reasons for the pronounced effects found in barley compared to wheat could be that the pesticide applications in this crop were more efficient because of the more open structure, allowing the pesticides to penetrate deeper into the canopy. Weeds may also affect the microclimate relatively more in barley than in wheat because of the more open canopy structure in barley, benefiting arthropods at the higher weed density found at quarter dosage. Furthermore, the early insecticide spraying in barley may have affected more arthropod species at critical stages. The insecticide application history of barley and wheat are quite similar. When the insecticide applications in barley and beets are compared, obviously barley was sprayed more intensively than beets and often with more broad-ranged products, probably resulting in more devastating effects. Furthermore, weed hoeing in beets was consistently conducted at half and quarter dosage, whereas hoeing in normal dosage plots was only carried out at Gjorslev and Oremandsgaard. Generally it may be assumed that soil-tilling has a negative impact on arthropods (Holm ***et al.*** unpubl.), probably counteracting the effect of reduced dosages, since weed hoeing mostly was conducted in plots treated with reduced pesticide dosages.

The obvious question is which specific mechanism(s) caused this effect of increased arthropod dry weight at reduced dosages. Due to the complexity of this project it is not possible to answer this question precisely, since it is impossible to isolate and quantify all the specific mechanisms, and not least their interactions. It might, however, be expected to find a positive correlation between the two trophic levels, weeds and arthropods, through effects of weeds on food availability and microclimate. The combined analyses of the biomass of arthropods, estimated by suction sampling, in relation to vegetational data did, however, not reveal any explainable significant findings. This result may not be surprising, since the vast majority of the arthropods in arable land inevitably have to be generalists in order to survive the constantly changing environment. Weeds as a food resource may therefore be less important compared to the effect of weeds on the microclimate. Dominating arthropod groups, however, which may benefit from an altered microclimate due to their location near the ground are not extracted in high numbers by suction. The most obvious example is the important ***Carabidae*** (ground beetles), which contribute significantly to the fauna both as food items and as predators. The lack of precise estimates of their dry weight in the suction samples may consequently affect the analyses of arthropod biomass in relation to vegetation (carabids were efficiently sampled by fenced pitfalls, see later).

The fact that no general correlation between arthropod dry weight and the weed community was revealed does not mean that no correlations between the two trophic levels were found. Significant correlations, which were not dosage related, were among others found for ***Symphyta*** (sawfly) larvae (Fig. 6.1), ***Lepidoptera*** (butterfly and moth) larvae (Fig. 6.2), ***Miridae*** (plant bug) adults (Fig. 6.3) and ***Curculionidae*** (weevil) adults (Fig. 6.4); all true herbivores and important food items. This is in line with findings of Chiverton & Sotherton (1991), who found that headland that was not sprayed with herbicides supported significantly higher densities of non-target arthropods, especially some species that are important in the diet of insect-eating game-bird chicks.

The estimated total carabid dry weight in wheat differed significantly between quarter and normal dosages. This effect could only be revealed by use of fenced pitfalls, because suction sampling is an insufficient method for sampling carabids. For the dominating family ***Carabidae***, weed cover may be an explanatory factor of the significant dosage effect found in wheat. In the field the canopy often protects the epigaeic carabids by inhibiting the routes of exposure of pesticides (Gyldenkærne ***et al***. 2000). Nocturnal species may also be protected from direct exposure within the refuges at the time of insecticide application, resulting in lower mortality. Furthermore, the relatively large size of carabids also reduces their susceptibility to insecticides. Overall weed cover, rather than a lethal effect of insecticides, may play a key role in the differences found between dosages. The most abundant species of ***Pterostichus***, of which the population was significantly higher in quarter dosage, are nocturnal and desiccation may be a problem. Therefore they probably prefer the dense plant cover found in quarter dosage whereas the most abundant ***Bembidion*** species, which occurred at significantly higher density at normal dosage, are known to prefer open soils and thus a less dense plant cover as found at full dosage. Generally, when evaluating population results, competition should be considered in line with other factors, which of course complicates the analyses. In this example ***Bembidion*** is part of the diet of ***Pterostichus***, a fact that may also enhance the populations of ***Bembidion*** at lower densities of ***Pterostichus***.

Insecticides may be of greater importance than the herbicides/weed community for the significant dosage differences of arthropod dry weight that were revealed by suction sampling. The significant covariate ***treatment intensity index of insecticides*** in the dry weight analyses from barley and wheat, compared with the lack of correlation between arthropod dry weight and weeds, leads to the conclusion that insecticides have the biggest overall impact on the amount of available estimated arthropod food. This was supported by the fact that it actually was possible to reveal a significant difference between dosages for arthropod biomass in beets, but only on data comprising the 14-day period after ***insecticide*** application. One of the problems with isolating a pure insecticide effect is that some herbicides may act as insecticides (Candolfi ***et al.*** 1999) and that various insecticides used affect arthropods differently. The widely used aphid specific Pirimicarb does not harm most predators directly whereas Dimethoate and pyrethoids (e.g. “Karate”) have broad ranged effects. The impact of lethal effects of herbicides can be considered minor, because the predominant herbivores and many predatory insect groups are little active in the field early in the season when herbicide application occurs. It is therefore most likely that the direct lethal effects on arthropods are effects of insecticide applications.

Non-parametric tests revealed that numbers of the most common arthropod groups generally increased under a reduced pesticide regime, except for the non-carnivore taxa in wheat. Overall there was a clear effect of quarter dosage, whereas there was no general effect of half dosage. The dominating pest problem of Danish farmland crops is ***Aphididae*** (aphids), and most insecticide applications are directed entirely against these pests. Generally in this experiment, a dosage effect on aphids was found in all three crops, with higher populations at reduced dosages. The aphicide Pirimor (Pirimicarb), which is considered less harmful to most arthropod predators, proved more effective than pyrethoids and Dimethoate. Furthermore, in the cereals quarter dosage seemed to be at the borderline of the required minimum. It is apparent that a major part of the most affected arthropod carnivores in all three crops are aphid specific, often at their juvenile stages. It is possible that the effect was due to prey removal, rather than being a direct lethal effect on the predators. On the other hand, aphid-specific carnivores are among the most exposed to insecticide applications due to their location high in the canopy, which may lead to increased lethal effects.

7.3 Birds

With the field-nesting Skylark as an obvious exception, the common farmland bird species breed in natural and semi-natural vegetation outside the agricultural fields. The vast majority of these species, however, in some period(s) of the year make use of the resources available inside the fields. In general, the number of birds visiting the fields has been found to increase during the breeding season (early May to early August), especially in July. This increase is far more pronounced in beets than in cereals and accompanies the increase in structural diversity of the crop vegetation. A parallel rise in the total abundance (dry weight) of arthropods inside the fields has been found, especially in beets. It can be presumed that the birds exploit this food resource, so that there is a causal relationship between the increase in arthropod abundance in the fields and the number of birds visiting the fields. This relationship may be enhanced by the fact that the amount of arthropods available in the surrounding hedgerows probably decreases from early July onwards (Nielsen & Sell 1986).

In the Skylark, the changing use of the different crops during the breeding season is probably mainly due to changes in the value of each crop as a nesting habitat, although the strongly increasing amount of arthropods in beet fields from mid-June onwards may be part of the explanation for the increasing use of this crop. Food accessibility is just as important as food abundance, and as a crop grows tall and dense it becomes less suited to the Skylarks' feeding behaviour. Odderskær ***et al***. (1997b) found that Skylarks preferred tramlines and unsown patches to the interior of the fields, even if the latter held higher densities of food items. Jenny (1990a) states that when ground coverage exceeds 50%, the Skylarks' use of a crop for foraging is severely impeded, and he concludes that food accessibility (rather than food abundance) is a limiting factor. Viewed in this light, it is not surprising that our analyses did not reveal any significant relationship between Skylark abundance and arthropod biomass as measured by the suction sampler. Odderskær ***et al***. (1997a) were also unable to relate Skylark nestling survival to food abundance (measured by D-vac sampling) in their regression analyses.

Within certain limits, the presence of weeds inside a field improves breeding conditions for Skylarks (Schläpfer 1988). This may explain the positive effect of weed species richness on Skylark densities in barley fields (Fig. 6.1). It may be surprising that weed diversity, rather than weed density, is the factor of significance in the present analysis. However, the two weed variables are mutually correlated (r = 0.57), and it may to some extent be accidental which of them turns out as the best predictor in an analysis of covariance (actually, the effect of Weeddens is almost significant (p = 0.051)). In wheat fields, no effect of weed diversity or weed density is seen − and no effect was to be expected, because the crop alone gives a ground coverage above the 35-60% regarded as optimal (Toepfer & Stubbe 2001). A positive effect might be expected in beets, where ground coverage is even lower than in barley. Green (1980) found that Skylark densities in beet fields in April and May were positively correlated with weed seedling density. Later in the season the pattern may well be distorted by the hoeing which (at least in theory) may cause severe disturbance of nesting attempts in a ground-nesting species like Skylark. Generally, however, the effect of mechanical weed control on birds of arable fields is not well known and should be a subject of future research.

Whitethroats chiefly search their food in the hedgerows, especially in the hedge-bottom, but locally and on occasion a major part of their foraging takes place in agricultural crops (Cracknell 1986, Nielsen & Sell 1986) - probably as a response to a flourishing of suitable prey items. In the present study, a positive effect of total arthropod dry weight on Whitethroat densities has been found in all three crops, although the effect is not significant in barley (which is used the least). The effect is strongest in beets (Fig. 6.4 A-B); beet fields are mainly used from July onwards.

Whitethroats are the most specialised insectivores among the bird species analysed, so it makes good sense that it is in this species a clear relationship between arthropod and bird abundance is revealed. In the analyses of covariance, total arthropod dry weight proved a better predictor of Whitehroat densities than dry weight of "preferred birds' food items", possibly because the latter group was selected mainly with Skylarks in mind (cf. chapter 3). Important Whitethroat prey items are larval and adult ***Lepidoptera*** (esp. ***Geometridae*** and ***Noctuidae***), spiders, ***Hymenoptera*** (esp. ***Tenthredinidae*** larvae), ***Hemiptera*** (***Aphidoidea, Psylloidea, Cicadellidae***) and ***Coleoptera*** (esp. ***Curculionidae*** and ***Chrysomelidae***) (Cramp & Simmons 1977-94, Nielsen & Sell 1986, Christensen ***et al***. 1996). In beet fields, ***Elateridae*** and larval ***Silphidae*** may also be of importance (P. Odderskær pers. comm.).

In the small seed-eaters, the ancovas revealed a highly significant, negative correlation between weed densities and bird numbers. There are no obvious reasons for this and, as discussed in section 6.2.2, the correlation may well be accidental. This conclusion is supported by the fact that, unlike in the other species, the analyses of morning and afternoon counts of seed-eaters resulted in different models with respect to the covariates. Also, analyses of (more or less homogeneous) species groups may be subject to greater variation and more difficult to interpret than analyses of single species.

Nevertheless, the labelling of a highly significant correlation as "accidental" is of course debatable. Invariably, it calls for caution with respect to the interpretation of the relationships found for Skylark and Whitethroat, although those models, at least on the face of it, seem more credible.

Comparison of the models with and without covariates reveals that the covariates mainly explains density differences between years (Whitethroat) and farms (Skylark), but only to a minor degree differences between dosages.

That is, in all three species (groups) analysed, there are significant (or almost significant) between-dosages differences in bird densities during the breeding season which cannot be explained by the measured variation in arthropod abundance, weed density or weed diversity. These dosage effects do not vary significantly between crops, nor do they vary between years, and the few cases of an apparent farm dependence may be explained by the lack of full comparability of plots (cf. section 4.4).

The largest differences between dosages are found in Whitethroats and the second largest in small seed-eaters, whereas the differences in Skylark densities are less pronounced (section 4.4.1). As might be expected, a 75% reduction of the dosages of herbicides and insecticides results in a greater increase in bird densities than a 50% reduction, but the latter has significant effects on all three species (groups) as well. A tentative conclusion could be that at least half of the effect achieved by a 75% reduction of the herbicide and insecticide input may also be achieved by reducing the dosages to 50%.

The differences in bird density largely result from a redistribution of birds at the local scale; the population effects (if any) are unknown. Odderskær ***et al.*** (1997a), studying Skylarks in barley fields, did not find any differences in territory density between pesticide sprayed and unsprayed fields. However, the number of successful breeding attempts was higher in unsprayed fields (especially in late season), perhaps because a more abundant and diverse food supply allowed the birds to stay in a better body condition. Based on estimated breeding success and survival rates, Wilson ***et al.*** (1997) concluded that two or three nesting attempts per season are necessary for a Skylark population to be self-sustaining and that suitable conditions for this rarely exist in conventional cereal fields. By attracting higher numbers of birds and providing them with a richer food resource (as indicated in the present study), areas with reduced pesticide use may help increasing breeding success, and hence population size.

It must be assumed that the differences in bird occurrence between dosage plots found in the breeding season have been caused by the experimental differences in pesticide treatments. It is unlikely that the products used have appreciable direct effects on birds. Thus, the pesticides must affect the birds chiefly through indirect means, i.e. through a deterioration of habitat structure or food supply. Insecticides reduce the amount of arthropod food items directly, whereas herbicides affect vegetation structure directly and food abundance indirectly by reducing the amount of suitable host plants (e.g. Campbell ***et al***. 1997). Nonetheless, in the analyses the differences in bird occurrence are only to a minor degree explained by differences in arthropod abundance and weed density/diversity. This does not mean that the positive effects of reduced pesticide use are not mediated through improved supplies of arthropod food items or a more suitable (weed) vegetation structure. Rather, it probably means that the variables used as predictors in the analyses have been too crude to include sufficiently detailed information about the resources available within a plot. Birds are often opportunistic in their choice of food items and feeding sites, and direct modelling of bird density as a function of resource availability may just be possible on a (spatially or temporally) fairly small scale.

After the breeding season, many farmland bird species gradually switch to a vegetable diet (mainly seeds) as the availability of arthropods declines. On the autumn counts, no effects of pesticide dosage on the distribution of birds on the fields were found. Also, bird densities could not be related to the amount of seeds available on the ground surface. Arthropod abundance was not measured. In the botanical as well as in the ornithological investigations, the variation between farms and fields was large, and this may, in combination with the incomplete, unbalanced design (cf. section 4.2.2), be one reason for the lack of significant results. Another reason, however, may be that food on stubble fields in early autumn is superabundant, so that other factors, e.g. the risk of predation, are the major distributing factors. In winter, when resources are sparse and the demand for energy-rich food is high, differences in seed densities may be of greater importance. Robinson & Sutherland (1999) and Wakeham-Dawson & Aebischer (1998) found that densities of Skylarks and Yellowhammers on stubble fields in winter were positively correlated with seed density. However, Donald ***et al.*** (2001) were unable to detect any correlation between soil surface seed density and Skylark occurrence in November-March.

British studies have demonstrated that many bird species, especially seed-eaters, strongly prefer stubble fields to other field types during the winter, probably due to the rich supplies of weed seeds and spilt grain (e.g.Wilson ***et al***. 1996, Robinson & Sutherland 1999, Donald ***et al.*** 2001). The value of these fields increases with increasing weed cover (Wilson ***et al***. 1995 cited in Campbell ***et al***. 1997) whereas undersown fields are less used by birds (Robinson & Sutherland 1999). The importance of stubble fields as foraging sites is so high that the loss of winter stubbles, caused by the switch from spring to autumn sown crops, may be one of the major reasons for the widespread population declines in many farmland birds (e.g. Baillie ***et al***. 1997, Evans 1998).

7.4 Yield and economy

It has to be noticed that while investigations of plants, insects and birds were high priorities the effects of reduced yields of dosages only had to be considered as a fair background for possible compensations to landowners. Therefore of course also aspects of economy were treated in another way than if it was an area of high priority.

This being said, the picture was, however, rather uniform. Thus losses in cereals never reached any serious level. Only in 3 of 58 cases yields were significantly below the corresponding normal dosages (Appendix E.2). All the three cases were at quarter dosage. Similarly in sugar beets only in 5 of 32 cases yields were significantly decreased (Table 5.3). The proportionally higher occurrence of decreased yields in sugar beets corresponds very well with both the much more crucial weed situation in the less competitive sugar beets and the difficulties with the very precise field operations (band spraying and mechanical hoeing).

The follow-up on the above results with economic scenarios (Tables 5.4.1 and 5.4.2) shows that to some degree the few cases of yield losses in winter wheat are counterbalanced by cost savings on herbicides and insecticides when applied at reduced dosage levels. The overall picture very clearly is that on the short term the pesticide reduction is rather unproblematic, at least in cereals. However, the costs of cleaning up particular weed patches after the projects points at a problem-area not fully incorporated in the present project but at the same time a problem which may easily be avoided in practice. The clue of course will be not to continuously reduce the dosages of all herbicides on the same piece of land but rather record problem patches and treat these accordingly at some intervals. Such a strategy will also counterbalance the slight decrease in production stability which might be a side effect of a more widespread use of reduced dosages. In this connection also the possibly increased cost of management is a factor which might also deserve some attention.

7.5 Biodiversity vs. economy: getting the balance right

The botanical, entomological and ornithological studies clearly indicate that a reduction of the pesticide dosages leads to increased biodiversity in the fields (see section 1.2.1 for a definition of "biodiversity" as used here). At the primary production level, a general increase in weed density and weed species richness at reduced dosages was found, and a greater proportion of species reached the flowering stage. The most prominent density responses occurred in target weed species, but effects on non-target weed species (weak competitors), including some scarce species, were also found. Arthropod amounts tended to increase at reduced dosages, with respect to total biomass as well as to numbers of individuals of a broad range of taxonomic groups. The clearest differences were found in barley fields. Both herbivores and carnivores showed a response, but the experimental design did not allow a separation of direct and indirect pesticide effects. Finally, all three bird species studied developed a preference for areas treated with reduced dosages as the summer progressed. The largest differences (100% increase) occurred in the purely insectivorous Whitethroat, whereas the weakest response (20-25% increase) was found in the more omnivorous Skylark.

Comparable responses to the dosage reductions were recorded at all trophic levels, strongly suggesting the existence of causal relationships. However, directly relating population densities at one trophic level to densities at another level in the statistical analyses proved not straightforward, partly because of temporal or spatial scale problems, partly because the measurements were not targeted towards analyses of energy flow.

Across all trophic levels, the largest gains occurred at quarter dosage. The general density of weeds was also significantly increased at half dosage and did not differ between half and quarter dosage. As for the weed species richness, however, half dosage held an intermediate position between quarter and normal dosage, with a 16% increase at half dosage (relative to normal dosage) and 28% increase at quarter dosage. The increase in the proportion of flowering species was only significant at quarter dosage. The estimated amounts of arthropods at half dosage showed no general tendency and very few significant differences between half and normal dosage were found. In many cases, the number (or biomass) of arthropods at half dosage was closer to normal than to quarter dosage. In the ornithological studies, an evaluation of the effects of half dosage is hampered by the lack of full comparability of plots. With due reservation, it may be concluded that at least half of the increase in bird numbers achieved at quarter dosage (cf. above) also occurs at half dosage. Contrary to the other studies, however, the differences in bird numbers between dosage plots result from a local redistribution of birds (reflecting feeding site preferences) rather than from differences in population sizes.

A comparison of the gains at half and quarter dosage suggests a logarithmic (rather than a linear) relationship between dosage and biodiversity. In the present study, plots without any herbicide and insecticide input only occurred in the small-scale yield experiments. It is clear from the weed counts performed there that the increase in weed density and species richness from quarter to zero dosage is at least of the same magnitude as the increase associated with a change from normal to quarter dosage (cf. Fig. 5.2). This further points towards a strongly curvilinear dose-response relationship, coinciding with dose-response curves describing the response of single species of weeds to single herbicides (e.g. Streibig 1992).

From the yield experiments and the economic calculations it can be concluded that a halving of herbicide and insecticide dosages in cereals by and large may be carried into effect without negative economic consequences. A 75% reduction may be more problematic, especially if implemented through several years, as average yield declines are larger and contribution margins may suffer. The 3-year duration of the project does not allow an evaluation of the extent to which reduced dosages lead to an accumulation of weed problems. Also Salonen (1992a) found no increase in the number of weed seeds in the soil bank after continuous application of one-third of recommended dosage over three consecutive years. The clean-up decisions, however, indicate that some problematic species, especially ***Elymus repens***, may spread quite quickly if dosages of the appropriate herbicides are reduced. Long-term field studies of reduced herbicide use have revealed an accumulation of seeds in the topsoil (Jones ***et al.*** 1997) or a significant higher density of problem weeds as ***Apera spica-venti*** (Pallutt 1999).

In sugar beets, no differences in average yield were detected between half and quarter dosage; but in all three years, average yields were lower at reduced dosages than at normal dosage. Also, and more important, beet yields at reduced dosages were very variable – to an extent which is verging on the unacceptable in a high-value crop. Obviously, the combination of band spraying and hoeing at present does not provide the same production security as broad swath application, but reducing herbicide dosages in a broad swath is no alternative (as amply demonstrated in the pilot year).

On balance, a 50% reduction of herbicide and insecticide dosages in cereal crops results in a modest increase in biodiversity at all trophic levels without notable cultivation problems, at least in the short run. Biodiversity gains are increased, maybe following a logarithmic dose-response relationship, as pesticide dosages are reduced, but at quarter dosage the risk of significant yield losses (and hence reduced contribution margins) is no longer negligible, and a 75% reduction cannot be used indiscriminately. In sugar beet, a 50% (or even greater) reduction of pesticide amounts by band spraying ***may*** work well in combination with mechanical hoeing, but production risk is markedly increased. The dose-response relationship for the biodiversity gains seems comparable to that in cereals.

The treatment intensity indices calculated on the basis of the "normal" dosages chosen by the farm managers were in the case of herbicides within the same range as the Danish mean values for the three crops calculated on the basis of consumptions 1997-99 (Table 1.1). The "half" dosages of the project farms were well below the values stated as goal for 2002 in the Pesticide Action Plan II (spring barley 0.48 vs. 0.70, winter wheat 0.74 vs. 1.20, sugar beet 0.96 vs. 2.40). For insecticides, the picture was quite different, the "normal" dosage in spring barley being almost triple of the 1997-99 mean for Denmark, while normal in wheat was more than twice the Danish 1997-99 mean and normal in sugar beets was almost 70% higher than the Danish mean (Table 1.1). It should be noticed that all the farms hosting the project are situated on rich, heavy soils where especially aphid problems tend to be more frequent than on less rich soils. As for insecticide use in winter wheat and sugar beets, mean treatment intensity indices in Denmark were further reduced in 2000 (0.12 and 0.21, respectively (Danmarks Statistik 2001)), thus being below the goals for 2002 (Table 1.1). Apart from being possibly influenced by differences in weather, the values for 2000 may be an indication of improved use of the aphid forecastings (fewer sprayed fields) rather than of treatments with reduced dosages.

8 Conclusions and perspectives (Esbjerg, P. & Johnsen, I.)

8.1 Conclusions

The reader should kindly notice that this chapter is short and only presents the main conclusions and derived suggestions supported by very few discussing remarks. The broader underlying discussions have been presented in chapter 7.

While investigations of target organism responses to particular pesticides in varying dosages are part of the systematic evaluation of these chemicals in Denmark, no project has previously elucidated the effects of several dosage levels of several different pesticides on organisms from several trophic layers within the same fields. Viewed in this light ***the most important result of the present project is the finding that by reducing the dosages of herbicides and insecticides higher densities or abundances are obtained at all the three major trophic levels represented by plants, insects and birds***.

Taking into account the amount of disturbing variation, the above result is very promising. Thus the three nominated dosage levels include a considerable variation due to local geographic and year to year differences. Also the farmers' choices of normal dosage have caused dosage variation. As the main result has come out despite these conditions the following general conclusion can be drawn: ***dosage reductions to at least half of normal will result in a richer nature in the agricultural fields.*** To this statement should, however, be added that the best guarantee for reaching such an improvement of the nature content in arable fields will be a dosage reduction to one quarter of the normal level used in the present investigation. By this reduction all the remarkable improvements linked to plants, insects and birds were safely obtained. It should, however, be noticed that the dosages and their effect are merely a sort of ruler. Thus the choice of, for example, a more potent herbicide might not lead to the same improvement at quarter dosage because of more powerful effects. Therefore ***the really important aspect is the acceptance from farmers and advisory people of a certain level of plants and insects as non-detrimental to the production economy.***

For improvement of the nature content of the arable land the half dosage level is also of interest despite the less clear effects. At this dosage level cultivation problems are non-existent or negligible, at least on short term (< 4 years), while interestingly the biologically more rewarding quarter dosage level is also the level representing a zone of emerging agricultural problems.

While the overall picture is that even quarter dosage is often sufficient from a grower's angle there are cases of evident agricultural problems connected mainly with particular weeds and their local occurrence. For instance the lack of effect of reduced dosages of glyphosate on quackgrass (***Elymus repens***) is confirmed. Also the patchwise accumulated weed problems within certain fields at the end of the third growing season calls for particular attention in case of a more wide spread use of the quarter dosage level for longer periods.

However, this sort of a problem can probably easily be solved when use of Global Position Systems in field practice during pesticide application becomes more common.

In a few cases of aphid control the renewed occurrence of aphids 10 days after control indicates that quarter dosage seems to be close to the required minimum.

8.2 Perspectives for the future

Through the present investigations we have identified a problem, which needs further attendance: consequences for biodiversity in agricultural fields of mechanical methods for pest control. Reduction or even abandonment of pesticide use in future agricultural practice may strongly increase the use of various mechanical methods to control weeds in particular and maybe also some insects. For instance the possible negative influence on flora and fauna of mechanical hoeing, with different methods and at different intensities and timings, remains an important unanswered question. This question deserves attention in connection with the growing interest for organic farming. The present results also call for a better understanding of the mechanism behind the effects of reduced pesticide dosages, particularly on animal populations. This aspect might be elucidated by more specific investigations targeted towards population dynamics of a few carefully selected species.

In the interface between agriculture and protection of natural flora and fauna the results of this project indicate room for potential changes. The positive effects on flora and fauna of a pesticide reduction to quarter dosage already in the first year calls for an immediate use. The risk of accumulating weed problems may be avoided basically by identifying “high risk spots” which should be kept under more strict control. If such an idea is brought a step further, then creation of a dynamic field patchwork (the spatial dimension) with different dosage levels between zero and normal being applied over time (the temporal dimension) could be envisaged. E.g. this practice would establish an escape route for animals to a neighbouring new low dosage field to counteract the negative effect when full dosage follows low dosage in a particular field. For plants the existence of at least a certain area with quarter or zero treatment levels will be a significant improvement compared to present practice. Such an approach would be one among several steps towards a much-improved nature content in the agricultural fields. It is, however, questionable whether the resources of the farmers and the advisory service are sufficient for such a step towards complication of planning and management. It can also be debated which incitement may be necessary to promote such a step.

9 References

Altieri, M.A. & Whitcomb, W.A. (1979): The potential use of weeds in manipulation of beneficial insects. ***Horticience*** 14: 12-18.

Andreasen, C., Streibig, J.C. & Haas, H. (1991): Soil properties affecting the distribution of 37 weed species in Danish fields. ***Weed Research*** 31: 181-188.

Andreasen, C., Stryhn, H. & Streibig, J.C. (1996): Decline of the flora in Danish arable fields. ***Journal of Applied Ecology*** 33: 619-626.

Angelstam, P., Hansson, L. & Pehrsson, S. (1987): Distribution borders of field mice ***Apodemus***: the importance of seed abundance and landscape composition. ***Oikos*** 50: 123-130.

Baillie, S.R., Gregory, R.D. & Siriwardena, G.M. (1997): Farmland bird declines: patterns, processes and prospects. ***British Crop Protection Council Symposium Proceedings*** 69: 65-87.

Beijerinck, W. (1947): ***Zadenatlas der nederlandsche flora, ten behoeve van de botanie, palaeontologie, bodemcultuur en warekennis. Omvattende, naast de inheemsche flora, onze belangrijkste cultuurgewassen en verschillende adventiefsoorten***. H. Veenman & Zonen, Wageningen.

Berthelsen, J.P., Rasmussen, K. & Kjellsson, G. (1997): Fouragerende fugles udnyttelse af ukrudtsfrøpuljen. Metodeudvikling og vurdering af fødemuligheder i relation til pesticidpåvirkning. ***Bekæmpelsesmiddelforskning fra Miljøstyrelsen*** 28. Miljø- og Energiministeriet, Miljøstyrelsen. København.

Biber, O. (1993): Raumnutzung der Goldammer ***Emberiza citrinella*** für die Nahrungssuche zur Brutzeit in einer intensiv genutzten Agrarlandschaft (Schweizer Mittelland). ***Ornithol. Beob.*** 90: 283-296.

Boström, U. & Fogelfors, H. (1999): Type and time of autumn tillage with and without herbicides at reduced rates in southern Sweden: 2. Weed flora and diversity. ***Soil & Tillage Research*** 50: 283-293.

Braae, L., Nøhr, H. & Petersen, B.S. (1988): Fuglefaunaen på konventionelle og økologiske landbrug. ***Miljøprojekt*** 102. Miljøstyrelsen.

Campbell, L.H., Avery, M.I., Donald, P., Evans, A.D., Green, R.E. & Wilson, J.D. (1997): A review of the indirect effects of pesticides on birds. ***JNCC Report*** No. 227. Joint Nature Conservation Committee, Peterborough.

Candolfi, M.P., Bakker, F., Cañez, V., Miles, M., Neumann, Ch., Pilling, E., Primiani, M., Romijn, K., Schmuck, R., Storck-Weyhermüller, S., Ufer, A., Waltersdorfer, A. (1999): Sensitivity of non-target arthropods to plant protection products: Could ***Typhlodromus pyri*** and ***Aphidius*** spp. be used as indicator species. ***Chemosphere*** 39: 1357-1999.

Cashmore, W.J. & Caseley, J.C. (1995): Effects of low doses of herbicides, temperature and simulated harrowing on the survival of three weed species. ***British Crop Protection Conference: Weeds***: 719-724.

Chamberlain, D.E. & Gregory, R.D. (1999): Coarse and fine scale habitat associations of breeding Skylarks ***Alauda arvensis*** in the UK. ***Bird Study*** 46: 34-47.

Chamberlain, D.E., Wilson, A.M., Browne, S.J. & Vickery, J.A. (1999): Effects of habitat type and management on the abundance of skylarks in the breeding season. ***Journal of Applied Ecology*** 36: 856-870.

Chiverton, P.A. & Sotherton, N.W. (1991): The effects on beneficial arthropods of the exclusion of herbicides from cereal crop edges. ***Journal of Applied Ecology*** 28: 1027-1039.

Christensen, K.D., Falk, K. & Petersen, B.S. (1996): Feeding Biology of Danish Farmland Birds. A Litterature Study**. *Working Report*** No. 12, 1996. Ministry of Environment and Energy, Danish Environmental Protection Agency.

Christensen, S. & Rasmussen, J. (1998): Ukrudtsøkologi. Kapitel 2, side 13-40 i "***Ukrudtsbekæmpelse i landbruget***". Danmarks Jordbrugsforskning. Ministeriet for Fødevarer, Landbrug og Fiskeri.

Clements, D.R., Weise, S.F. & Swanton, C.J. (1994): Integrated weed management and weed species diversity. ***Phytoprotection*** 75: 1-18.

Courtney, A.D. & Johnston, R.T. (1986): An assessment of weed populations and yield response in spring barley subjected to a programme of reduced herbicide usage. ***Proceedings, EWRS symposium on economic weed control***: 301-308.

Cracknell, G.S. (1986): The effects on songbirds of leaving cereal crop headlands unsprayed. Report to The Game Conservancy. British Trust for Ornithology, Tring.

Cramp, S. & Simmons, K.E.L. (eds.) (1977-94): ***The Birds of the Western Palearctic,*** Vol. I-IX. Oxford University Press, Oxford.

Cromar, H.E., Murphy, S.D. & Swanton, C.J. (1999): Influence of tillage and crop residue on postdispersal predation of weed seeds. ***Weed Science*** 47: 184-194.

Danielsen, J. (1992): Registreringsmetode for bladlus i vårbyg. ***Nordisk Planteværnskonference***, Roskilde

Danish Agricultural Advisory Centre (2000): ***Planteavlsorientering*** 3, maj 2000. Nr. 09.459, Arkiv 681.1-3.

Danmarks Jordbrugsforskning & Landbrugets Rådgivningscenter (1997): ***Vejledning i Planteværn***. Landskontoret for Uddannelse, Skejby.

Danmarks Jordbrugsforskning & Landbrugets Rådgivningscenter (1998): ***Vejledning i Planteværn***. Landskontoret for Uddannelse, Skejby.

Danmarks Jordbrugsforskning & Landbrugets Rådgivningscenter (1999): ***Vejledning i Planteværn***. Landskontoret for Uddannelse, Skejby.

Danmarks Jordbrugsforskning & Landbrugets Rådgivningscenter (2000): ***Vejledning i Planteværn***. Landskontoret for Uddannelse, Skejby.

Danmarks Statistik (1992): Landbrugets anvendelse af pesticider i planteavlen 1981-1991. ***Statistiske Efterretninger, Miljø*** 1992:3, 1-15.

Danmarks Statistik (2001): Pesticidsalget og pesticidanvendelsen i landbrugets planteavl 2000. ***Statistiske Efterretninger, Miljø og Energi*** 2001:13, 1-16.

Davies, D.H.K., Lawson, H.M. & Wright, G.M. (1993): The response of Scottish cereal weed flora to reduced herbicide input strategies. ***Proceedings of a conference on crop protection in Northern Britain***: 61-66.

Davies, D.H.K. & Whiting, A.J. (1990): Effect of reducing herbicide dose on weed regrowth and crop safety in cereals and consequences for grain quality and harvesting. ***Proceedings, EWRS symposium on integrated weed management in cereals***: 331-338.

Davies, D.H.K., Whiting, A.J. & Whytock, G.M. (1989): Yield responses to herbicide use and weed levels in winter wheat and spring barley in Scottish trials and consequences for economic models**. *Brighton Crop Protection Conference: Weeds***: 955-960.

De Ruiter, H. & Meinen, E. (1998): Influence of water stress and surfactant on the efficacy, absorption and translocation of glyphosate. ***Weed Science*** 46: 289-296.

Debaeke, P. (1988): Population dynamics of some broad-leaved weeds in cereals: II. Survival and seed production. ***Weed Research*** 28: 265-280.

Derksen, D.A., Thomas, A.G., Lafond, G.P., Loeppky, H.A. & Swanton, C.J. (1995): Impact of post-emergence herbicides on weed community diversity within conservation-tillage systems. ***Weed Research*** 35: 311-320.

Diaz, M. (1990): Interspecific patterns of seed selection among granivorous passerines: Effects of seed size, seed nutritive value and bird morphology. ***Ibis*** 132: 467-476.

Dietrick, E.J. (1961): An improved backpack motor fan for suction sampling of insect populations. ***Journal of Economic Entomology*** 54: 394-395.

Dietrick, E.J., Schlinger, E.I. & van den Bosch, R. (1959): A new method for sampling arthropods using a suction collecting machine and modified Berlése funnel separator. ***Journal of Economic Entomology*** 52: 1085-1091.

Donald, P.F., Buckingham, D.L., Moorcroft, D., Muirhead, L.B., Evans, A.D. & Kirby, W.B. (2001): Habitat use and diet of skylarks ***Alauda arvensis*** wintering on lowland farmland in southern Britain. ***Journal of Applied Ecology*** 38: 536-547.

Ebadi, A., Sedgley, M., May, P. & Coombe, B.G. (1996): Seed development and abortion in ***Vitis vinifera*** L, cv Chardonnay. ***International Journal of Plant Sciences*** 157: 703-712.

Elmegaard, N., Rasmussen, P.N. & Poulsen, J.G. (1994): Arthropod food items in the Skylark (***Alauda arvensis***) in Danish fields. ***Working Report*** No. 46, 1996. Ministry of Environment and Energy, Danish Environmental Protection Agency.

Elmegaard, N.E., Andersen, P.N., Odderskær, P. & Prang, A. (1999): Food supply and breeding activity of Skylarks in fields with different pesticide treatment. In: Adams, N.J. & Slotow, R.H. (eds.) ***Proc. 22 Int. Ornithol. Congr., Durban***: 1058-1069. Birdlife South Africa, Johannesburg.

Erviö, L.R., Tanskanan, T. & Salonen, J. (1991): Profitability of chemical weed control in spring cereals. ***Annales Agriculturae Fenniae*** 30: 199-206.

Evans, A.D. (1998): Seed-eaters, stubble fields and set-aside. ***Brighton Crop Protection Conference 1997***: 907-914.

Fielder, A.G. (1987): Management options for field margins - an agricultural advisor's view. ***British Crop Protection Council Monograph*** 35: 85-94.

Fisher, N.M., Davies, D.H.K., Whytock, G.P. & Heppel, V.A.F. (1993): Factors affecting the dose response to herbicides in cereals. ***Proceedings of a conference on crop protection in Northern Britain***: 67-72.

Green, R. (1979): The ecology of wood mice (***Apodemus sylvaticus***) on arable farmland. ***Journal of Zoology*** 188: 357-378.

Green, R.E. (1980): Food selection by skylarks and grazing damage to sugar beet seedlings. ***Journal of Applied Ecology*** 17: 613-630.

Greig-Smith, P., Frampton, G. & Hardy, T. (1992): ***Pesticides, Cereal Farming and the Environment. The Boxworth Project***. - HMSO, London.

Gross, K.L. (1990): A comparison of methods for estimating seed numbers in the soil. ***Journal of Ecology*** 78: 1079-1093.

Grundy, A.C., Froud-Williams, R.J. & Boatman, N.D. (1993): The use of cultivar, crop seed rate and nitrogen level for the suppression of weeds in winter wheat. ***Brighton Crop Protection Conference: Weeds***: 997-1002.

Grøntved, J. & Sørensen, T. (1941): ***Nøgle til bestemmelse af danske græsser i blomsterløs tilstand***. Munksgaard, København.

Gyldenkærne, S., Ravn, H.P. & Halling-Sørensen, B. (2000): The effect of dimethoate and cypermethrin on soil-dwelling beetles under semi-field conditions. ***Chemosphere*** 41: 1045-1057.

Haas, H. & Laursen, F. (1994): ***Ukrudtskimplanter. Frøukrudt på bekæmpelsesstadiet***, 5. udgave. Jordbrugsforlaget, København.

Hald, A.B. (1993): Seed setting of a non-target wild plant species at sublethal herbicide doses. Proceedings, ***8th EWRS symposium on quantitative approaches in weed and herbicide research and their practical application***: 631-638.

Hald, A.B. (1997): Growth and Seed Production of 3 Weed Species at Sublethal Herbicide Dosage. ***Pesticides Research*** 30. Ministry of Environment and Energy, Denmark.

Hald, A.B. (1999): The impact of changing the season in which cereals are sown on the diversity of the weed flora in rotational fields in Denmark. ***Journal of Applied Ecology*** 36: 24-32.

Hald, A.B. & Lund, T. (1994): Fire sprøjtefri driftsformer af markers randzoner. Konsekvenser for vilde planter, insekter og økonomi. ***Faglig rapport fra DMU*** 103. Miljø- og Energiministeriet, Danmarks Miljøundersøgelser.

Hald, A.B., Overgaard Nielsen, B., Samsøe-Petersen, L., Hansen, K., Elmegaard, N. & Kjølholt, J. (1988): Sprøjtefri randzoner i kornmarker. ***Miljøprojekt*** 103. Miljøstyrelsen, København.

Hald, A.B. & Reddersen, J.T. (1990): Fugleføde i kornmarker - insekter og vilde planter. ***Miljøprojekt*** 125. Miljø- og Energiministeriet, Miljøstyrelsen, København.

Hanf, M. (1990): ***Ackerunkräuter Europas mit ihren Kimlingen und Samen***, 3rd edn. BLV Verlagsgesellschaft, München.

Hansen, K. (ed.) (1981): ***Dansk feltflora***. Gyldendal, København.

Hansen, M.S., Bromand, B. & Schulz, H. (1995): Fælles decimalskala for vækstudviklingen af planter (BBCH skala). ***Grøn viden*** 146: 1-16.

Hill, N.M., Patriquin, D.G. & Vander Kloet, S.P. (1989): Weed seed bank and vegetation at the beginning and end of the first cycle of a 4-course crop rotation with minimal weed control. ***Journal of Applied Ecology*** 26: 233-246.

Holm, S., Tersbøl, M. & Kristensen, H. (sine anno): ***Optimal ressourceudnyttelse i økologiske sædskifter – registrering, diagnosticering og varsling af skadegørere.*** Unpublished report.

Holm-Nielsen, C. (1998): ***Frø fra det dyrkede land***. Danmarks Jordbrugsforskning, Forskningscenter Flakkebjerg.

Hurka, H. & Haase, R. (1982): Seed ecology of ***Capsella bursa-pastoris*** (Cruciferae): Dispersal mechanism and the soil seed bank. ***Flora*** 172: 35-46.

Jenny, M. (1990a): Nahrungsökologie der Feldlerche ***Alauda arvensis*** in einer intensiv genutzten Agrarlandschaft des schweizerischen Mittellandes. ***Ornithol. Beob.*** 87: 31-53.

Jenny, M. (1990b): Territorialität und Brutbiologie der Feldlerche ***Alauda arvensis*** in einer intensiv genutzten Agrarlandschaft. ***Journal für Ornithologie*** 131: 241-265.

Jensen, H.A. (1969): Content of buried seeds in arable soil in Denmark and its relation to the weed population. ***Dansk Botanisk Arkiv*** 27: 1-56.

Jensen, H.A. & Kjellsson, G. (1995): Frøpuljens størrelse og dynamik i moderne landbrug 1. Ændringer af frøindholdet i agerjord 1964-1989. ***Bekæmpelsesmiddelforskning fra Miljøstyrelsen*** 13. Miljø- og Energiministeriet, Miljøstyrelsen. København.

Jensen, J.E. (2001): Sådan sprøjter landmændene – analyse af behandlingsindeks og måltal fra 1700 bedrifter. Abstract fra bilag til Efterårskonferencen 2. oktober 2001 afholdt på Hotel Nyborg Strand. Landbrugets Rådgivningscenter.

Jensen, P.K. (1985): A review of yield responses to weed control in one thousand spring barley experiments. ***British Crop Protection Conference: Weeds***: 687-692.

Jensen, P.K. (1986): Skadetærskler for tokimbladet ukrudt i vårbyg. ***Tidsskrift for Planteavl*** 90: 369-376.

Jensen, P.K. (1991): Behov og økonomi ved ukrudtsbekæmpelse i landbrugsafgrøder. ***Bilag til Møder om Planteværn, Landbrugsafgrøder***: 14-16. Landbrugets Rådgivningscenter, Landskontoret for Planteavl, Skejby.

Jensen, P.K. (1996): Comparison of different weed-rankings as predictors of yield loss. ***Pesticides Research*** 22. Ministry of Environment and Energy, Danish Environmental Protection Agency.

Jones, N.E., Burn, A.J. & Clarke, J.H. (1997): The effects of herbicide input level and rotation on winter seed availability for birds. ***Brighton Crop Protection Conference: Weeds***: 1161-1166.

Kennedy, K.A. & Addison, P.A. (1987): Some considerations for the use of visual estimates of plant cover in biomonitering. ***Journal of Ecology*** 75: 151-157.

Kjær, C. & Elmegaard, N. (1996): Effect of herbicide treatment on host plant quality for a leaf-eating beetle. ***Pesticide Science*** 47: 319-325.

Kjær, C. & Jepson, P.C. (1995): The toxic effects of direct pesticide exposure for a nontarget weed-dwelling chrysomelid beetle (***Gastrophysa polygoni***) in cereals. ***Environmental Toxicology and Chemistry*** 14: 993-999.

Korsmo, E. (1926): ***Ogräs. Ogräsarternas Liv och Kampen mot dem i Nutidens Jordbruk***. Albert Bonniers Förlag, Stockholm.

Kudsk, P. (1989): Experiences with reduced herbicide doses in Denmark and the development of the concept of factor-adjusted doses. ***Brighton Crop Protection Conference: Weeds***: 545-554.

Kudsk, P. & Mathiassen, S.K. (1991): Reducerede doser at ukrudtsmidler. ***Bilag til Møder om Planteværn, Landbrugsafgrøder***: 11-13. Landbrugets Rådgivningscenter, Landskontoret for Planteavl, Skejby.

Landboforeningerne (2001): ***Landøkonomisk Oversigt 2001***. Landboforeningerne.

Landbrugets Rådgivningscenter (1998): ***Budgetkalkuler 98 for de enkelte produktionsgrene 1997 og 1998***. Landskontoret for Uddannelse, Skejby.

Landbrugets Rådgivningscenter (1999a): ***Budgetkalkuler 99 for de enkelte produktionsgrene 1998 og 1999***. Landskontoret for Uddannelse, Skejby.

Landbrugets Rådgivningscenter (1999b): ***Oversigt over Landsforsøgene. Forsøg og undersøgelser i de landøkonomiske foreninger 1999.*** Landsudvalget for Planteavl, Landbrugets Rådgivningscenter, Skejby.

Landbrugets Rådgivningscenter (2000a): ***Budgetkalkuler 2000 for de enkelte produktionsgrene 1999 og 2000***. Landskontoret for Uddannelse, Skejby.

Landbrugets Rådgivningscenter (2000b): ***Oversigt over Landsforsøgene. Forsøg og undersøgelser i de landøkonomiske foreninger 2000.*** Landsudvalget for Planteavl, Landbrugets Rådgivningscenter, Skejby.

Leguizamon, E.S. & Roberts, H.A. (1982): Seed production by an arable weed community. ***Weed Research*** 22: 35-39.

Lindroth, C.H. (1985): The Carabidae (Coleoptera) of Fennoscandia and Denmark. ***Fauna Entomologica Scandinavica*** 15 (1). E.J. Brill, Scandinavian Science Press Ltd. Leiden & Copenhagen.

Lindroth, C.H. (1986): The Carabidae (Coleoptera) of Fennoscandia and Denmark. ***Fauna Entomologica Scandinavica*** 15 (2). E.J. Brill, Scandinavian Science Press Ltd. Leiden & Copenhagen.

Lövei, G.L. & Sunderland, K.D. (1996): Ecology and behaviour of ground beetles (Coleoptera: Carabidae). ***Annual Review of Entomology*** 41: 231-256.

Marshall, E.J.P. (1989): Distribution patterns of plants associated with arable field edges. ***Journal of Applied Ecology*** 26: 247-258.

McLaughlin, A. & Mineau, P. (1995): The impact of agricultural practices on biodiversity. ***Agriculture, Ecosystems & Environment*** 55: 201-212.

Melander, B. (1993): Beskrivelse of ukrudtsarterne. I: ***Ukrudtsbekæmpelse i landbruget***: 41-186. Statens Planteavlsforsøg, Flakkebjerg.

Mikkelsen, V.M. (1989): Cultivated fields. *Opera Botanica* **96**: 73-80.

Milberg, P., Hallgren, E. & Palmer, M.W. (2000): Interannual variation in weed biomass on arable land in Sweden. ***Weed Research*** 40: 311-321.

Miljøstyrelsen (1998): Bekæmpelsesmiddelstatistik 1997. Salg 1995, 1996, 1997: Behandlingshyppighed 1997. ***Orientering fra Miljøstyrelsen*** nr. 6 1998. Miljø- og Energiministeriet. Miljøstyrelsen. Danmark.

Miljøstyrelsen (1999): Bekæmpelsesmiddelstatistik 1998. Salg 1996, 1997, 1998: Behandlingshyppighed 1998. ***Orientering fra Miljøstyrelsen*** nr. 5, 1999. Miljø- og Energiministeriet. Miljøstyrelsen. Danmark.

Miljøstyrelsen (2000): Bekæmpelsesmiddelstatistik 1999. Salg 1997,1998 og 1999: Behandlingshyppighed 1999. ***Orientering fra Miljøstyrelsen*** nr. 11, 2000. Miljø- og Energiministeriet. Miljøstyrelsen. Danmark.

Moreby, S.J. (1997): The effects of herbicide use within cereal headlands on the availability of food for arable birds. ***Brighton Crop Protection Conference: Weeds***: 1197-1202.

Mortimer, A.M. (1976): Aspects of the seed population dynamics of ***Dactylis glomerata*** L., ***Holcus lanatus*** L., ***Plantago lanceolata*** L. and ***Poa annua*** L. ***British Crop Protection Conference: Weeds***: 687-694.

Nielsen, G.C., Juhl, O., Andreasen, F.M. (2000): ***Planteværn – vurdering og dosering – kursusmaterialer om skadedyr i vinterhvede.*** Landbrugets rådgivningscenter, Danmark.

Nielsen, N.P.O. & Sell, H. (1986): ***Betydningen af insektfauna, flora og pesticidsprøjtninger for Tornsanger*** Sylvia communis ***i læhegn.*** Unpublished M.Sc. thesis, Institut for Zoologi og Zoofysiologi, Aarhus Universitet, Danmark.

Odderskær, P., Prang, A., Elmegaard, N. & Andersen, P.N. (1997a): Skylark Reproduction in Pesticide Treated and Untreated Fields. ***Pesticides Research*** 32. Ministry of Environment and Energy, Danish Environmental Protection Agency.

Odderskær, P., Prang, A., Poulsen, J.G., Andersen, P.N. & Elmegaard, N. (1997b): Skylark ***(Alauda arvensis)*** utilisation of micro-habitats in spring barley fields. ***Agriculture, Ecosystems & Environment*** 62: 21-29.

Ogunremi, E.A. (1986): Effects of nitrogen fertilization and harvest time on sunflower (***Helianthus annuus***) yield and hollow seededness. ***Field Crops Research*** 13: 45-54.

Olofsdotter, M., Olesen, A., Andersen, S.B. & Streibig, J.C. (1994): A comparison of herbicide bioassays in cell cultures and whole plants. ***Weed Research*** 34: 387-394.

Pallutt, B. von (1999): Einfluss von Fruchtfolge, Bodenbearbeitung und Herbizidanwendung auf Populationsdynamik und Konkurrenz von Unkräutern in Wintergetreide. ***Gesunde Pflanzen*** 51: 109-120.

Petersen, B.S. (1996): The distribution of birds in Danish farmland. ***Pesticides Research*** 17. Ministry of Environment and Energy, Danish Environmental Protection Agency.

Petersen, B.S. & Nøhr, H. (1992): Pesticiders indflydelse på gulspurvens levevilkår. ***Bekæmpelsesmiddelforskning fra Miljøstyrelsen*** 1. Miljø- og Energiministeriet, Miljøstyrelsen. København.

Potts, G.R. (1986): The Partridge. Pesticides, Predation and Conservation. Collins, London.

Rasmussen, I.A. (1993a): Seed production of a mixture of two Polygonum species at normal to very low herbicide doses. ***Brighton Crop Protection Conference: Weeds***: 281-286.

Rasmussen, I.A. (1993b): Seed production of ***Chenopodium album*** in spring barley sprayed with different herbicides in normal to very low doses. Proceedings ***8th EWRS symposium on quantitative approaches in weed and herbicide research and their practical application***: 639-646.

Rasmussen, I.A., Melander, B., Rasmussen, K. & Rasmussen, J. (1997): Regulering af ukrudt. ***SP-rapport*** 15: 63-86.

Roberts, H.A. (1981): Seed banks in soils. ***Advances in Applied Biology*** 6: 1-55.

Roberts, H.A. & Ricketts, M.E. (1979): Quantitative relationships between the weed flora after cultivation and the seed population in the soil. ***Weed Research*** 19: 269-271.

Robinson, R.A. & Sutherland, W.J. (1999): The winter distribution of seed-eating birds: habitat structure, seed density and seasonal depletion. ***Ecography*** 22: 447-454.

Rogers, L.E., Hinds, W.T. & Buschbom, R.L. (1977): A general weight vs. length relationship for insects. ***Annals of Entomological Society of America*** 69: 387-389.

Salisbury, E.J. (1942): ***The Reproduction Capacity of Plants. Studies in Quantitative Biology***. G. Bell and Sons Ltd., London.

Salonen, J. (1992a): Efficacy of reduced herbicide doses in spring cereals of different competitive ability. ***Weed Research*** 32: 483-491.

Salonen, J. (1992b): Yield responses of spring cereals to reduced herbicide doses. ***Weed Research*** 32: 493-499.

Salonen, J. (1993a): Performance of reduced herbicide doses in spring cereals. ***Agricultural Science in Finland*** 2: 537-549.

Salonen, J. (1993b): Reducing herbicide use in spring cereal production. ***Agricultural Science in Finland Suppl.*** 2: 7-43.

Salonen, J. (1993c): Weed infestation and factors affecting weed incidence in spring cereals in Finland - a multivariate approach. ***Agricultural Science in Finland*** 2: 525-535.

Samsøe-Petersen, L. (1993): Effects of 45 insecticides, acaricides and molluscicides on the rove beetle ***Aleochara bilineata*** (Col.: Staphylinidae) in the laboratory. ***Entomophaga*** 38: 371-382.

Samsøe-Petersen (1995a): Effects of 67 herbicides and plant growth regulators on the rove beetle ***Aleochara bilineata*** (Col.: Staphylinidae) in the laboratory. ***Entomophaga*** 40: 95-104.

Samsøe-Petersen (1995b): Effects of 37 fungicides on the rove beetle ***Aleochara bilineata*** (Col.: Staphylinidae) in the laboratory. ***Entomophaga*** 40: 145-152.

SAS Institute (1990): ***SAS/STAT user's guide***, version 6, 4th edition. SAS Institute, Cary, NC.

SAS Institute (1999): ***Statistical Analysis System,*** version 8.00. SAS Institute, Cary NC, USA.

Schläpfer, A. (1988): Populationsökologie der Feldlerche ***Alauda arvensis*** in der intensiv genutzten Agrarlandschaft. ***Ornithol. Beob.*** 85: 309-371.

Scragg, E.B. (1980): Cost-effective weed control in spring barley in the north of Scotland. ***British Crop Protection Conference: Weeds***: 69-74.

Sheppard, B.W., Richards, M.C. & Pascal, J.A. (1984): Agronomic effects from the control of ***Agropyron repens*** in barley by pre-harvest application of glyphosate. ***Weed Research*** 24: 9-16.

Silvertown, J. & Dale, P. (1991): Competitive hierarchies and the structure of herbaceous plant communities. ***Oikos*** 61: 441-444.

Skorda, E.A., Adamidis, T.H. & Efthimiadis, P.G. (1995): Long-term effects of reduced herbicide use on weed populations and crop yield in wheat. ***Brighton Crop Protection Conference: Weeds***: 695-700.

Smartt, P.F.M., Meacock, S.E. & Lambert, J.M. (1974): Investigations into the properties of quantitative vegetational data. I. Pilot study. ***Journal of Ecology*** 62: 735-759.

Sotherton, N.W. (1982): The effects of herbicides on the chrysomelid beetsle ***Gastrophysa polygoni*** (L.) in laboratory and field. ***Zeitschrift für Angewandte Entomologie*** 7: 1996-1999.

Sotherton, N.W. & Moreby, S.J. (1992): The importance of beneficial arthropods other than natural enemies in cereal fields. ***Aspects of Applied Biology*** 31: 11-18.

Steenfeldt, S., Rasmussen, P.N. & Jensen, T.S. (1991): Food selection in a population of Partridge *Perdix perdix* in Danish arable farmland. *Dansk Ornitologisk Forenings Tidsskrift* **85**: 67-76.

Stevens, O.A. (1932): The number and weight of seeds produced by weeds. ***American Journal of Botany*** 19: 784-795.

Stoate, C., Moreby, S.J. & Szczur, J. (1998): Breeding ecology of farmland Yellowhammers ***Emberiza citrinella***. ***Bird Study*** 45: 109-121.

Stoltze, M. & Pihl, S. (eds.) (1998): ***Rødliste 1997 over planter og dyr i Danmark***. Miljø- og Energiministeriet, Danmarks Miljøundersøgelser og Skov- og Naturstyrelsen, København.

Streibig, J.C. (1992): *Quantitative Assessment of Herbicide Phytotoxicity with Dilution Assay.* Ph.D.-thesis. Department of Agricultural Sciences, Royal Veterinary and Agricultural University, Copenhagen.

Streibig, J.C., Jensen, J.E., Olofsdotter, M., Haas, H., Andreasen, C. & Lawaetz, E. (1993): Testing hypotheses with dose-response curves. *8th EWRS Symposium "Quantitative approaches in weed and herbicide research and their practical application"*: 423-431.

Stryhn, H. (1996): ***Longitudinale data: Simple univariate analysemetoder***. Institute of Mathematics and Statistics. Royal Veterinary and Agricultural University, Copenhagen.

Sunderland, K.D. & Vickerman, P. (1980): Aphid feeding by some polyphagous predators in relation to aphid density in cereal fields. ***Journal of Applied Ecology*** 17: 389-396.

Sunderland, K.D., De Snoo, G.R., Dinter, A., Hance, T., Heleniuss, J., Jepson, P., Kromp, B., Lys, J.-A., Samu, F., Sotherton, N.W., Toft, S. & Ulber, B. (1995): Density estimation for invertebrate predators in agroecosystems. In: Toft, S. & Riedel, W. (eds.). Arthropod natural enemies in arable land I / Density, spatial heterogeneity and dispersal. ***Acta Jutlandica*** 70 (2): 133-162.

Thiele, H.-U. (1977): ***Carabid Beetles in their Environments***. Springer-Verlag, Berlin.

Thomas, C.F.G. & Marshall, E.J.P. (1999): Arthropod abundance and diversity in differently vegetated margins of arable fields. ***Agriculture, Ecosystems and Environment*** 72: 131-144.

Thompson, B.K., Weiner, J. & Warwick, S.I. (1991): Size-dependent reproductive output in agricultural weeds. *Canadian Journal of Botany* **69**: 442-446.

Toepfer, S. & Stubbe, M. (2001): Territory density of the Skylark ***(Alauda arvensis)*** in relation to field vegetation in central Germany. ***Journal für Ornithologie*** 142: 184-194.

Traugott, T. (1998): Larval and adult species composition, phenology and life cycles of carabid beetles (Coleoptera: Carabidae) in an organic potato field. ***Eur. J. Soil Biol 34***: 184-197.

Tsuyuzaki, S. (1993): Seed viability after immersion in K_2CO_3 solution. ***Seed Science and Technology*** 21: 479-481.

Tutin, T.G., Heywood, V.H., Burges, N.A., Valentine, D.H., Walters, S.M. & Webb, D.A. (eds.) (1964-1980): ***Flora Europaea*** (1-5). University Press, Cambridge.

Valenti, S.A. & Wicks, G.A. (1992): Influence of nitrogen rates and wheat (***Triticum aestivum***) cultivars on weed control. ***Weed Science*** 40: 115-121.

Van der Wolf, H.W. (1992): The host-plants and larval cases of ***Coleophora therinella*** and ***Coleophora peribenanderi*** (Lepidoptera: Coleophoridae). ***Entomologische Berichten*** 52: 47-49.

Wakeham-Dawson, A. & Aebischer, N.J. (1998): Factors determining winter densities of birds on Environmentally Sensitive Area arable reversion grassland in southern England, with special reference to skylarks (***Alauda arvensis***). ***Agriculture, Ecosystems and Environment*** 70: 189-201.

Watkinson, A.R. (1980): Density-dependence in single-species populations of plants. ***Journal of Theoretical Biology*** 83: 345-358.

Whiting, A.J., Davies, D.H.K., Brown, H. & Whytock, G.P. (1991): The field use of reduced doses of broad-leaved weed herbicides in cereals. ***Brighton Crop Protection Conference: Weeds***: 1209-1216.

Wilson, B.J. (1986): Yield responses of winter cereals to the control of broadleaved weeds. ***Proceedings, EWRS symposium on economic weed control***: 75-82.

Wilson, B.J. & Lawson, H.M. (1992): Seedbank persistence and seedling emergence of seven weed species in autumn-sown crops following a single year's seeding. ***Annals of Applied Biology*** 120: 105-116.

Wilson, B.J. & Wright, K.J. (1987): Variability in the growth of cleavers (***Galium aparine***) and their effect on wheat yield. ***British Crop Protection Conference: Weeds***: 1051-1058.

Wilson, B.J. & Wright, K.J. (1990): Predicting the growth and competitive effects of annual weeds in wheat. ***Weed Research*** 30: 201-212.

Wilson, B.J., Wright, K.J. & Caseley, J.C. (1994): Weed population trends with reduced inputs over five years. ***Aspects of Applied Biology*** 40: 393-397.

Wilson, J.D., Evans, J., Browne, S.J. & King, J.R. (1997): Territory distribution and breeding success of skylarks ***Alauda arvensis*** on organic and intensive farmland in southern England. ***Journal of Applied Ecology*** 34: 1462-1478.

Wilson, J.D., Taylor, R. & Muirhead, B. (1996): Field use by farmland birds in winter: an analysis of field type preferences using resampling methods. ***Bird Study*** 43: 320-332.

Wilson, P.J. & Aebischer, N.J. (1995): The distribution of dicotyledonous arable weeds in relation to distance from the field edge. ***Journal of Applied Ecology*** 32: 295-310.

Herbicide and insecticide applications 1996-1999

Appendix A.1. Herbicides and insecticides used in the pilot year (1996), trade name, normal dosage per hectare, active ingredient(s) and treatment intensity index. Normal dosage is not equal recommended dosage, see section 1.2.4 for a definition of normal dosage. A treatment intensity index of 1.00 for a particular product is given for application of the recommended dosage in a certain crop according to the list of recommended dosages (Statens Planteavlsforsøg 1997). All herbicides and insecticides have been applied in reduced dosages at the plots destined for reduced dosages.

Farm and Year	Crop	Date	Trade name	Normal dosage/ha		Active ingredient(s)			Treatment intensity index
				Herbicides					
Gjorslev 1996	Barley	14 May	Arelon	2.00	l	Isoproturon	500	g a.i./l	0.80
		1 June	Express	0.50	tb *	Tribenuron-methyl	500	g a.i./kg	0.25
			Oxitril	0.20	l	Ioxynil	200	g a.i./l	0.20
						Bromoxynil	200	g a.i./l	
	Wheat[1]								
	Beets	2 May	Ethosan	0.10	l	Ethofumesat	500	g a.i./l	0.13
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
			Herbasan	1.00	l	Phenmedipham	160	g a.i./l	0.17
			Matrigon	0.20	l	Clopyralid	100	g a.i./l	0.17
		8 May	Ethosan	0.10	l	Ethofumesat	500	g a.i./l	0.13
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
			Herbasan	1.00	l	Phenmedipham	160	g a.i./l	0.17
			Matrigon	0.20	l	Clopyralid	100	g a.i./l	0.17
				Insecticides					
	Barley	-	-	0.00	-	-	-	-	0.00
	Wheat	-	-	0.00	-	-	-	-	0.00
	Beets	8 May	Karate	0.20	l	Lambda-cyhalothrin	25	g a.i./l	0.67
		22 July	Perfekthion EC 40	0.80	l	Dimethoate	400	g a.i./l	1.00
		18 July	Karate	0.30	l	Lambda-cyhalothrin	25	g a.i./l	1.00
		4 Aug	Pirimor	0.30	kg	Pirimicarb	500	g a.i./kg	1.00

[1]All herbicides applications in wheat was performed autumn 1995 and was therefore identical in all plots.
* one tablet (tb) weights 7.5 gram.

Appendix A.2. Herbicides and insecticides used in the growing season 1996/1997, trade name, normal dosage per hectare, active ingredient(s) and treatment intensity index. Normal dosage is not equal recommended dosage, see section 1.2.4 for a definition of normal dosage. A treatment intensity index of 1.00 for a particular product is given for application of the recommended dosage in a certain crop according to the list of recommended dosages (Statens Planteavlsforsøg 1997). All herbicides and insecticides have been sprayed at reduced dosages in the plots destined for reduced dosages, the exceptions are herbicides in italics, which have been sprayed at normal dosage in all plots.

Farm and Year	Crop	Date	Trade name	Normal dosage/ha		Active ingredient(s)			Treatment intensity index
				Herbicides					
Gjorslev 1997	Barley	15 May	Express	0.50	tb *	Tribenuron-methyl	500	g a.i./kg	0.25
			Oxitril	0.20	l	Ioxynil	200	g a.i./l	0.20
						Bromoxynil	200	g a.i./l	
		28 Sept	*Kvikdown*	*2.00*	*l*	*Glyphosate*	*360*	*g a.i./l*	*1.00*
	Wheat	10 Oct	IPU	1.00	l	Isoproturon	500	g a.i./l	0.40
			Stomp SC	1.00	l	Pendimethalin	400	g a.i./l	0.25
		4 Sept	*Kvikdown*	*2.00*	*l*	*Glyphosate*	*360*	*g a.i./l*	*1.00*
	Beets	9 May	Ethosan	0.10	l	Ethofumesat	500	g a.i./l	0.13
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
			Herbasan	1.00	l	Phenmedipham	160	g a.i./l	0.17
			Matrigon	0.20	l	Clopyralid	100	g a.i./l	0.17
		16 May	Ethosan	0.20	l	Ethofumesat	500	g a.i./l	0.25
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
			Herbasan	1.00	l	Phenmedipham	160	g a.i./l	0.17
			Matrigon	0.20	l	Clopyralid	100	g a.i./l	0.17
				Insecticides					
	Barley	7 July	Pirimor	0.12	kg	Pirimicarb	500	g a.i./kg	0.48
	Wheat	10 July	Pirimor	0.10	kg	Pirimicarb	500	g a.i./kg	0.40
	Beets	18 May	Karate	0.20	l	Lambda-cyhalothrin	25	g a.i./l	0.67
		9 July	Perfekthion EC 40	1.00	l	Dimethoate	400	g a.i./l	1.20
		18 July	Pirimor	0.30	kg	Pirimicarb	500	g a.i./kg	1.00
				Herbicides					
Oremandsgård 1997	Barley	15 May	Express	0.10	tb*	Tribenuron-methyl	500	g a.i./kg	0.05
		30 May	Express	0.50	tb*	Tribenuron-methyl	500	g a.i./kg	0.25
			Metaxon	1.50	l	MCPA	750	g a.i./l	0.75
			Starane 180	0.25	l	Fluroxypyr	180	g a.i./l	0.36
	Wheat	23 Oct	Flexidor	0.05	l	Isoxaben	500	g a.i./l	0.20
			Mylone Power	0.50	l	Ioxynil	160	g a.i./l	0.25
						Mechlorprop	480	g a.i./l	
			Tolkan	1.50	l	Isoproturon	500	g a.i./l	0.60
		15 May	Express	1.00	tb*	Tribenuron-methyl	500	g a.i./kg	0.50
			Starane 180	0.30	l	Fluroxypyr	180	g a.i./l	0.38
	Beets	8 May	Ethosan	0.15	l	Ethofumesat	500	g a.i./l	0.19
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
			Herbasan	1.25	l	Phenmedipham	160	g a.i./l	0.21
			Matrigon	0.30	l	Clopyralid	100	g a.i./l	0.25
		16 May	Ethosan	0.15	l	Ethofumesat	500	g a.i./l	0.19
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
			Herbasan	1.25	l	Phenmedipham	160	g a.i./l	0.21
			Matrigon	0.30	l	Clopyralid	100	g a.i./l	0.25
		2 June	Ethosan	0.15	l	Ethofumesat	500	g a.i./l	0.19
			Goltix	0.50	kg	Metamitron	700	g a.i./kg	0.11
			Herbasan	1.25	l	Phenmedipham	160	g a.i./l	0.21
				Insecticides					
	Barley	23 June	Karate	0.15	l	Lambda-cyhalothrin	25	g a.i./l	0.50
	Wheat	7 July	Pirimor	0.10	kg	Pirimicarb	500	g a.i./kg	0.40
	Beets	8 May	Karate	0.15	l	Lambda-cyhalothrin	25	g a.i./l	0.50
		9 July	Perfektion EC20	1.00	l	Dimethoate	200	g a.i./l	Field edge

Appendix A.2 continued

Farm and Year	Crop	Date	Trade name	Normal dosage/ha		Active ingredient(s)			Treatment intensity index
					Herbicides				
Lekkende 1997	Barley	24 Apr	DLG Flux	1.75	l	Clopyralid	20	g a.i./l	0.88
						Fluroxypyr	40	g a.i./l	
						MCPA	200	g a.i./l	
		14 Aug	Roundup	2.00	l	Glyphosate	360	g a.i./l	0.67
	Wheat	11 Oct	IPU	1.50	l	Isoproturon	500	g a.i./l	0.60
			Mylone Power	0.50	l	Ioxynil	160	g a.i./l	0.25
						Mechlorprop	480	g a.i./l	
		9 May	DLG Flux	1.50	l	Clopyralid	20	g a.i./l	0.50
						Fluroxypyr	40	g a.i./l	
						MCPA	200	g a.i./l	
			Starane 180	0.20	l	Fluroxypyr	180	g a.i./l	0.25
		6 Aug	Roundup Bio	2.50	l	Glyphosate	360	g a.i./l	0.83
	Beets	9 May	Betasana Flow	1.00	l	Phenmedipham	160	g a.i./l	0.17
			Ethuron	0.13	l	Ethofumesat	500	g a.i./l	0.16
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
		17 May	Betasana Flow	1.20	l	Phenmedipham	160	g a.i./l	0.20
			Ethuron	0.13	l	Ethofumesat	500	g a.i./l	0.16
			Goltix	0.60	kg	Metamitron	700	g a.i./kg	0.13
			Matrigon	0.20	l	Clopyralid	100	g a.i./l	0.17
		6 June	Betasana Flow	1.50	l	Phenmedipham	160	g a.i./l	0.25
			Ethuron	0.15	l	Ethofumesat	500	g a.i./l	0.19
			Goltix	0.50	kg	Metamitron	700	g a.i./kg	0.11
					Insecticides				
	Barley	25 June	Decis	0.20	l	Deltamethrin	25	g a.i./l	0.80
	Wheat	25 June	Decis	0.20	l	Deltamethrin	25	g a.i./l	1.00
	Beets	9 May	Decis	0.30	l	Deltamethrin	25	g a.i./l	1.00
		17 May	Decis	0.30	l	Deltamethrin	25	g a.i./l	1.00
					Herbicides				
Nøbøllegård 1997	Barley	26 May	Express	0.75	tb*	Tribenuron-methyl	500	g a.i./kg	0.38
			Herbatox D500	0.50	l	2,4-D	500	g a.i./l	0.50
		3 June	*Primera*	*0.50*	*l*	*Fenoxaprop-p-ethyl*	*69*	*g a.i./l*	*0.63*
	Wheat	*11 Oct*	*IPU 500*	*1.00*	*l*	*Isoproturon*	*500*	*g a.i./l*	*0.40*
			Stomp	*1.00*	*l*	*Pendimethalin*	*400*	*g a.i./l*	*0.25*
		4 June	*Express*	*0.50*	*tb**	*Tribenuron-methyl*	*500*	*g a.i./kg*	*0.25*
			Starane 180	*0.60*	*l*	*Fluroxypyr*	*180*	*g a.i./l*	*0.75*
	Beets	*16 May*	*Betasana Flow*	*1.00*	*l*	*Phenmedipham*	*160*	*g a.i./l*	*0.17*
			Ethuron	*0.10*	*l*	*Ethofumesat*	*500*	*g a.i./l*	*0.13*
			Goltix	*1.00*	*kg*	*Metamitron*	*700*	*g a.i./kg*	*0.22*
		23 May	Betasana Flow	1.50	l	Phenmedipham	160	g a.i./l	0.25
			Ethuron	0.15	l	Ethofumesat	500	g a.i./l	0.19
			Goltix	0.50	kg	Metamitron	700	g a.i./kg	0.11
		4 June	Gallant	1.25	l	Haloxyfop	125	g a.i./l	0.63
			Matrigon	1.00	l	Clopyralid	100	g a.i./l	0.83
		11 June	Betasana Flow	2.00	l	Phenmedipham	160	g a.i./l	0.33
			Ethuron	0.20	l	Ethofumesat	500	g a.i./l	0.25
					Insecticides				
	Barley	-	-	0.00	-	-	-	-	0.00
	Wheat	2 July	Pirimor	0.10	kg	Pirimicarb	500	g a.i./kg	0.40
	Beets	-	-	0.00	-	-	-	-	0.00

continues

Appendix A.2 continued

Farm and Year	Crop	Date	Trade name	Normal dosage/ha		Active ingredient(s)			Treatment intensity index
				Herbicides					
Nordfeld 1997	Barley	24 May	Express	1.00	tb*	Tribenuron-methyl	500	g a.i./kg	0.50
			Starane 180	0.20	l	Fluroxypyr	180	g a.i./l	0.29
		18 June	Danacetat	1.00	l	MCPA	750	g a.i./l	0.50
	Wheat	15 Nov	Flexidor	0.05	l	Isoxaben	500	g a.i./l	0.20
			IPU	1.75	l	Isoproturon	500	g a.i./l	0.70
			Mylone Power	0.75	l	Ioxynil	160	g a.i./l	0.38
						Mechlorprop	480	g a.i./l	
		15 May	Express	1.00	tb*	Tribenuron-methyl	500	g a.i./kg	0.50
			Starane 180	0.40	l	Fluroxypyr	180	g a.i./l	0.50
		5 Aug	Kvikdown2000	1.60	l	Glyphosate	400	g a.i./l	0.80
	Beets	9 May	Ethosan	0.09	l	Ethofumesat	500	g a.i./l	0.11
			Goltix WG	0.95	kg	Metamitron	700	g a.i./kg	0.21
			Herbasan	1.23	l	Phenmedipham	160	g a.i./l	0.21
		16 May	Ethosan	0.10	l	Ethofumesat	500	g a.i./l	0.13
			Goltix WG	1.03	kg	Metamitron	700	g a.i./kg	0.23
			Herbasan	1.55	l	Phenmedipham	160	g a.i./l	0.26
		5 June	Ethosan	0.16	l	Ethofumesat	500	g a.i./l	0.20
			Herbasan	1.55	l	Phenmedipham	160	g a.i./l	0.26
			Safari	20.7	g	Triflusulfuron-methyl	1000	g a.i./kg	0.23
				Insecticides					
	Barley	18 June	Sumi-Alpha 5 FW	0.10	l	Esfenvalerat	50	g a.i./l	0.50
	Wheat	26 June	Sumi-Alpha 5 FW	0.10	l	Esfenvalerat	50	g a.i./l	0.50
	Beets	16 May	Sumi-Alpha 5 FW	0.10	l	Esfenvalerat	50	g a.i./l	0.40

* one tablet (tb) weights 7.5 gram.

Appendix A.3. Herbicides and insecticides used in the growing season 1997/1998, trade name, normal dosage per hectare, active ingredient(s) and treatment intensity index. Normal dosage is not equal recommended dosage, see section 1.2.4 for a definition of normal dosage. A treatment intensity index of 1.00 for a particular product is given for application of the recommended dosage in a certain crop according to the list of recommended dosages (Statens Planteavlsforsøg 1998). All herbicides and insecticides have been sprayed at reduced dosages in the plots destined for reduced dosages.

Farm and Year	Crop	Date	Trade name	Normal dosage/ha		Active ingredient(s)			Treatment intensity index
			Herbicides						
Gjorslev 1998	Barley	15 May	Express	0.75	tb *	Tribenuron-methyl	500	g a.i./kg	0.38
			Oxitril	0.30	l	Ioxynil	200	g a.i./l	0.30
						Bromoxynil	200	g a.i./l	
	Wheat	25 Sept	Stomp SC	1.00	l	Pendimethalin	400	g a.i./l	0.25
			Tolkan	1.50	l	Isoproturon	500	g a.i./l	0.60
		14 May	MCPA (75%)	1.00	l	MCPA	750	g a.i./l	0.50
	Beets	2 May	Ethosan	0.10	l	Ethofumesat	500	g a.i./l	0.13
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
			Herbasan	1.00	l	Phenmedipham	160	g a.i./l	0.17
			Matrigon	0.20	l	Clopyralid	100	g a.i./l	0.17
		10 May	Ethosan	0.20	l	Ethofumesat	500	g a.i./l	0.25
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
			Herbasan	1.00	l	Phenmedipham	160	g a.i./l	0.17
			Matrigon	0.20	l	Clopyralid	100	g a.i./l	0.17
			Insecticides						
	Barley	11 June	Pirimor	0.20	kg	Pirimicarb	500	g a.i./kg	0.80
	Wheat	24 June	Pirimor	0.08	kg	Pirimicarb	500	g a.i./kg	0.32
	Beets	10 May	Karate	0.20	l	Lambda-cyhalothrin	25	g a.i./l	0.67
		8 July	Karate	0.20	l	Lambda-cyhalothrin	25	g a.i./l	0.67
		24 July	Pirimor	0.30	kg	Pirimicarb	500	g a.i./kg	1.00
			Herbicides						
Oremandsgård 1998	Barley	15 May	Express	1.50	tb*	Tribenuron-methyl	500	g a.i./kg	0.75
			Starane 180	0.40	l	Fluroxypyr	180	g a.i./l	0.57
		17 Sept	Touchdown	3.00	l	Glyphosate-trimesium	480	g a.i./l	1.20
	Wheat	10 Nov.	Stomp SC	1.00	l	Pendimethalin	400	g a.i./l	0.25
			Tolkan	1.00	l	Isoproturon	500	g a.i./l	0.40
		9 May	Express	1.00	tb*	Tribenuron-methyl	500	g a.i./kg	0.50
			Starane 180	0.40	l	Fluroxypyr	180	g a.i./l	0.50
		13 Oct.	Touchdown	3.00	l	Glyphosate-trimesium	480	g a.i./l	1.20
	Beets	10 May	Betasana Flow	1.30	l	Phenmedipham	160	g a.i./l	0.22
			Ethuron	0.10	l	Ethofumesat	500	g a.i./l	0.13
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
		18 May	Betasana Flow	1.50	l	Phenmedipham	160	g a.i./l	0.25
			Ethuron	0.15	l	Ethofumesat	500	g a.i./l	0.19
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
		28 May	Betasana Flow	1.00	l	Phenmedipham	160	g a.i./l	0.17
			Ethuron	0.20	l	Ethofumesat	500	g a.i./l	0.25
			Goltix	0.75	kg	Metamitron	700	g a.i./kg	0.17
			Safari	20	g	Triflusulfuron-methyl	1000	g a.i./kg	0.22
			Insecticides						
	Barley	16 June	Pirimor	0.05	kg	Pirimicarb	500	g a.i./kg	0.20
			Mavrik 2F	0.05	l	Tau-fluvalinat	240	g a.i./l	0.25
	Wheat	23 June	Mavrik 2F	0.10	l	Tau-fluvalinat	240	g a.i./l	0.50
	Beets	22 July	Pirimor	0.30	kg	Pirimicarb	500	g a.i./kg	1.00

continues

Appendix A.3 continued

Farm and Year	Crop	Date	Trade name	Normal dosage/ha		Active ingredient(s)			Treatment intensity index
					Herbicides				
Lekkende 1998	Barley	14 May	Express	2.00	tb*	Tribenuron-methyl	500	g a.i./kg	1.00
			Oxitril	0.50	l	Ioxynil	200	g a.i./l	0.50
						Bromoxynil	200	g a.i./l	
		2 June	MCPA (75%)	1.50	l	MCPA	750	g a.i./l	0.75
		6 Aug	Roundup	2.00	l	Glyphosate	360	g a.i./l	0.67
	Wheat	7 Oct	Boxer	0.80	l	Prosulfocarb	800	g a.i./l	0.20
			Isoproturon	0.60	l	Isoproturon	500	g a.i./l	0.24
			Stomp SC	0.80	l	Pendimethalin	400	g a.i./l	0.20
		1 May	Starane 180	0.40	l	Fluroxypyr	180	g a.i./l	0.50
	Beets	11 May	Betasana Flow	1.50	l	Phenmedipham	160	g a.i./l	0.25
			Ethuron	0.15	l	Ethofumesat	500	g a.i./l	0.19
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
			Matrigon	0.20	l	Clopyralid	100	g a.i./l	0.17
		19 May	Betasana Flow	1.50	l	Phenmedipham	160	g a.i./l	0.25
			Ethuron	0.20	l	Ethofumesat	500	g a.i./l	0.25
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
			Matrigon	0.25	l	Clopyralid	100	g a.i./l	0.21
		29 May	Betasana Flow	1.50	l	Phenmedipham	160	g a.i./l	0.25
			Ethuron	0.20	l	Ethofumesat	500	g a.i./l	0.25
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
			Matrigon	0.25	l	Clopyralid	100	g a.i./l	0.21
			Safari	20	g	Triflusulfuron-methyl	1000	g a.i./kg	0.22
					Insecticides				
	Barley	14 June	Decis	0.10	l	Deltamethrin	25	g a.i./l	0.40
	Wheat	11 June	Decis	0.20	l	Deltamethrin	25	g a.i./l	1.00
		3 July	Decis	0.20	l	Deltamethrin	25	g a.i./l	1.00
	Beets	12 May	Decis	0.25	l	Deltamethrin	25	g a.i./l	0.83
		19 May	Decis	0.25	l	Deltamethrin	25	g a.i./l	0.83
		29 May	Decis	0.25	l	Deltamethrin	25	g a.i./l	0.83
		5 July	Pirimor	0.30	kg	Pirimicarb	500	g a.i./kg	1.00

continues

Appendix A.3 continued

Farm and Year	Crop	Date	Trade name	Normal dosage/ha		Active ingredient(s)			Treatment intensity index
						Herbicides			
Nøbøllegård 1998	Barley	19 May	Express	0.50	tb*	Tribenuron-methyl	500	g a.i./kg	0.25
			Oxitril	0.30	l	Ioxynil	200	g a.i./l	0.30
						Bromoxynil	200	g a.i./l	
		11 Aug	*Roundup 2000*	*2.00*	*l*	*Glyphosate*	*400*	*g a.i./l*	*1.00*
	Wheat	27 Sep	IPU 500	1.50	l	Isoproturon	500	g a.i./l	0.60
			Stomp SC	1.00	l	Pendimethalin	400	g a.i./l	0.25
	Beets	14 May	Betasana Flow	1.50	l	Phenmedipham	160	g a.i./l	0.25
			Ethuron	0.10	l	Ethofumesat	500	g a.i./l	0.13
			Goltix	1.25	kg	Metamitron	700	g a.i./kg	0.28
		23 May	Betasana Flow	1.50	l	Phenmedipham	160	g a.i./l	0.25
			Ethuron	0.15	l	Ethofumesat	500	g a.i./l	0.19
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
		30 May	Betasana Flow	1.50	l	Phenmedipham	160	g a.i./l	0.25
			Ethuron	0.15	l	Ethofumesat	500	g a.i./l	0.19
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
		11 June	Ethuron	0.10	l	Ethofumesat	500	g a.i./l	0.13
			Goltix	0.50	kg	Metamitron	700	g a.i./kg	0.11
			Herbasan	0.50	l	Phenmedipham	160	g a.i./l	0.08
			Matrigon	0.50	l	Clopyralid	100	g a.i./l	0.42
						Insecticides			
	Barley	5 June	Sumi-Alfa	0.30	l	Esfenvalerat	50	g a.i./l	1.50
		26 June	Pirimor	0.10	kg	Pirimicarb	500	g a.i./kg	0.40
	Wheat	15 June	Sumi-Alfa	0.13	l	Esfenvalerat	50	g a.i./l	0.65
	Beets	14 May	Sumi-Alfa	0.11	l	Esfenvalerat	50	g a.i./l	0.55
		18 May	Sumi-Alfa	0.20	l	Esfenvalerat	50	g a.i./l	0.80
						Herbicides			
Nordfeld 1998	Barley	11 May	Express	0.75	tb*	Tribenuron-methyl	500	g a.i./kg	0.38
			Starane 180	0.20	l	Fluroxypyr	180	g a.i./l	0.29
		6 Aug	Roundup	2.00	l	Glyphosate	360	g a.i./l	0.67
	Wheat	25 Sept	Isoproturon	1.50	l	Isoproturon	500	g a.i./l	0.60
			Stomp SC	1.00	l	Pendimethalin	400	g a.i./l	0.25
		1 May	Starane 180	0.40	l	Fluroxypyr	180	g a.i./l	0.50
		29 May	MCPA (75%)	1.00	l	MCPA	750	g a.i./l	0.50
		5 Aug	Roundup	2.50	l	Glyphosate	360	g a.i./l	0.83
	Beets	11 May	Ethosan	0.10	l	Ethofumesat	500	g a.i./l	0.13
			Goltix	1.25	kg	Metamitron	700	g a.i./kg	0.28
			Herbasan	1.00	l	Phenmedipham	160	g a.i./l	0.17
		18 May	Ethosan	0.10	l	Ethofumesat	500	g a.i./l	0.13
			Goltix	0.50	kg	Metamitron	700	g a.i./kg	0.11
			Herbasan	1.00	l	Phenmedipham	160	g a.i./l	0.17
						Insecticides			
	Barley	14 June	DLG Dimethoat	0.50	l	Dimethoate	400	g a.i./l	0.50
	Wheat	14 June	DLG Dimethoat	0.50	l	Dimethoate	400	g a.i./l	0.50
	Beets	18 May	Sumi-Alfa	0.15	l	Esfenvalerat	50	g a.i./l	0.60
		17 July	DLG Dimethoat	1.20	l	Dimethoate	400	g a.i./l	1.20

* one tablet (tb) weights 7.5 gram.

Appendix A.4. Herbicides and insecticides used in the growing season 1998/1999, trade name, normal dosage per hectare, active ingredient(s) and treatment intensity index. Normal dosage is not equal recommended dosage, see section 1.2.4 for a definition of normal dosage. A treatment intensity index of 1.00 for a particular product is given for application of the recommended dosage in a certain crop according to the list of recommended dosages (Statens Planteavlsforsøg 1999). All herbicides and insecticides have been sprayed at reduced dosages in the plots destined for reduced dosages.

Farm and Year	Crop	Date	Trade name	Normal dosage/ha		Active ingredient(s)			Treatment intensity index
				Herbicides					
Gjorslev 1999	Barley	19 May	Harmony Plus	0.50	tb*	Tribenuron-methyl	167	g a.i./kg	0.17
						Thifensulfuron-methyl	333	g a.i./kg	
			Oxitril	0.20	l	Ioxynil	200	g a.i./l	0.20
						Bromoxynil	200	g a.i./l	
	Wheat	8 Apr	Ally	10	g	Metsulfuron methyl	200	g a.i./kg	0.33
	Beets	29 Apr	Ethosan	0.10	l	Ethofumesat	500	g a.i./l	0.13
			Goliath	1.00	kg	Metamitron	700	g a.i./kg	0.22
			Herbasan	1.00	l	Phenmedipham	160	g a.i./l	0.17
			Matrigon	0.20	l	Clopyralid	100	g a.i./l	0.17
		7 May	Ethosan	0.20	l	Ethofumesat	500	g a.i./l	0.25
			Goliath	1.00	kg	Metamitron	700	g a.i./kg	0.22
			Herbasan	1.00	l	Phenmedipham	160	g a.i./l	0.17
			Matrigon	0.20	l	Clopyralid	100	g a.i./l	0.17
				Insecticides					
	Barley	17 June	Mavrik 2F	0.05	l	Tau-fluvalinat	240	g a.i./l	0.25
	Wheat	15 June	Mavrik 2F	0.05	l	Tau-fluvalinat	240	g a.i./l	0.25
	Beets	7 July	Pirimor	0.20	kg	Pirimicarb	500	g a.i./kg	0.67
				Herbicides					
Oremandsgård 1999	Barley	10 May	Express	1.00	tb*	Tribenuron-methyl	500	g a.i./kg	0.50
			Oxitril	0.30	l	Ioxynil	200	g a.i./l	0.30
						Bromoxynil	200	g a.i./l	
		7 June	Metaxon	1.00	l	MCPA	750	g a.i./l	0.50
	Wheat	2 Nov	Boxer	0.80	l	Prosulfocarb	800	g a.i./l	0.20
			Stomp SC	0.80	l	Pendimethalin	400	g a.i./l	0.20
			Tolkan	0.50	l	Isoproturon	500	g a.i./l	0.20
		10 May	Express	1.00	tb*	Tribenuron-methyl	500	g a.i./kg	0.50
			Starane 180	0.30	l	Fluroxypyr	180	g a.i./l	0.38
	Beets	4 May	Ethosan	0.12	l	Ethofumesat	500	g a.i./l	0.15
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
			Herbasan	1.50	l	Phenmedipham	160	g a.i./l	0.25
		17 May	Ethosan	0.12	l	Ethofumesat	500	g a.i./l	0.15
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
			Herbasan	1.50	l	Phenmedipham	160	g a.i./l	0.25
		31 May	Ethuron	0.15	l	Ethofumesat	500	g a.i./l	0.19
			Herbasan	1.50	l	Phenmedipham	160	g a.i./l	0.25
			Safari	25	g	Triflusulfuron-methyl	1000	g a.i./kg	0.28
				Insecticides					
	Barley	15 June	Mavrik 2F	0.10	l	Tau-fluvalinat	240	g a.i./l	0.50
	Wheat	15 June	Mavrik 2F	0.10	l	Tau-fluvalinat	240	g a.i./l	0.50
	Beets	-	-	0.00	-	-	-	-	0.00

continues

Appendix A.4 continued

Farm and Year	Crop	Date	Trade name	Normal dosage/ha		Active ingredient(s)			Treatment intensity index
				Herbicides					
Lekkende 1999	Barley	19 May	Ariane Super	0.50	l	Clopyralid	20	g a.i./l	0.50
						Fluroxypyr	40	g a.i./l	
						MCPA	200	g a.i./l	
			Express	1.00	tb*	Tribenuron-methyl	500	g a.i./kg	0.50
	Wheat	27 Apr	Ariane Super	0.75	l	Clopyralid	20	g a.i./l	0.50
						Fluroxypyr	40	g a.i./l	
						MCPA	200	g a.i./l	
			Express	1.00	tb*	Tribenuron-methyl	500	g a.i./kg	0.50
	Beets	28 Apr	Ethosan	0.10	l	Ethofumesat	500	g a.i./l	0.13
			Goltix	0.50	kg	Metamitron	700	g a.i./kg	0.11
			Herbasan	1.00	l	Phenmedipham	160	g a.i./l	0.17
		6 May	Ethosan	0.13	l	Ethofumesat	500	g a.i./l	0.16
			Goltix	0.50	kg	Metamitron	700	g a.i./kg	0.11
			Herbasan	1.40	l	Phenmedipham	160	g a.i./l	0.23
			Matrigon	0.20	l	Clopyralid	100	g a.i./l	0.17
		25 May	Ethosan	0.15	l	Ethofumesat	500	g a.i./l	0.19
			Goltix	0.50	kg	Metamitron	700	g a.i./kg	0.11
			Herbasan	1.50	l	Phenmedipham	160	g a.i./l	0.25
			Safari	10	g	Triflusulfuron-methyl	1000	g a.i./kg	0.11
				Insecticides					
	Barley	16 June	Sumi-Alpha	0.20	l	Esfenvalerat	50	g a.i./l	1.00
	Wheat	16 June	Mavrik 2F	0.10	l	Tau-fluvalinat	240	g a.i./l	0.50
	Beets	6 May	Sumi-Alpha	0.20	l	Esfenvalerat	50	g a.i./l	1.00
		13 July	Pirimor	0.30	kg	Pirimicarb	500	g a.i./kg	1.00
				Herbicides					
Nøbøllegård 1999	Barley	3 May	Harmony Plus	0.50	tb*	Tribenuron-methyl	167	g a.i./kg	0.17
						Thifensulfuron-methyl	333	g a.i./kg	
			Oxitril	0.19	l	Ioxynil	200	g a.i./l	0.19
						Bromoxynil	200	g a.i./l	
	Wheat	15 Oct	IPU	1.00	l	Isoproturon	500	g a.i./l	0.40
			Stomp SC	1.00	l	Pendimethalin	400	g a.i./l	0.25
	Beets	7 May	Ethosan	0.09	l	Ethofumesat	500	g a.i./l	0.11
			Goliath	0.75	kg	Metamitron	700	g a.i./kg	0.17
			Herbasan	0.93	l	Phenmedipham	160	g a.i./l	0.16
		18 May	Ethosan	0.10	l	Ethofumesat	500	g a.i./l	0.13
			Goliath	0.77	kg	Metamitron	700	g a.i./kg	0.17
			Herbasan	1.23	l	Phenmedipham	160	g a.i./l	0.20
			Safari	12.3	g	Triflusulfuron-methyl	1000	g a.i./kg	0.14
		2 June	Ethosan	0.19	l	Ethofumesat	500	g a.i./l	0.24
			Herbasan	1.17	l	Phenmedipham	160	g a.i./l	0.21
			Safari	14.7	g	Triflusulfuron-methyl	1000	g a.i./kg	0.16
				Insecticides					
	Barley	15 June	Pirimor	0.10	kg	Pirimicarb	500	g a.i./kg	0.40
	Wheat	15 June	Mavrik 2F	0.05	l	Tau-fluvalinat	240	g a.i./l	0.25
	Beets	7 July	Pirimor	0.30	kg	Pirimicarb	500	g a.i./kg	1.00

continues

Appendix A.4 continued

Farm and Year	Crop	Date	Trade name	Normal dosage/ha		Active ingredient(s)			Treatment intensity index
				Herbicides					
Nordfeld 1999	Barley	17 May	Express	0.70	tb*	Tribenuron-methyl	500	g a.i./kg	0.35
			Starane 180	0.25	l	Fluroxypyr	180	g a.i./l	0.36
			Oxitril	0.30	l	Ioxynil	200	g a.i./l	0.30
						Bromoxynil	200	g a.i./l	
	Wheat	27 Apr	Express	2.00	tb*	Tribenuron-methyl	500	g a.i./kg	1.00
			Starane 180	0.40	l	Fluroxypyr	180	g a.i./l	0.50
		7 Sept	*Roundup 2000*	*2.35*	*l*	*Glyphosate*	*400*	*g a.i./l*	*1.17*
	Beets	28 Apr	Ethosan	0.10	l	Ethofumesat	500	g a.i./l	0.13
			Goltix	1.00	kg	Metamitron	700	g a.i./kg	0.22
			Herbasan	1.00	l	Phenmedipham	160	g a.i./l	0.17
		7 May	Ethosan	0.15	l	Ethofumesat	500	g a.i./l	0.19
			Goltix	0.25	kg	Metamitron	700	g a.i./kg	0.06
			Herbasan	1.25	l	Phenmedipham	160	g a.i./l	0.21
			Safari	8	g	Triflusulfuron-methyl	1000	g a.i./kg	0.09
		1 June	Safari	20	g	Triflusulfuron-methyl	1000	g a.i./kg	0.22
				Insecticides					
	Barley	15 June	Mavrik 2F	0.10	l	Tau-fluvalinat	240	g a.i./l	0.50
	Wheat	15 June	Mavrik 2F	0.08	l	Tau-fluvalinat	240	g a.i./l	0.40
	Beets	-	-	0.00	-	-	-	-	0.00

* one tablet (tb) weights 7.5 gram.

Basic field treatments

		Field 1		Field 2		Field 3	
Description		Size: 25 ha. Soil type: JB no. 6		Size: 23 ha. Soil type: JB no. 6		Size: 24 ha. Soil type: JB no. 6	
Gjorslev	1996		Maize		Spring barley		Winter wheat
				19.06	Ploughing / sowing wheat	Dec.	Manure / ploughing
	1997	07.03	Ploughing / sowing barley	Mar.	Fertilizer	Mar.	2 x hoeing / fertilizer
		Late Mar.	Fertilizer	Apr.	Fertilizer	01.04	Sowing beets
		Mid May	Fertilizer	07.07	Fungicide	05.06	Weed hoeing (1/2, 1/4)
		09.07	Fungicide	20.08	Harvest	18.06	Weed hoeing (1/1, 1/2, 1/4)
		13.08	Harvest			26.06	Milling field edge
						Sept.	Harvest
		05.09	Ploughing / sowing wheat	09.12	Manure / ploughing		
	1998	26.03	Fertilizer	24.03	Hoeing	Mid Mar.	Stubble hoeing
		15.04	Fertilizer	29.03	Fertilizer	28.03	Ploughing/sowing barley
		14.05	Fungicide	31.03	Hoeing / sowing Beets	30.03	Fertilizer
		11.06	Fungicide	29.05	Weed hoeing (1/1, 1/2, 1/4)	20.05	Fertilizer
		07.09	Harvest	05.06	Weed hoeing (1/1, 1/2, 1/4)	11.06	Fungicide
				16.06	Milling field edge	06.09	Harvest
		08.12	Manure	23.09	Harvest		
		21.12	Ploughing			09.10	Ploughing / sowing wheat
	1999	01.04	2 x hoeing	30.03	Stubble hoeing	21.03	Fertilizer
		02.04	Fertilizer	01.04	Ploughing / sowing barley	18.05	Fertilizer
		03.04	Hoeing / sowing beets	02.04	Fertilizer	20.05	Fungicide
		28.04	Fertilizer	17.05	Fertilizer	15.06	Fungicide
		26.05	Weed hoeing (1/2, 1/4)	27.05	Fertilizer	26.08	Harvest
		15.06	Weed hoeing (1/1, 1/2, 1/4)	17.06	Fungicide		
		14.09	Harvest	07.08	Harvest		

continues

Appendix B continued

		Field 1		Field 2		Field 3	
Description		Size: 31 ha. Soil type: JB no. 6		Size: 30 ha. Soil type: JB no. 6		Size: 31 ha. Soil type: JB no. 6	
	1996		Sugar beets		White clover		Winter wheat
		15.11	Ploughing	23.09	Ploughing/sowing wheat	04.11	Ploughing
	1997	20.03	Fertilizer	10.03	Fertilizer	12.03	Hoeing
		31.03	Sowing barley	23.04	Fertilizer	13.03	Hoeing
		15.05	Fungicide	15.05	Fungicide	21.03	Fertilizer
		30.05	Fungicide	20.06	Fungicide	10.04	Hoeing
		05.06	Fertilizer	21.08	Harvest	12.04	Sowing beets
		23.06	Fungicide			11.06	Fertilizer
		10.08	Harvest			03.06	Weed hoeing (1/2, 1/4)
						12.06	Weed hoeing (1/2, 1/4)
						26.06	Weed hoeing (1/1, 1/2, 1/4)
						Oct.	Harvest
		18.09	Ploughing / sowing wheat	01.11	Ploughing	01.12	Ploughing
Oremandsgård	1998	27.03	Fertilizer	01.04	Hoeing / fertilizer	30.03	Hoeing
		14.04	Fertilizer	14.04	Hoeing	31.03	Fertilizer
		02.06	Fungicide	10.06	Weed hoeing 1/2, 1/4	18.04	Sowing barley
		22.06	Fungicide	14.04	Hoeing	15.05	Fungicide
		Aug.	Harvest	17.04	Fertilizer	16.06	Fungicide
				23.04	Sowing beets	23.08	Harvest
				11.05	Weed hoeing (1/2, 1/4)		
				19.05	Weed hoeing (1/2, 1/4)		
				10.06	Weed hoeing (1/2, 1/4)		
				18.06	Weed hoeing (1/1)		
				25.06	Weed hoeing (1/2, 1/4)		
				22.07	Fungicide		
				23.11	Harvest		
		05.11	Ploughing	25.11	Ploughing	7.10	Ploughing / sowing wheat
	1999	04.04	Hoeing	01.04	Fertilizer / hoeing	26.03	Fertilizer
		05.04	Fertilizer	03.04	Sowing barley	14.04	Fertilizer
		07.04	Hoeing / fertilizer	07.05	Rolling	26.05	Fungicide
		18.04	Hoeing	08.06	Fertilizer	17.06	Fungicide
		19.04	Sowing beets	15.06	Fungicide	25.08	Harvest
		20.05	Weed hoeing (1/2, 1/4)	18.06	Harvest	10.09	Stubble hoeing
		25.05	Weed hoeing (1/2, 1/4)	30.08	Stubble hoeing		
		08.06	Fertilizer				
		16.06	Weed hoeing (1/2, 1/4)				
		28.06	Weed hoeing (1/1, 1/2, 1/4)				
		Nov.	Harvest				

continues

Appendix B continued

		Field 1		Field 2		Field 3	
Description		Size: 22 ha. Soil type: JB no. 5-6		Size: 28 ha. Soil type: JB no. 5-6		Size: 19 ha. Soil type: JB no. 5-6	
Lekkende	1996		Spring barley		Sugar Beets		Winter wheat
		22.08	Stubble hoeing				
		16.09	Ploughing / sowing wheat	10.11	Ploughing	10.10	Ploughing
	1997	10.03	Fertilizer	18.03	Hoeing	04.04	Hoeing
		23.04	Fertilizer	02.04	Hoeing / sowing barley	10.04	Hoeing / fertilizer
		28.04	Fertilizer	17.04	Fertilizer	14.04	Sowing beets / fertilizer
		30.04	Fertilizer	25.06	Fungicide	04.06	Weed hoeing (1/2, 1/4)
		28.05	Fungicide / growth regulator / fertilizer	14.08	Harvest	12.06	Weed hoeing (1/2, 1/4)
		05.06	Fungicide			19.06	Fungicide
		25.06	Fungicide			25.06	Weed hoeing (1/2, 1/4)
		16.08	Harvest	18.09	Ploughing		
		Mid Sept.	Ploughing	19.09	Sowing wheat	Mid Nov.	Ploughing
	1998	01.04	Hoeing / fertilizer	23.03	Fertilizer	31.03	Hoeing / fertilizer
		25.04	Hoeing / sowing beets	26.03	Fertilizer	01.04	Sowing barley
		13.05	Weed hoeing (1/2, 1/4)	01.04	Fertilizer	13.05	Fertilizer
		22.05	Weed hoeing (1/2, 1/4)	02.05	Fungicide / growth regulator	13.05	Fungicide
		30.05	Weed hoeing (1/2, 1/4)	20.05	Fungicide	02.06	Fertilizer
		10.08	Fungicide	11.06	Fungicide	14.06	Fungicide
		Early Nov.	Harvest	Late Aug.	Harvest	Early Nov.	Harvest
		Mid Nov	Ploughing	Oct.	Ploughing	25.09	Ploughing / sowing wheat
	1999	01.04	Hoeing	30.03	Hoeing	18.03	Fertilizer
		05.04	Fertilizer / sowing barley	01.04	Sowing beets / fertilizer	29.03	Fertilizer
		19.05	Fungicide	Early Apr.	Weed hoeing (1/2, 1/4)	27.04	Fungicide / growth regulator
		16.06	Fungicide / fertilizer	May	2 x weed hoeing (1,2, 1/4)	18.05	Fungicide / fertilizer
		Early Sept	Harvest	13.07	Fertilizer	08.06	Fertilizer
				Early Nov	Harvest	16.06	Fungicide
						Early Sep.	Harvest

continues

Appendix B continued

Description		Field 1		Field 2		Field 3	
		Size: 27 ha. Soil type: JB no. 6		Size: 22 ha. Soil type: JB no. 6		Size: 32 ha. Soil type: JB no. 6	
Nøbøllegård	1996		Winter wheat		Barley		Winter wheat
		Early Nov.	Ploughing	26.09	Ploughing / sowing wheat	Oct.	Ploughing
	1997	01.04	Hoeing	11.03	Fertilizer	10.04	Fertilizer
		07.04	Sowing barley/ fertilizer	28.04	Fertilizer	12.04	Fertilizer
		25.05	Fertilizer	01.05	Fertilizer	13.04	Sowing beets
		30.05	Fertilizer	13.05	Fungicide	13.06	Weed hoeing (1/2, 1/4)
		17.06	Fungicide	04.06	Fungicide	18.06	Fertilizer
				02.07	Fungicide	20.06	Weed hoeing (1/2, 1/4)
						02.09	Fungicide
		03.09	Ploughing / sowing wheat	Oct.	Ploughing	Oct.	Ploughing
	1998	25.03	Fertilizer	15.02	Fertilizer	31.03	Hoeing
		20.04	Fertilizer	30.03	Fertilizer	01.04	Sowing barley / fertilizer
		30.04	Fertilizer	24.04	Sowing beets / fertilizer	19.05	Fungicide
		05.05	Fungicide / growth regulator	16.06	Weed hoeing (1/2, 1/4)	05.06	Fungicide
		25.05	Fungicide	01.11	Harvest	Aug.	Harvest
		15.06	Fungicide				
		Mid Aug.	Harvest				
		Nov.	Ploughing	Nov.	Ploughing	Sept.	Ploughing / sowing wheat
	1999	01.04	Fertilizer	01.04	Hoeing	30.03	Fertilizer
		20.04	Sowing beets / fertilizer	03.04	Sowing barley / fertilizer	01.04	Fertilizer
		25.05	Weed hoeing (1/2, 1/4)	15.06	Fungicide	09.04	Fertilizer
		17.06	Weed hoeing (1/2, 1/4)	Aug.	Harvest	01.05	Fungicide / growth regulator
		Nov.	Harvest			14.06	Fungicide
						Aug.	Harvest

continues

Appendix B continued

		Field 1		Field 2		Field 3	
Description		Size: 28 ha. Soil type: JB no. 6-7		Size: 28 ha. Soil type: JB no. 6-7		Size: 25 ha. Soil type: JB no. 6-7	
Nordfeld	1996		Meadow grass		Spring barley		Winter wheat
		Oct.	Ploughing	07.10	Ploughing / sowing wheat	Oct.	Ploughing
	1997	26.03	Hoeing / fertilizer	12.03	Fertilizer	09.04	Hoeing / fertilizer
		01.04	Sowing barley / fertilizer	25.03	Fertilizer	11.04	Hoeing / Sowing beets / fertilizer
		24.05	Fungicide	30.04	Fertilizer	17.06	Fertilizer
		18.06	Fungicide	13.05	Fungicide	Mid June	Weed hoeing (1/2, 1/4)
		11.08	Harvest	03.06	Fungicide	09.07	Weed hoeing (1/2, 1/4)
				26.06	Fungicide	20.11	Harvest
				16.08	Harvest		
				09.10	Kalsium		
		02.09	Ploughing / sowing wheat	Oct.	Ploughing	Nov.	Ploughing
	1998	21.03	Fertilizer	21.04	Hoeing / fertilizer	23.04	Hoeing / fertilizer
		25.03	Fertilizer	22.04	Hoeing / fertilizer	30.03	Sowing barley
		01.05	Fungicide / growth regulator	05.06	Sowing beets	11.05	Fungicide
		06.05	Fertilizer	12.06	Weed hoeing (1/1, 1/2, 1/4)	14.06	Fungicide
		31.05	Fungicide	16.06	Weed hoeing (1/2, 1/4)	Aug.	Harvest
		14.06	Fungicide	Nov.	Harvest		
		Aug.	Harvest				
		Oct.	Ploughing	Nov.	Ploughing	03.10	Ploughing / sowing wheat
	1999	Early Apr.	Hoeing	Late Mar.	Hoeing	22.03	Fertilizer
		10.04	Hoeing / sowing beets / fertilizer	31.03	Sowing barley / fertilizer	28.03	Fertilizer
		20.05	Weed hoeing (1/2, 1/4)	17.05	Fungicide	27.04	Growth regulator
		26.05	Weed hoeing (1/2, 1/4)	15.06	Fungicide	16.05	Fertilizer
		16.06	Weed hoeing (1/2, 1/4)	05.08	Harvest	15.06	Fungicide
		18.08	Fungicide			11.08	Harvest
		02.11	Harvest				

Weed species found in the vegetation and the seed rain

Appendix C.1. Species present in the vegetation study – Latin name, Danish name and number of plots sprayed with normal, half or quarter dosage, where the species has been found at least once during 1997-1999, 15 observations are then possible per dosage. An asterisk is present if the species did flower. Nomenclature follows Tutin *et al.* (1964-80).

Latin name	**Danish name**	**Pesticide dosages**			**Flowering**
		Normal	**Half**	**Quarter**	
Acer pseudoplatanus L.	Ahorn	0	0	1	
Achillea millefolium L.	Alm. Røllike	0	0	1	
Aethusa cynapium L.	Hundepersille	11	9	10	*
Alopecurus myosuroides Hudson	Ager-Rævehale	0	0	1	
Anagallis arvensis L.	Rød Arve	12	11	12	*
Aphanes arvensis L.	Alm. Dværgløvefod	2	5	5	*
Arabidopsis thaliana (L.) Heynh	Gåsemad	0	1	0	
Arenaria serpyllifolia L.	Alm. Markarve	0	0	2	*
Artemisia vulgaris L.	Grå Bynke	1	1	2	
Atriplex patula L.	Svine-Mælde	1	7	8	*
Avena fatua L.	Flyve-Havre	0	1	0	*
Beta vulgaris (L.) ssp. *vulgaris*	Roe	0	0	1	
Bidens tripartita L.	Fliget Brøndsel	0	0	1	*
Bilderdykia convolvulus (L.) Dumort.	Snerle-Pileurt	12	13	13	*
Brassica napus L. ssp. *napus*	Raps	4	4	3	*
Capsella bursa-pastoris (L.) Medicus	Hyrdetaske	8	12	13	*
Carduus crispus L.	Kruset Tidsel	0	1	1	*
Cerastium fontanum ssp. *triviale* (Link) Jalas	Hønsetarm	1	0	3	
Chaenorhinum minus (L.) Lange	Liden Torskemund	0	2	0	*
Chamomilla recutita (L.) Rauschert	Vellugtende Kamille	4	3	5	*
Chamomilla suaveolens (Pursh) Rydb.	Skive-Kamille	6	7	7	*
Chenopodium album L.	Hvidmelet Gåsefod	14	13	14	*
Cirsium arvense (L.) Scop.	Ager-Tidsel	8	10	13	*
Cirsium vulgare (Savi) Ten.	Horse-Tidsel	0	0	1	*
Crataegus L. sp.	Hvidtjørn	only before spraying			
Elymus repens (L.) Gould	Alm. Kvik	12	13	13	*
Epilobium parviflorum Schreber	Dunet Dueurt	0	0	1	
Equisetum arvense L.	Ager-Padderok	5	5	2	
Erodium cicutarium (L.) L`Hér.	Hejrenæb	only before spraying			
Euphorbia exigua L.	Liden Vortemælk	4	6	7	*
Euphorbia helioscopia L.	Skærm-Vortemælk	9	9	7	*
Euphorbia peplus L.	Gaffel-Vortemælk	4	3	1	*
Festuca rubra L.	Rød Svingel	1	0	3	
Filaginella uliginosum (L.) Opiz	Sump-Evighedsblomst	0	1	0	*
Fraxinus excelsior L.	Ask	1	0	0	
Fumaria officinalis L.	Læge-Jordrøg	2	2	2	*
Galeopsis tetrahit L.	Alm. Hanekro	0	1	2	*

continues

Appendix C.1 continued

Latin name	Danish name	Normal	Half	Quarter	Flowering
Galium aparine L.	Burre-Snerre	10	7	10	*
Geranium pusillum L.	Liden Storkenæb	0	1	0	
Hordeum vulgare L.	Byg	0	4	0	*
Juncus bufonius L.	Tudsesiv	1	0	0	*
Kickxia elatine (L.) Dumort.	Spydbladet Torskemund	3	3	4	*
Lamium amplexicaule L.	Liden Tvetand	8	12	11	*
Lamium hybridum Vill.	Fliget Tvetand	8	10	8	*
Lamium purpureum L.	Rød Tvetand	7	8	9	*
Lolium perenne L.	Alm. Rajgræs	4	5	4	*
Matricaria perforata Merat	Lugtløs Kamille	4	8	8	*
Medicago lupulina L.	Humle-Sneglebælg	1	2	0	*
Myosotis arvensis (L.) Hill	Mark-Forglemmigej	1	2	4	*
Papaver dubium L.	Gærde-Valmue	0	0	2	*
Papaver rhoeas L.	Korn-Valmue	0	2	2	*
Plantago major L.	Glat Vejbred	6	6	8	*
Poa annua L.	Enårig Rapgræs	14	14	15	*
Poa trivialis L. ssp. *trivialis*/*Poa pratensis* L.	Alm./Eng-Rapgræs	1	3	3	*
Polygonum aviculare L.	Vej-Pileurt	12	14	15	*
Polygonum lapathifolium L.	Bleg Pileurt	3	2	4	*
Polygonum persicaria L.	Fersken-Pileurt	6	7	9	*
Ranunculus acris L. ssp. *acris*	Bidende Ranunkel	0	0	1	*
Ranunculus repens L.	Lav Ranunkel	4	1	6	
Raphanus raphanistrum L.	Kiddike	0	0	1	*
Rumex crispus L.	Kruset Skræppe	0	0	1	
Salix L. sp.	Pil	2	0	0	
Sambucus nigra L.	Alm. Hyld	1	0	2	
Secale cereale L.	Alm. Rug	0	0	1	
Senecio vulgaris L.	Alm. Brandbæger	4	7	7	*
Silene noctiflora L.	Nat-Limurt	6	7	5	*
Sinapis arvensis L.	Ager-Sennep	7	8	10	*
Solanum nigrum L. ssp. *nigrum*	Sort Natskygge	3	3	4	*
Sonchus asper (L.) Hill	Ru Svinemælk	1	1	4	*
Sonchus oleraceus L.	Alm. Svinemælk	1	2	3	*
Spergula arvensis L.	Alm. Spergel		only before spraying		
Stachys arvensis L.	Ager-Galtetand	1	1	3	*
Stellaria media (L.) Vill.	Fuglegræs	14	15	15	*
Taraxacum sp. L.	Mælkebøtte	12	14	13	*
Thlaspi arvense L.	Pengeurt	0	1	0	
Trifolium repens L.	Hvid-Kløver	5	7	5	*
Triticum aestivum L.	Alm. Hvede	3	3	4	*
Urtica dioica L.	Stor Nælde		only before spraying		
Urtica urens L.	Liden Nælde	4	2	4	*
Veronica agrestis L.	Flerfarvet Ærenpris	3	7	10	*
Veronica arvensis L.	Mark-Ærenpris	1	4	4	*
Veronica hederifolia L.	Vedbend-Ærenpris	0	1	0	
Veronica persica Poiret	Storkronet Ærenpris	9	11	12	*
Viola arvensis Murray	Ager-Stedmoderblomst	11	11	13	*
Viola tricolor L. ssp. *tricolor*	Alm. Stedmoderblomst	0	0	1	*

Appendix C.2. Species present in the seed rain – Latin names, Danish names, mean seed weight and numbers.
Seed weights were found in literature. If literature is *, then the seeds have been weighed in the laboratory. If more than one paper is mentioned in literature, the seed weight used is a mean of the seed weights given in the papers. Seed weight of a taxon at genus level was calculated from the seed distribution on identified species in that genus.

Latin name	Danish name	Seed weight (mg)	Literature	Number of seeds
Aethusa cynapium L.	Hundepersille	1.645	Korsmo 1926, Salisbury 1942	2869
Anagallis arvensis L.	Rød Arve	0.5	Melander 1993	275
Aphanes arvensis L.	Alm. Dværgløvefod	0.22	*	4
Atriplex patula L./*Chenopodium album* L.	Svine-Mælde/Hvidmelet Gåsefod	0.689	*	1132
Betula pendula Roth./*Betula pubescens* Ehrh.	Vorte-Birk/Dun-Birk	0.15	*	180
Bilderdykia convolvulus (L.) Dumort.	Snerle-Pileurt	7.488	*	547
Brassica napus L. ssp. *napus*/*Raphanus raphanistrum* L./ *Sinapis arvensis* L.	Raps/Kiddike/Ager-Sennep	1.96 (for *Sinapis arvensis*)	Salisbury 1942	254
Capsella bursa-pastoris (L.) Medicus	Hyrdetaske	0.1	Korsmo 1926, Salisbury 1942	428
Carduus crispus L./*Cirsium arvense* (L.) Scop./*Cirsium vulgare* (Savi) Ten.	Kruset Tidsel/Ager-Tidsel/Horse-Tidsel	1.363		3
Chamomilla recutita (L.) Rauschert/*Chamomilla suaveolens* (Pursh) Rydb.	Vellugtende Kamille/Skive-Kamille	0.15		1
Chamomilla suaveolens (Pursh) Rydb.	Skive-Kamille	0.15	Korsmo 1926	85
Cirsium arvense (L.) Scop.	Ager-Tidsel	1.363	Korsmo 1926, Stevens 1932	11
Compositae	Kurvblomst	0.345		2
Dicotyledones	Tokimbladet	0.887		56
Elymus repens (L.) Gould	Alm. Kvik	3.9	Korsmo 1926	7
Epilobium L. sp.	Dueurt	0.12 (for *E. montanum*)	Salisbury 1942	2
Euphorbia exigua L.	Liden Vortemælk	0.51	Salisbury 1942	133
Euphorbia helioscopia L.	Skærm-Vortemælk	2.67	Korsmo 1926, Salisbury 1942	6
Euphorbia peplus L.	Gaffel-Vortemælk	0.559	Korsmo 1926, Salisbury 1942	29
Galium aparine L.	Burre-Snerre	3.7	Korsmo 1926, Melander 1993	153
Gramineae	Græs	0.41		1
Hordeum vulgare L.	Alm. Byg	39.75	*	4712
Lamium amplexicaule L./*Lamium hybridum* Vill./ *Lamium purpureum* L.	Liden Tvetand/Fliget Tvetand/Rød Tvetand	0.6 (for *L. amplexicaule*)	Melander 1993	133
Matricaria perforata Merat	Lugtløs Kamille	0.35	Korsmo 1926	3361
Myosotis arvensis (L.) Hill	Mark-Forglemmigej	0.3	Korsmo 1926	38

continues

Appendix C.2 continued.

Latin name	Danish name	Seed weight (mg)	Literature	Number of seeds
Papaver dubium L./*Papaver rhoeas* L.	Gærde-Valmue/Korn-Valmue	0.138 (for *P. rhoeas*)	Salisbury 1942	14
Plantago lanceolata L.	Lancet-Vejbred	0.75	*	1
Plantago major L.	Glat Vejbred	0.217	Korsmo 1926, Stevens 1932, Salisbury 1942	2
Poa annua L.	Enårig Rapgræs	0.4	Melander 1993	1673
Polygonum L. sp	Pileurt	4.55		37
Polygonum aviculare L.	Vej-Pileurt	1.57	*	488
Polygonum lapathifolium L./*Polygonum persicaria* L.	Bleg Pileurt/Fersken-Pileurt	2.406	Korsmo 1926, Stevens 1932	59
Ranunculus acris L. ssp. acris/*Ranunculus repens* L.	Bidende Ranunkel/Lav Ranunkel	1.975	Korsmo 1926	3
Senecio vulgaris L.	Alm. Brandbæger	0.275	Korsmo 1926, Melander 1993	131
Silene noctiflora L.	Nat-Limurt	0.92	Salisbury 1942	48
Solanum nigrum L. ssp. *nigrum*	Sort Natskygge	0.775	Salisbury 1942, Gross 1990	10
Sonchus asper (L.) Hill	Ru Svinemælk	0.3	Korsmo 1926, Salisbury 1942	192
Sonchus oleraceus L.	Alm. Svinemælk	0.42	Salisbury 1942	12
Stachys arvensis L.	Ager-Galtetand	0.84	*	2
Stellaria media (L.) Vill.	Fuglegræs	0.362	*	6463
Taraxacum L. sp.	Mælkebøtte	0.779	Korsmo 1926, Salisbury 1942	2
Trifolium L. sp.	Kløver	0.536		1
Trifolium repens L.	Hvidkløver	0.536	Salisbury 1942, Gross 1990	3
Triticum aestivum L.	Alm. Hvede	38.93	*	3208
Type A	Type A	0.391	*	55
Veronica agrestis L./*Veronica persica* Poiret	Flerfarvet Ærenpris/Storkronet Ærenpris	0.5	Melander 1993	548
Veronica arvensis L.	Mark-Ærenpris	0.122	Salisbury 1942	32
Viola arvensis Murray/*Viola tricolor* L. ssp. *tricolor*	Ager-Stedmoderblomst/Alm. Stedmoderblomst	0.4 (for *V. arvensis*)	Melander 1993	494

Aphid counts

Appendix D. Percentages of cereal ears and beet plants with *Aphididae* before and after insecticide application. The dominant aphid species were in wheat and barley *Sitobion avenae*, *Rhopalosiphum padi* and in beet *Aphis fabae*.

1997	**Wheat**				**Barley**				**Beets**			
	Date	**Normal**	**Half**	**Quarter**	**Date**	**Normal**	**Half**	**Quarter**	**Date**	**Normal**	**Half**	**Quarter**
Gjorslev	25 June	12	12	19	25 June	7	11	3				
	7 July		Pirimor		9 July		Pirimor					
	14 July	13	20	53	14 July	2	1	6				
Oremands-gård	24 June	2	1	5	23 June	0	0	3				
	7 July		Pirimor		25 June		Karate					
	16 July	5	13	56	16 July	4	6	10				
Lekkende	24 Jun	1	5	8	25 June		Decis		Aphid populations in beet 1997 were minor and no aphid specific insecticide applications were conducted.			
	25 June		Decis		25 June	0	0	1				
	16 July	32	49	47	16 July	5	6	10				
Nøbølle	18 June	3	9	12	25 June	15	17	19				
	26 June	18	31	26	28 June	6	4	3				
	2 July		Pirimor		-		No insecticide application					
	28 July	3	2	3								
Nordfeld	24 June	25	14	10	18 June		Sumi-Alpha 5 FW					
	26 June		Sumi-Alpha 5 FW		26 June	4	3	3				
	28 July	45	52	42	28 July	1	2	3				
1998	**Wheat**				**Barley**				**Beets**			
	Date	**Normal**	**Half**	**Quarter**	**Date**	**Normal**	**Half**	**Quarter**	**Date**	**Normal**	**Half**	**Quarter**
Gjorslev	13 June	44	30	47	11 June	58	73	90	8 July	38	45	60
	24 June		Pirimor		11 June		Pirimor		8 July		Karate	
	2 July	65	83	99	24 June	1	4	33	22 July	49	62	63
	13 July	20	21	63	13 July	10	19	14	24 July		Pirimor	
									28 July	8	13	10
Oremands-gård	15 june	55	39	43	15 June	98	100	100	13 July	3	1	4
	23 June		Mavrik		16 June		Pirimor/Mavrik 2F		22 July		Pirimor	
	29 June	45	55	73	29 June	3	6	16	28 July	0	0	0
	13 July	2	17	47	13 July	0	0	12				
Lekkende	11 June		Decis		13 June	58	39	46	8 July	13	8	4
	13 June	13	27	19	24 June		Decis		17 July		Pirimor	
	3 July		Decis		13 July	17	27	43	28 July	0	0	0
	13 July	2	5	0								
Nøbølle	12 June	25	20	33	5 June		Sumi-Alpha 5 FW		15 July	6	16	26
	15 June		Sumi-Alpha 5 FW		12 june	2	4	26	-		No insecticide application	
	24 June	24	44	51	26 June		Pirimor					
	15 July	19	21	51	15 July	0	0	1				
Nordfeld	12 June	44	52	50	12 June	42	46	52	15 July	74	77	74
	14 June		DLG Dimethoat		14 June		DLG Dimethoat		17 July		DLG Dimethoat	
	23 June	16	50	25	23 June	4	11	42	27 July	82	77	73
	15 July	31	23	39	15 July	9	4	5				

continues

Appendix D continued.

1999	Wheat				Barley				Beets			
	Date	**Normal**	**Half**	**Quarter**	**Date**	**Normal**	**Half**	**Quarter**	**Date**	**Normal**	**Half**	**Quarter**
Gjorslev	14 June	11	17	20	14 June	14	27	41	23 June	1	2	4
	15 June		Mavrik 2F		17 June		Mavrik 2F		30 June	16	13	16
	23 June	15	26	33	23 June	79	80	77	7 July	38	38	45
	30 June	16	29	35	30 June	6	22	22	7 July		Pirimor	
					05 July	6	9	9	14 July	8	8	14
Oremands-gård	14 June	3	2	4	14 June	7	8	16	23 June	2	3	2
	15 June		Mavrik 2F		16 June		Mavrik 2F		30 June	8	7	9
	23 June	3	3	3	23 june	11	7	7	7 July	27	21	24
	30 June	0	3	5	30 June	0	1	0	14 July	57	84	89
									-		No insecticide application	
Lekkende	16 June	4	5	2	16 June	15	17	14	23 June	0	0	0
	16 June		Mavrik 2F		16 June		Sumi Alpha 5 FW		30 June	17	26	16
	23 June	0	0	0	23 June	6	22	4	7 July	28	33	9
	30 June	5	10	9	30 June	2	4	8	13 July		Pirimor	
									22 July	0	2	1
Nøbølle	15 june		Pirimor		14 June	32	57	63	23 June	0	2	0
	16 June	10	14	9	14 June		Pirimor		30 June	7	22	14
	23 June	64	39	48	23 June	19	40	92	7 July	56	73	47
	30 June	73	87	80	30 June	2	9	45	7 July		Pirimor	
	05 July	38	22	20					14 July	4	3	2
Nordfeld	14 June	7	3	6	14 June	39	55	57	23 June	4	3	2
	15 June		Mavrik 2F		15 June		Mavrik 2F		30 June	20	8	5
	23 June	4	20	25	23 June	53	81	80	7 July	35	23	28
	30 June	21	27	29	30 June	0	6	10	14 July	77	93	95
									-		No insecticide application	

Yield and vegetation in cereals

Appendix E.1. Densities of weed species occurring with more than 5 plants per square meter after spraying in winter wheat (A) and spring barley (B) field trials. The maximal yield decrease (%) at reduced or zero dosages compared to yield at normal dosage is mentioned. In addition, the weed density for all species after spraying is listed as a mean for all treatments. Placement of the weed species on the line between strong and weak competitors is relative and based on data of crop equivalents from Wilson (1986), Wilson and Wright (1990), Jensen (1991, 1996) as well as the authors' knowledge about the species. *Galium aparine* is a very strong competitor even in small densities and are therefore always mentioned in the table. Each value is a mean of 12-16 plots.

A Winter wheat				*Strong competitors ← ---→ Weak competitors*											
Farm	Year	Max. yield decrease (%)	Total weed density after spraying (mean of all treatments)	*Galium aparine*	*Sinapis arvensis/Brassica napus/ Raphanus raphanistrum*	*Poa pratensis/trivialis*	*Stellaria media*	*Myosotis arvensis*	*Aethusa cynapium*	*Veronica arvensis/agrestis/persica*	*Viola arvensis/tricolor ssp. tricolor*	*Polygonum aviculare*	*Trifolium* sp.	*Poa annua*	*Capsella bursa-pastoris*
Nøbøllegård	98	11.0	207				149							46	
Lekkende	98	10.0	34	0.5										21	
Nordfeld	99	9.7	95	5.7	12		7					59			
Gjorslev	98	9.3	28	5.2			18								
Nordfeld	98	8.3	147			17						37	18	57	16
Oremandsgård	98	8.0	5												
Lekkende	99	6.8	59				17	7		6	9			11	
Oremandsgård	97	4.5	23			22									
Gjorslev	99	4.2	90						16		15	51			
Gjorslev	97	3.2	18	2.4			9								
Oremandsgård	99	2.3	21						9						
Nøbøllegård	99	2.1	146				121						12		
Nordfeld	97	0.5	134											132	
Lekkende	97	0.3	56									20		30	

B Spring barley

Strong competitors ⟵--⟶ *Weak competitors*

Farm	Year	Max. yield decrease (%)	Total weed density after spraying (mean of all treatments)	*Galium aparine*	*Sinapis arvensis/Brassica napus/ Raphanus raphanistrum*	*Polygonum aviculare*	*Trifolium* sp.	*Chenopodium album*	*Bilderdykia convolvulus*	*Chamomilla recutita/suaveolens/ Matricaria perforata*	*Lamium amplixicaule/hybridum/ purpureum*	*Stellaria media*	*Veronica arvensis/agrestis/ persica*	*Viola arvensis/tricolor* ssp. *tricolor*	*Aethusa cynapium*	*Poa annua*	*Anagallis arvensis*	*Plantago major*	*Euphorbia helioscopia*	*Euphorbia peplus*	*Euphorbia exigua*	*Capsella bursa-pastoris*
Oremandsgård	99	34.6	513		242		39		11		14		169	23								
Nordfeld	98	13.4	150	6.0	45	64													12			
Nøbøllegård	98	11.5	243				154					49				14						
Gjorslev	99	8.3	350			193			45						43		24		15		16	
Gjorslev	98	7.4	291			95						35		140	16							
Oremandsgård	97	6.7	7	3.5																		
Oremandsgård	98	5.5	147				8		8		7			12	32			37		14	10	
Lekkende	98	4.4	102						14	14			17	39		6						
Nøbøllegård	99	4.3	313	3.9		45		17	106	36		59		8			19					
Lekkende	99	3.6	188			43								16		120						
Nordfeld	99	2.6	65								7					43						
Nøbøllegård	97	1.0	85					7	13			16	22			20						
Nordfeld	97	0.3	75										14			43						11
Gjorslev	97	0	49	1.0								31										
Lekkende	97	0	105	1.7							8		15			65						

Appendix E.2. Results from analyses of each field trial in spring barley and winter wheat. In addition the treatment intensity index, yield at normal dosage and weed density in spring are listed. Statistical significance of explanatory factors is indicated as follows: ns: p>0.10, +: 0.05≤p<0.10, *: 0.01≤p<0.05, **: 0.001≤p<0.01 and ***: p<0.001. Notice that non-sprayed plots were not included in the experiments in 1997.

Farm	Year	Treatment intensity index [1]	Yield at normal dosage (tons/ha)	Mean density of weed in spring (number/m^2)	Effect of block	Effect of weed density	Effect of species richness	Effect of dosage	Differences between dosages (pairwise tests)	Variation explained by the model (%)
Spring barley										
Gjorslev	97	0.45	5.75	120	*	+	ns	+		94
Oremandsgård	97	1.41	6.78	408	+	+	+	*	1/4<1/1	94
Lekkende	97	0.88	6.11	120	*	ns	**	ns		97
Nøbøllegård	97	0.88	5.11	110	ns	ns	ns	ns		84
Nordfeld	97	1.29	7.59	420	ns	ns	ns	ns		72
Gjorslev	98	0.68	7.27	346	*	*	ns	**	0<1/4, 1/2, 1/1	89
Oremandsgård	98	1.32	6.70	179	*	ns	ns	ns		88
Lekkende	98	2.25	7.53	169	**	ns	ns	+		86
Nøbøllegård	98	0.55	6.35	280	***	+	+	***	0<1/4, 1/2, 1/1	97
Nordfeld	98	0.67	6.55	213	ns	*	ns	ns		91
Gjorslev	99	0.37	6.47	760	ns	ns	ns	ns		53
Oremandsgård	99	1.30	5.34	870	*	ns	ns	ns		95
Lekkende	99	1.17	4.23	151	ns	ns	ns	ns		87
Nøbøllegård	99	0.37	6.48	351	+	ns	ns	ns		88
Nordfeld	99	1.01	6.92	55	ns	ns	ns	ns		65
Winter wheat										
Gjorslev	97[2]	0.65	9.08	25	*	ns	+	no		89
Oremandsgård	97	1.93	9.10	199	***	**	ns	***	1/4<1/2,1/1	99
Lekkende	97	1.60	8.48	76	ns	ns	ns	no		38
Nordfeld	97	2.28	9.81	190	ns	ns	ns	no		68
Gjorslev	98	1.35	8.17	63	ns	ns	ns	**	0<1/2, 1/ ; 1/4<1/1	86
Oremandsgård	98	1.65	9.64	27	ns	ns	ns	+		88
Lekkende	98	1.14	9.89	13	ns	ns	ns	no		74
Nøbøllegård	98[2]	0.85	9.75	56	ns	ns	+	**	0<1/4, 1/2, 1/1	95
Nordfeld	98	1.85	10.31	282	+	ns	ns	**	0<1/4, 1/1	90
Gjorslev	99[3]	0.33	10.69	53	ns	ns	ns	+		77
Oremandsgård	99	1.48	9.55	71	+	ns	ns	no		76
Lekkende	99[3]	1.00	8.24	78	ns	ns	ns	no		75
Nøbøllegård	99[2]	0.65	9.74	49	+	ns	ns	no		82
Nordfeld	99[3]	1.50	10.25	224	ns	ns	ns	**	0<1/4, 1/2, 1/1	93

[1]*Treatment intensity index for herbicides against broad-leaved species only.*
[2]*Sprayed in autumn only.*
[3]*Sprayed in spring only.*

Economy

Appendix F.1. Change in product value, costs I, costs II and profit with ½ and ¼ dosage of insecticides and herbicides in the period 1997-1999. Results are presented in DKK per hectare in current prices. **Gjorslev Gods.**

Crop	Winter wheat			Spring barley			Sugar beets		
Dosage	1	0.5	0.25	1	0.5	0.25	1	0.5	0.25
96/97									
Product value	9,049	-276	9	5,743	113	-9	21,837	1,257	650
- Costs I	1,644	-132	-197	897	-55	-82	3,567	-642	-963
= Profit before costs II	7,406	-144	206	4,846	168	73	18,270	1,899	1,613
- Costs II	2,603	0	0	2,378	0	0	3,656	260	260
= Profit	4,803	-144	206	2,468	168	73	14,614	1,639	1,353
97/98									
Product value	8,268	-116	-401	7,186	-125	0	24,786	2,619	-420
- Costs I	1,976	-341	-512	732	-32	-48	3,406	-628	-942
= Profit before costs II	6,292	225	111	6,454	-92	48	21,380	3,247	522
- Costs II	2,742	0	0	2,289	0	0	3,985	0	0
= Profit	3,550	225	111	4,165	-92	48	17,395	3,247	522
98/99									
Product value	10,188	-179	-366	6,140	-451	-459	25,099	-1,027	-30
- Costs I	1,548	-56	-83	952	-55	-83	3,372	-562	-843
= Profit before costs II	8,640	-123	-282	5,187	-396	-377	21,728	-466	813
- Costs II	2,619	0	0	2,499	0	0	3,630	254	254
= Profit	6,021	-123	-282	2,688	-396	-377	18,098	-720	559

Appendix F.2. Change in product value, costs I, costs II and profit with ½ and ¼ dosage of insecticides and herbicides in the period 1997-1999. Results are presented in DKK per hectare in current prices. **Oremandsgård.**

Crop	Winter wheat			Spring barley			Sugar beets		
Dosage	1	0.5	0.25	1	0.5	0.25	1	0.5	0.25
96/97									
Product value	9,147	-142	-365	6,656	-183	-409	24,166	-1,399	262
- Costs I	1,765	-184	-277	1,606	-100	-150	3,725	-713	-1,069
= Profit before costs II	7,382	42	-88	5,050	-83	-259	20,441	-686	1,332
- Costs II	2,603	0	0	2,488	0	0	3,656	520	520
= Profit	4,779	42	-88	2,562	-83	-259	16,785	-1,206	812
97/98									
Product value	9,683	-134	-223	6,652	9	-294	22,693	1,322	149
- Costs I	2,521	-284	-426	1,710	-125	-187	3,759	-818	-1,227
= Profit before costs II	7,162	151	204	4,942	134	-107	18,934	2,140	1,377
- Costs II	2,742	0	0	2,625	0	0	3,720	795	795
= Profit	4,420	151	204	2,317	134	-107	15,214	1,345	582
98/99									
Product value	9,142	9	43	5,638	111	-315	27,550	-718	-1,452
- Costs I	2,313	-514	-384	1,399	-126	-189	3,576	-651	-976
= Profit before costs II	6,830	523	427	4,239	237	-126	23,974	-67	-475
- Costs II	2,853	0	0	2,616	0	0	3,376	762	762
= Profit	3,977	523	427	1,623	237	-126	20,598	-829	-1,237

Appendix F.3. Change in product value, costs I, costs II and profit with ½ and ¼ dosage of insecticides and herbicides in the period 1997-1999. Results are presented in DKK per hectare in current prices. **Lekkende gods.**

Crop	Winter wheat			Spring barley			Sugar beets		
Dosage	1	0.5	0.25	1	0.5	0.25	1	0.5	0.25
96/97									
Product value	8,702	-18	-9	6,099	9	96	27,006	-2,091	-3,392
- Costs I	2,499	-325	-487	1,335	-163	-245	3,696	-638	-957
= Profit before costs II	6,204	307	478	4,764	172	341	23,310	-1,453	-2,435
- Costs II	2,713	0	0	2,378	0	0	3,396	780	780
= Profit	3,491	307	478	2,386	172	341	19,914	-2,233	-3,215
97/98									
Product value	9,763	62	-89	7,008	-27	89	25,344	-3,448	-5,571
- Costs I	2,420	-199	-299	1,581	-232	-348	4,626	-1,181	-1,771
= Profit before costs II	7,343	261	210	5,428	205	437	20,718	-2,267	-3,799
- Costs II	2,854	0	0	2,849	0	0	3,455	795	795
= Profit	4,489	261	210	2,579	205	437	17,263	-3,062	-4,594
98/99									
Product value	8,199	-17	-153	4,457	162	-9	27,831	-4,788	-2,837
- Costs I	2,202	-142	-213	1,226	-111	-166	3,554	-645	-968
= Profit before costs II	5,997	125	60	3,231	272	157	24,277	-4,143	-1,870
- Costs II	2,736	0	0	2,499	0	0	3,551	762	762
= Profit	3,261	125	60	732	272	157	20,726	-4,905	-2,632

Appendix F.4. Change in product value, costs I, costs II and profit with ½ and ¼ dosage of insecticides and herbicides in the period 1997-1999. Results are presented in DKK per hectare in current prices. **Nøbøllegård.**

Crop	Winter wheat			Spring barley			Sugar beets		
Dosage	1	0.5	0.25	1	0.5	0.25	1	0.5	0.25
96/97									
Product value				5,203	209	-52	22,117	2,116	1,893
- Costs I				1,557	-161	-242	4,054	-886	-1,329
= Profit before costs II				3,647	370	189	18,062	3,002	3,222
- Costs II				2,488	0	0	3,396	0	0
= Profit				1,159	370	189	14,666	3,002	3,222
97/98									
Product value	9,861	-142	-312	6,385	0	-71	22,252	-1,203	420
- Costs I	2,442	-243	-308	1,551	-195	-292	4,126	-995	-1,493
= Profit before costs II	7,419	101	-3	4,835	195	221	18,126	-208	1,912
- Costs II	2,742	0	0	2,737	0	0	3,625	265	265
= Profit	4,677	101	-3	2,098	195	221	14,501	-473	1,647
98/99									
Product value	9,355	111	51	6,225	94	-25	26,999	-2,385	-836
- Costs I	2,359	-190	-284	1,127	-53	-79	3,512	-633	-949
= Profit before costs II	6,995	300	335	5,098	146	54	23,487	-1,752	113
- Costs II	2,736	0	0	2,499	0	0	3,551	254	254
= Profit	4,259	300	335	2,599	146	54	19,936	-2,006	-141

Appendix F.5. Change in product value, costs I, costs II and profit with ½ and ¼ dosage of insecticides and herbicides in the period 1997-1999. Results are presented in DKK per hectare in current prices. **Nordfeld Gods.**

Crop	Winter wheat			Spring barley			Sugar beets		
Dosage	1	0.5	0.25	1	0.5	0.25	1	0.5	0.25
96/97									
Product value	9,770	-36	-9	7,370	-26	-26	29,437	-3,525	-2,733
- Costs I	2,290	-263	-395	1,471	-89	-134	3,523	-613	-919
= Profit before costs II	7,480	227	386	5,899	63	107	25,914	-2,912	-1,813
- Costs II	2,713	0	0	2,378	0	0	3,396	0	0
= Profit	4,767	227	386	3,521	63	107	22,518	-2,912	-1,813
97/98									
Product value	10,066	98	-80	6,715	-62	-418	24,577	359	-1,762
- Costs I	2,276	-183	-274	1,263	-68	-102	2,981	-426	-639
= Profit before costs II	7,790	281	194	5,452	5	-317	21,596	785	-1,123
- Costs II	2,742	0	0	2,625	0	0	3,720	265	265
= Profit	5,048	281	194	2,827	5	-317	17,876	520	-1,388
98/99									
Product value	9,890	9	-298	6,624	34	-34	29,669	-590	1,876
- Costs I	2,798	-154	-231	1,205	-123	-184	3,142	-441	-661
= Profit before costs II	7,092	163	-66	5,419	157	150	26,527	-149	2,537
- Costs II	2,736	0	0	2,499	0	0	3,551	762	762
= Profit	4,356	163	-66	2,920	157	150	22,976	-911	1,775