Unsprayed field margins: implications for environment, biodiversity and agricultural practice

The Dutch Field Margin Project
in the Haarlemmermeerpolder

PROEFSCHRIFT

ter verkrijging van de graad van Doctor
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op gezag van de Rector Magnificus Dr. L. Leertouwer,
hoogleraar in de faculteit der Godgeleerdheid,
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door

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geboren te Zeist in 1961

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NWO

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Op een kevertje

Op een met landbouwgif bespoten
stuk land liep op zijn laatste poten
een kevertje van graf tot graf
al zijn familieleden af.
Dat deed het arme stakkertje
daar op zijn dooie akkertje.

(uit: Kees Stip, Lachen in een leeuw
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Samenvatting

Dit proefschrift doet verslag van een experimenteel veldonderzoek ten behoeve van de ontwikkeling van een beheerstrategie voor het gebruik van bestrijdingsmiddelen in perceelsranden in akkerbouwgebieden op kleigronden in Nederland. Het onderzoek is een exponent van de 'verwevingsstrategie op bedrijfsniveau', waarin gezocht wordt naar mogelijkheden om de agrarische bedrijfsvoering en natuur- en milieubehoud met elkaar te combineren. Het onderzoek, uitgevoerd bij het Centrum voor Milieukunde van de Rijksuniversiteit Leiden, vond plaats in de periode 1990-1994. Het onderzoek had een interdisciplinair karakter en was gericht op de analyse van zowel ecologische en milieuhygiënische als ook sociaal-economische aspecten die samenhangen met het beperken van het gebruik van bestrijdingsmiddelen in akkerranden.
In het onderzoek hebben drie vragen centraal gestaan:

- In hoeverre kan door vermindering van het gebruik van bestrijdingsmiddelen in de randen van de akkers de emissie van bestrijdingsmiddelen naar de omgeving van de percelen worden teruggedrongen?
- In hoeverre is het mogelijk om door specifiek akkerrandenbeheer ten aanzien van het gebruik van bestrijdingsmiddelen de biodiversiteit in agrarische gebieden te verhogen?
- In hoeverre is het achterwegelaten van het gebruik van bestrijdingsmiddelen in de randen van de akkers inpasbaar in de bedrijfsvoering?

Het onderzoek is uitgevoerd op 16 gangbare akkerbouwbedrijven in de Haarlemmermeerpolder. Op de bedrijven worden suikerbieten, aardappelen en wintertarwe in roulatie verbouwd. De percelen zijn omgeven door sloten. Ten behoeve van het onderzoek werden op 6 bedrijven in ieder van deze 3 gewassen stroken van 3 meter breed en 100 meter lang aan de rand van de akker niet bespoten met herbiciden en insekticiden. Tevens is op 10 bedrijven het gebruik van herbiciden en insekticiden achterwege gelaten in wintertarweranden van 6 meter breed en 450 meter lang. De bemesting van de randen werd gehandhaafd, en het gebruik van fungiciden was toegestaan. De onbespoten akkerranden zijn steeds vergeleken met bespoten stroken op hetzelfde bedrijf.

Het onderhavige proefschrift bestaat uit 5 delen. Na een algemene introductie (deel 1) zijn de 3 centrale onderzoeksvragen uitgewerkt in de delen 2, 3 en 4 van dit proefschrift, te weten een milieuhygiënisch deelonderzoek, een ecologisch deelonderzoek en een sociaal-economisch deelonderzoek. In deel 5 ten slotte, worden de belangrijkste conclusies van het onderzoek samengevat en worden aanbevelingen en perspectieven gepresenteerd.

Deel 1: Introductie

In hoofdstuk 1 worden de 3 centrale onderzoeksvragen gesteld en wordt de opzet van het proefschrift beschreven. Vervolgens vindt in hoofdstuk 2 karakterisering plaats van de betekenis van akkerranden vanuit milieuhygiënisch, ecologisch en bedrijfskundig perspectief. Daarbij wordt een overzicht gepresenteerd van de internationale stand van wetenschap op het gebied van akkerrandenbeheer. Naast de mogelijkheden van randenbeheer in suikerbieten, aardappelen en granen worden ook varianten zoals gras-, braak- en bloemranden besproken.

Deel 2: Milieuhygiënisch onderzoek

Het milieuhygiënisch onderzoek bestaat uit 2 delen. Allereerst is het gebruik van bestrijdingsmiddelen aan de rand van de akker geïnventariseerd door het interviewen van akkerbouwers. Vervolgens is het overwaaien van bestrijdingsmiddelen naar aangrenzende sloten gemeten bij de 2 belangrijkste typen bespuitingen: het gebruik van de veldspuit om het gewas te bespuiten en het gebruik van de rugspuit om de insteek te bespuiten. Bij de veldbespuitingen is tevens onderzocht in hoeverre bufferzones van 3 en 6 meter breed het overwaaien van bestrijdingsmiddelen naar de omgeving van het perceel kunnen reduceren.

Gebruik van bestrijdingsmiddelen

Uit interviews met 88 akkerbouwers in de Haarlemmermeerpolder blijkt dat de randen van de akkers intensief worden bespoten met bestrijdingsmiddelen (hoofdstuk 3). Dit betreft zowel de gewasrand, de insteek, de slootkant als de slootbodem. De insteek wordt door circa 85% van de akkerbouwers bespoten, gelijktijdig met de veldbespuitingen. Ongeveer 95% van de akkerbouwers bespuit de insteek een tot twee keer per jaar ook afzonderlijk met de rugspuit, daarbij voornamelijk glyfosaat gebruikend. De slootkant wordt door circa 60% van de akkerbouwers bespoten met veelal glyfosaat en MCPA. Daarnaast wordt nog een breed scala van andere middelen gebruikt. Het grootste deel daarvan is voor dit doel evenwel niet toegelaten. Zo'n 30% van de akkerbouwers bespuit de slootbodem (glyfosaat en dalapon). De gebruikte dosering van de middelen is in vele gevallen hoger dan wat is voorgeschreven en varieert met een factor 60 tussen de geïnterviewden.

Overwaaien van bestrijdingsmiddelen

Hoofdstuk 4 behandelt het overwaaien van bestrijdingsmiddelen naar aangrenzende sloten en slootkanten bij het gebruik van de veldspuit op het perceel. Hiertoe zijn depositiemetingen verricht met watergevoelige papierstroken. Voor het bespoten gedeelte wordt de depositie hierbij op 100% gesteld. De metingen zijn verricht met verschillende spuitdoppen en onder verschillende windsnelheden. Bij zeer lage windsnelheden (<0,5 m/s), is geen depositie in de sloot gemeten en maximaal 6,0% depositie halverwege de slootkant. Bij een windsnelheid van 3 m/s zijn deze waarden respectievelijk 2,2% en 25,1%. Bij deze windsnelheid komt de belasting in de sloot overeen met de dosis die wordt gebruikt om de risico's voor waterorganismen te schatten bij de toelating van bestrijdingsmiddelen (1-2%). Neemt de windsnelheid toe, dan is ook de belasting van de sloot hoger. Bij 5 m/s, een windsnelheid waarbij ook nog regelmatig in de praktijk wordt gespoten, is de depositie in de sloot circa 7%. Bij deze windsnelheid bestaan er op basis van een risicoanalyse met het SLOOTBOX-model bij 8 van de 17 onderzochte middelen risico's voor algen, watervlooien en ook vissen. Bij 4 middelen is zelfs sprake van grote tot zeer grote risico's.

Het aanleggen van een onbespoten bufferzone van slechts 3 meter breed vermindert het overwaaien naar de sloot met minimaal 95% (windsnelheid maximaal 4,5 m/s). Bij een bufferzone van 6 meter breed kon geen depositie in de sloot worden vastgesteld. De 3-meter brede onbespoten randen zijn afdoende om te voldoen aan de emissiereductiedoelstellingen voor oppervlaktewater, zoals die zijn gesteld in het Meerjarenplan Gewasbescherming (MJP-G, 1991). Bij het aanleggen van bufferzones van 3 meter breed blijken op basis van de gehanteerde risico-analyse slechts bij 4 van de 17 onderzochte middelen (kleine) risico's aanwezig.

In hoofdstuk 5 is het overwaaien van bestrijdingsmiddelen bij het gebruik van de rugspuit op de insteek onderzocht. Het blijkt dat er bij lage windsnelheden (<3,5 m/s) en een windrichting naar de sloot toe, nauwelijks middelen in de sloot terecht komen: <0,1% van de depositie op het bespoten gedeelte (= 100% depositie). Op de slootkant daarentegen is tot maximaal 9% depositie gemeten. Neemt de windsnelheid toe, dan is ook de belasting van de sloten en de slootkant groter. Bij een windsnelheid van 5 m/s wordt een depositie van maximaal 3,2% in de sloot gemeten. Het overwaaien van bestrijdingsmiddelen bij deze toepassingsvorm is technisch goed tegen te gaan door spuitdoppen te gebruiken met een tophoek van minder dan 60 graden.

Deel 3: Ecologisch onderzoek

In het ecologisch onderzoek is onderzocht in hoeverre het voorkomen van akkerkruiden, evertebraten en vertebraten kan worden bevorderd door in de buitenste meters van het perceel het gebruik van bestrijdingsmiddelen achterwege te laten. Hierbij is tevens een vergelijking gemaakt tussen de potenties van 3- en 6- meter brede randen om de biodiversiteit te bevorderen.

Akkerkruiden

In hoofdstuk 6 worden de effecten op de vegetatie beschreven. Hiertoe is de presentie en de abundantie van akkerkruiden in de onbespoten randen vergeleken met die van bespoten randen en met die het centrum van het perceel (Braun-Blanquêt-methode). Het blijkt dat in alledrie de onderzochte gewassen de bedekking van de akkerkruiden toeneemt: in suikerbieten van 10 naar 44%, in aardappelen van 4 naar 11% en in wintertarwe van 2 naar 32%. Ook het aantal soorten akkerkruiden neemt sterk toe, in suikerbieten van gemiddeld 6 naar 24 soorten, in aardappelen van 8 naar 17 soorten en in wintertarwe van 6 naar 17 soorten. De toename wordt hoofdzakelijk veroorzaakt door dicotyle soorten, hetgeen relevant is voor het voorkomen van andere organismen in het agro-ecosysteem zoals bloembezoekende insekten. Veelvuldig dominante soorten in de onbespoten randen zijn in suikerbieten Witte krodde (*Thlaspi arvense*), Stippelganzevoet (*Chenopodium ficifolium*) en Melganzevoet (*Chenopodium album*), in aardappelen Klein kruiskruid (*Senecio vulgaris*) en in wintertarwe Echte kamille (*Matricaria recutita*), Zwaluwtong (*Polygonum convolvulus*) en Kleefkruid (*Galium aparine*). Veel soorten, zoals Klaprozen (*Papaver* spec.), Rood guigelheil (*Anagallis arvensis*) en Duivekervel (*Fumaria officinalis*), zijn vrijwel uitsluitend in de onbespoten randen aangetroffen en niet elders op het perceel.

De toename van de akkerkruiden betreft voor het overgrote deel algemene soorten. Op basis van een natuurwaarderingsmaat, waarin de zeldzaamheid van de afzonderlijke soorten is gecombineerd met de populatietendens van de betreffende soorten, is ook een toename van de natuurwaarde van de vegetatie op de onbespoten stroken te zien: in suikerbieten met een factor 5,2, in aardappelen met een factor 2,8 en in wintertarwe met een factor 7,2. In het centrum van het perceel is zowel de presentie en abundantie van de

akkerkruiden, als de natuurwaarde van de vegetatie steeds lager dan op de (bespoten) rand van de akker.
Landschappelijk zien de onbespoten wintertarweranden er aantrekkelijk uit door de dominantie van witbloeiende kamille met hier en daar een klaproos. Bij suikerbieten is het visuele beeld negatief door de overwoekering van het gewas. In dit gewas neemt ook de bedekking van de suikerbietplanten in de onbespoten stroken af. Bij onbespoten aardappelstroken is in de meeste gevallen nauwelijks een verandering te zien, omdat de akkerkruiden veelal niet boven het gewas uitkomen.

Evertebraten
In de hoofdstukken 7 en 8 worden de effecten beschreven op de insekten die voorkomen in de hogere delen van de vegetatie (gewas en akkerkruiden). De aanwezigheid van deze groepen is geïnventariseerd met behulp van zichtwaarnemingen en sleepnetten. Het onderzoek heeft zich hierbij gericht op wintertarwe en aardappelen. Er is speciale aandacht besteed aan het voorkomen van dagvlinders.
In de onbespoten wintertarweranden is de insekten-dichtheid in de hogere delen van de vegetatie 3 tot 4 keer zo hoog als in bespoten randen (hoofdstuk 7). Het betreft zowel bloembezoekende insekten zoals Zweefvliegen (Syrphidae), als ook natuurlijke vijanden van bladluizen zoals Lieveheersbeestjes (Coccinellidae). Ook het aantal insektengroepen neemt in de onbespoten stroken toe, met een factor 1,4. Hoewel in de onbespoten stroken het aantal bladluizen in de tarwe toenam, blijkt dat de bladluizen in de stroken zich niet verspreiden naar de rest van het veld.
Uit de vlindertellingen (hoofdstuk 8) blijkt dat 6 soorten in de rand dominant zijn, te weten Bruin zandoogje (*Maniola jurtina*), Argusvlinder (*Lasiommata megera*), Hooibeestje (*Coenonympha pamphilus*), Klein koolwitje (*Pieris rapae*), Geaderd witje (*Pieris napi*) en Zwartsprietdikkopje (*Thymelicus lineola*). Het aantal dagvlinders is in de onbespoten wintertarweranden 4 tot 5 keer zo hoog als in bespoten randen (van 2,3 naar 11,0 individuen per 300 m^2). Ook het aantal soorten dagvlinders neemt toe van gemiddeld 1,5 naar 3,5 soorten per 100 m. In de onbespoten graanranden is het aantal vlinders ongeveer 2 tot 3 keer zo hoog als in de onbespoten aardappelranden. In 1 van de 2 jaren dat de dagvlinders zijn geïnventariseerd neemt ook in de onbespoten aardappelranden het aantal vlinderindividuen significant toe.
Bij het voorkomen van insekten speelt de interactie met de slootkant naast de onbespoten strook een belangrijke rol. Zo bevinden zich van nature meer dagvlinders op de slootkant dan in de gewasrand. Op de slootkant naast de onbespoten strook neemt het aantal vlinders toe met een factor 1,6: van 12,8 naar 19,2 individuen per 100 m gemiddeld. Er zijn aanwijzingen dat het aanleggen van een onbespoten strook midden in de akker, zonder verbinding met een landschapselement zoals een slootkant, voor deze soortengroep nauwelijks zin heeft.

De effecten op de epigeïsche bodemevertebraten zijn onderzocht met behulp van vangpotten (hoofdstuk 9 en 11). In de onbespoten randen is het aantal epigeïsche bodemevertebraten (aktiviteitsdichtheid) nauwelijks hoger dan in bespoten randen. Van de 4 dominante evertebratengroepen, te weten Coleoptera, Araneida, Hymenoptera en Diptera, werden alleen de Araneida in de wintertarwe en de Coleoptera in de suikerbieten in 1 van de 2 onderzoeksjaren iets vaker gevangen in de onbespoten stroken (circa een factor 1,2).

De loopkevers (Carabidae) vormden het overgrote deel van de biomassa van de epigeïsche bodemevertebraten en zijn nader uitgewerkt (hoofdstuk 9). In totaal zijn meer dan 70 verschillende soorten loopkevers gevangen. Zes soorten waren dominant, namelijk: *Pterostichus melanarius*, *Bembidion tetracolum*, *Nebria brevicollis*, *Trechus quadristriatus*, *Harpulus rufipes* en *Agonum dorsale*. In de randen van aardappelpercelen werden aanzienlijk minder loopkevers (soorten en individuen) gevangen dan in de randen van wintertarwe- en suikerbietenpercelen. In de onbespoten stroken was de activiteitsdichtheid van loopkevers in wintertarwe, in beide onderzoeksjaren en in suikerbieten in 1 jaar, een factor 1,3 hoger dan in de bespoten stroken. In alledrie de gewassen werd in een jaar een positief effect op het aantal soorten loopkevers gevonden. Op soortsniveau konden alleen effecten worden aangetoond op herbivore Carabidae uit de genera *Harpalus* en *Amara*.

Vertebraten

De effecten op akkervogels zijn bestudeerd in 6 meter brede wintertarweranden (hoofdstuk 10). Hierbij is de bezoekfrequentie van de Gele kwikstaart (*Motacilla flava flava*), Veldleeuwerik (*Alauda arvensis*) en Graspieper (*Anthus pratensis*) aan de onbespoten randen vergeleken met die van bespoten randen. Uit de vogeltellingen blijkt dat onbespoten wintertarweranden zeer aantrekkelijk zijn voor de Gele kwikstaart. Deze randen worden in vergelijking met de bespoten randen 3 tot 4,5 keer zoveel door deze soort bezocht. Bij de Veldleeuwerik is geen verschil in bezoekfrequentie gevonden. Het verschil tussen beide vogelsoorten wordt waarschijnlijk verklaard door een verschillend voedselpakket en voedselzoekstrategie; de Gele kwikstaart zoekt zijn voedsel ook in de hogere delen van de vegetatie waar de effecten op insekten groot zijn (hoofdstuk 7), terwijl de veldleeuwerik uitsluitend op de grond foerageert en veel plantaardig voedsel eet. De effecten op de Graspieper (*Anthus pratensis*) konden in het onderzoek niet worden onderzocht vanwege de lage dichtheid van deze soort in het onderzoeksgebied.
Uit de beperkte inventarisatie van kleine zoogdieren blijkt dat vooral graanranden door (veld)muizen worden bezocht (hoofdstuk 11). In de randen van suikerbieten- en aardappelpercelen zijn naar verhouding veel minder muizen gevangen. De onbespoten graanranden lijken iets aantrekkelijker te zijn voor muizen dan de bespoten randen: respectievelijk 38 tegenover 27 muizenvangsten.

Dimensies van de randen

Omdat in het onderzoek zowel onbespoten tarweranden van 3 m breed en 100 m lang zijn aangelegd als ook randen van 6 m breed en 450 m lang, was het mogelijk om deze onderling te vergelijken (hoofdstuk 12). Hieruit kunnen indicaties worden verkregen over de dimensies die de randen moeten hebben om het voorkomen van flora en fauna te bevorderen. Uit de vergelijking van de 3- en 6-meter brede randen blijkt dat voor het bevorderen van de vegetatie en de daarin levende insekten vooral de buitenste meters van het perceel van belang zijn. De buitenste 3 meter herbergt van oorsprong de meeste soorten. In de onbespoten situatie is er in de 6-meter brede stroken geen extra toename van de abundantie en presentie van akkerkruiden en het voorkomen van insekten ten opzichte van de 3-meter brede stroken. Dit pleit voor het aanleggen van lange onbespoten randen van 3-meter breed in plaats van 6-meter brede stroken met een kortere lengte. Bovendien is bij het aanleggen van lange stroken de winst voor natuur en milieu bij de slootkant en sloot groter.

Deel 4: inpasbaarheid in de bedrijfsvoering

Het onderzoek naar de inpasbaarheid van randenbeheer in de bedrijfsvoering bestaat uit 2 onderdelen. Eerst is een economische kosten-baten analyse gemaakt, waarin de opbrengstverliezen in de onbespoten gewasranden zijn afgezet tegen de besparingen op het bestrijdingsmiddelengebruik. Vervolgens is de sociale acceptatie van de maatregelen bij akkerbouwers onderzocht. Hierbij heeft een uitbreiding van het onderzoek plaatsgevonden en zijn interviews gehouden met akkerbouwers in diverse regio's in Nederland die ervaring hadden met randenbeheer. Naast de onbespoten gewasranden is daarbij tevens de acceptatie van andere beheersvarianten onderzocht, zoals een onbespoten grasrand en een braakrand.

Kosten-baten van onbespoten gewasranden

Voor het berekenen van de kosten van het aanleggen van onbespoten randen zijn de kwantitatieve en kwalitatieve opbrengstverliezen in de verschillende gewassen bepaald in de Haarlemmermeerpolder (hoofdstuk 13). In ieder gewas is tevens een vergelijking gemaakt tussen de opbrengst van het gewas van de bespoten strook en van het centrum van het perceel. Het blijkt dat in alle onbespoten stroken de opbrengst van het gewas lager is dan in bespoten stroken. Gemiddeld over de bedrijven en jaren is het opbrengstverlies in een onbespoten strook in suikerbieten ongeveer 30%, in aardappelen 2% en in wintertarwe 13%. De variatie tussen percelen en jaren is echter groot. Het grote opbrengstverlies in de suikerbieten werd veroorzaakt door de overwoekering van het gewas door de akkerkruiden. Vooral het achterwegelaten van de eerste herbicide-bespuiting had in dit gewas negatieve gevolgen voor de opbrengst. De kwaliteit van de oogst van de onbespoten randen was vrijwel altijd gelijk aan die van de bespoten randen. Er is geen verschil gevonden in het suikergehalte van de bieten, winbaarheid van de suiker, drogestofgehalte van de aardappelen en het vochtgehalte van het graan. Alleen in 1 jaar was er een iets kleinere sortering van de aardappelen in de onbespoten stroken.
Worden de kosten van de opbrengstverliezen afgezet tegen de besparingen op het bestrijdingsmiddelengebruik in de onbespoten rand, dan zijn de nettokosten in suikerbieten hoog: circa f 0,21 per m^2. Deze vorm van randenbeheer valt voor de praktijk af. In aardappelen worden de kosten van het opbrengstverlies gecompenseerd door de besparingen op het bestrijdingsmiddelengebruik. Er zijn in dit gewas geen nettokosten. In wintertarwe ten slotte zijn de kosten laag, circa f 0,01 per m^2. De opbrengstbepalingen tonen verder aan dat in de bespoten situatie de gewasrand altijd 10 tot 15% minder opbrengt dan het centrum van het perceel.

Sociale acceptatie van de maatregelen

Om inzicht te krijgen in de sociale acceptatie van randenbeheer door akkerbouwers is in samenwerking met de vakgroep Agrarisch Bedrijfseconomie van de Landbouwuniversiteit Wageningen een onderzoek uitgevoerd onder 31 akkerbouwers in Nederland die ervaring hadden met specifiek akkerrandenbeheer (hoofdstuk 14). De geïnterviewde akkerbouwers namen deel aan het CML-project in de Haarlemmermeerpolder, het Akkerrandenproject van de Provincie Gelderland en aan het project Herstel Leefgebieden Patrijs van de Stichting Behoud Natuur en Leefmilieu.
Worden verschillende beheerspakketten aan akkerbouwers voorgelegd, dan blijkt dat deze een duidelijke voorkeur hebben voor onbespoten graanranden of onbespoten grasranden. Onbespoten randen in aardappelen en braakranden scoren aanzienlijk lager. Graanranden

rond andere gewassen nemen een intermediaire positie in. Deze keuze blijkt hoofdzakelijk gebaseerd te worden op gewasbeschermingskundige argumenten, zoals de toename van akkerkruiden, ziekten en plagen in de rand en op de rest van het perceel. Voor grasranden geldt dat met name in laag-Nederland de hiervoor benodigde machines ontbreken. De attitude van de actoren in de omgeving van de akkerbouwer differentieert nauwelijks tussen de beheerspakketten. Opvallend is dat ondanks de lage kosten de onbespoten aardappelranden slecht scoren. Dit wordt waarschijnlijk veroorzaakt doordat men in dit hoog salderende gewas alle risico's wil vermijden.
Voorts blijkt dat voor de inpasbaarheid van akkerrandenbeheer in de agrarische bedrijfsvoering bovenal de breedte van de onbespoten rand van belang is. Daarbij gaat de voorkeur van de akkerbouwers uit naar een flexibele breedte. De akkerbouwers geven bij het randenbeheer de voorkeur aan conditiebetaling in plaats van een vergoedingensysteem dat gebaseerd is op de behaalde natuurresultaten. Het randenbeheer hoeft niet intensief te worden begeleid. De plaats van de rand mag over het bedrijf rouleren.
De motivatie van akkerbouwers om in akkerrandenprojecten te participeren, lijkt sterk afhankelijk van het vertrouwen in de contactpersoon van het project. Daarnaast speelt ook de belangstelling voor onderzoek een grote rol. Het tegengaan van het overwaaien van bestrijdingsmiddelen naar de omgeving van de percelen en/of het bevorderen van de biodiversiteit in agrarische gebieden, blijken ondergeschikte elementen in deze.

Deel 5: Conclusies, aanbevelingen en perspectieven

In het laatste deel van het proefschrift worden de belangrijkste uitkomsten van het onderzoek weergegeven in de vorm van conclusies en aanbevelingen. Samenvattend kan worden geconcludeerd dat voor de kleigronden in West-Nederland akkerrandenbeheer goede perspectieven biedt. Door het aanleggen van een relatief smalle spuitvrije strook van 3 meter breed kunnen de emissiedoelstellingen ten aanzien van het overwaaien van bestrijdingsmiddelen naar het oppervlaktewater worden gerealiseerd. Om de biodiversiteit van agrarische gebieden te verhogen biedt het creëren van onbespoten gewasranden in wintertarwe het meeste perspectief. De effecten lijken zich vooral te manifesteren in de toename van de akkerkruiden en de daaraan gebonden insektenfauna. Bovendien blijkt dat ook de in de hogere delen van de planten foeragerende Gele kwikstaart hiervan kan profiteren. De effecten op de bodemevertebraten lijken relatief geringer. In de wintertarwe zijn de kosten van de maatregelen gering. Bovendien staan ook akkerbouwers positief ten opzichte van onbespoten graanranden. Het aanleggen van onbespoten aardappelranden levert in vergelijking met wintertarwe minder natuurwinst op. Hoewel de kosten in aardappelen gemiddeld bijzonder laag zijn, hebben onbespoten randen in dit gewas niet de voorkeur van de akkerbouwers. Ook vanuit milieuhygiënisch oogpunt is het aanleggen van onbespoten randen in dit gewas minder voor de hand liggend, omdat het achterwegelaten van fungiciden bij veel aardappelrassen nauwelijks mogelijk is. Door het gebruik van deze middelen blijven risico's voor waterorganismen bestaan. In suikerbieten ten slotte, zijn de kosten van de maatregelen dermate hoog dat onbespoten randen in dit gewas voor de praktijk afvallen. Bij zowel suikerbieten als aardappelen kan bijvoorbeeld beter worden kozen voor een onbespoten graanrand of onbespoten grasrand rond het gewas.

Voor de invoering van specifiek akkerrandenbeheer in Nederland zijn ten minste 3 aanknopingspunten bij het huidige beleid aan te geven, namelijk in aansluiting op het milieubeleid ten aanzien van bestrijdingsmiddelen, het Europese landbouwbeleid, in het bijzonder de braaklegregeling, en ten derde in het kader van het natuurbeleid, met name de Relatienota of het soortenbeleid. In beide eerste beleidsperspectieven is het 'meeliften' van de bevordering van biodiversiteit geen opzichzelfstaand doel en mogelijk van tijdelijke aard. Vanuit het natuurbeleid is wellicht alleen een beperkte verbreiding van het randenbeheer mogelijk. Daarom wordt ten slotte gepleit dat als algemeen uitgangspunt voor Good Agricultural Practice zal gelden dat niet meer tot aan de rand van de sloot zal worden 'geboerd', maar dat standaard een strook van circa 1,5 meter zal worden vrijgehouden van bestrijdingsmiddelen. Hierdoor worden de milieurisico's van bestrijdingsmiddelen op voorhand beperkt, wordt een zekere mate van natuurbasiskwaliteit in het agrarisch gebied gerealiseerd en kan het maatschappelijk aanzien van de Nederlandse agrarische sector worden verbeterd.

Summary

This dissertation reports on an experimental field study aimed at developing a management strategy for pesticide use in field margins in arable farming areas on clay soils in the Netherlands. The study is an exponent of the 'interleaving strategy at farm level', which aims at identifying ways of combining farm management with nature conservation and environmental protection. The study, undertaken at the Centre of Environmental Science of Leiden University, took place during the period 1990-1994. The study was of an interdisciplinary nature and focused on the analysis of both the ecological/environmental and the socio-economic issues connected with the use of pesticides on field margins.

The study aimed to answer the following three key questions:

- To what extent can a reduction in the use of pesticides on arable field margins help to reduce pesticide emissions to the field surroundings?
- To what extent is it possible to enhance the biodiversity in farming areas by undertaking specific forms of arable field margin management relating to pesticide use?
- To what extent is discontinuation of pesticide application in arable field margins compatible with overall farm management?

The study was carried out on 16 conventionally managed farms in the Haarlemmermeerpolder, in the Netherlands. On these farms sugarbeet, potatoes and winter wheat are cultivated in rotation. The fields are bordered by ditches on all sides. For the purpose of the study, on 6 farms strips 3 metres wide and 100 metres long in each of these 3 crops were left unsprayed with herbicides and insecticides along the field margins. On 10 farms, strips 6 metres wide and 450 metres long were also left unsprayed with herbicides and insecticides along the edges of winter wheat fields. Along these margins the fertilizer regime remained unchanged, and the use of fungicides was allowed. In all cases the unsprayed field margins were compared with sprayed strips on the same farm.

The present dissertation consists of 5 parts. After a general introduction (Part 1) the 3 key research questions are elaborated in Parts 2, 3 and 4 of the dissertation, *viz.* a sub-study on aspects of environmental protection, a sub-study on ecological aspects and a sub-study on socio-economic aspects. In Part 5, finally, the main conclusions of the study are summarized, recommendations made and perspectives presented.

Part 1: Introduction

In Chapter 1 the 3 key research questions are presented and the structure of the dissertation described. Next, in Chapter 2, the significance of field margins is characterized from the angles of environmental protection, ecology and overall farm management. The international scientific 'state of the art' regarding field margin management is also reviewed. Besides the possibilities offered by margin management in sugarbeet, potato and cereal crops, such variants as margins sown in with grass or wildflowers and set-aside margins are also discussed.

Part 2: Environmental research

The environment-oriented sub-study consists of 2 parts. First of all pesticide use on field margins is inventoried by means of interviews with arable farmers. Next pesticide spray drift to adjacent ditches is measured for the two main modes of spraying: use of a field spraying unit to treat the crop and use of a knapsack sprayer to treat the sterile strip. In the case of field spraying, it was also investigated to what extent buffer zones 3 and 6 metres wide can reduce spray drift to the field surroundings.

Pesticide use

Interviews with 88 arable farmers in the Haarlemmermeerpolder indicated that field margins are sprayed intensively with pesticides (Chapter 3). This holds for the crop edge, the sterile strip, the ditch bank and the ditch bed. The sterile strip is sprayed by approx. 85% of farmers, simultaneously with spraying of the field. Approx. 95% of farmers also spray the sterile strip separately with a knapsack sprayer once or twice a year, using mainly glyphosate. The ditch bank is sprayed by approx. 60% of farmers, often with glyphosate and MCPA. In addition, a wide range of other agents are employed. The majority of these have not been approved for this application, however. About 30% of farmers spray the ditch bed (glyphosate and dalapon). In many cases the dosage employed is higher than recommended and varies by a factor 60 among the farmers interviewed.

Pesticide spray drift

In Chapter 4 pesticide spray drift to neighbouring ditches due to the use of field spraying units is discussed. To this end deposition measurements were carried out using water-sensitive paper strips. Deposition on the target crop was assumed to be 100%. The measurements were carried out with a variety of spray nozzles and at various different wind speeds. At very low wind speeds (<0.5 m/s) no deposition was measured in the ditch and a maximum of 6.0% halfway down the ditch bank. At a wind speed of 3 m/s these values were 2.2% and 25.1%, respectively. At this wind speed the ditch loading is equivalent to the dosage used to assess the risks of pesticides to aquatic organisms during the registration procedure (1-2%). With increasing wind speed, the ditch loading also increases. At 5 m/s, a wind speed at which spraying still regularly occurs in practice, deposition in the ditch is approx. 7%. Risk analysis using the SLOOTBOX model indicates that at this wind speed 8 of the 17 pesticides investigated pose a risk to algae, water fleas and fishes. For 4 pesticides the risk is even high to very high.
Creation of an unsprayed buffer zone only 3 metres wide reduces spray drift to the ditch by at least 95% (wind speed: max. 4.5 m/s). With a buffer zone 6 metres wide no deposition was observed in the ditch. The 3-metre-wide unsprayed margins are adequate to achieve the targets for reducing emissions to surface waters laid down in the Multi-year Crop Protection Plan (MJP-G, 1991). The risk analysis indicates that with a 3-metre buffer strip only 4 of the 17 pesticides investigated pose a (minor) risk.

In Chapter 5 pesticide spray drift is investigated during use of the knapsack sprayer on the sterile strip. It was found that at low wind speeds (<3.5 m/s), with the wind blowing towards the ditch, virtually no pesticide reaches the ditch: <0.1% of the deposition in the sprayed area (=100% deposition). On the ditch bank, on the other hand, a maximum of about 9% deposition was measured. As the wind speed increases, so too does the loading of the ditch and ditch bank. At a wind speed of 5 m/s a maximum of 3.2% deposition was measured in the ditch. With this mode of application, pesticide spray drift can be readily prevented by technical means, by using a spray nozzle with a tip angle of less than 60 degrees.

Part 3: Ecological research

In the ecological sub-study it was investigated to what extent the abundance of plants of arable land, invertebrates and vertebrates can be promoted by leaving the outermost metres of arable fields unsprayed with pesticides. In doing so, a comparison was also made of the potential of unsprayed strips 3 and 6 metres wide for enhancing biodiversity.

Plants of arable land

In Chapter 6 the effects on vegetation are described. To this end the presence and abundance of plant species of arable land were compared in the unsprayed margins and at the centre of the field (Braun-Blanquêt method). In all 3 crops the cover of farmland plant species was found to increase: in sugarbeet from 10 to 44%, in potatoes from 4 to 11% and in winter wheat from 2 to 32%. There was also a pronounced increase in the number of farmland plant species: on average, in sugarbeet from 6 to 24 species, in potatoes from 8 to 17 species and in winter wheat from 6 to 17 species. The increase was due mainly to an increase in dicotyledonous species, which is of relevance for the occurrence of other organisms in the agro-ecosystem, such as flower-visiting insects. Species found to be frequently dominant were Field Pennycress (*Thlaspi arvense*), Fig-leaved Goosefoot (*Chenopodium ficifolium*) and Fat Hen (*Chenopodium album*) in sugarbeet, Groundsel (*Senecio vulgaris*) in potatoes, and Scented Mayweed (*Matricaria recutita*), Black Bindweed (*Polygonum convolvulus*) and Common cleavers (*Galium aparine*) in winter wheat. Many species, such as Poppies (*Papaver* spp.), Scarlet Pimpernel (*Anagallis arvensis*) and Common Fumitory (*Fumaria officinalis*) were found almost exclusively in the unsprayed margins and nowhere else in the fields.
The increase in the number of plant species of arable land is due almost entirely to common species. On the basis of a conservation value yardstick, whereby the rarity of a given species is combined with the population trend of that species, it can be concluded that there is also an increase in the conservation value of the vegetation in the unsprayed strips: in sugarbeet by a factor 5.2, in potatoes by a factor 2.8 and in winter wheat by a factor 7.2. At the field centre the presence and abundance of farmland plant species as well as the conservation value of the vegetation were consistently lower than on the (sprayed) field margins.
From a scenic perspective, the unsprayed winter wheat field margins had an attractive appearance because of the dominance of white-flowering mayweed with here and there a poppy. With sugarbeet the visual appearance is negative, because the crop becomes overgrown. With this crop there is also reduced cover of sugarbeet plants in the unsprayed margins. In the case of the unsprayed potato margins there was generally little visual change, because the farmland plants did not usually exceed the crop in height.

Invertebrates

Chapters 7 and 8 describe the effects on the insects found in the upper parts of the vegetation (crop and farmland plants). The presence of this group of animals was inventoried by means of visual observation and using a sweep net. This part of the study focused on winter wheat and potatoes, with special attention being paid to the presence of butterflies.

In the unsprayed winter wheat margins the insect density in the upper parts of the vegetation was 3 to 4 times greater than in the sprayed margins (Chapter 7). This increase was due to flower-visiting insects such as Hover-flies (Syrphidae) and also to natural aphid predators such as Ladybirds (Coccinellidae). The number of insect groups also increased in the unsprayed margins, by a factor 1.4. Although aphids were more abundant in the unsprayed winter wheat margins, they did not spread to the rest of the field.
The butterfly inventory (Chapter 8) showed that 6 species predominated in the margins, *viz.* Meadow Brown (*Maniola jurtina*), Wall Brown (*Lasiommata megera*), Small Heath (*Coenonympha pamphilus*), Small White (*Pieris rapae*), Green-veined White (*Pieris napi*) and Essex Skipper (*Thymelicus lineola*). The number of butterflies in the unsprayed winter wheat margins was 4 to 5 times higher than in the sprayed margins (an increase from 2.3 to 11.0 individuals per 300 m^2). The number of butterfly species also increased, from 1.5 to 3.5 species per 100 m on average. The number of butterflies in the unsprayed cereal margins was about 2 to 3 times higher than in the unsprayed potato margins. In 1 of the 2 years that butterflies were inventoried there was also a significant increase in the number of butterfly individuals in the unsprayed potato margins.
The interaction with the ditch bank adjacent to the unsprayed margin has an important influence on the presence of insects. Butterflies naturally occur in greater numbers along the ditch banks than along the crop margins. On the ditch bank adjacent to the unsprayed margin, the number of butterflies increased by a factor 1.6: on average, from 12.8 to 19.2 individuals per 100 m. There are indications that creation of an unsprayed strip at the centre of the field, unconnected to an outside landscape element such as a ditch bank, is of virtually no benefit to this species group.

The impact on the epigeic soil invertebrates was investigated using pitfalls (Chapters 9 and 11). The number of these invertebrates (activity density) in the unsprayed margins was found to be only slightly higher than in the sprayed margins. Of the 4 dominant invertebrate groups, *viz.* Coleoptera, Araneida, Hymenoptera and Diptera, only the Araneida in winter wheat and the Coleoptera in sugarbeet were trapped slightly more frequently in 1 of the 2 years of study (by a factor of approx. 1.2).
Carabid beetles constituted the bulk of the biomass of the epigeic soil invertebrates and were investigated in greater detail (Chapter 9). In all, more than 70 different species of Carabidae were trapped. Six species predominated, *viz. Pterostichus melanarius*, *Bembidion tetracolum*, *Nebria brevicolis*, *Trechus quadristriatus*, *Harpalus rifipes* and *Agonum dorsale*. Considerably fewer carabid beetles (species and individuals) were trapped in the potato margins than in the winter wheat and sugarbeet margins. In the unsprayed winter wheat margins (in both years of study) and sugarbeet margins (one year) the activity density of Carabidae was greater than in the sprayed margins, by a factor 1.3. In one of the years of study a positive effect was found on the number of carabid species in all 3 crops. At the species level, the only clear effects were on herbivorous Carabidae in the genera *Harpalus* and *Amara*.

Vertebrates
The impact on farmland birds was studied in 6-metre-wide winter wheat margins (Chapter 10). To this end the frequencies of visits of the Blue-headed wagtail (*Motacilla flava flava*), Skylark (*Alauda arvensis*) and Meadow pipit (*Anthus pratensis)* to the sprayed and unsprayed margins were compared. The bird censuses indicated that unsprayed winter wheat margins are very attractive to Blue-headed Wagtails. Compared with the sprayed margins, these unsprayed strips are visited 3 to 4.5 times more frequently by this species. In the case of the Skylark no difference was found in the frequency of visits. The different results for these 2 species are probably due to differences in diet and foraging strategy: the Blue-headed wagtail forages in the upper parts of the vegetation, where there is a major impact on insect abundance (Chapter 7), while the Skylark forages exclusively on the ground, and is mainly herbivorous. The effects on the Meadow pipit (*Anthus pratensis)* could not be investigated in the present study, because of the low density of this species in the study area.
The limited inventory of small mammals undertaken indicated that it is above all cereal margins that are visited by (field) mice (Chapter 11). In the margins of sugarbeet and potato fields far fewer mice were caught. The unsprayed cereal margins appear to be more attractive to mice than the sprayed margins, as reflected in 38 compared with 27 mice caught.

Dimensions of the margins
In the study unsprayed winter wheat margins were created both 3 m wide and 100 m long and 6 m wide and 450 m long, enabling the 2 designs to be compared (Chapter 12). It was thus possible to gain an indication of the margin dimensions that are most appropriate for promoting the abundance of flora and fauna. Comparison of the margins 3 and 6 m wide showed that it is above all the outermost metres of the field that are important for the vegetation and the insects living there. The outer 3 metres originally harbour the greatest number of species. In the unsprayed situation there is no extra increase in the abundance and presence of arable plant species or insects in the 6-metre-wide strips relative to the 3-metre-wide strips. This argues for the creation of long unsprayed margins 3 metres wide rather than 6-metre-wide strips of shorter length. By creating longer margins, moreover, there is greater benefit to nature and the environment along the ditch bank and in the ditch itself.

Part 4: Compatibility with farm management

The sub-study on the compatibility of margin management with overall farm management consisted of 2 parts. First an economic cost-benefit analysis was performed, with the harvest losses in the unsprayed margins being compared with the savings on pesticide use. Next the social acceptance of the measures on the part of the arable farmers was investigated. In this context the scope of the study was extended, with interviews being held with arable farmers from various regions of the Netherlands with experience of field margin management. Besides the unsprayed margins, the acceptance of other types of margins was also investigated, such as unsprayed grass-sown margins and set-aside margins.

Cost-benefit analysis of unsprayed crop margins

To calculate the costs of creating unsprayed margins the quantitative and qualitative harvest losses were determined for the various crops in the Haarlemmermeerpolder (Chapter 13). In each crop a comparison was also made of the crop yield from the unsprayed strip and that from the centre of the field. In all the unsprayed margins the crop yield was lower than in the sprayed margins. On average over the various farms and years of study, the loss in yield amounted to about 30% in sugarbeet, 2% in potatoes and 13% in winter wheat. There was substantial variation from plot to plot and from year to year, however. The considerable loss in sugarbeet yield was due to the crop becoming overgrown with arable weeds. In this crop it was above all the absence of the first herbicide spraying session of the year that had a negative impact on the yield. The harvest from the unsprayed margins was almost of the same quality as that from the sprayed margins (Chapter 13). No difference was found in the sugar content of the sugarbeet, sugar extractability, dry-matter content of the potatoes or moisture content of the cereal grains. In one year only was there slightly less variety in potato size in the unsprayed margins.

A comparison of the costs of harvest losses with the savings on pesticide use achieved in the unsprayed margins indicates that the nett costs are high in sugarbeet: approx. Dfl. 0.21 per m^2. This type of field margin management is thus impractical. In a potato crop the costs of harvest losses are offset by the savings on pesticide use; with this crop there are zero nett costs. In winter wheat, finally, the nett costs are low: approx. Dfl. 0.01 per m^2. Yield measurements indicate, furthermore, that in the sprayed situation the crop margin always yields 10-15% less than the plot centre.

Social acceptance of the measures

In order to gain an indication of the social acceptance of field margin management by arable farmers, in collaboration with the Department of Farm Management of Wageningen Agricultural University a sub-study was conducted among 31 Dutch arable farmers with experience with specific forms of arable field margin management (Chapter 14). The farmers interviewed were participants in the CML Haarlemmermeerpolder project, the Field Margin project of the Gelderland provincial authority and the Partridge Habitat Recovery project of the Foundation for Conservation of Nature and Environment.

If various different management packages are proposed to arable farmers, there is found to be a clear preference for unsprayed cereal margins or unsprayed grass strips. Unsprayed margins in potato crops and set-aside strips score substantially lower. Cereal margins around other crops occupy an intermediate position. This choice is found to be based mainly on crop protection arguments, such as the increase in the abundance of arable plant species and in the occurrence of diseases and pests on the margins and in the rest of the field. In the case of grass-sown strips the lack of suitable farm machinery, particularly in the Dutch lowlands, was quoted as the main argument. In their attitudes, the actors in the environment of the arable farmers differentiated little between the various management options. It is surprising that unsprayed potato margins score so low, despite the low costs they entail. This is probably due to a desire to avoid all risks in this high-profit crop.

It was also found that the most important aspect determining the compatibility of field margin management with overall farm management is the width of the unsprayed margins. In this context there is a preference for a flexible width. The farmers showed a preference for a guaranteed payment rather than a system of reimbursement based on the

conservation results achieved. Margin management need not be supported by an intensive support programme. The location of the unsprayed margins can rotate within a given farm.
The motives of arable farmers for participating in field margin projects are highly dependent on the degree of trust in the project liaison officer. An additional factor of importance is the farmer's interest in the research. Prevention of spray drift to the field surroundings and/or enhancement of biodiversity in agricultural regions were found to play only a subordinate role.

Part 5: Conclusions, recommendations and perspectives

In the last part of this dissertation the main research results are presented in the form of conclusions and recommendations. Summarizing, it can be concluded that on the clay soils in the West of the Netherlands field margin management offers promising perspectives. By creating a relatively narrow strip 3 metres wide, the emission targets pertaining to pesticide spray drift to surface waters can be achieved. As a means of enhancing biodiversity in farming regions, the creation of unsprayed margins in winter wheat offers the most promising perspectives. The main effects appear to be an increase in the abundance and variety of farmland plant species and their associated insect fauna. The Blue-headed Wagtail, which forages in the upper parts of the plants, also appears to benefit from the situation. There appears to be relatively less impact on soil invertebrates. In winter wheat the measures involve little extra nett expense. Arable farmers have a positive attitude towards unsprayed cereal margins, moreover. In comparison with winter wheat, in potatoes the creation of unsprayed margins yields less conservation benefit. Although the costs in potatoes are extremely low on average, in this crop unsprayed margins are not popular with farmers. From the viewpoint of environmental protection, too, the creation of unsprayed margins serves less purpose in this crop, because with many varieties of potato it is scarcely possible to discontinue the use of fungicides. Through use of these chemicals aquatic organisms remain at risk. In sugarbeet, finally, the costs of the measures are so high as to make unsprayed margins impracticable in this crop. In the case of potatoes and sugarbeet a better option is to create an unsprayed cereal margin or unsprayed grass-sown strip around the crop, for example.

With a view to introducing specific field margin management in the Netherlands there are at least 3 potential links to current policy: environmental policy concerning pesticide use; European agricultural policy, in particular the set-aside scheme; and thirdly nature policy, in particular in the framework of the so-called Relation Paper (a government paper on the relation between agriculture and nature and landscape conservation) or policy on species. In the first 2 policy perspectives 'co-option' of biodiversity enhancement does not constitute an objective in its own right and may thus be of a temporary nature only. Linking up with nature policy may allow for only a limited extension of field margin management. Ultimately, it is therefore recommended that it should be taken as a general principle of Good Agricultural Practice that cultivation should no longer be practised up to the edge of the ditch, but that, as standard practice, a strip about 1.5 metres wide should be left free of pesticides. In this way the environmental risks of pesticide residues can be pro-actively restricted, a certain degree of 'basic nature quality' (as laid down in government conservation policy) can be achieved in farming areas, and the public's perception of the Dutch agricultural sector can be improved.

Annex Unsprayed field margins on arable land

G.R. de Snoo

Abstract

In the Dutch Field Margin Project in the Haarlemmermeerpolder (1990-1994) a management strategy is being developed for promoting nature conservation on arable land and reducing pesticide drift to non-target areas. To this end, 3- and 6-m wide strips along the edges of winter wheat, sugar beet and potato crops have been left unsprayed with herbicides or insecticides and compared with sprayed edges. The effects on weeds, invertebrates, vertebrates, pesticide drift and costs to the farmer are being studied. This article reviews the results obtained to date.

In the unsprayed edges weed cover increased substantially, as did the overall number of weed species. The impact on soil invertebrates such as carabids (activity density) was relatively minor. However, there was a pronounced effect on insects living on plants. Butterflies were 3-4 times more abundant in unsprayed winter wheat edges than in sprayed edges. The number of visits by Motacilla flava flava (Blue-headed wagtail), an insectivorous bird, was also 3-4 times higher. Interviews with farmers indicated that field margins were sprayed intensively. Drift measurements using water-sensitive paper demonstrated that pesticide deposition in adjacent ditches was < 0.1% of the deposition in the target area for knapsack sprayers and max. 2.2% for field sprayers at low wind speed (3 m/s). At higher wind speed (5 m/s) these figures are 3.2% and about 7%, respectively. The creation of unsprayed buffer zones of 3 m wide proves to be a very effective way of reducing pesticide drift to the ditch (by about 90%). Compared with sprayed edges, the average yield loss in unsprayed edges of 3 m wide was 2% in potatoes, 13% in winter wheat and 30% in sugar beet. Cost-benefit analysis shows that in winter wheat and potatoes unsprayed crop edges can well be adopted in agricultural practice. In sugar beet, however, the cost is too high.

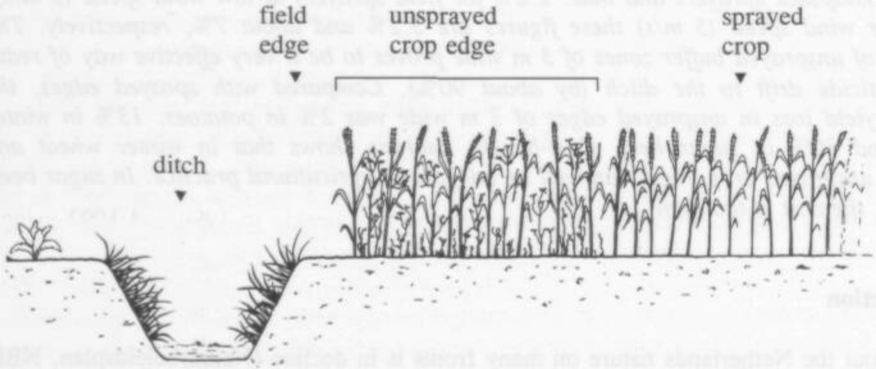
Introduction

Throughout the Netherlands nature on many fronts is in decline (Natuurbeleidsplan, NBP, 1990). In this respect, nature in arable regions is no exception. In the period 1930-1980 there was a marked decline in the diversity of the flora of arable land and there was a similar trend in the fauna of this habitat, for example in the abundance of birds like the Partridge. This decline is due to a number of factors, many of them related to the intensification of agricultural operations. In the case of arable farming, one of the most significant factors is pesticide use. Use of these compounds on Dutch arable farmland is extremely high: 19 kg active ingredient/ha.year (Meerjarenplan Gewasbescherming, MJP-G, 1991).

In recent years it has become clear that the natural values of arable land can be substantially improved by reducing pesticide use along field margins (Figure 1). This leads to a marked increase in the abundance of wildflowers, insects and birds in the unsprayed crop edges (e.g. Schumacher, 1984; Rands, 1985; Rands & Sotherton, 1986; Boatman, 1994). A major advantage of such crop edge management is that by implementing measures in a small portion of a field, it is in principle possible to guarantee species abundance over a much larger area. Moreover, establishment of unsprayed crop edges in essence can create a system of 'green veins' through arable regions, by which distribution of species can be increased. This type of management also enables a reduction of pesticide emissions to the surrounding area to be achieved. The creation of buffer zones decreases pesticide drift to adjacent non-target areas. In terms of agricultural management, crop edges are of less economic value than field interiors. The management of crop edges often requires additional effort and yields are generally lower.

Together, these considerations indicate that a specific management regime for crop edges represents an instrument worth looking at more closely. With the aim of developing, for the Dutch situation, a management strategy for pesticide use along field margins, since 1990 the Leiden Centre of Environmental Science has been engaged in a field study on conventional arable farms. This research programme has as its objective to increase the natural values of arable regions and reduce pesticide emissions to adjacent ditches. A basic premise of the programme is that the strategy developed should be compatible with conventional agricultural practice. This article provides a review of the results of the programme to date.

Figure 1. Constituent parts of a field margin



Method

Study area

The study was carried out in the Haarlemmermeerpolder. In this polder, reclaimed about 150 years ago, most parcels are 1000 m long and 200 m wide and bordered by ditches. Ditch bank vegetation consists mainly of perennial grasses such as *Elymus repens* (Common couch) and *Festuca rubra* (Red fescue). Two or three times a year ditch banks are mown or chopped, and the swath left lying. The clay soil contains about 23% silt (0-16 μm diam.) and 3% organic matter. The size of most fields investigated was about 500 x 100 m. The most common rotation on the farms is winter wheat followed by potatoes and a second winter wheat crop and finally sugar beet. To investigate the consequences for nature, the environment and the farm economy, strips 100 m long and 3 m wide were left unsprayed with herbicides and insecticides along the edges of these crops on 6 farms. In addition in winter wheat, unsprayed strips measuring 450 x 6 m were created on 10 farms. In all, 43 unsprayed winter wheat strips, 14 sugar beet strips and 18 potato strips were monitored. The unsprayed strips were compared with sprayed strips, almost always in the same field. Spraying with fungicides was permitted, because discontinuation appears to be virtually incompatible with cultivation of the potato cultivars in question. Fertilizer regimes remained unchanged. Because of abundant growth on a number of sugar beet fields, at the farmers' request weeds had to be partly removed by hand in some unsprayed edges. The study was discontinued in the course of 1992 in this crop. In some winter wheat fields *Matricaria recutita* (Scented mayweed) was likewise partly removed at request.

Sampling programme

Ecological research

For the ecological component of the research programme, each year the abundance of various species of farmland flora and total cover were studied in early summer, using the Braun-Blanquet method (sample area: about 75 m^2 per crop edge). Insects on the vegetation (crop and weeds) were collected at the same time of year using sweep nets. Special attention was given to butterflies, which were recorded weekly in 1990 and 1992 using a linear transect census method. Soil invertebrates (> 2 mm) were studied in 1990 and 1991 using pitfall traps (4 or 5 per 100 m); carabids were identified at the species level, other groups generally at the family or order level. Farmland songbirds were studied in 1992 and 1993 in the 6-m wide unsprayed winter wheat edges; the frequency of visits by *Motacilla flava flava* (Blue-headed wagtail), *Alauda arvensis* (Sky lark) and *Anthus pratensis* (Meadow pipit) to the unsprayed crop edges was compared with visits to sprayed edges.

Environmental research

For the environmental research component, type and frequency of pesticide use along field margins was inventoried by means of interviews with almost 90 farmers in the Haarlemmermeerpolder. Next, measurements were made of the pesticide drift resulting from spraying of the field edge with a knapsack sprayer. The drift deposition occurring at various distances from the field was measured for different nozzle types and under various wind speed conditions using water-sensitive paper. In addition pesticide drift from crop treatment with a field sprayer was recorded. A specific aim was to investigate to what extent creation of a 3 or 6-m wide buffer zone can reduce pesticide emissions to non-target areas such as adjacent ditches.

Agro-economic research
To calculate the cost of creating unsprayed margins, yield losses were determined for the various crops, with both quantitative and qualitative yield losses being measured. To this end, in the potato crop an area of 12-18 m^2 was harvested by hand for 3 years in succession in both the sprayed and unsprayed strips. The total yield was weighed, and the size and dry matter content of the potatoes measured. In the sugar beet crop in 1990 and 1991 an area of 12 m^2 was harvested in each strip, and the total yield, sugar content and sugar extractability measured. In winter what, finally, in each of the 3 years the total yield and moisture content of the grain were determined. To this end, a plot combine was used to harvest an area of 60-220 m^2. In each crop a comparison was also made of the crop yield in the sprayed strip and at the centre of the parcel.

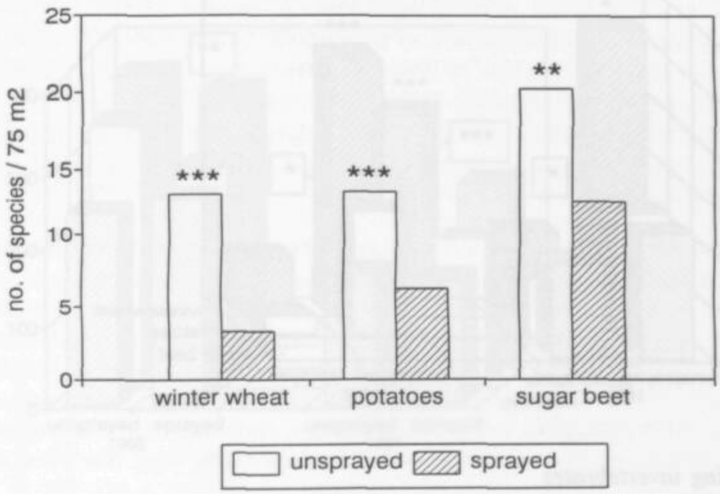
Results

The results of the study indicate major differences in flora and fauna abundance and/or crop yields from farm to farm. At one and the same farm, too, there are sometimes considerable differences between individual fields. By making a pairwise comparison between the sprayed and unsprayed crop edge in a given field, however, a number of general conclusions can be drawn about ecological and economic effects. Below, the effects on nature, the environment and farm economy are presented.

Nature

Farmland wildflowers
In all crops, there was a marked increase in the number of species of broad-leaved farmland wildflowers: in winter wheat by a factor 3, in potatoes by a factor 2 and in sugar beet by a factor 0.5 (Figure 2). In absolute terms, the greatest number of species was found in the sugar beet crop. In all crops, the plants concerned were mainly common species. Some species were encountered almost exclusively in the unsprayed strips, for example *Myosotis arvensis* (Field forget-me-not), *Anagallis arvensis* (Scarlet pimpernel) and *Papaver rhoeas* (Common poppy). Compared with the sprayed strips, the number of graminaceous species remained approximately the same. In the unsprayed strips, the vegetation cover was also markedly denser. In the winter wheat crop, the increase was due mainly to such species as *Matricaria recutita* (Scented mayweed), *Polygonum aviculare* (Knotgrass) and *Senecio vulgaris* (Groundsel). In the sugar beet and potato crop, there is also greater cover with species like *Chenopodium album* (Fat hen) and *Polygonum persicaria* (Redshank). Because of the dominance of white-flowering Scented mayweed, interspersed with the occasional poppy, the edges of the unsprayed winter wheat crop are a visually attractive landscape element. In the case of sugar beet, the field is less attractive visually, as the crop becomes overgrown. In the unsprayed strips in the potato crop, in most cases there was at a landscape level scarcely any difference to be seen, because the weeds were usually not taller than the crop.

Figure 2. Average number of broad-leaved weed species per relevé (75 m²) in the various years investigated in sprayed and unsprayed crop edges (** = $P < 0.01$; *** = $P < 0.001$)

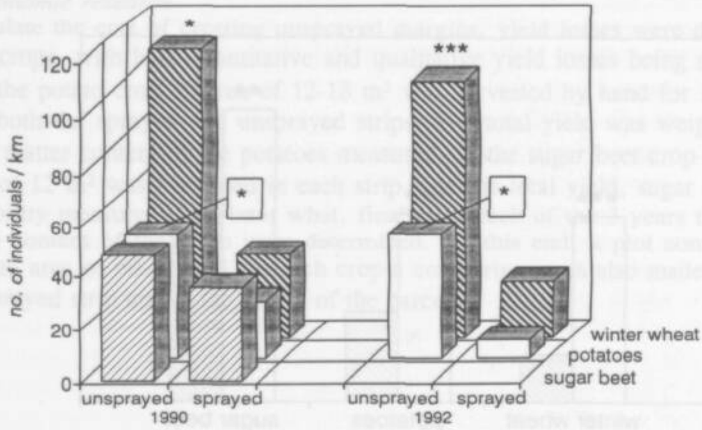


Invertebrates on the vegetation

On the vegetation in the unsprayed strips there is a pronounced increase in the number of insects (individuals and families). This holds both for the number of aphids and for the number of aphid predators such as Coccinellidae (Ladybirds) and Chrysopidae (Green lace-wings). The number of flower-visiting insects, such as Syrphidae (Hover-flies), also increases in the unsprayed edges. Further investigation in winter wheat showed that the increased abundance of aphids was restricted to the unsprayed edges, with absolutely no increase in aphid abundance being found in the directly adjacent crop in the rest of the parcel.

In the field margins studied, a total of 13 butterfly species was found, with 6 species predominating: *Maniola jurtina* (Meadow brown), *Lasiommata megera* (Wall brown), *Coenonympha pamphilus* (Small heath), *Thymelicus lineola* (Essex skipper), *Pieris rapae* (Small white) and *P. napi* (Green-veined white). The study showed that the number of butterflies increased significantly in the unsprayed winter wheat and potato crop edges; in sugar beet the increase was not significant (Figure 3). The number of individuals found in the unsprayed winter wheat edges was four times higher than in the sprayed edges. In winter wheat, in both years investigated, and in potatoes, in 1992, there was also a significant increase in the number of butterfly species in the unsprayed strip. On the ditch bank and field edge bordering on unsprayed crop edges, too, there was in one or both years a significant rise in the number of butterfly individuals and species. This is probably due to the increased abundance of wildflowers on both the field edge and ditch bank resulting from discontinuation of herbicide use (drift).

Figure 3. Number of butterfly individuals in sprayed and unsprayed crop edges of sugar beet, potatoes and winter wheat (* = $P < 0.05$; *** = $P < 0.001$)



Ground-dwelling invertebrates

Catches in pitfalls showed that most ground-dwelling invertebrates belong to the Linyphiidae (Money spiders), Carabidae (Carabid beetles), Staphylinidae (Staphylinid beetles) and Diptera (Two-winged flies), with the carabids constituting most of the biomass. A total of more than 70 different carabid species was trapped. Overall, 6 common carabid species predominated, together accounting for more than 80% of the total number of individuals: *Pterostichus melanarius*, *Bembidion tetracolum*, *Nebria brevicollis*, *Trechus quadristriatus*, *Harpulus rufipes* and *Agonum dorsale*. The activity density of carabids in winter wheat (both 1990 and 1991) and in sugar beet (1991) was significantly higher in the unsprayed margins (Figure 4). However, the increase in the number of insects trapped was relatively small. In these crops the number of species was significantly higher in 1991. In potatoes there was only a significant difference in the number of species (1990). At the species level, species of the carabid genera *Amara* and *Harpalus*, both herbivorous, show the most marked increase (De Snoo *et al.*, 1994b). The results for other groups of ground-dwelling invertebrates are still being processed.

Songbirds

The bird censuses held in 1992 and 1993 indicated that unsprayed winter wheat crop edges are very attractive to *Motacilla flava flava* (Blue-headed wagtail) (De Snoo *et al.*, 1994a). Compared with the sprayed edges, these edges are visited 3 to 4 times as frequently by this species (Figure 5). For *Alauda arvensis* (Sky lark) no such difference was found. The difference between these two species may be due to their different dietary preferences: *Motacilla flava flava* is insectivorous, while *Alauda arvensis* is partly herbivorous. In addition, the latter species feeds mainly on the ground, where effects on the ground-dwelling fauna are found to be relatively minor, while *Motacilla flava flava* also feeds in the upper part of the vegetation. The species *Anthus pratensis* (Meadow pipit) was observed in very low numbers only.

Figure 4. Number of carabid beetles (activity density) in sprayed and unsprayed crop edges of potatoes, winter wheat and sugar beet (** = $P < 0.01$; *** = $P < 0.001$). N.B. Trapping liquids and trapping period were not the same in the two years of study

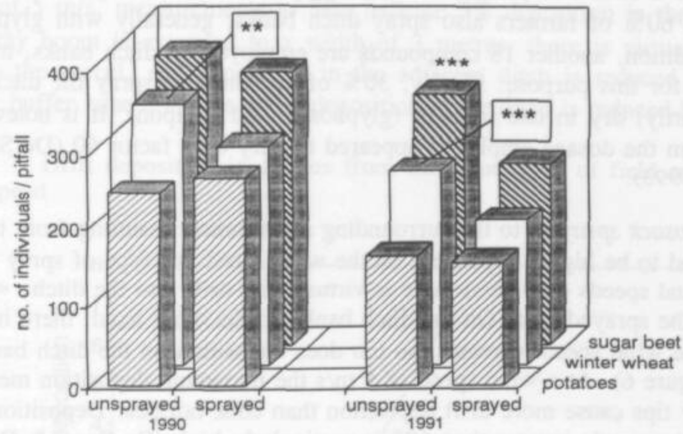
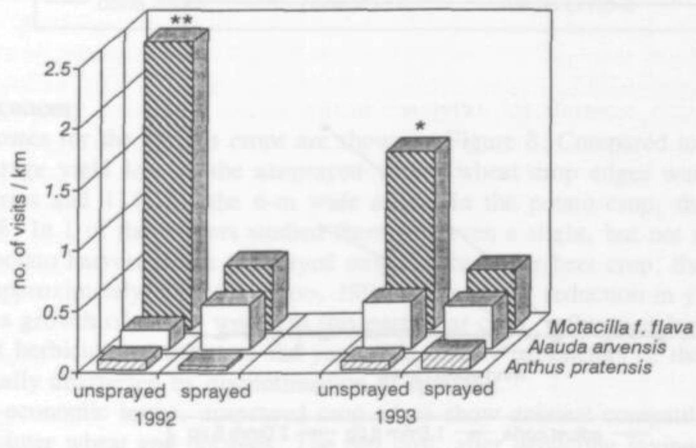


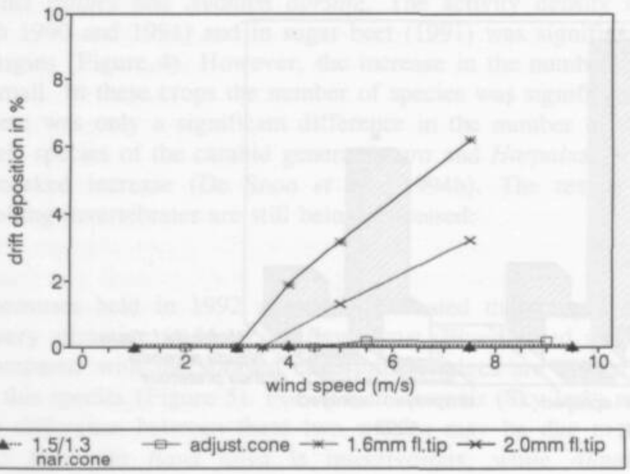
Figure 5. Number of farmland songbirds in 6 metre wide sprayed and unsprayed crop edges of winter wheat (* = $P < 0.05$; ** = $P < 0.01$)



Environment
It was found that field margins are sprayed very frequently with pesticides. The inventory showed that when spraying the crop, more than 85% of farmers also spray the field edge. Moreover, 95% of those interviewed reported separate spraying of the field edge once or twice a year to create a sterile strip. In most cases glyphosate (Round up) was used for this purpose. Almost 60% of farmers also spray ditch banks, generally with glyphosate and/or MCPA. In addition, another 18 compounds are employed on ditch banks, most of which are prohibited for this purpose. Finally, 30% of farmers also spray the ditch bed, when the ditch is (partly) dry in late summer (glyphosate and dalapon). It is noteworthy that from farm to farm the dosage employed appeared to vary by a factor 60 (De Snoo & Wegener Sleeswijk, 1993).

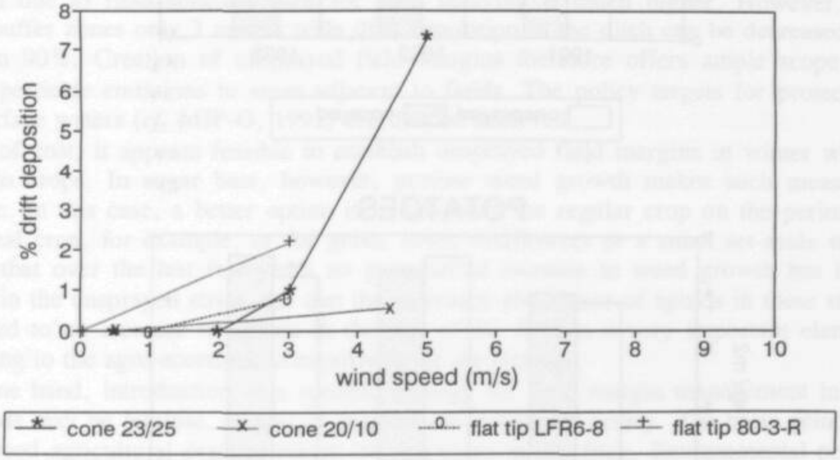
Pesticide drift of *knapsack sprayers* to the surrounding environment resulting from the use on field edges is found to be highly dependent on the wind speed and type of spray nozzle employed. At low wind speeds (≤ 3 m/s) there is virtually no drift into the ditch: $<0.1\%$ of the deposition on the sprayed area. On the ditch bank, on the other hand, there is up to 9% deposition. As the wind speed increases, so too does deposition on the ditch bank and in the ditch itself (Figure 6). At a wind speed of 5 m/s the maximum deposition measured was 3.2%. Flat spray tips cause more drift deposition than cone nozzles. Deposition from spray nozzles with a top angle greater than 60° is particularly high (De Snoo & De Wit, 1993).

Figure 6. Drift deposition in ditches from different types of knapsack sprayers in relation to wind speed



To date, only a limited number of measurements have been made of the deposition resulting from *field spraying*, and then mainly at low wind speeds. These measurements show that under practical working conditions pesticides are frequently deposited in ditches. The quantity deposited is highly dependent on wind direction and speed. At low wind speeds (≤3 m/s) a maximum of 2.2% deposition was measured in the ditch. At a higher wind speed of 5 m/s, measurements to date indicate 7% deposition in the ditch (Figure 7). If the spray boom is extended to a width of 3 metres, there is virtually no pesticide drift outside the parcel, and deposition in the adjacent ditch is reduced by more than 90%. With a buffer zone 6 metres wide, deposition in the ditch is reduced by almost 100%.

Figure 7. Drift deposition in ditches from different types of field sprayers in relation to wind speed

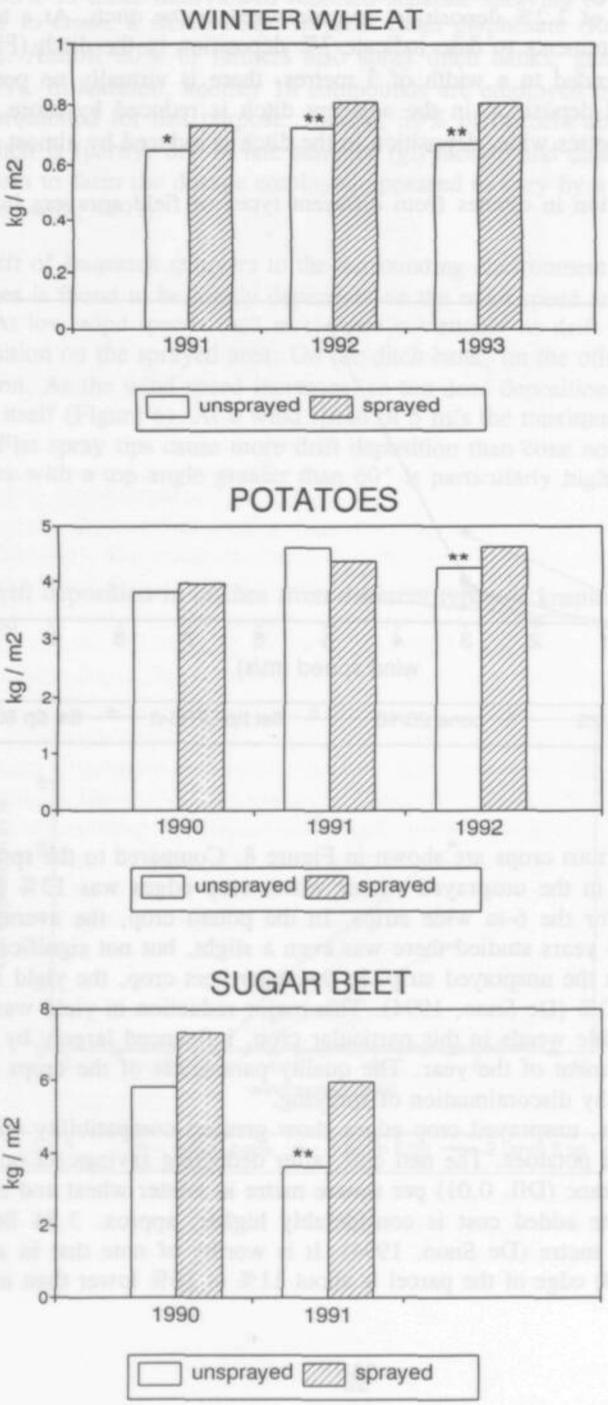


Agro-economy

Yield losses for the various crops are shown in Figure 8. Compared to the sprayed edges, the average yield loss in the unsprayed winter wheat crop edges was 13% for the 3-m wide strips and 11% for the 6-m wide strips. In the potato crop, the average loss was only 2%. In 1 of the 3 years studied there was even a slight, but not significant, increase in the potato harvest in the unsprayed strip. In the sugar beet crop, the yield loss amounted to approximately 30% (De Snoo, 1994). This major reduction in yield was due to the vigorous growth of arable weeds in this particular crop, influenced largely by leaving out the first herbicide treatment of the year. The quality parameters of the crops appeared to be virtually unaffected by discontinuation of spraying.

In agro-economic terms, unsprayed crop edges show greatest compatibility with cultivation of winter wheat and potatoes. The nett cost, after deducting savings on pesticides, are approx. 0.18 Belgian franc (Dfl. 0.01) per square metre in winter wheat and zero in potatoes. In sugar beet, the added cost is considerably higher: approx. 3.84 Belgian franc (Dfl. 0.21) per square metre (De Snoo, 1994). It is worthy of note that in all crops the yield from the (sprayed) edge of the parcel is about 11% to 16% lower than in the middle of the crop.

Figure 8. Yield quantity in sprayed and unsprayed crop edges of winter wheat, potatoes and sugar beet (* = $P < 0.05$; ** = $P < 0.01$)



Conclusions

The results of the study in the Haarlemmermeerpolder show that leaving field margins unsprayed has a positive impact on the abundance of wildflowers, invertebrates and birds. In winter wheat, particularly, the benefit to nature is often high. The impact appears to be most visible in the increased abundance of flowering plants and attendant insect fauna. In addition, the bird species *Motacilla flava flava*, which feeds on the upper parts of the vegetation, appears to benefit. The impact on ground-dwelling invertebrates is found to be relatively less pronounced. In general, it can be concluded that establishment of unsprayed crop edges offers a promising approach to ecological recovery of intensively managed arable farmland in the Netherlands.

From the survey it was concluded that field margins are sprayed intensively. Drift deposition in ditches from knapsack sprayers used on field edges is relatively minor. Drift deposition due to field sprayers used for crop spraying is much higher. However, by creating buffer zones only 3 metres wide drift deposition in the ditch can be decreased by more than 90%. Creation of unsprayed field margins therefore offers ample scope for reducing pesticide emissions to areas adjacent to fields. The policy targets for protecting Dutch surface waters (*cf.* MJP-G, 1991) can thus be achieved.

In terms of cost, it appears feasible to establish unsprayed field margins in winter wheat and potato crops. In sugar beet, however, profuse weed growth makes such measures unrealistic. In this case, a better option is to substitute the regular crop on the perimeter for a cereal crop, for example, or for grass, sown wildflowers or a small set-aside strip. The fact that over the last few years no pronounced increase in weed growth has been observed in the unsprayed strips and that the increased abundance of aphids in these strips has not led to an increase of aphids in the rest of the field is a very important element contributing to the agro-economic compatibility of the strategy.

On the one hand, introduction of a specific strategy for field margin management in the Netherlands may be feasible, as part of existing environmental policy. The basic principle is then: good agricultural practice means no pesticides in the ditch. Environmental policy then has to determine the width of the buffer zone. On the other hand, if this buffer zone is established (partly) for the purpose of achieving nature conservation objectives, farmers could be given a specific reimbursement. Besides a system of 'commands and controls' relating to agricultural management, also, a remuneration scheme based on the conservation results achieved could be envisaged (*cf.* Melman, 1994). If the regular crop is cultivated in the buffer zone, when setting the rate for any financial compensation, it should be borne in mind that in the sprayed situation there is almost always an approx. 11-16% difference in crop yield between the edge and centre of the parcel.

References

Boatman, N.D., 1994. Field margins: Integrating agriculture and conservation, BCPC Monograph No. 58, 404 p.

Meerjarenplan Gewasbescherming (MJP-G), 1991. Regeringsbeslissing, Tweede Kamer, vergaderjaar 1990-1991, 21677, nrs. 3-4. SDU uitgeverij, Den Haag.

Melman, Th.C.P., 1994. Field margins as a nature conservation objective in the Netherlands and Germany for nature conservation; policy, practice and innovative research. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC Monograph No. 58, 367-376.
Natuurbeleidsplan (NBP), 1990. Regeringsbeslissing, Tweede Kamer, vergaderjaar 1989-1990, 21149, nrs. 2-3. SDU uitgeverij, Den Haag.
Rands, M.R.W., 1985. Pesticide use on cereals and the survival of grey partridge chicks: a field experiment. Journal of Applied Ecology 22, 49-54.
Rands, M.R.W. & N.W. Sotherton, 1986. Pesticide use on cereal crops and changes in abundance of butterflies on arable land. Biological Conservation 36, 71-82.
Schumacher, W., 1984. Gefährdete Ackerwildkräuter können auf ungespritzten Feldrändern erhalten werden. Mitteilungen der LÖLF 9 (1), 14-20.
Snoo, G.R. de, 1994. Cost-benefits of unsprayed crop edges in winter wheat, sugar beet and potatoes. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC Monograph No. 58, 197-201.
Snoo, G.R. de, R.T.J.M. Dobbelstein & S. Koelewijn, 1994a. Effects of unsprayed crop edges on farmland birds. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC Monograph No. 58, 221-226.
Snoo, G.R. de, R.J. van der Poll, & J. de Leeuw, 1994b. Carabids in sprayed and unsprayed crop edges of winter wheat, sugar beet and potatoes. Acta Jutlandica in press.
Snoo, G.R. de, & A. Wegener Sleeswijk, 1993. Use of pesticides along field margins and ditch banks in the Netherlands. Med. Fac. Landbouww. Univ. Gent 58/3a, 921-926.
Snoo, G.R. de & P.J. de Wit, 1993. Pesticide drift from knapsack sprayers to ditches and ditch banks. Proceedings Brighton Crop Protection Conference - Weeds -1993 (3), 379-884.

Part 1

Introduction

1 Research questions and dissertation structure

In recent years there has been growing interest in enhancing environmental quality and biodiversity on conventionally managed farms. In the Netherlands the main focus has been on ditch banks in grassland areas (Melman, 1991; Van Strien, 1991). During the '90s there has also been increasing interest in the margins of arable fields. In other countries, especially in Germany and England, more experience has been gained with specific management strategies for field margins in terms of pesticide use (Schumacher, 1984; Way & Greig-Smith, 1987; Boatman, 1994). The most important results of these studies are that the abundance and diversity of farmland flowers, invertebrates and vertebrates in farmland areas can thus be increased and that the measures are compatible with overall farm management.

These results from other countries cannot simply be adopted for the Dutch situation; there are countless ecological and agronomic differences. The foreign studies focus on (permanent) cereal crops on lighter soils, and the plots are frequently bordered by hedgerows. In the Dutch lowlands, particularly, arable farming is on clay soils, with the crop rotation generally comprising potatoes, winter wheat and sugarbeet. In these areas there are no hedgerows, but the fields are generally bordered by ditches.

This dissertation reports on an experimental field study aimed at developing a management strategy for pesticide use in field margins in arable farming areas on clay soils in the Netherlands. The study is an exponent of the 'interleaving strategy at farm level', which aims at identifying ways of combining farm management with nature conservation and environmental protection (Melman, 1991).
The study, undertaken at the Centre of Environmental Science of Leiden University, was carried out in the period 1990-1994 on 16 farms in the Haarlemmermeerpolder, in the Netherlands. The study was of an interdisciplinary nature and focused on the analysis of both the ecological/environmental and the socio-economic issues connected with the use of pesticides on field margins.

The study aimed to answer the following 3 key questions:

- To what extent can a reduction in the use of pesticides on arable field margins help to reduce pesticide emissions to the field surroundings?
- To what extent is it possible to enhance the biodiversity in farming areas by undertaking specific forms of arable field margin management relating to pesticide use?
- To what extent is discontinuation of pesticide application in arable field margins compatible with overall farm management?

The Haarlemmermeerpolder is a marine clay polder where sugarbeet, potatoes and winter wheat are cultivated in rotation. The fields are bordered by ditches on all sides. For the purpose of the study, in each of these three crops strips 3 metres wide and 100 metres long along the field margins were left unsprayed with herbicides and insecticides. In winter wheat margins 6 metres wide and 450 metres long were also left unsprayed with herbicides and insecticides. Along these margins the fertilizer regime remained unchanged. In all cases the unsprayed field margins were compared with sprayed strips on the same farm. Despite the ecological and agronomic differences among farms, this pairwise comparison allows more general conclusions to be drawn on the potential of the unsprayed margins for reducing surface water pollution and for promoting both biodiversity and compatibility with overall farm management.

Dissertation structure

This dissertation consists of 5 parts. In the first part the significance of field margins is characterized from the angles of environmental protection, ecology and overall farm management (Chapter 2). The international scientific 'state of the art' regarding field margin management is also reviewed. Besides the possibilities offered by margin management in sugarbeet, potato and cereal crops, such variants as margins sown in with grass or wildflowers and set-aside margins are also discussed.

The 3 key research questions are elaborated in Parts 2, 3 and 4 of the dissertation, *viz.* a sub-study on aspects of environmental protection, a sub-study on ecological aspects and a sub-study on socio-economic aspects. The second part of the dissertation describes the results of the environmental studies in the Haarlemmermeerpolder. Following an inventory of pesticide use on field margins (Chapter 3), the degree of pesticide drift to adjacent ditches during spraying of arable fields with field sprayers and the field edge with knapsack sprayers is discussed (Chapters 4 and 5, respectively). In Chapter 4 it is also investigated to what extent the creation of unsprayed buffer zones 3 and 6 metres wide can reduce spray drift to the field surroundings.

The third part of the dissertation is an ecological sub-study covering the following aspects of the agro-ecosystem: the effects on the vegetation (Chapter 7), butterflies (Chapter 8), carabid beetles (Chapter 9) and birds of arable land (Chapter 10). In Chapter 11 some additional information is presented with respect to epigeïc soil invertebrates, partridges and small mammals. Chapter 12 is concerned with the dimensions of the margins required to enhance the abundance of several of these groups.

Part 4 of the dissertation deals with the compatibility of margin management with overall farm management. First the costs and benefits of the measures are discussed, with the harvest losses in the unsprayed margins being compared with the savings on pesticide use (Chapter 13). Next the social acceptance of the measures by the arable farmers is discussed (Chapter 14). Besides unsprayed crop margins, other types of margin management are also discussed.

In Part 5, finally, the main conclusions of the study are summarized and recommendations and future perspectives presented.

References

Boatman, N.D., 1994. Field margins: Integrating agriculture and conservation, BCPC monograph No. 58. Nottingham: BCPC Publications.

Melman, Th.C.P., 1991. Slootkanten in het veenweidegebied. Mogelijkheden voor behoud en ontwikkeling van natuur in het agrarisch grasland. Doctoral thesis, Leiden University.

Rands, M.R.W., 1985. Pesticide use on cereals and the survival of grey partridge chicks: a field experiment. J. Applied Ecology 22: 49-54.

Schumacher, W., 1984. Gefährdete Ackerwildkräuter können auf ungespritzten Feldrändern erhalten werden. Mitteilungen der LÖLF 9 (1): 14-20.

Strien, A.J. van, 1991. Maintenance of plant species diversity on dairy farms. Doctoral thesis, Leiden University.

Way, J.M. & P.W. Greig-Smith, 1987. Field margins. BCPC monograph no 35, Thornton Heath: BCPC Publications.

2 Unsprayed field margins: implications for environment, biodiversity and agricultural practice

G.R. de Snoo & H.A. Udo de Haes

Abstract

An overview is presented of the potential of unsprayed crop edges for promoting biodiversity and for environmental protection. Creation of unsprayed crop edges can benefit farmland plants, insects, birds and mammals. Buffer zones only 3 to 6 metres wide prove to be very effective in reducing pesticide drift to adjacent ditch banks and ditches. In the case of cereals, the cost to the farmer of not spraying the crop edges is low. For sugar beet the cost appears to be too high. For this crop grass strips, flower strips or small strips of set-aside land seem to be good alternatives. For potatoes the cost is low, but because of the relatively small positive effects on nature values, alternative strips are recommended for this crop as well.

Introduction

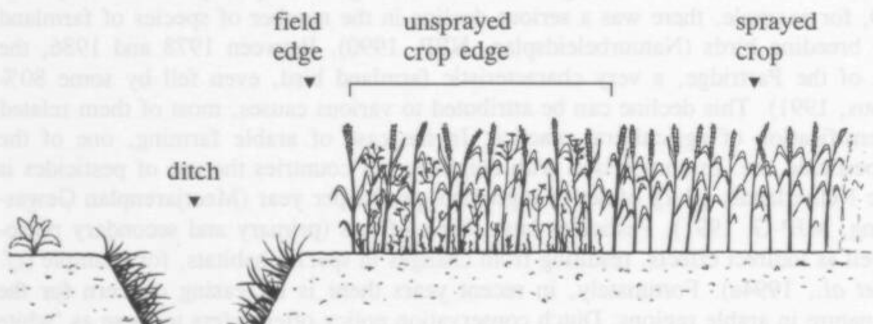
In the Netherlands nature in arable regions is deteriorating in many respects. In the period 1930-1980, for example, there was a serious decline in the number of species of farmland plants and breeding birds (Natuurbeleidsplan, NBP, 1990). Between 1978 and 1986, the abundance of the Partridge, a very characteristic farmland bird, even fell by some 80% (Anonymous, 1991). This decline can be attributed to various causes, most of them related to the intensification of agricultural practice. In the case of arable farming, one of the causes is pesticide use. In comparison with neighbouring countries the use of pesticides is high in the Netherlands: 19 kg of active ingredient per ha per year (Meerjarenplan Gewasbescherming, MJP-G, 1991). Pesticides have direct effects (primary and secondary poisoning) as well as indirect effects, resulting from changes in species habitats, for example (*cf.* De Snoo *et al.*, 1994a). Fortunately, in recent years there is increasing concern for the quality of nature in arable regions; Dutch conservation policy often refers to these as 'white areas', and aims to interlace them with so-called 'green veins' (Natuurbeleidsplan, 1990; Tamis *et al.*, 1993). Following interest in roadside verges (Zonderwijk, 1979; Sykora *et al.*, 1993) and ditch banks (Melman, 1991; Van Strien, 1991) there is now also a growing interest on the potential of arable field margins. This article reviews the status of research on field margins in the Netherlands and elsewhere and discusses a variety of management options.

Characterization of field margins

Species-rich field margins

In arable fields the greatest number of plant species is found in the outer few metres of the crop: the crop edge (see Figure 1; Marshall, 1989; Wilson, 1989). The plants found in the crop edge comprise both species of the cropped field itself as well as species from the surrounding area (Marshall, 1989; Hald *et al.*, 1988). In England it has been found that in cereal fields some 30% of the farmland plants from surrounding hedgerows are also found in the field. Of these, the majority were found growing in the outer 2.5 m of the field. Conversely, half the species encountered in the field were also found in the surrounding hedgerow. Crop edges are also attractive for fauna. Insects are more abundant in the outer 5 m of the field than at the field centre (Green, 1984). In contrast to farmland plants, which can conclude their entire lifecycle in the field, many invertebrates that live and reproduce in the field in the summer, certain carabid beetles and ladybirds, for example, are dependent for winter survival on the area outside the field, with perennial vegetation (Hald *et al.*, 1988; Basedow *et al.*, 1991; Sotherton, 1984; Coombes & Sotherton, 1986; Riedel, 1991). Management of the direct vicinity of the field - ditch banks, for instance, or verges or hedges - therefore also goes to determine the abundance of invertebrates within the field. For birds, too, crop edges represent an attractive summer habitat. Species such as the Pheasant and Partridge, which feed almost exclusively in arable fields, prefer to search for food (insects) with their chicks in the outer 25 m of fields (Hill, 1985; Green, 1984). The greater abundance of farmland plants and insects is certainly of influence here. For birds and mammals, too, fields are less attractive in the winter, because of the lack of cover they provide (Tew *et al.*, 1994).

Figure 1. Constituent parts of a field margin



Pesticide use and emissions along field margins

Large quantities of pesticides are used along the edges of fields. It is not only normal pesticide use on the crop that is involved, but also specific spraying of field margins, ditch banks or ditch beds. Pesticide use on field margins makes a relatively large contribution to pesticide emissions to adjacent biotopes. A survey of 88 farmers in the Haarlemmermeerpolder showed that almost 90% of the farmers spray the field edge (see Figure 1) along with the rest of the field. Moreover, 95% of the farmers also spray these edges separately using a knapsack sprayer. Of those interviewed, 60% spray ditch banks and 30% the ditch beds as well (De Snoo & Wegener Sleeswijk, 1993). Measurements indicate that when field margins are sprayed with a knapsack sprayer, pesticide deposition

halfway down the ditch bank is max. 9% of the dosage on the field margin (at a wind speed of 3.5 m/s). Deposition in the ditch is consistently less than 0.1% (De Snoo & De Wit, 1993). At higher wind speeds, though, deposition increases rapidly.
The Dutch Pesticide Approval Board (College voor Toelating van Bestrijdingsmiddelen) estimates that during full-field spraying 2% of the dosage per unit area drifts to the ditch (crop height > 25 cm). In the case of field-margin spraying, the Board assumes a 5% emission percentage to the ditch (EPPO, 1993). Emission measurements in the Haarlemmermeerpolder using water-sensitive paper strips (droplet drift only) have confirmed that under practical conditions at low wind speeds (≤3 m/s) approximately 2% of the dosage per unit area indeed drifts to the ditch. At higher wind speed (5 m/s), though, the amount reaching the ditch is found to far higher (approx. 7%; De Snoo, 1994b). In Germany, it is assumed that beyond 10 m from the sprayed field there is no longer any significant drift; in England a distance of 6 m is generally taken for field spraying and a distance of 1 m for knapsack spraying (EPPO, 1993).
In various types of study (field studies, bioassays and risk analyses based on laboratory and emission data) it has now been demonstrated that pesticide drift is likely to have an impact on the flora and fauna (honeybees, butterflies and aquatic organisms, for example) in the area around the field (Marrs *et al.*, 1989; 1991a; 1991b; Davis & Williams, 1990; Sinha *et al.*, 1990; Davis *et al.*, 1991a, 1993; Breeze *et al.*, 1992; De Jong & Bergema, 1993).

Lower economic appeal of crop edges
From the viewpoint of farm management, crop edges are economically less valuable than the field interior. Management of the edges often requires additional effort - in the case of wedge-shaped fields, for instance - which does not improve farming efficiency. Yields from crop edges are also often lower. In England the edges of cereal fields were found to yield an average of 18% less than the crop centre (Boatman & Sotherton, 1988). In the Dutch situation, for potatoes, sugar beet and winter wheat an 11 to 16% difference in yield was found between the crop edge and centre (De Snoo, 1994a). The following causes of depressed yield along crop edges have been reported (*cf.* Boatman & Sotherton, 1988):

- the inferior crop site factors, such as suboptimal fertilization due to less accurate fertilizer distribution, suboptimal hydrological conditions, due to the dumping of ditch spoil, for example, or inferior soil structure due to soil compaction resulting from farm machinery;
- the competition between the crop and vegetation from outside the field, due to shade or infestation by perennial weeds;
- the greater damage resulting from the feeding habits of pheasants, wild boar, rabbits and mice, and
- the direct damage to the crop due to the intensive use of the edges by machinery, turning tracks on headlands, for example, and tracks made during ditch cleaning.

Summarizing, it can be said that the outer metres of a crop are of major importance for the abundance of flora and fauna in arable regions. At the same time, pesticides are frequently used on field margins and this will, by definition, make a relatively large contribution to the pollution of the area surrounding the field. In economic terms, the crop edges are less valuable. A specific management regime for field margins should therefore focus on integrating these various aspects. Below we shall discuss a number of strategies for improving the situation, based either on extensifying the conventional crop along the edge or on replacing it with alternative vegetation. In this article, we first of all discuss the consequences for nature and the environment of not spraying the crop edges and the compatibility of the measures for farm management. Next, a number of alternative management regimes for crop edges are described, such as creation of a marginal strip sown to grass or flowering plants, or simply left fallow.

Unsprayed crop edges: effects on nature

Outside the Netherlands

Studies carried out in other European countries have demonstrated that the natural values of arable regions can be vastly improved by reducing pesticide use on field margins. In Germany, under the so-called Ackerrandstreifenprogramm there has been experience since 1978 with leaving the outer 3 m of cereal fields unsprayed with herbicides. The results of this programme demonstrate that even rare species of farmland plants can return (Schumacher, 1984). Since the mid-80s, field margin programmes have been introduced in most German states; the programmes also include provisions for financial compensation. There are now hundreds of kilometres of field margins in Germany that are not sprayed with herbicides (Schumacher, 1987; Melman, 1994). In a number of areas projects have been initiated in which insecticide spraying has also been discontinued. These unsprayed (and unfertilized) strips, with an abundance of flowering plants, harbour less aphids and more predators (carabid beetles, ladybirds, spiders and hoverflies) than conventional margins (Welling *et al.*, 1988; Ruppert & Molthan, 1991; Storck-Weyhermüller & Welling, 1991).
In England The Game Conservancy Trust has been carrying out the Cereals and Gamebirds Research Project since 1983. The primary aim of this project was initially to achieve a recovery of the Partridge population, but it was soon extended to encompass recovery of other elements of the agro-ecosystem. In the project, neither insecticides nor herbicides for broad-leaved farmland plants are used along the outer 6 m of cereal field ('Conservation Headlands'). In addition, no fungicides toxic to invertebrates are applied. The experiments show that in the unsprayed margins there is an increase in the abundance of farmland plants, butterflies and insect groups of importance to gamebirds, such as flower-bugs, leaf-beetles and weevils (Rands, 1985; Rands & Sotherton, 1986; Dover *et al.*, 1990; Chiverton & Sotherton, 1991). Positive effects have also been found for vertebrates. Owing to increased insect abundance, there is an improvement in gamebird chick survival, benefiting Partridge abundance, for example (Rands, 1985). The unsprayed cereal edges are also attractive for wood mice (Tew *et al.*, 1992; 1994). Today, there are several hundred kilometres of unsprayed arable field margins in England, too (Thompson, 1992).
Following the example of Germany and England, field margin projects have also been initiated in a large number of other European countries. The results of studies in Scandinavia (Denmark since 1985, Sweden since 1991 and Finland since 1992) confirm the positive effects on farmland plants, invertebrates and gamebirds found in England (Hald *et al.*, 1988; Chiverton & Sotherton, 1991; Chiverton, 1994; Helenius, 1994). In Switzerland, Austria, Ireland, Belgium, Luxembourg and France field margin studies are either in progress or in preparation (Schumacher, 1987; Anonymous, 1994).

The Netherlands

Since the beginning of the 1990s there has been major interest in field margins in the Netherlands, too. At the department of Theoretical Production Ecology of Wageningen Agricultural University the abundance of farmland plants has been studied in sprayed and unsprayed crop edges of 6 metres wide. Since 1993 a project has been carried out to investigate the interaction between the crop edge and the area outside the field. To this end, at 4 test sites the farmland flora has been inventoried in a 4-m unsprayed, unfertilized cereal strip, a strip sown to grass or flowering plants and a narrow strip left fallow (Marshall *et al.*, 1994). At the Centre of Environmental Science of Leiden University field margin studies have been underway since 1990 on about 15 farms in the Haarlemmermeer-polder. The aim of these studies is to improve the natural values (flora and fauna) of the farmland area and reduce pesticide emissions to areas adjacent to fields. In these studies, 3 m and 6 m strips in winter wheat, potatoes and sugar beet are left unsprayed with herbicides and insecticides (De Snoo, 1994b).

In the Netherlands a number of demonstration projects are being carried out, some of them supported also by inventory studies. For example, as part of its Partridge Habitat Recovery Programme, the Foundation for Conservation of Nature and Environment (SBNL) has been carrying out a Partridge Demonstration Project since 1991. In 5 areas in the Netherlands unsprayed cereal edges have been created to encourage Partridge chick survival and margins sown to grass and laid fallow to improve cover for Partridges in the winter. In these demonstration areas, Partridge abundance has been compared with abundance in nearby control areas (Maris, 1993). Moreover, the provincial authorities of Gelderland, Noord-Holland and Flevoland are also doing practical studies on field margin management options, and inventorying flora and fauna in unsprayed (and unfertilized) crop edges, margins sown to grass and flowering plants and uncropped margins (Meijer, 1991; Anonymous, 1993).

In 1992, finally, the government's Service for Land Management of the Ministery of Agriculture, Nature Conservation and Fisheries (DBL) started a field margin experiment with the aim of investigating, in the context of the government's so-called Relation Paper (concerned with the relation between agriculture and the nature and landscape conservation), the potential for concluding management contracts for the margins of arable fields. The experiment aims to determine whether, in addition to the regular 'conditional' remuneration scheme (for zero fertilizer and herbicide use), it is feasible to introduce a 'result' scheme based on the recovery of certain field flowers (Melman, 1994).

Dutch research results indicate that on sandy soils 1.5 to 2 times as many species of farmland plants are found in unsprayed and unfertilized cereal edges as in sprayed, fertilized margins (Smeding & Joenje, 1990). In the unsprayed margins almost all the species found are common plants (Joenje & Klein, 1994). On the clay soils of the Haarlemmermeerpolder a substantial increase was also found in the average number of broad-leaved farmland plants growing in the unsprayed edges: in winter wheat by a factor 3, in potatoes by a factor 2 and in sugar beet by a factor 1.5 (De Snoo, 1994b). Here, too, almost all the species are common. Certain species, such as poppies, are found almost exclusively in the unsprayed margins, however. In the unsprayed crop margins there is also a large increase in the number of invertebrates, mainly plant insects such as flower visitors (e.g. hoverflies and butterflies; see Figure 2) and aphid predators (ladybirds). The impact on ground-dwelling invertebrates such as carabids is less pronounced (De Snoo, 1994b; De Snoo *et al.*, 1994c). For birds, too, positive effects have been found. In comparison with sprayed edges, unsprayed cereal edges are visited 3 to 4 times as frequently by the Blue-headed wagtail (see Figure 3); for the Sky lark there was no apparent difference (De Snoo *et al.*, 1994b). The initial results of the SBNL project indicate that the average density of Partridge breeding pairs in the spring of 1993 was greater in the demonstration fields than in the control fields (pers. comm. W. Maris, 1994).

From the above it can be concluded that throughout Europe there is major interest in field margin management. The projects demonstrate that leaving the outer metres of the crop unsprayed with pesticides promotes the occurrence of farmland plants, insects, birds and mammals. Generally speaking, the greatest focus is on cereal fields. Although some of the Dutch results are still being processed, they confirm that in our country, too, a substantial improvement in natural values can be achieved in arable regions by introducing a specific management regime for field margins.

Figure 2. Number of butterflies per km in sprayed and unsprayed winter wheat crop edges in the Haarlemmermeerpolder in 1990 and 1992 (*cf.* De Snoo, 1994b)

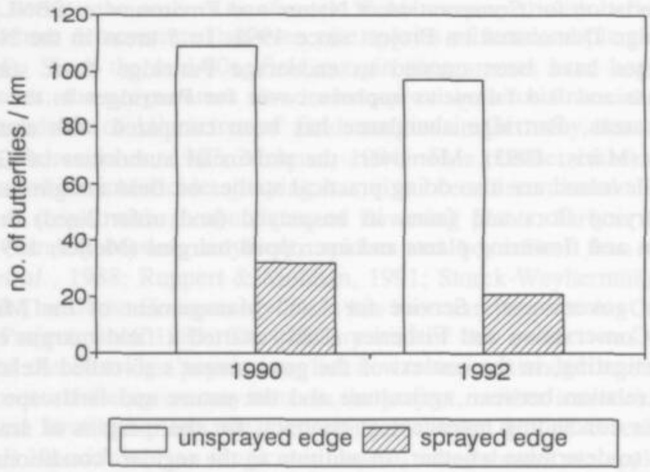
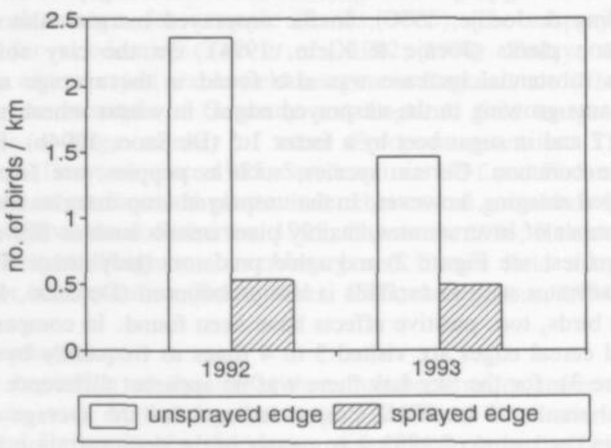


Figure 3. Number of visits of *Motacilla flava flava* per km in sprayed and unsprayed winter wheat edges in the Haarlemmermeerpolder in 1992 and 1993 (*cf.* De Snoo *et al.*, 1994b)



Unsprayed crop edges as environmental buffer zones

Besides the possibilities for improving the natural values of arable land offered by unsprayed field margins, margin management is also of great importance for reducing pesticide emissions to adjacent areas. More specifically, it reduces drift resulting from field spraying as well as the spraying of adjacent vegetation such as field margins. Restricting spraying in field margins is in line with the current Dutch policy laid down in the government's Multi-year Crop Protection Plan (MJP-G, 1991). One of the objectives of this policy is to reduce emissions to surface waters by 70 to 80% in 1995 relative to 1991. To achieve such a reduction, pesticide use is to be prohibited in and along operational ditches. In addition, a 50-cm unsprayed zone is to be prescribed along waterways. In Noord-Holland's provincial Water Management Plan, an unsprayed zone of 1 m has already been recommended (Provincie Noord-Holland, 1991). In a number of West European countries, including Germany, there are also already regulations laying down, for each compound and application, the distance to be maintained between sprayed fields and nearby water bodies. In the case of arable land, the buffer zone is usually 10 m. Farmers disobeying these regulations may incur an extremely high fine (max. DM 50.000; Jörg & Zweck, 1992; pers. comm. Jörg, 1994).

Research by Cuthbertson & Jepson (1988) has demonstrated that, in wheat, creation of a 6-m unsprayed strip can give a 70-75% reduction of pesticide emissions to adjacent hedges (wind speed: 4.0-6.4 m/s). Measurements in the Netherlands indicate that establishing a 3-m unsprayed crop margin can already lead to a very large reduction (>90%) of pesticide spray drift to adjacent ditches (wind speed 3 m/s; distance between outer crop edge and ditch centre approx. 2.8 m). With a 6-m unsprayed crop edge, spray drift to adjacent ditches is reduced by about 99% (De Snoo, 1994b). Bioassays show that a 2-m buffer zone is generally sufficient to prevent the death of plants around a field sprayed with herbicides, although it is sometimes necessary to maintain a 6-m zone (max. wind speed 3.5 m/s). Sublethal effects on the reproduction or establishment of young plants, which may lead to changes in species composition, are found over greater distances. To minimize the impact on neighbouring vegetation, it is recommended to maintain a buffer zone of 6-10 m (Marrs *et al.*, 1989; 1991a; 1991b; Breeze *et al.*, 1992).

With respect to invertebrates, the effects of 6 insecticides on young caterpillars of the Large white have been investigated, this being the most vulnerable stage of the lifecycle. It was found that for 3 compounds buffer zones less than 1 metre wide were sufficient to achieve less than 50% caterpillar mortality (wind speed max. 5.3 m/s). For 3 other insecticides very toxic to caterpillars, such as diflubenzuron, buffer zones of 8 - 14 m are generally adequate, but sometimes even wider zones are required (max. 23 m; Sinha *et al.*, 1990; Davis *et al.*, 1991a; 1993; De Jong and Van der Nagel, 1994). The caterpillars of other butterflies such as the Green-veined white, Common blue and Gatekeeper appear to be less sensitive (Davis *et al.*, 1991b). On the basis of laboratory data on 20 insecticides and drift data, Davis and Williams (1990) have calculated, for honeybees, the distance at which 50% mortality occurs. For field spraying, at low wind speeds (2.5-3 m/s) this distance is found to be less than 5 m for 17 compounds (≤1 m for 14 compounds), but 21 m for 1 compound. At higher wind speeds (4 m/s) these distances increase substantially, with only 11 compounds below the 5 m limit. At these higher wind speeds, 3 insecticides require a buffer zone of more than 40 m.

In summary, it can be said that creation of a 3 to 6 m wide unsprayed zone along the crop edge can give a very major reduction in pesticide emissions to the surrounding area. With such relatively narrow buffer zones, however, effects on flora and fauna can still not be completely prevented when compounds that are highly toxic to the organisms in question are involved. Particularly in the case of insecticides, which are often sprayed in smaller droplets that are more prone to drift, effects on fauna have been observed over far larger distances. With current spraying methods, it is not recommended to spray at wind speeds exceeding 3 m/s.

Economic compatibility of unsprayed crop edges

The economic compatibility of unsprayed crop edges is determined on the one hand by the direct costs of reduced harvests and/or additional labour and on the other by indirect costs such as the possible impact of the measure on the rest of the field and possible long-term effects. These costs must be weighed up against the savings on pesticide use and any other benefits. British studies indicate that in 6 m unsprayed zones in cereal fields, the loss of harvest relative to sprayed margins is 3% for winter wheat and 6% for spring barley (Boatman & Sotherton, 1988; Boatman, 1990). In the Dutch situation harvest measurements are available for the Haarlemmermeerpolder (De Snoo, 1994a). Here, it was found that in winter wheat harvest losses were an average of 13% in a 3-m buffer zone, and 11% in a 6-m zone. In a potato crop the average loss was 2%. With sugar beet a far higher loss was found: 30%. With regard to indirect effects of the measures, it is certainly the case that in the unsprayed zone and possibly elsewhere farmland plant seeds accumulate in the soil. However, the question is whether this also leads to greater weed problems. In England the long-term effects have been found to be readily manageable. In this context, Boatman & Sotherton (1988) report that because of the use of broad-spectrum herbicides, which are generally employed preventively in the British situation, any discussion about the stock of seeds in the soil soon becomes academic. Until now, the Haarlemmermeerpolder studies give little indication of weeds constituting a problem in the unsprayed margins with time. However, there have not yet been any studies on long-term effects. Besides this, there is another obvious issue: to what degree do aphids spread to the rest of the field? The Haarlemmermeerpolder studies have not given any indication that higher aphid densities in unsprayed cereal margins lead to greater infestation in the rest of the crop (De Snoo & De Leeuw, in prep.). In practice, leaving margins unsprayed involves virtually no additional work.

Besides costs, benefits are also likely to accrue if field margins are no longer sprayed. In the first place, there are direct savings from reduced pesticide use, amounting to several Dutch cents per square metre. In addition, there may be extra income from hunters. In England the costs of leaving margins unsprayed are more than fully compensated by an increase in revenue from hunting rights due to increases in Partridge and Pheasant populations (Boatman, 1990). As a result, the vast majority of farmers willingly participate in the field margin scheme. In the Haarlemmermeerpolder, if the revenue lost due to reduced harvests is offset against savings on pesticide use, it is found that the nett cost of a 3-m unsprayed cereal strip is approximately Dfl. 0.01 per square metre. For a 6-m unsprayed cereal strip this figure is about Dfl. 0.005 per square metre. Creation of an unsprayed strip along a potato crop involves no nett expense. For a sugar beet crop, on the other hand, the

nett cost is Dfl. 0.21 per square metre (De Snoo, 1994a).
On the basis of the above, it can be concluded that creating unsprayed strips along cereal and potato crops is economically viable. In sugar beet, maintaining an unsprayed strip is unrealistic, because of the high costs incurred due to serious intrusion of weeds into this crop. In the case of sugar beet, and perhaps also for other open crops such as maize, it may be better to adopt an alternative regime for crop margins.

Alternative uses of crop edges

Besides the possibility of reducing pesticide use along existing crop edges, it is also conceivable to substitute the perimeter of the standing crop for a strip of cereal, or sow the edges to grass or flowering plants, or leave them fallow. Apart from the cereal option, all these regimes involve a reduction in the area of productive land. Such regimes are therefore relatively expensive unless they are offset by additional income or savings. On the basis of studies to date, the following management variants are feasible for field margins. In all cases, creation of a buffer zone yields environmental benefits, with the potential for increasing natural values varying from regime to regime.

Cereal margins

Sowing a strip of cereal along the edge of other crops is already no rare occurrence in Dutch arable farming practice. Cereals are sometimes sown on the headlands of onion and sugar beet fields. This is done to avoid having to harvest field corners (necessary on extensively mechanized farms) or to straighten out tapering fields. The potential for increasing natural values (farmland plants, insects and vertebrates) by leaving these margins unsprayed is not likely to differ from that of unsprayed margins constituting part of a larger cereal crop. The cost of a cereal margin is higher, however, because of the lower yield of cereal relative to a crop like potatoes. At a number of locations in the Netherlands cereal margin trials are presently underway (Provincie Gelderland and SBNL). Unsprayed cereal margins appear to be well compatible with farm management.

Grass margins

Instead of establishing a cereal margin along another crop, the margin can alternatively be sown to grass. Such a grass margin can prevent less desirable weeds intruding into the crop; in this context, it is important to keep fertilizer use as low as possible. Marshall (1990) has demonstrated that infestation with Common couch can thus be reduced by a factor 10. This kind of margin offers little potential for farmland plants, however. By lowering the nutrient regime of the margins (by removing mown grass), an interesting verge-type vegetation may arise. Margins sown to grass may also benefit invertebrate abundance in arable fields. Many invertebrates, such as certain carabid species, move out from the permanent vegetation to colonize fields in the spring. Establishing grass margins is found to promote biological pest control (aphids) by predatory invertebrates (Klinger, 1987; Welling *et al.*, 1988). The same line of reasoning can be employed to argue for the creation of grassland at the centre of large arable fields. A regime of this nature increases the abundance of spiders and carabid and staphynilid beetles, leading some authors to refer to such spaces as Beetle Banks (Thomas *et al.*, 1991). It is as yet unclear to what extent ditch banks in the Netherlands play a part in the winter survival of invertebrates and how ditch bank management might be adapted accordingly.

Grass margins, finally, have the potential for improving winter cover for field birds. In spring, moreover, such margins provide greater potential for nesting. In the Netherlands, this approach is being taken to boost Partridge numbers (Maris, 1993). In the provinces of Noord-Holland and Flevoland, the impact on mouse abundance is also being studied. The costs of this regime might be offset by the enhanced biological control of crop pests (aphids), possibly allowing the frequency of insecticide spraying to be reduced. On this basis Thomas *et al.* (1991) have calculated that, in the British context, despite the loss of productive land it is in fact economically attractive to establish a grass strip in the middle of a 20-hectare wheat field. A grass strip created along a ditch bank can be used as a track for the vehicles employed in ditch-cleaning. Given the experience of the SBNL, where 50% of the marginal areas established took the form of grass strips, as well as the experience of Gelderland provincial authorities, establishing grass-sown margins would appear to be an interesting management option for arable farmers (Maris, 1993).

Flowering plant margins
Another option is to sow flowering plants along the margins of cropped fields, as part of an integrated pest control programme, for instance. Examples of this approach include sowing narrow strips to White mustard, *Phacelia* or wild flower assortments along the edges of wheat fields. Experience shows that sowing a 1 to 1.5 m wide strip with flowering plants promotes the abundance of hoverflies, lacewings, ladybirds, carabid beetles and spiders, both within the strips and in the field as a whole (Klinger, 1987; Welling *et al.*, 1988; Blake, 1990; Lys & Nentwig, 1992a; 1992b; Nentwig 1992). Overwintering opportunities for many groups of predatory and parasitic invertebrates are also thus improved (Bürki, 1993). As a result, the potential for biological control of pests is also vastly increased. In this context, the maximum potential is utilized if such strips are also created within the field itself, 24 metres apart (Nentwig, 1992). On a small scale, in the Netherlands, too, experiments with margins sown to flowering plant are in progress (Hospers, 1991; Meijer, 1991; Marshall, 1994). It is unlikely that field flowers benefit from the establishment of such margins. There may be positive effects on invertebrates, though, if the strips are not ploughed under in the winter. The costs of the measures may be compensated by potential savings on pesticide use, as the increased abundance of pest antagonists in the field may prevent cases of mass infestation. This measure would thus appear to be well compatible with farm management.

Fallow margins
Instead of sowing margins to a crop, grass or wild flowers, a decision can also be made to leave margins to develop naturally, as an 'uncropped wildlife strip' or 'Öko-Wertstreife'. Annual farmland plants will become readily established in such strips, making for an attractive sight. In this approach it is important to continue conventional soil tillage in these strips each year, for otherwise annual farmland plants will soon be overrun by perennial grasses. For some ground-dwelling invertebrates (spiders and carabid beetles, for example) an uncropped strip is found to be more attractive than an unsprayed grass strip (Hassall *et al.*, 1992; Hawthorne & Hassall, 1994). Positive effects on the abundance of gamebirds, songbirds and hares have also been reported (Anonymous, 1990). Besides improving the food supply of vertebrates, such strips can also provide cover and nesting sites. It is unclear to what extent an uncropped strip is acceptable to farmers, especially when the farmland plants are in mass flower and go to seed. Until now, farmer participation in this kind of management scheme is disappointing, both in the SBNL and the Gelderland project. The

appeal of this option would be improved substantially if creation of such uncropped strips were to be integrated in the set-aside scheme, allowing costs to be compensated.

Evaluation

Research to date indicates that the natural values of arable farmland can be improved substantially by discontinuing the spraying of herbicides and insecticides on field margins. In unsprayed crop edges - especially in winter wheat - farmland plants, invertebrates, birds and mammals have been found to increase in abundance. A major benefit of such a field margin regime is that by implementing measures on a small fraction of arable land a substantial positive overall conservation effect can be achieved. By reducing pesticide use on margins, relatively large environmental gains can also be achieved in the vicinity of the field. In winter wheat and potatoes, the nett cost of the measures is low. In sugar beet the measures are unrealistic due to the development of profuse weed vegetation. With these and similar crops, along the crop edge it is more advisable to substitute the regular crop for cereals, grass, flowering plants or an uncropped strip. This holds for potatoes, too, because there is relatively little to gain in this crop in terms of natural values. Depending on the envisaged objective - more farmland plants, more aphid predators or more birds - a given management regime will offer more or less potential: 'Choose your edge' (see Table 1). A basic point of departure, as a minimum aim, might be to achieve an environmental target: no pesticide emissions to the surrounding area. In that case, the width of the margins is derived from the emission reduction envisaged under the terms of the environmental policy in force. Subsequently, there can be differentiation in terms of conservation objectives. In this context, it is also possible to combine various types of margin management regimes: a narrow grass-sown strip along the field perimeter adjacent to an unsprayed cereal edge, for example. The grass strip will provide cover for fauna in winter and nesting sites in spring. while in summer the unsprayed cereal margin provides a biotope for farmland plants and can serve as a food source for flower-visiting insects and field birds, for example. For many species of fauna, the presence of a summer and a winter habitat in arable regions is a precondition for continued survival.
Acceptance of these measures by farmers depends not only on the direct financial consequences, but also, particularly, on the degree to which the effects of such measures prove manageable in the longer term. It is above all the spontaneous development of field weeds following establishment of unsprayed cereal margins and uncropped margins that can lead to opposition. This is not surprising, given the fact that for generations farmers have worked on combatting the growth of plants that are now to be tolerated along field margins, with remuneration in some cases even being given for encouraging the abundance of certain species. However, the fact that many practical attempts are currently being made, from widely differing angles, to integrate agricultural practice with nature and the environment on field margins is an indication that a major change in thinking is occurring. If new forms of margin management are to be introduced on a larger scale, however, there should be greater focus on these more psychological aspects. In this context, additional knowledge of medium-term agronomic effects may prove to be of importance.

Table 1. Different types of field margins and their contribution to reducing pesticide drift, *promoting nature conservation and their consequences for farm management*

	cereal edge	grass edge	flower edge	fallow edge
environment				
emission reduction	+	+	+	+
nature				
farmland plants	+	0	0	+[1]
insects on vegetation	+	0	+	+
ground invertebrates	+	+[2]	+[2]	+
birds	+	+[2]	±[2]	+
mammals	+	+[2]	?	?
farm management				
harvest losses	about 15%	100%	100%	100%
compensation costs	±	±[3]	±[3]	?
farmer acceptance	±	+	+	?

+ = positive 0 = no effect
± = possibly positive ? = unknown

[1] (annual) set-aside with 'one-turn' tillage
[2] positive effects mainly as winter habitat
[3] compensation possible when created round wheat fields, but unlikely with other higher-yield crops

References

Anonymous, 1990. Öko-Wertstreifen in Ackerbaugebieten. Jagd und Hege 12: 5-7.

Anonymous, 1991. Herstelplan Leefgebieden Patrijs. Ministerie van Landbouw, Natuurbeheer en Visserij, 's-Gravenhage.

Anonymous, 1993. Inschrijfformulier Akkerrandenbeheer, Project Akkerrandenbeheer, Provincie Gelderland 1993, 1 p.

Anonymous, 1994. Technical Seminar Field Margin-Strip Programmes, 25-27 May 1994 Mainz, Germany. Landesanstalt für Pflanzenbau und Pflanzenschutz, Final Programme, 4 p.

Basedow, Th., C. Braun, A. Lühr, J. Naumann, T. Norgall & G. Yanes Yanes, 1991. Abundanz, Biomassa und Artenzahl epigaïscher Raubarthropoden auf unterscheidlich intensiv bewirtschafteten Weizen- und Rübenfeldern: Unterschied und ihre Ursachen. Ergebnisse eines dreistufigen Vergleichs in Hessen, 1985 bis 1988. Zool. Jb. Syst. 118: 87-116.

Blake, A., 1990. Flower borders could soon give aphids the blues. Farmers Weekly, 09-11-1990: 46-47.

Boatman, N.D., 1990. Conservation headlands and the economics of wild game production. In: Lumeij, J.T. & Y.R. Hoogeveen: De toekomst van de wilde hoenderachtigen in Nederland. Elinkwijk B.V., Utrecht: 198-206.

Boatman, N.D. & N.W. Sotherton, 1988. The agronomic consequences and costs of managing field margins for game and wildlife conservation. Aspects of Applied Biology 17: 47-55.

Breeze, V., G. Thomas & R. Butler, 1992. Use of a model and toxicity data to predict the risks to some wild plant species from drift of four herbicides. Ann. Applied Biology 121: 667-677.

Bürki, H-M., 1993. Überwinterung von Arthropoden im Boden unter künstlich angelegten Ackerkrautstreifen. Verhandlungen der Gesellschaft für Ökologie 22: 345-38.

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

Chiverton, P.A., 1994. Large-scale field trials with conservation headlands in Sweden. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 185-190.

Coombes, D.S. & N.W. Sotherton, 1986. The dispersal and distribution of polyphagous predatory Coleoptera in cereals. Ann. Appl. Biol. 108: 461-474.

Cuthbertson, P.S. & P.C. Jepson, 1988. Reducing pesticide drift into the hedgerow by inclusion of an unsprayed field margin. Proc. Brighton Crop Protection Conference, Pests and diseases: 747-751.

Davis, B.N.K., K.H. Lakhani, T.J. Yates & A.J. Frost., 1991a. Bioassays on insecticide spray drift: the effects of wind speed on the mortality of *Pieris brassicae* larvae (Lepidoptera) caused by diflubenzuron. Agriculture, Ecosystems and Environment 36: 141-149.

Davis, B.N.K., K.H. Lakhani, & T.J. Yates., 1991b. The hazards of insecticides to butterflies of field margins. Agriculure, Ecosystems and Environment 36: 151-161.

Davis, B.N.K., K.H. Lakhani, T.J. Yates, A.J. Frost & R.A. Plant, 1993. Insecticide drift from ground-bases, hydraulic spraying of peas and brussels sprouts: bio-assays for determining bufferzones. Agriculture, Ecosystems and Environment 43: 93-108.

Davies, B.N.K. & C.T. Williams, 1990. Buffer zone widths for honeybees from ground and aerial spraying of insecticides. Environmental Pollution 63: 247-259.

Dover, J.W., N.W. Sotherton & K. Gobbett, 1990. Reduced pesticide inputs on cereal field margins: the effects on butterfly abundance. Ecological Entomology 15: 17-24.

EPPO, 1993. European and Mediterranean Plant Protection Organization, Council of Europe. Decision-making scheme for the environmental risk assessment of plant protection products. EPPO Bull. 23:73-98.

Green, R.E., 1984. The feeding ecology and survival of partridge chicks (*Alectoris rufa* and *Perdix perdix*) on arable farmland in East Anglia, UK. J. Applied Ecology 21: 817-830.

Hald, A.B., B.O. Nielsen, L. Samsøe-Petersen, K. Hansen, N. Elmegaard & J. Kjoholt, 1988. Sprojtefri randzoner i kornmarker. Miljoprojekt nr. 103. Miljostyrelsen, Copenhagen.

Hassall, M., A. Hawthorne, M. Maudsley, P. White & C. Cardwell, 1992. Effects of headland management on invertebrate communities in cereal fields. Agriculture, Ecosystems and Environment 40: 155-178.

Hawthorne, A. & M. Hassall, 1994. Effects of management treatments on carabid communities of cereal field margins. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 313-318.

Helenius, J., 1994. Adoption of conservation headlands to Finnish farming. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 191-196.

Hill, D.A., 1985. The feeding ecology and survival of pheasant chicks on arable farmland. J. Applied Ecology 22: 645-654.

Hospers, A.J.T.M., 1991. Bloemen tegen luizen: de inzaai van bloemstroken langs akkerranden. Louis Bolk Instituut, Driebergen.

Joenje, W. & D. Klein, 1994. Plant distribution across arable field ecotones in the Netherlands. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conser-va-tion, BCPC monograph No. 58: 323-328.

Jong, F.M.W., de & W.F. Bergema, 1993. Field bio-assays for side-effects of pesticides - progress report -. CML report 100, Leiden.

Jong, F.M.W., de & M.C. van der Nagel, 1994. A field bioassay for side-effects of insecticides with larvae of the Large White Butterfly *Pieris brassicae* (L.). Med. Fac. Landbouww. Univ. Gent, 59 (2a): 347-355.

Jörg, E. & W. Zweck, 1992. Planzenschutzmittel und Wasserschutz. Stand: Juli 1992. Rheinland-Pfalz, Landespflanzenschutzdienst, Mainz-Bretzenheim, 2nd Edition, 36 p.

Klinger, K., 1987. Auswirkungen eingesäter Randstreifen an einem Winterweizen-Feld auf Raubarthropodenfauna und den Getreideblattlausbefall. J. Applied Entomology 104: 47-58.

Lys, J-A. & W. Nentwig, 1992a. Förderung von Laufkäfern (Coleoptora, Carabidae) in einem Getreidefeld durch Künstlich angesäte Krautstreifen. Mitt. Dtsch. Ges. Allg. Angew. Ent. 8:128-132.

Lys, J-A. & W. Nentwig, 1992b. Augmentation of benificial arthropods by strip-management. 4. Surface activity, movements and activity density of abundant carabid beetles in a cereal field. Oecologia 92: 373-382.

Marshall, E.J.P., 1989. Distribution patterns of plant associated with arable field edges. J. Applied Ecology 26: 247-257.

Marshall, E.J.P., 1990. Interference between sown grasses and the growth of rhizome of *Elymus repens* (couch grass). Agriculture, Ecosystems and Environment 33: 11-22.

Marshall, E.J.P., C.F.G. Thomas, W. Joenje, D. Klein, F. Burel & D. le Coeur, 1994. Establishing vegetation strips in contrasted European farm situations. In: N.D. Boat-man (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 335-340.

Maris, W., 1993. 'Demonstratieproject Beheermaatregelen ten behoeve van de patrijs'. Jaarverslag 1992. Stichting Behoud Natuur en Leefmilieu, Wijk bij Duurstede.

Marrs, R.H., C.T. Williams, A.J. Frost & R.A. Plant, 1989. Assessment of the effects of herbicide spray drift on a range of plant species of conservation interest. Environmental Pollution 59: 71-86.

Marrs, R.H., A.J. Frost & R.A. Plant, 1991a. Effects of herbicide spray drift on selected species of nature conservation interest: the effects of plant age and surrounding vegetation structure. Environmental Pollution 69: 223-235.

Marrs, R.H., A.J. Frost & R.A. Plant, 1991b. Effect of mecoprop drift on some plant species of conservation interest when grown in standardized mixures in microcosms. Environmental Pollution 73: 25-42.

Meerjarenplan Gewasbescherming, 1991. Regeringsbeslissing. Tweede Kamer, vergaderjaar 1990-1991, 21677, nrs. 3-4. SDU uitgeverij, Den Haag.

Meijer, W., 1991. Handleiding Akkerrandenbeheer provincie Gelderland, 5 p.

Melman, Th.C.P., 1991. Slootkanten in het veenweidegebied. Mogelijkheden voor behoud en ontwikkeling van natuur in het agrarisch grasland. Doctoral thesis, Leiden University.

Melman, Th.C.P., 1994. Field margins as a nature conservation objective in the Netherlands and Germany for nature conservation; policy, practice and innovative research. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 367-376.

Natuurbeleidsplan, 1990. Regeringsbeslissing. Tweede Kamer, 1989-1990, 21149, nrs. 2-3. SDU uitgeverij, Den Haag.

Nentwig, W., 1992. Die nützlingsfördernde Wirkung von Unkrautern in angesäten Unkrautstreifen. Z. Pflanzenkrankheiten und Pflanzenschutz, Sonderheft XIII: 33-40.

Provincie Noord-Holland, 1991. Waterhuishoudingsplan Natuurlijk Water. Provincie Noord-Holland, Haarlem.

Rands, M.R.W., 1985. Pesticide use on cereals and the survival of grey partridge chicks: a field experiment. J. Applied Ecology 22: 49-54.

Rands, M.R.W. & N.W. Sotherton, 1986. Pesticide use on cereal crops and changes in abundance of butterflies on arable land. Biological Conservation 36: 71-82.

Riedel, W., 1991. Overwintering and spring dispersal of *Bembidion lampros* (Coleoptera: Carabidae) from established hibernation sites in a winter wheat field in Denmark. In: L. Polgár, R.J. Chambers, A.F.G. Dixon & I. Hodek (Ed.): Behaviour and Impact of Aphidophaga: 235-241. Academic Publishing bv, The Hague, The Netherlands.

Ruppert, V. & J. Molthan, 1991. Augmentation of aphid antagonists by field margins rich in flowering plants. Behaviour and impact of Aphidophaga: 243-247.

Schumacher, W., 1984. Gefährdete Ackerwildkräuter können auf ungespritzten Feldrändern erhalten werden. Mitteilungen der LÖLF 9 (1): 14-20.

Schumacher, W., 1987. Measures taken to preserve arable weeds and their associated communities in Central Europe. In: J.M. Way & P.W. Greig-Smith (Ed.): Field margins. BCPC monograph No 35: 109-112.

Sinha, S.N., K.H. Lakhani & B.N.K. Davis. 1990. Studies on the toxicity of insecticidal drift to the first instar larvae of the Large White butterfly Pieris brassicae (lepidoptera: Pieridae). Ann. Appl. Biol. 116: 27-41.

Smeding, F.W. & W. Joenje, 1990. Onbespoten en onbemeste perceelsranden in graanakkers. In: J.M. Groenendael, W. Joenje & K.V. Sykora: 10 jaar Zonderwijk & V.P.O. Wageningen 129-134.

Snoo, G.R. de, 1994a. Cost-benefits of unsprayed crop edges in winter wheat, sugar beet and potatoes. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 197-201.

Snoo, G.R. de, 1994b. Unsprayed field margins in arable land. Med. Fac. Landbouww. Univ. Gent, 59/2b: 549-559.

Snoo, G.R. de, K.J. Canters, F.M.W. de Jong & R. Cuperus, 1994a. Integral hazard assessment of side effects of pesticides in the Netherlands - a proposal. J. Environmental Toxicology and Chemistry 13 (8): 1331-1340.

Snoo, G.R. de, R.T.J.M. Dobbelstein & S. Koelewijn, 1994b. Effects of unsprayed crop edges on farmland birds. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 221-226.

Snoo, G.R. de, R.J. van der Poll & J. de Leeuw, 1994c. Carabids in sprayed and unsprayed crop edges of winter wheat, sugar beet and potatoes. Acta Jutlandica in press.

Snoo, G.R. de & A. Wegener Sleeswijk, 1993. Use of pesticides along field margins and ditch banks in the Netherlands. Med. Fac. Landbouww. Univ. Gent 58 (3a): 921-926.

Snoo, G.R. de & P.J. de Wit, 1993. Pesticide drift from knapsack sprayers to ditches and ditch banks. Proc. Brighton Crop Protection Conference - Weeds - 1993 (2): 879-884.

Sotherton, N.W., 1984. The distribution and abundance of predatory arthropods overwintering on farmland. Ann. Appl. Biol. 105: 423-429.

Storck-Weyhermüller, S. & M. Welling, 1991. Regulationsmöglichkeiten von Schad- und Nutzarthropoden im Winterweizen durch Ackerschonstreifen. Mitt. BBA Land- und Forstwirtschaft Berlin-Dahlem, Heft 273.

Strien, A.J. van, 1991. Maintenance of plant species diversity on dairy farms. Doctoral thesis, Leiden University.

Sykora, K.V., L.J. de Nijs & T.A.H.M. Pelsma, 1993. Plantengemeenschappen van Nederlandse wegbermen. Stichting Uitgeverij Koninklijke Nederlandse Natuurhistorische Vereniging, Utrecht.

Tamis, W.L.M., R. Kouwenhoven & K.J. Canters, 1993. Van wit naar groen... Beschrijving en realisatie van de algemene natuurkwaliteit in de provincie Zuid-Holland. CML report 96, Leiden.

Tew, T.E., D.W. MacDonald & M.R.W. Rands, 1992. Herbicide application affects microhabitat use by arable wood mice (*Apodemus sylvaticus*). J. Applied Ecology 29: 532-539.

Tew, T.E., I.A. Todd & D.W. MacDonald, 1994. Field margins and small mammals. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 85-94.

Thomas, M.B., S.D. Wratten & N.W. Sotherton, 1991. Creation of 'island' habitats in farmland to manipulate populations of beneficial arthropods: predator densities and emigration. J. Applied Ecology 28: 906-917.

Thompson, P., 1992. Field officer's 1991 report. The Game Conservancy Review of 1991, Fordingbridge 44-46.

Welling, M., R.A. Pötzl & D. Jürgens, 1988. Untersuchungen in Hessen über Auswirkung und Bedeutung von Ackerschonstreifen. 3: Epigäische Raubarthropen. In: M. Welling, Auswirkungen von Ackerschonstreifen. Mitteilungen aus der BBA für Land- und Forstwirtschaft. Heft 247. Berlin 55-63.

Wilson, P.J., 1989. The distribution of arable weed seedbanks and the implications for the conservation of endangered species and communities. Proc. Brighton Crop Protection Conference - Weeds 1989: 1081-1086.

Zonderwijk, P., 1979. De bonte berm. Zomer en Keuning, Ede.

Part 2

Environmental research

3 Use of pesticides along field margins and ditch banks in the Netherlands

G.R. de Snoo & A. Wegener Sleeswijk

Abstract

Dutch crop protection policy has as one of its aims to reduce pesticide emissions to areas adjacent to farmland. Interviews held with 88 arable farmers in the Haarlemmermeerpolder indicate that field margins are sprayed intensively with herbicides. Almost 90% of the farmers interviewed create a 'sterile strip' along the field edge when spraying fields. Some 95% of the farmers also treat this strip with backpack sprayers. The principal compound employed is glyphosate, used to prevent infestation with Common Couch (Elymus repens)*. Of the farmers interviewed, 60% spray ditch banks with backpack sprayers, sprayguns or tractor-mounted booms, with MCPA and glyphosate as compounds most frequently used. A wide variety of other pesticides are also used, many of which are prohibited in such applications. More than 30% of the farmers also spray ditch beds, mainly with glyphosate and dalapon. Compound dosages vary enormously from farm to farm (by a factor 60). It can be concluded that the spraying of field margins may constitute an important source of pesticide emissions to adjacent ditches.*

Introduction

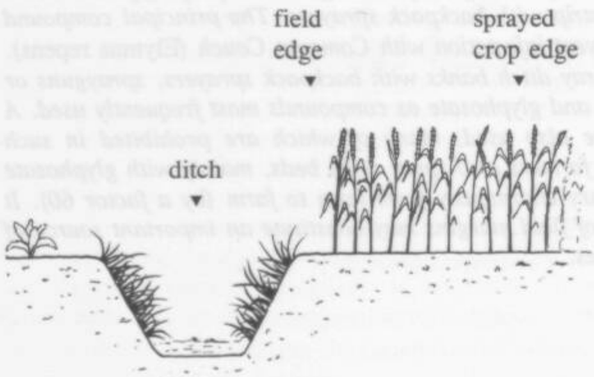
In comparison with other European countries, the quantities of pesticides applied per hectare in the Netherlands are extremely high: 20 kg active ingredient/ha/year (Meerjarenplan Gewasbescherming, MJP-G, 1991). Dutch government policy aims to restrict pesticide use, thereby also minimizing the risk of impact on areas adjacent to farmland. To reduce pesticide emissions to surface waters, it is to become obligatory to leave an untreated zone 0.5 metres wide along operational waterways (MJP-G, 1991). Some authorities even advocate a 1-metre unsprayed zone (Provinciaal Waterhuishoudingsplan Noord-Holland, 1991). The main objective of these buffer zones is to prevent droplet drift and run-off. Emissions to ditches along fields may occur in either of 2 ways: as a result of spraying in the field itself (field spraying) and through direct application of pesticides along field margins. The second of these routes is the subject of the present article.

Haarlemmermeerpolder study: project design

To assess the nature and extent of pesticide use along field margins and ditch banks and in ditches in the Netherlands, an inventory was made among a group of 88 arable farmers in the Haarlemmermeerpolder (21 in 1990, 67 in 1992). The study formed part of the Dutch Field Margin project being undertaken by the Centre of Environmental Science, Leiden University. The aim of this project is to improve the nature value of this agricultural region and reduce local pesticide emissions by restricting pesticide use along field margins (De Snoo, 1991; De Snoo & Udo de Haes, 1993).

Pesticide use was investigated by holding interviews with farmers, most of whom were willing to participate (84% participation). The average length of the interviews was 25 minutes. Besides chemical management of waterways, mechanical management was also discussed. Neighbouring farmers were not interviewed, in view of possible joint management of waterways. For the purposes of the inventory field margins were broken down into three zones: field edge, ditch bank and ditch bed (Figure 1). Some of the ditches in the Haarlemmermeerpolder sometimes run dry in the summer.

Figure 1. Schematic view of a field margin

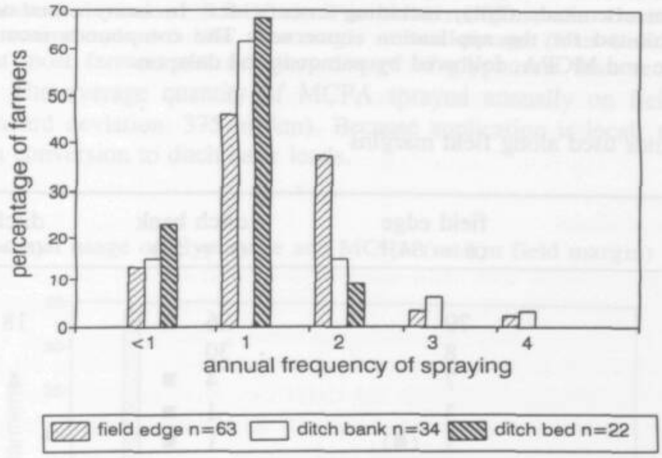


Results

The interview study showed that of the 88 farmers questioned 86% include the field edge when spraying the rest of the field. By far the majority also carry out additional spraying of the field edge, ditch bank and/or ditch bed: 95% of the farmers spray the field edge, 59% the ditch banks and 32% the ditch beds. Farmers estimate that a 'sterile strip' of on average 35 cm width is maintained along the field edge. With respect to the treatment of ditch banks, many farmers indicated that spraying is local in nature.

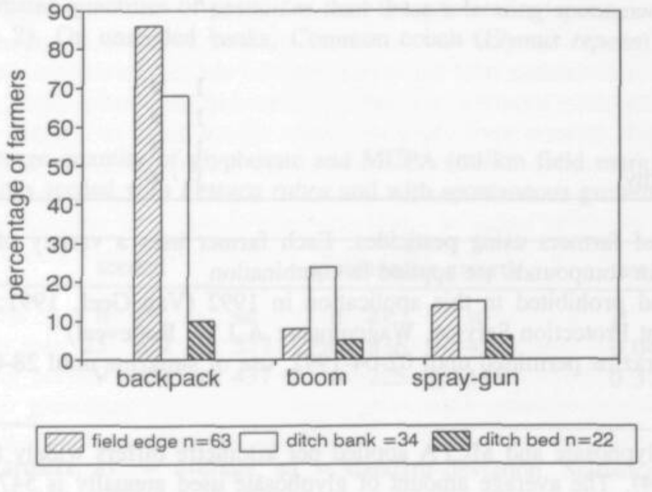
The frequency of treatment varies widely from farm to farm. Figure 2 shows that field edges are generally sprayed once or twice a year. Ditch banks are usually treated once yearly and ditch beds once yearly or less. Spraying takes place in the period April to November. Most spraying (approx. 70%) of field edges and ditch banks is done in the period April to July. In more than 80% of the cases studied, spraying of ditch beds occurs in the period July to October.

Figure 2. Frequency of field margin spraying



Spraying is carried out with backpack sprayers, sprayguns or tractor-mounted booms. As can be seen from Figure 3, the field edge is almost always treated with a backpack sprayer. In one case a potato killer was used. For the treatment of ditch beds, tractor-mounted booms and sprayguns are more frequently used. Local treatment is difficult with this equipment. On average, farmers take 3 quarters of an hour to 1 hour to spray one kilometre of field edge, ditch bank or ditch bed.

Figure 3. Equipment used to spray field margins



Overall, a wide variety of compounds are used (Table 1). While only a limited number of compounds are used on field edges and ditch beds, ditch banks are treated with a large number of different chemicals (20!), including insecticides. In many cases use of these compounds is prohibited for the application concerned. The compounds most frequently used are glyphosate and MCPA, followed by paraquat and dalapon.

Table 1. Compounds used along field margins

	field edge (n = 84)*	ditch bank (n = 52)	ditch bed (n = 28)
herbicides:			
glyophosate	79	26 ■	18
MCPA	8	30	
paraquat	7	4 ■	4
diquat	3	1 ■	
atrazine	3 (■)	1 ■	
simazine	2 (■)		
mecoprop-P	1	2 ■	
triclopyr	1 ■	1 ■	
bentazone	1 ■		
dalapon		7	8
2,4-D		4	
fluroxypyr		2 ■	
dicamba		2 ■	
metsulfuron-methyl		1 ■	
dichloroprop		1 ■	
flurenol		1 ■	
ioxynil		1 ■	
benazolin		1 ■	
unknown		2	2
insecticides:			
thiometon		1 ■	
phosfamidon		1 ■	
parathion		1 ■	
oxydemeton-methyl		1 ■	

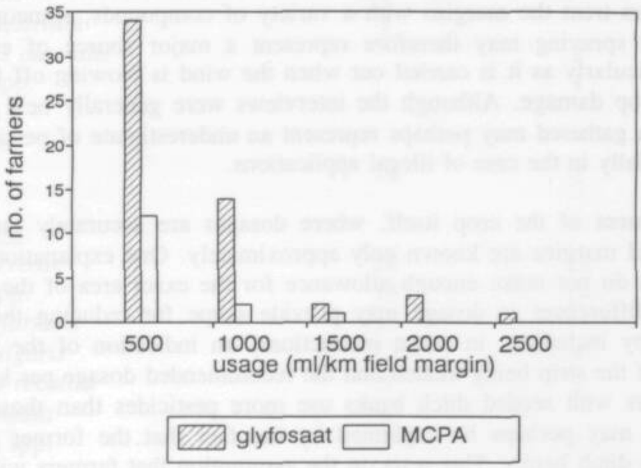
* = Number of farmers using pesticides. Each farmer uses a variety of compounds and certain compounds are applied in combination

■ = Compound prohibited in this application in 1992 (Van Geel, 1991; information from Plant Protection Service, Wageningen: A.J.W. Rotteveel)

(■) = Use of atrazine permitted until 02-04-1992, use of simazine until 28-04-1992

The quantity of glyphosate and MCPA applied per kilometre differs widely from farm to farm (see Figure 4). The average amount of glyphosate used annually is 547 ml/km field margin (standard deviation: 550 ml/km). On the field edge, the average dosage (per unit area) per spraying operation is 9.7 l/ha, varying from 0.4 to a maximum of 27 l/ha (n=38, standard deviation: 8.9 l/ha). For field margins, the Dutch Crop Protection Handbook recommends 4-6 l/ha as a single annual dosage (Van Geel, 1991). It is thus striking that most farmers use a higher dosage of glyphosate than recommended on the field edge. The average quantity of MCPA sprayed annually on field margins is 387 ml/km (standard deviation: 375 ml/km). Because application is local, there is little point in making a conversion to ditch bank loads.

Figure 4. Annual usage of glyphosate and MCPA (ml/km field margin)



It is striking that, on average, farmers who seed ditch banks with Red Fescue (*Festuca rubra*) use greater quantities of pesticides than those tolerating spontaneous growth on the banks (Table 2). On unseeded banks, Common couch (*Elymus repens*) usually predominates.

Table 2. Average quantity of glyphosate and MCPA (ml/km field margin) used on farms with ditch banks seeded with *Festuca rubra* and with spontaneous growth on banks

	seeded				spontaneous growth				test
	n	av.		sd	n	av.		sd	*P*
glyphosate	23	671	±	577	30	436	±	452	0.04 *
MCPA	9	494	±	437	6	225	±	186	0.37 ns

n = no. of farmers, av. = average, sd = standard deviation. Statistical test: (z) Mann-Whitney U-test; two-tailed * = $P < 0,05$; ns = not significant

Questioned as to the object of pesticide treatment, farmers named a wide variety of weeds and several animal pests (Table 3). The main weeds controlled on field edges and ditch banks are Common couch (*Elymus repens*), Creeping thistle (*Cirsium arvense*), (Perennial) Sow-thistle (*Sonchus* spp.), Colt's-foot (*Tussilago farfara*) and Groundsel (*Senecio vulgaris*). Apart from the last species, all of these are perennial weeds. In ditches, the main weeds controlled are Sweet-grass (*Glyceria* spp.) and, to a lesser extent, Common reed (*Phragmites australis*).

Discussion and conclusions

The interview results indicate that field margins are sprayed very intensively. A large percentage of farmers treat the margins with a variety of compounds, sometimes several times a year. Such spraying may therefore represent a major source of emissions to surface waters, particularly as it is carried out when the wind is blowing off the crop, to avoid the risk of crop damage. Although the interviews were generally held in an open atmosphere, the data gathered may perhaps represent an underestimate of pesticide use on field margins, especially in the case of illegal applications.

In contrast to treatment of the crop itself, where dosages are accurately recorded, the dosages used on field margins are known only approximately. One explanation for this is the fact that farmers do not make enough allowance for the exact area of the strip being treated. The large differences in dosage may provide scope for reducing the quantities used, for example by including, in usage instructions, an indication of the relationship between the width of the strip being treated and the recommended dosage per kilometre.
The fact that farmers with seeded ditch banks use more pesticides than those tolerating spontaneous growth may perhaps be explained by the fact that the former may attach greater value to neat ditch banks. This rests on the assumption that farmers with carefully planned ditch bank vegetation are less tolerant towards the invasion of other species than those with banks on which spontaneous growth is allowed.

Almost all farmers spray the field edge to create a sterile (weed-free) strip between the crop and the ditch bank. Interviews with cereal farmers in England indicate that some 30% of them maintain a sterile strip between crops and hedges. In addition to glyphosate, paraquat is also frequently used for this purpose (Marchall & Smith, 1986). The percentage of Dutch arable farmers spraying ditch banks (about 60%) is roughly equal to the percentage of British arable farmers spraying hedge undergrowth (Marchall & Smith, 1986). In both cases the motive given by farmers is that the direct surroundings of fields constitute a major source of influx of weeds (and animal pests). In reality, however, there is only marginal similarity between ditch bank vegetation and field (weed) vegetation. Any weed problems originating on ditch banks are probably due in part to the high soil nutrient levels. On the banks there is a regular input of artificial fertilizer, and mechanical maintenance consists of mowing or combined mowing and chopping, with the swath left lying. The latter method also creates openings in the vegetation, favouring invasion of the fastest growing pioneer species. Decreasing nutrient levels by removing the swath (by using a mower with a collection device, for example) and more accurate distribution of fertilizer along ditch banks would probably lead to a change in vegetation composition, this reducing the need for bank maintenance.

Table 3. Principal weeds controlled by farmers

	field edge (n = 63)*	ditch bank (n = 35)	ditch bed (n = 22)
<u>monocotyledons</u>:			
Elymus repens	49	6	
Alopecurus myosuroides	4	1	
Festuca rubra	4		
Lolium spp.	2		
Cyperaceae	1	1	3
Poa trivialis	1		
Triticum aestivum	1		
Phragmites australis		2	7
Glyceria spp.		1	21
Typha spp.			1
Lemnaceae			1
misc.	12	2	
<u>dicotyledons</u>:			
Cirsium arvense	26	18	
Sonchus spp.	18	15	
Tussilago farfaris	13		
Senecio vulgaris	12	4	
Matricaria recutita	9	3	
Stellaria media	6		
Equisetum spp.	5	3	
Urtica spp.	2		
Polygonum aviculare	2		
Taraxacum spp.	1	2	
Capsella bursa-pastoris	1	1	
Sinapis arvensis	1	1	
Ranunculus repens	1		
Rubus spp.	1		
Stachys palustris	1		
Lamium purpureum	1		
Polygonum persicaria	1		
Polygonum amphibium	1		
Glechoma hederacea		1	
misc.	2	1	1
<u>pests</u>:			
aphids		1	
slugs		1	

* Number of farmers; several weeds mentioned by each farmer

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References

Geel, W.C.A. van, 1991. Gewasbeschermingsplan 1991. Handboek voor de bestrijding van ziekten, plagen en onkruiden en de toepassing van groeiregulatoren in de akkerbouw, veehouderij, tuinbouw en het openbaar groen. IKC/PD, Wageningen.

Marchall, E.J.P. & B.D. Smith, 1986. Field margin flora and fauna; interaction with agriculture. BCPC Monograph no. 35: 23-33.

Meerjarenplan Gewasbescherming (MJP-G), 1991. Tweede Kamer, vergaderjaar 1990-1991, 21 677, nrs. 3-4, SDU uitgeverij, Den Haag.

Provinciaal Waterhuishoudingsplan Noord-Holland, 1991. Natuurlijk Water: Plan. Provincie Noord-Holland, Haarlem.

Snoo, G.R. de, 1991. Promotion of nature value in arable land by restrictive use of pesticides in field margins. Proc. of the EWRS-MSA 3 Meeting, 17/18 June, 1991, Wageningen p. 26-27.

Snoo, G.R. de & H.A. Udo de Haes, 1993. Unsprayed field margins in agro-ecosystems. Poster, 1st SETAC World Congress, Lisbon, 1993.

4 Unsprayed crop edges for reducing pesticide drift from field sprayers to ditches and ditch banks

G.R. de Snoo & P.J. de Wit

Abstract

Pesticide drift from field sprayers fitted with different types of spray nozzles was investigated under various wind speed conditions. Using water-sensitive papers, droplet drift was measured adjacent to the sprayed field, on the ditch bank and in the ditch. Measurements were carried out in the normal sprayed situation and with an unsprayed buffer zone 3 or 6 metres wide. The results show that there are major differences between spray nozzles. Drift deposition increases with wind speed. In the sprayed situation and with a wind speed of 0.5 m/s, there was a maximum of 6.0% drift deposition halfway down the ditch bank and no drift deposition in the ditch. At 3 m/s wind speed these figures are 25.1% and 2.2% respectively. At 5 m/s wind speed 7.2% drift deposition was measured in the ditch. Risk assessment carried out with 18 pesticides used in the study area indicated that aquatic organisms may well be at risk. Creation of a 3-m buffer zone decreases drift deposition in the ditch by a minimum of 95%. Adjacent to the buffer zone there is no longer any risk to aquatic organisms. With a 6-m buffer zone no drift deposition in the ditch could be measured (wind speed max. 4.5 m/s).

Introduction

In the Netherlands extremely large quantities of pesticides are used in comparison with neighbouring countries: on arable farms approximately 19 kg active ingredient per hectare per year (Meerjarenplan Gewasbescherming, MJP-G, 1991). A substantial proportion of these pesticides eventually ends up in surface waters, by a variety of routes. Measurements carried out at some 400 monitoring sites in the Netherlands have shown that in the period 1986-1989 the so-called 'basic quality' standards for surface water were exceeded at about 60% of the sites (Faasen, 1992). An extensive study by the National Institute of Public Health and Environmental Protection (RIVM) has demonstrated that, on the basis of laboratory studies and model calculations, nearly 30% of the 243 compounds investigated pose an ecotoxicological risk to aquatic organisms in one or more applications (Linders *et al.*, 1994).

In the present study it was investigated to what extent the creation of buffer zones can decrease pesticide emissions to adjacent ditch banks and ditches. At the same time it was calculated whether such a measure sufficiently reduces the risk to aquatic organisms. In the study a comparison was made between the drift deposition adjacent to sprayed field margins and that adjacent to unsprayed buffer zones 3 and 6 metres wide. A comparison was also made between field sprayers with different types of spray nozzles under various weather conditions (wind speed). The research forms part of the Dutch Field Margin Project in the Haarlemmermeerpolder, in which a management strategy is being developed to promote the natural values of arable fields and reduce pesticide drift to non-target areas. In this project the effects on farmland flowers, insects and birds have also been studied, as well as the costs and benefits of the measures taken to the farmer (De Snoo, 1994).

Methods

Deposition measurements

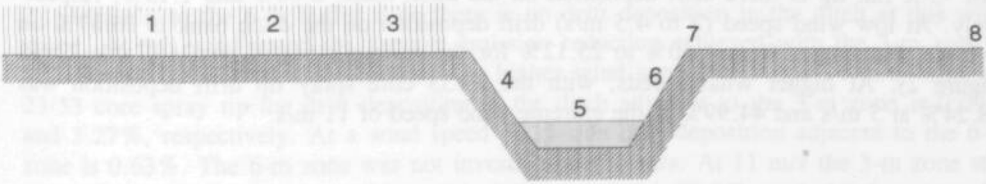
The experiment focused on 3 variables: spray nozzles, wind speed and width of the buffer zone. In the experiment 4 field sprayers with different types of spray nozzle were used, loaned from different farmers. One field sprayer was used twice, with 2 different nozzle types. All machines and spray nozzles had been technically approved. Details about the spraying conditions, such as amount of water used, driving speed, pressure, boom height above the crop, temperature and humidity were given in Table 1. To investigate the influence of the buffer zones on drift deposition, spray booms were switched off in the outer 3 and 6 metres of the field, to compare the sprayed situation with that with a 3 and 6 metre wide buffer zone. To this end the sprayers were driven parallel to the ditch, spraying a swath of at least 50 m length. For each spraying variant, measurements were made in duplo, with 15 m between the measuring points. Spraying was with water only. Wind speed, wind direction and humidity were measured at the experimental site. The experiments were carried out with the wind blowing perpendicular to the ditch and at 2 wind speeds: with virtually no wind (< 0.5 m/s) and at a low wind speed of about 3 m/s. As far as possible, all measurements at a certain wind speed, were carried out on the same day, on the same field. Crop height was always less than 40 cm, with the exception of the measurements with the 80°-3-R and 110°-6-R flat tips at a wind speed of 3 m/s, where crop height was 80 cm. With one type of spray nozzle it was also investigated what the emission level was when spraying was carried at high to very high wind speeds (up to 11 m/s).

Table 1. Investigated spray nozzles and spraying conditions; appl. = application and hum. = humidity

nozzle type	appl. l/ha	speed km/h	pressure bar	height cm	temperature °C	hum. %
23/53 core spray tip	400	3.5	3.1	75	10.8-29.0	62-74
20/10 core spray tip	400-600	4.5-5.5	4.0	60	20.5-30.0	63-72
LFR6-80° flat tip	400	7.0	2-3	50-70	13.5-29.0	72-75
80°-3-R flat tip	200	7.0	3.5	60	21.0-30.5	68-72
110°-6-R flat tip	400	7.0	3.5	60	14.6-20.5	67-72

Drift deposition was measured at different distances from the sprayed field (Figure 1). The ditch had a width of 1.3 m at the water surface, the ditch bank was approx. 1.8 m wide and the field edge had a width of approx. 0.50 m. The drift deposition (droplet drift only) was measured using water-sensitive paper (WSP, Ciba Geigy). These yellow papers turn blue when sprayed with water, the amount of blue indicating the quantity of water deposited. WSP measuring 12.5 by 2.5 cm was placed on a piece of triplex 5 cm above the vegetation. The amount of blue was measured directly with a video area meter (De Snoo & De Wit, 1993). In that study it was concluded that the use of WSP for measuring drift deposition is a reliable method up to 80% coverage of the WSP. Above this value there is no linear relation between the amount of blue of the WSP and the quantity of water sprayed. The detection limit is a coverage of 0.01%. Drift deposition was calculated as a percentage of the deposition on the sprayed area.

Figure 1. Deposition measurements in the arable field and adjacent area. 1 = 7 m into the sprayed field; 2 = 4 m into the field; 3 = 1 m into the field; 4 = halfway down the ditch bank; 5 = ditch; 6 = opposite ditch bank; 7 = opposite field edge; 8 = opposite field at 7 m



Risk assessment

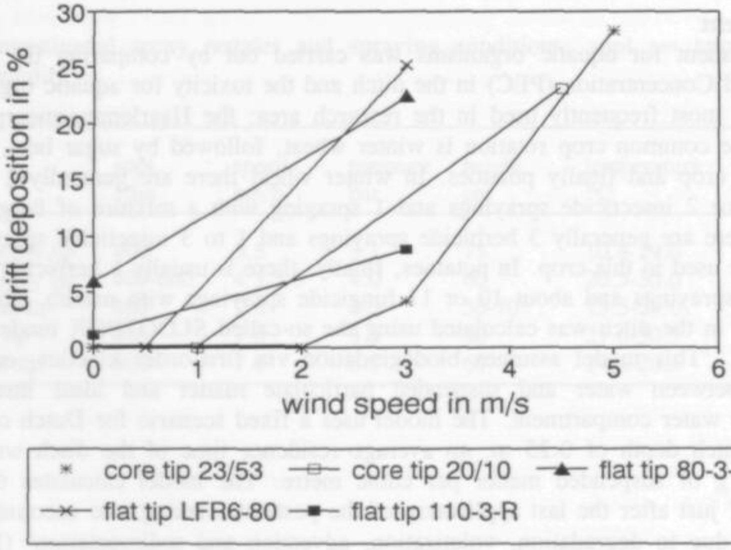
A risk assessment for aquatic organisms was carried out by comparing the Predicted Environmental Concentration (PEC) in the ditch and the toxicity for aquatic organisms of the pesticides most frequently used in the research area: the Haarlemmermeerpolder. In this polder the common crop rotation is winter wheat, followed by sugar beet, a second winter wheat crop and finally potatoes. In winter wheat there are generally 2 herbicide sprayings, 1 or 2 insecticide sprayings and 1 spraying with a mixture of fungicides. In sugar beet there are generally 3 herbicide sprayings and 1 to 3 insecticide sprayings. No fungicides are used in this crop. In potatoes, finally, there is usually 1 herbicide spraying, 2 insecticide sprayings and about 10 or 11 fungicide sprayings with maneb. The PEC of the pesticides in the ditch was calculated using the so-called SLOOTBOX model (Linders *et al.*, 1990). 'This model assumes biodegradation via first-order kinetics, equilibrium partitioning between water and suspended particulate matter and ideal instantaneous mixing of the water compartment. The model uses a fixed scenario for Dutch conditions, including a ditch depth of 0.25 m, an average residence time of the ditch water of 50 days and 15 g of suspended matter per cubic metre. The model calculates the 'initial concentration' just after the last application of the pesticide, taking into account losses of the pesticide due to degradation, volatization, advection and sedimentation' (Linders *et al.*, 1994). Contamination of the surface water was calculated on the basis of the drift deposition measured in the present study, for both the normal sprayed situation as well as with a 3 or 6-m buffer zone. Risk assessment for aquatic organisms was carried out by dividing the PEC by the LC50 (crustaceans and fishes) and the EC50/NOEC (algae). The calculations were based on the highest recommended pesticide dose and frequency for arable fields and current agricultural practice in the research area (*cf.* Mandersloot, 1993). The toxicity data and physicochemical properties of the pesticides were taken from Linders *et al.* (1994).

Results

Drift deposition in the ditch bank

The results show that drift deposition adjacent to the sprayed field depends on wind speed and nozzle type. The wind speed has a major influence on drift deposition. Figure 2 shows, for each nozzle type, the relation between wind speed and drift deposition on the ditch bank in the sprayed situation. For all nozzle types, drift deposition increases with wind speed. At a given wind speed the various nozzle types give rise to very different levels of drift deposition on the ditch bank (factor 6, see also Table 2). As shown in Figure 2, with (virtually) no wind (max. 0.5 m/s) only with the 80°-3-R flat tip and the 110°-3-R flat tip is there drift deposition on the ditch bank: 6.00% and 1.13%, respectively. At low wind speed (3 to 4.5 m/s) drift deposition on the ditch bank is 16.87% on average, but ranges from 4.10% to 25.12% for the various types of nozzle (Table 2 and Figure 2). At higher wind speeds, with the 23/53 core spray tip drift deposition was 28.24% at 5 m/s and 44.99% at the extreme wind speed of 11 m/s.

Figure 2. Drift deposition from 5 nozzle types under different wind speed conditions on the *ditch bank* (location no. 4) sprayed situation



Drift deposition on the ditch bank adjacent to the 3-m buffer zone is much lower than in the normal sprayed situation, on average 0.03% (range: 0-0.08%; see Figure 4 and Table 2). Adjacent to the 6-m buffer zone there is even less drift deposition; only the 80°-3-R flat spray tip caused a measurable deposition (0.02%). However, the greatest reduction is already achieved with the 3-m zone. At a wind speed of 3 m/s the 3-m zone reduces drift deposition on the ditch bank by a minimum of 99.5%, and the 6-m zone by virtually 100%. Although the relative reduction decreases with increasing wind speed, at a wind speed of 11 m/s (23/53 core spray tip) the 3-m zone still reduces drift deposition on the ditch bank by 92.7%, and the 6-m zone by 95.0%.

Drift deposition in the ditch

Figure 3 shows the relation between wind speed and drift deposition in the ditch in the sprayed situation for the various nozzle types. With no wind (max. 0.5 m/s) there is no deposition in the ditch. At low wind speed (max. 4.5 m/s) the average drift deposition in the ditch is 1.06% (range: 0.56-2.19%; see Figure 3,4 and Table 2). The 80°-3-R flat tip gives the highest drift deposition. As the wind speed increases, so too does the drift deposition in the ditch. At a wind speed of 5 m/s the 23/53 core spray tip causes 7.24% drift deposition, while at the extreme wind speed of 11 m/s 29.00% was measured.

At low wind speed drift deposition in the ditch adjacent to the 3-m buffer zone is much less than in the sprayed situation (average 0.02%; range 0-0.07%, see Figure 4 and Table 2). Adjacent to the 6-m buffer zone there is no drift deposition in the ditch at this wind speed. At this wind speed the average emission reduction achieved with the 3-m zone is 97.9%, and 100% with the 6-m zone. At higher wind speeds of 5 and 11 m/s, with the 23/53 core spray tip the drift deposition in the ditch adjacent to the 3-m zone is 0.09% and 3.27%, respectively. At a wind speed of 11 m/s drift deposition adjacent to the 6-m zone is 0.63%. The 6-m zone was not investigated at 5 m/s. At 11 m/s the 3-m zone still reduces drift deposition from this nozzle in the ditch by 88.7%, and the 6-m zone by 97.8%.

Figure 3. Drift deposition from 5 nozzle types under different wind speed conditions in the *ditch* (location no. 5) in the sprayed situation

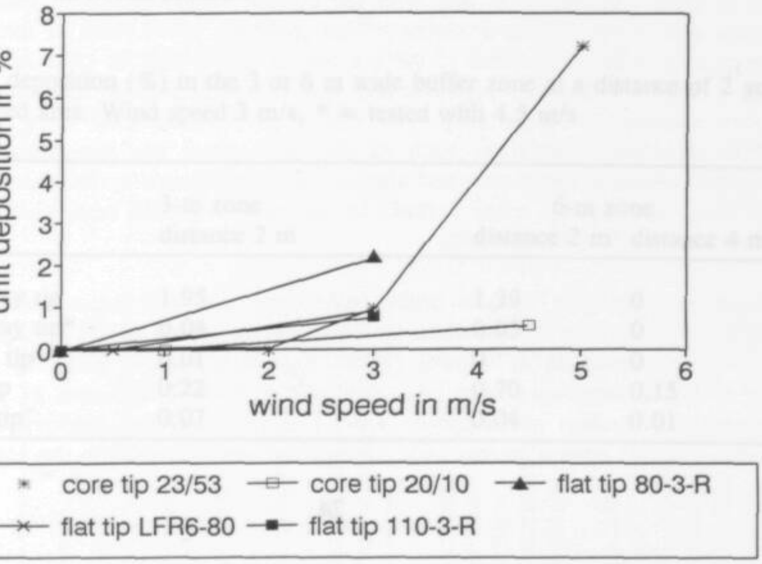


Figure 4. Average drift deposition at a wind speed of 3-4.5 m/s at different distances from the sprayed field. First sprayed situation, second unsprayed crop edge 3 m wide and third unsprayed crop edge 6 m wide

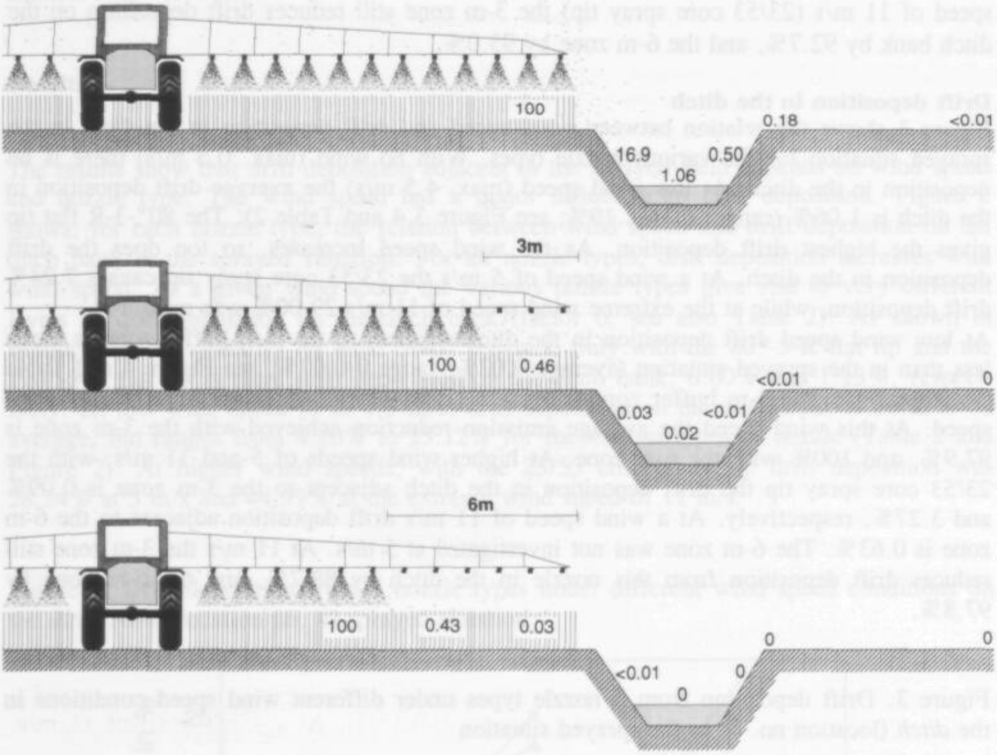


Table 2. Drift deposition (%) adjacent to the arable field on the ditch bank and in the ditch at 3 m/s in the sprayed situation and with a buffer zone of 3 or 6 m wide; sprayed area = 100% drift deposition; * = tested with wind speed of 4.5 m/s

	normal	3 m buffer	6 m buffer
ditch bank			
23/53 core spray tip	4.10	0.08	0
20/10 core spray tip*	23.96	0.03	0
LFR6-80° flat tip	25.12	0	0
80°-3-R flat tip	22.39	0.02	0.02
110°-6-R flat tip	8.79	0.01	0
ditch			
23/53 core spray tip	0.98	0.02	0
20/10 core spray tip*	0.56	0.03	0
LFR6-80° flat tip	0.83	0	0
80°-3-R flat tip	2.19	0.07	0
110°-6-R flat tip	0.76	0	0

Drift deposition in the buffer zone

Table 3 and Figure 4 give the drift deposition in the buffer zone itself, at distances of 2 and 4 m from the sprayed field. In the 3-m zone, at a distance of 2 m from the sprayed field and at a wind speed of 3-4.5 m/s the average drift deposition is 0.46% (range: 0.01-1.95%). At wind speeds of 5 m/s and 11 m/s these figures are 4.47% and 24.77%, respectively, for the 23/53 core spray tip. In the 6-m zone, at a distance of 2 m from the sprayed area the average drift deposition is 0.43% (range: 0-1.39%; wind speed: 3-4.5 m/s). This is in good agreement with the value measured at the same distance in the 3-m buffer zone: 0.46% on average. At a wind speed of 11 m/s, 37.23% drift deposition was measured 2 m into the 6-m zone. At a distance of 4 m into the 6-m zone, drift deposition at low wind speed is 0.03% on average (range: 0-0.15%). At a wind speed of 11 m/s, 4.79% was measured at this distance.

Table 3. Drift deposition (%) in the 3 or 6 m wide buffer zone at a distance of 2 and 4 m from the sprayed area. Wind speed 3 m/s, * = tested with 4.5 m/s

	3-m zone	6-m zone	
	distance 2 m	distance 2 m	distance 4 m
23/53 core spray tip	1.95	1.39	0
20/10 core spray tip*	0.04	0.03	0
LFR6-80° flat tip	0.01	0	0
80°-3-R flat tip	0.22	0.70	0.15
110°-6-R flat tip	0.07	0.04	0.01

Risk assessment for aquatic organisms

With the SLOOTBOX model the PEC in the ditch was calculated for a wind speed of 5 m/s, considered to be a realistic worst-case situation because at this wind speed farm spraying was still observed to take place. At 5 m/s drift deposition in the ditch is 7.2% in the sprayed situation (23/53 core spray tip) and 0.07% adjacent to the 3-m buffer zone. Table 4 shows the short-term toxic risks to aquatic organisms of the pesticides most frequently used in the various crops in the Haarlemmermeerpolder in both the normal sprayed situation and in the presence of a 3-m buffer zone. It is clear that in the sprayed situation many pesticides may well have toxic effects on algae, crustaceans and fishes. Creation of a 3-m buffer zone reduces the short-term toxic risks to aquatic organisms substantially; in this situation the risks are in most cases negligible. Only the use of parathion, oxydemeton and fentin-acetate causes a small risk for crustaceans or algae. When maneb is used there is still a risk present for crustaceans.

Discussion

The Dutch Pesticide Approval Board estimates that during full-field spraying 1-2% of the dosage per unit area drifts to the ditch (EPPO, 1993). This is in good agreement with the ditch loads measured in the present study at low wind speeds (0.5-2.2% for the various spray nozzles). At slightly higher wind speeds, however, deposition in the adjacent ditches increases sharply, with 7.2% deposition already being measured at 5 m/s. In farming practice spraying is still carried out at this kind of wind speed. At high wind speeds deposition on the ditch bank is also high. With 3 of the 5 nozzles investigated, deposition *halfway down* the ditch bank exceeded 22%. Comparison of the results with the field sprayers with earlier measurements of drift from the knapsack sprayers used for spraying the field edges (De Snoo & De Wit, 1993) shows that the presently investigated field sprayers cause far greater drift deposition. At low wind speeds knapsack sprayers cause max. 9.1% drift deposition on the ditch bank and 0.03% in the ditch (max. wind speed 3.5 m/s).

Field margins are sprayed intensively (De Snoo & Wegener Sleeswijk, 1993). Restricting spraying in field margins is in line with the current Dutch policy as laid down in the government's Multi-year Crop Protection Plan (MJP-G, 1991). One of the objectives of this policy is to reduce emissions to surface waters by 70-80% in 1995 relative to 1991. To achieve such a reduction, pesticide use is to be prohibited in and along operational ditches. In addition, a 50-cm unsprayed zone is to be prescribed along waterways. In some West European countries, such as Germany, there are also already regulations laying down, for each compound and application, the distance to be maintained between sprayed fields and nearby water bodies. In the case of arable land, the buffer zone is usually 10 m (Jörg & Zweck, 1992).

Unsprayed field margins have a major impact on the drift deposition. However, an unsprayed zone of only 50-cm wide, as proposed in Dutch policy, will be too small. Research by Cuthbertson & Jepson (1988) has demonstrated that, in winter wheat, creation of a 6-m unsprayed crop edge can give a 70-75% reduction of pesticide emissions to adjacent hedges (wind speed: 4.0-6.4 m/s). From our research it can be concluded that a buffer zone 6 metres wide can prevent pesticide drift to the adjacent ditch.

Table 4. The 17 most frequently used pesticides in 1990-1993 in the sprayed edges of the various crops (winter wheat 27 fields, sugar beet 10 fields and potatoes 13 fields; no toxicity data available of metribuzin and prochloraz). Assessment of short term risk to aquatic organisms in the normal sprayed situation and adjacent to a 3-m buffer zone, based on drift deposition measured at 5 m/s in the present study and the SLOOTBOX model *cf.* Linders *et al.* (1990). Risk assessment (PEC/L(E)C50): N = negligible risk (<0.01); S = small risk (0.01-0.1); P = risk present (0.1-1); L = large risk (1-10) and VL = very large risk (>10); - = no data available

pesticide	dose kg/ha	freq. year	algae EC50 mg/l	NOEC mg/l	risk normal	risk 3m	crustaceans LC50 mg/l	risk normal	risk 3m	fishes LC50 mg/l	risk normal	risk 3m
herbicides												
MCPA	1	1	-	56	N	N	1100	N	N	2000	N	N
bentazone	1	1	279	25.7	N	N	64	N	N	510	N	N
ethofumesate	0.125	2	0.06	-	**S**	N	295	N	N	10.92	N	N
phenmedipham	0.225	2	1.4	-	N	N	6.5	N	N	2.7	N	N
metamitron	4.2	1	0.2	0.1	**P**	N	100	N	N	440	N	N
mecoprop-p	2.4	1	220	56	N	N	420	N	N	147	N	N
metsulfuron-m	0.006	1	100	6.25	N	N	150	N	N	150	N	N
fluroxypyr	0.2	1	100	56	N	N	100	N	N	100	N	N
insecticides												
dimethoate	0.4	1	300	32	N	N	2.9	N	N	30	N	N
parathion	0.25	1	-	-	-	-	0.0018	**L**	**S**	0.71	**S**	N
oxydemeton-m.	0.25	1	100	100	N	N	0.0033	**L**	**S**	1.9	N	N
pirimicarb	0.25	1	140	50	N	N	0.019	**P**	N	32	N	N
fungicides												
maneb	0.85	11	3.2	-	**P**	N	0.0024	**VL**	**P**	0.34	**S**	N
fentin-acetaat	0.275	11	0.002	-	**L**	**S**	0.011	**P**	N	0.01	**P**	N
propiconazol	0.125	1	0.76	0.32	N	N	11.5	N	N	3.3	N	N
triadimenol	0.125	1	3.7	1	N	N	2.5	N	N	17.4	N	N
anilazin	0.48	1	1.02	1	**S**	N	0.97	**S**	N	0.15	**S**	N

Moreover, even a relatively narrow buffer zone 3 metres wide appears to be adequate; even at a wind speed of 11 m/s drift deposition is reduced by 88.7%. Creating unsprayed buffer zones of 3- and 6-m wide also significantly reduces the short-term toxic risks to aquatic organisms. Earlier field research has demonstrated that rare farmland flora may recolonize unsprayed crop edges 3 to 6 metres wide (Schumacher, 1984), and in the unsprayed edges the number of insects (butterflies, for example) also increases sharply and populations of Galliformes may recover (Rands, 1986; Hald *et al.*, 1988; Dover *et al.*, 1992; De Snoo, 1994). However, experiments with bioassays show that although a buffer zone of 6-10 m will be generally sufficient to minimize the impact of pesticides on neighbouring vegetation (*cf.* Marrs *et al.*, 1989; 1991a; 1991b; Breeze *et al.*, 1992) specially young stages of the lifecycle, such as seedlings sometimes require wider buffer zones (up to about 20 m; Marrs *et al.*, 1993). With respect to invertebrates, such as young caterpillars of *Pieris brassicae* (Large white) this is also true (Sinha *et al.*, 1990; Davis *et al.*, 1991; 1993; De Jong and Van der Nagel, 1994).

In summary, it can be said that with current spraying methods, it is not recommended to spray at wind speeds exceeding about 3 m/s. Creation of a 3 to 6-m wide unsprayed zone along the crop edge can give a very major reduction in pesticide emissions to the surrounding area. These relatively narrow buffer zones may be adequate to protect flora and fauna in agriculural areas. However, on sites adjacent to nature reserves wider buffer zones may be needed.

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References

Breeze V., G. Thomas & R. Butler, 1992. Use of a model and toxicity data to predict the risks to some wild plant species from drift of four herbicides. Ann. Applied Biology 121: 667-677.

Cuthbertson, P.S. & P.C. Jepson, 1988. Reducing pesticide drift into the hedgerow by inclusion of an unsprayed field margin. Proc. Brighton Crop Protection Conference, Pests and diseases: 747-751.

Davis, B.N.K., K.H. Lakhani, T.J. Yates & A.J. Frost., 1991. Bioassays on insecticide spray drift: the effects of wind speed on the mortality of *Pieris brassicae* larvae (Lepidoptera) caused by diflubenzuron. Agriculture, Ecosystems and Environment 36: 141-149.

Davis, B.N.K., K.H. Lakhani, T.J. Yates, A.J. Frost & R.A. Plant, 1993. Insecticide drift from ground-bases, hydraulic spraying of peas and brussels sprouts: bioassays for determining bufferzones. Agriculture, Ecosystems and Environment 43: 93-108.

Davis, B.N.K. & C.T. Williams, 1990. Buffer zone widths for honeybees from ground and aerial spraying of insecticides. Environmental Pollution 63: 247-259.

Dover, J.W., N.W. Sotherton & K. Gobbett, 1990. Reduced pesticide inputs on cereal field margins: the effects on butterfly abundance. Ecological Entomology 15: 17-24.

EPPO, 1993. European and Mediterranean Plant Protection Organization, Council of Europe. Decision-making scheme for the environmental risk assessment of plant protection products. EPPO Bull. 23:73-98.

Faasen, R., 1992. Landbouwbestrijdingsmiddelen in oppervlaktewater, een situatieschets. H_2O 25 (2): 30-33.

Hald, A.B., B.O. Nielsen, L. Samsøe-Petersen, K. Hansen, N. Elmegaard & J. Kjoholt, 1988. Sprojtefri randzoner i kornmarker. Miljoprojekt nr. 103. Miljostyrelsen, Copenhagen.

Jong, F.M.W., de & M.C. van der Nagel, 1994. A field bioassay for side-effects of in secticides with larvae of the Large White Butterfly *Pieris brassicae* (L.). Med. Fac. Landbouww. Univ. Gent 59(2b): 347-355.

Jörg, E. & W. Zweck, 1992. Planzenschutzmittel und Wasserschutz. Stand: Juli 1992. Rheinland-Pfalz, Landespflanzenschutzdienst, Mainz-Bretzenheim, 2e Auflage 36 p.

Linders, J.B.H.J., R. Luttik, J.M. Knoop and D. van de Meent, 1990. Appreciation of the behaviour of pesticides in surface water in relation to exposition of aquatic organisms. RIVM Report 678611002.

Linders, J.B.H.J., J.W. Jansma, B.J.W.G. Mensink & K. Otermann, 1994. Pesticides: benefaction or pandora's box? A synopsis of the environmental aspects of 243 pesticides. RIVM Report 679101014.

Mandersloot, H.J., 1993. Gewasbeschermingsgids 1993. Handboek voor de bestrijding van ziekten, plagen en onkruiden en de toepassing van groeiregulatoren in de akkerbouw, veehouderij, tuinbouw en het openbaar groen. Informatie- en KennisCentrum Akker- en Tuinbouw en Plantenziektenkundige Dienst, Wageningen.

Marrs, R.H., C.T. Williams, A.J. Frost & R.A. Plant, 1989. Assessment of the effects of herbicide spray drift on a range of plant species of conservation interest. Environmental Pollution 59: 71-86.

Marrs, R.H., A.J. Frost & R.A. Plant, 1991a. Effects of herbicide spray drift on selected species of nature conservation interest: the effects of plant age and surrounding vegetation structure. Environmental Pollution 69: 223-235.

Marrs, R.H., A.J. Frost & R.A. Plant, 1991b. Effect of mecoprop drift on some plant species of conservation interest when grown in standardized mixtures in microcosms. Environmental Pollution 73: 25-42.

Marrs, R.H., A.J. Frost, R.A. Plant & P. Lunnis, 1993. Determination of buffer zones to protect seedlings of non-target plants from the effects of glyphosate spray drift. Agriculture, Ecosystems and Environment 45: 283-293.

Meerjarenplan Gewasbescherming (MJP-G), 1991. Regeringsbeslissing. Tweede Kamer, vergaderjaar 1990-1991, 21677, nrs. 3-4. SDU Uitgeverij, Den Haag.

Rands, M.R.W., 1985. Pesticide use on cereals and the survival of grey partridge chicks: a field experiment. J. Applied Ecology 22: 49-54.

Sinha, S.N., K.H. Lakhani & B.N.K. Davis. 1990. Studies on the toxicity of insecticidal drift to the first instar larvae of the Large White butterfly *Pieris brassicae* (Lepidoptera: Pieridae). Ann. Appl. Biol. 116: 27-41.

Snoo, G.R. de, 1994. Unsprayed field margins in arable land. Med. Fac. Landbouww. Univ. Gent 59 (2b): 549-559.

Snoo, G.R. de & A. Wegener Sleeswijk, 1993. Use of pesticides along field margins and ditch banks in the Netherlands. Med. Fac. Landbouww. Univ. Gent 58 (3a): 921-926.

Snoo, G.R. de & P.J. de Wit, 1993. Pesticide drift from knapsack sprayers to ditches and ditch banks. Proc. Brighton Crop Protection Conference - Weeds - 1993 (2): 879-884.

Schumacher, W., 1984. Gefährdete Ackerwildkräuter können auf ungespritzten Feldrän dern erhalten werden. Mitteilungen der LÖLF 9 (1): 14-20.

5 Pesticide drift from knapsack sprayers to ditches and ditch banks

G.R. de Snoo & P.J. de Wit

Abstract

Pesticide drift from knapsack sprayers fitted with different types of nozzle was investigated along a field edge. Drift deposition was measured at various wind speeds using water-sensitive paper. Drift deposition depends on nozzle type and wind speed. Flat spray tips cause more drift deposition than cone nozzles, probably owing to the larger spray angle. Deposition increases with wind speed. At a wind speed of 2.5-3.5 m/s, there was max. 9.08% drift deposition halfway down the ditch bank and 0.03% in the ditch (2.0-mm flat spray tip). At 7.5 m/s for flat spray tips these figures are max. 49.17% and 6.21%, respectively. All cone nozzles except the adjustable nozzle cause a max. deposition of 0.93% halfway down the ditch bank and 0.06% in the ditch.

Introduction

In the Netherlands, field edges, ditch banks and even ditch beds are frequently sprayed with herbicides (De Snoo & Wegener Sleeswijk, 1993). Of 88 farmers interviewed, 95% create a 'sterile strip' about 35 cm wide along the perimeter of their arable fields. In most cases knapsack sprayers are used for this purpose, with the herbicide Glyphosate being most commonly applied, to combat *Elymus repens* (Common couch). Little is known about herbicide drift from knapsack sprayers used along field edges. In the context of Dutch pesticide policy there is an ongoing debate as to whether it is necessary and possible to prohibit spraying along the outermost 50 cm of arable fields (MANF, 1991). In this study the drift deposition from knapsack sprayers fitted with different types of nozzle was investigated under various weather conditions (wind speed). This research forms part of the Dutch Field Margin Project in the Haarlemmermeerpolder.

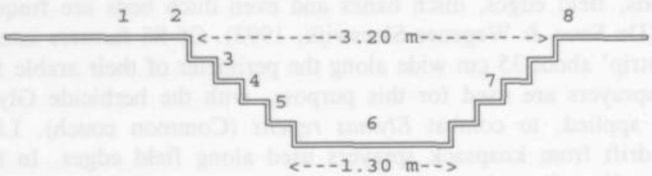
Method summary

The experiment focuses on 2 variables: nozzle type and wind speed. Other factors that might be important for pesticide drift were kept as constant as possible. Sprayers were filled with water only, with a working pressure of 2 bar. The wind direction was always perpendicular to the ditch. The walking speed was about 4.6 kilometres per hour. The spray height varied between 15 and 30 cm and was dependent on the nozzle type. Seven nozzle types from 6 farmers were used (Table 1) with a single type of knapsack sprayer (Birchmeyer, hand pump). Drift deposition resulting from the nozzles was measured at different distances from the sprayed field edge (Figure 1).

Table 1. Investigated spray nozzles (from Birchmeyer, 1991) with measured spray angles and flow rate in ml/min

nozzle type	trademark	spray angle	flow rate
cone nozzle, 1.5-mm	Duro	60°	530
cone nozzle, 1.3-mm	Duro	45°	650
adjustable nozzle (1.3-mm hollow cone)	Birchmeyer	70°	280
cone nozzle, '120'	Birchmeyer	55°	600
narrow cone nozzle	Birchmeyer	45°	550
flat spray tip, 1.6-mm	Floodjet	105°	910
flat spray tip, 2.0-mm	Floodjet	130°	1350

Figure 1. Deposition measurements along field edge; 1 = 0.5 m into field; 2 = field edge (spray target); 3 = 0.3 m down ditch bank; 4 = 0.6 m down ditch bank (halfway); 5 = 0.9 m down ditch bank; 6 = ditch; 7 = opposite ditch bank; 8 = opposite field edge



Drift deposition was measured using water-sensitive papers (WSP, Ciba Geigy). These yellow papers turn blue when sprayed with water, the amount of blue indicating the quantity of water deposited. WSP measuring 12.5 by 2.5 cm was placed on a piece of triplex 10 cm above ground level. The amount of blue was measured directly with a video-area meter. With this set-up there is no need for a copying machine, as used by Sinha *et al.* (1990), to increase resolution. Each WSP was measured on three 10 cm^2 sample areas (total sample area about 25 cm^2). The detection limit was a covering of 0.01%. Drift deposition was calculated as a percentage of the deposition on the field edge itself.

The deposition on the field edge might be more than indicated by the amount of blue, owing to overlapping droplets that do not spread out. The dose-area relation was therefore investigated in a separate experiment in which the WSP was sprayed several times with a standardized spray burst from a set distance. The experiment was carried out twice with the 1.5-mm cone nozzle (fine droplets) and twice with the 1.6-mm flat spray tip (large droplets).

The accuracy of the method was also investigated using a calcium tracer. For this purpose a standard spraying run was carried out with a solution of 5 g $CaCl_2 2H_2O$ per litre. The experiment was performed with the 1.5-mm cone nozle and the 2.0-mm flat spray tip. The calcium solution was sprayed on the WSP as well as on adjacent strips of filter paper (12.5 x 2.5 cm). The calcium in the filter paper was subsequently extracted with HCl and titrated with 0.001 M EDTA-Complex (Skoog, 1977).

Results

The relation between the quantity of sprayed water and the amount of blue (dose-area relation) is linear up to 80% coverage of the WSP (Figure 2). Above this value the curve levels off. The results of the tracer experiment indicate a linear relation between the amount of blue and the quantity of calcium, for both the cone nozzle and the flat spray tip (Figure 3). These two control experiments show that the use of WSP to measure the deposition from knapsack sprayers is a reliable method.

Figure 2. Dose-area relation between amount of blue on WSP (%) and quantity of sprayed water

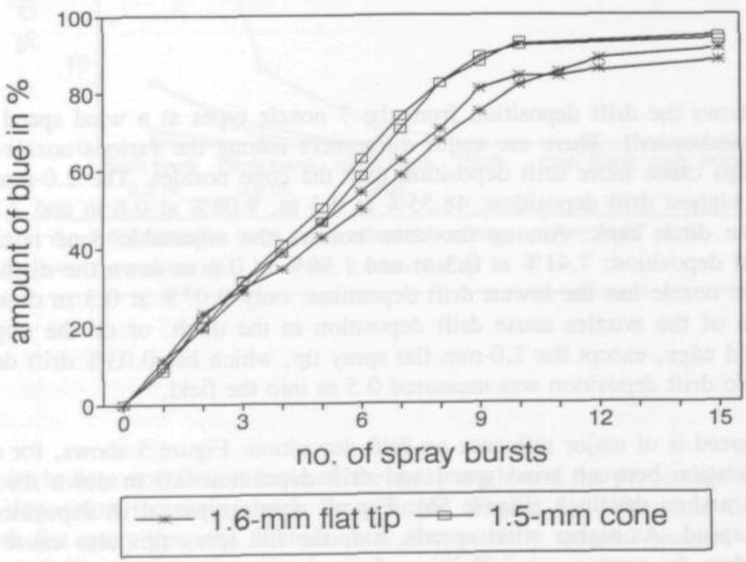


Figure 3. Relation between amount of blue on WSP and quantity of calcium tracer

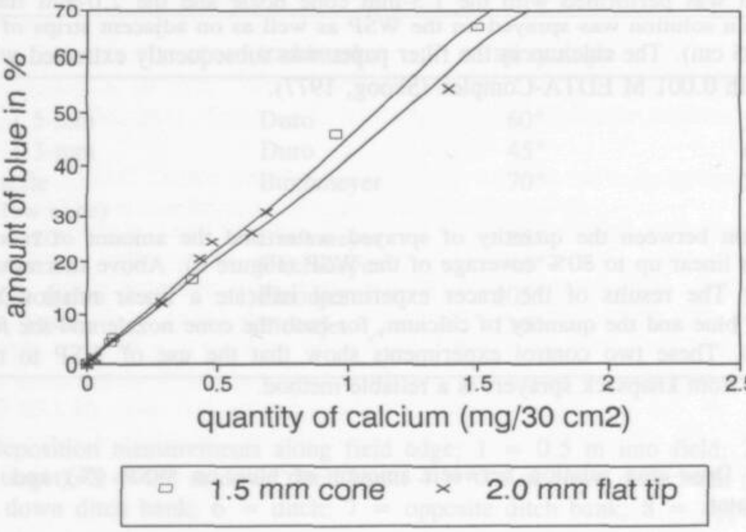
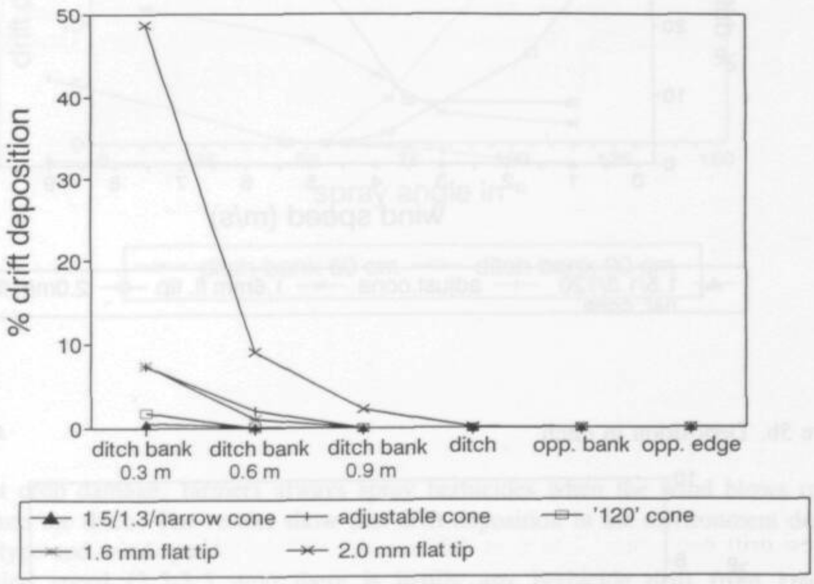


Figure 4 shows the drift deposition from the 7 nozzle types at a wind speed of 2.5-3.5 m/s (low wind speed). There are major differences among the various nozzle types. The flat spray tips cause more drift deposition than the cone nozzles. The 2.0-mm flat spray tip has the highest drift deposition: 48.55% at 0.3 m, 9.08% at 0.6 m and 2.25% at 0.9 m down the ditch bank. Among the cone nozzles the adjustable cone nozzle has the highest drift deposition: 7.41% at 0.3 m and 1.98% at 0.6 m down the ditch bank. The narrow cone nozzle has the lowest drift deposition: only 0.07% at 0.3 m down the ditch bank. None of the nozzles cause drift deposition in the ditch, or on the opposite ditch bank or field edge, except the 2.0-mm flat spray tip, which has 0.03% drift deposition in the ditch. No drift deposition was measured 0.5 m into the field.

The wind speed is of major influence on drift deposition. Figure 5 shows, for each nozzle type, the relation between wind speed and drift deposition 0.6 m down the ditch bank (Figure 5a) and in the ditch (Figure 5b). For all nozzle types, drift deposition increases with wind speed. At higher wind speeds, too, the flat spray tips also cause more drift deposition than the cone nozzles. Halfway down the ditch bank (0.6 m), the 2.0-mm flat spray tip has a drift deposition varying from 8.77% at 1 m/s to 49.17% at 7.5 m/s. The 1.6-mm flat tip and the adjustable cone tip also cause high drift deposition on the ditch bank: maximum 22.93% and 12.67%, respectively. The other 4 nozzle types have a maximum drift deposition of 0.93% halfway down the ditch bank. The '120' cone nozzle has the lowest drift deposition: from 0 at 1 m/s to 0.20% at 9.5 m/s.

Measured in the ditch, the flat-tip nozzles again have the highest drift deposition: up to 6.21% at 7.5 m/s wind speed. The cone nozzles cause no more than 0.06% drift deposition in the ditch, apart from the adjustable cone nozzle, with 0.18%. The '120' and 1.3-mm cone nozzles cause no drift deposition at all in the ditch, even at very high wind speeds. It is noteworthy that the 1.6-mm flat spray tip has a higher in-ditch drift deposition than the 2.0-mm flat spray tip (3.22%), although the latter tip causes more drift deposition at other distances.

Figure 4. Drift deposition from knapsack sprayers with seven different spray nozzles at 2.5-3.5 m/s wind speed



There appears to be a correlation between the spray angle and the percentage drift deposition, drift deposition increasing with spray angle (Figure 6). When the field edge is sprayed with flat spray tips, the ditch bank is also partially sprayed because of the large spray angle (*cf.* Figure 5a: at very low wind speed, drift deposition is also about 6-9%). The cone nozzles have a small, tight aperture, causing a small emission. The 1.3-mm adjustable cone nozzle has a larger emission because of the wide, hollow cone.

Figure 5. Drift deposition from seven nozzle types under different wind speed conditions

Figure 5a. Deposition 0.6 m down ditch bank

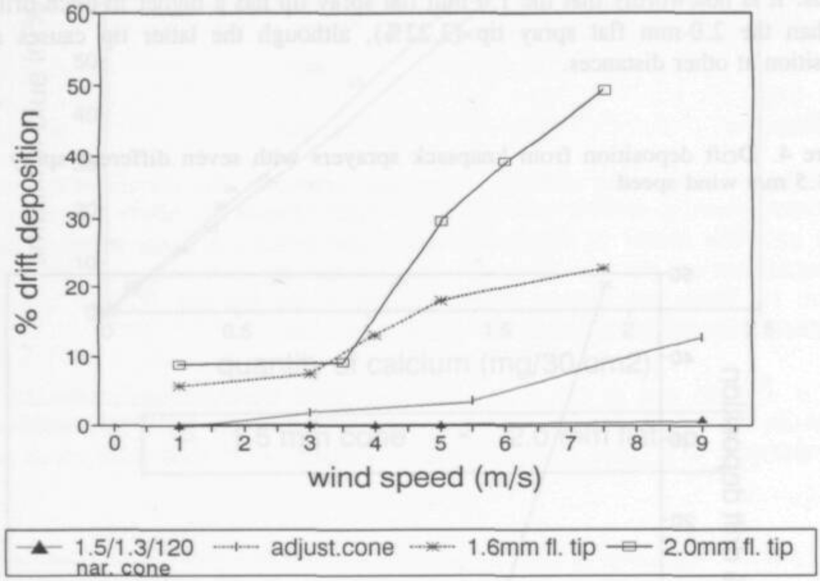


Figure 5b. Deposition in ditch

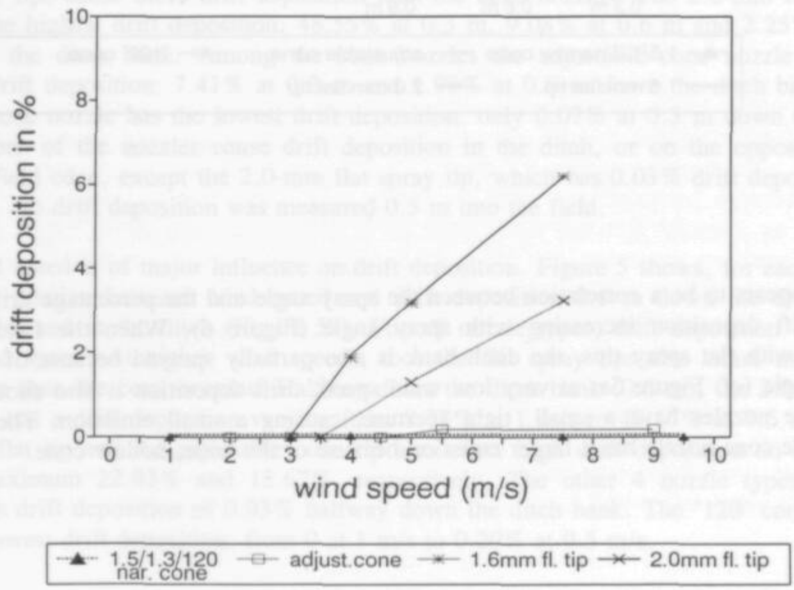
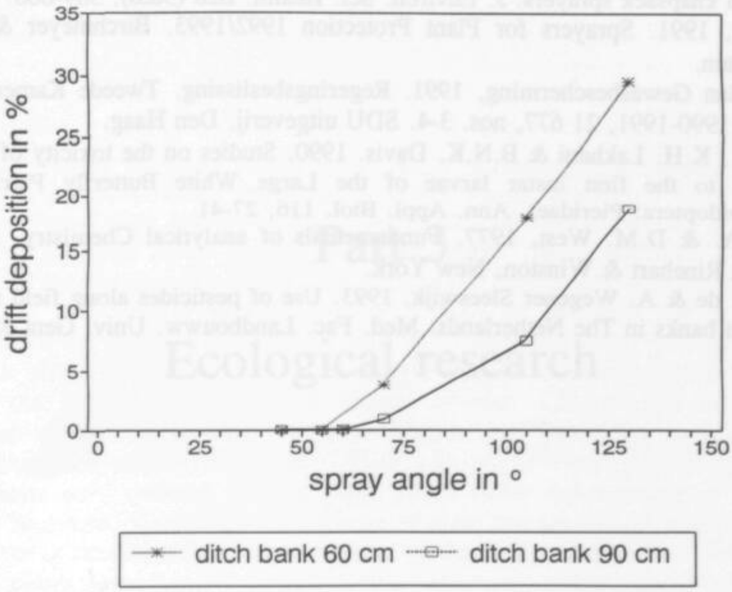


Figure 6. Relation between spray angle and drift deposition 0.6 m and 0.9 m down ditch bank at 5 m/s wind speed



Discussion

To prevent crop damage, farmers always spray herbicides when the wind blows off the crop and into the ditch. The results show that drift deposition in the environment depends on nozzle type and wind speed.

At low wind speed (2.5-3.5 m/s) there is hardly any herbicide drift from knapsack sprayers into the ditch. However, there is substantial deposition on the ditch bank when flat spray tips are used. As the wind speed increases, drift deposition also increases, reaching relatively high values with the flat spray tips as well as the adjustable cone nozzle. Because of their wide spray angle, the flat spray tips and the adjustable cone nozzle are less suitable for spraying field edges.

To reduce drift deposition from knapsack sprayers it is recommended not to spray at a wind speed above 3.5 m/s and to prohibit the use of nozzles with spray angles greater than 60°. Moreover, it has been demonstrated that the use of spray shields can reduce pesticide emissions to the environment (by 63%), at the same time increasing the efficiency of spraying operations (Awadhwal *et al.*, 1991).

References

Awadhwal, N.K., E.F. Cabrido & G.R. Quick, 1991. Minimizing drift and exposure from knapsack sprayers. J. Environ. Sci. Health. B26 (5&6), 589-600.

Birchmeyer, 1991. Sprayers for Plant Protection 1992/1993. Birchmeyer & Cie. AG. Künten.

Meerjarenplan Gewasbescherming, 1991. Regeringsbeslissing. Tweede Kamer, vergaderjaar 1990-1991, 21 677, nos. 3-4. SDU uitgeverij, Den Haag.

Sinha, S.N., K.H. Lakhani & B.N.K. Davis. 1990. Studies on the toxicity of insecticidal drift to the first instar larvae of the Large White Butterfly Pieris brassicae (Lepidoptera: Pieridae). Ann. Appl. Biol. 116, 27-41.

Skoog, D.A. & D.M. West, 1977. Fundamentals of analytical Chemistry. 3rd edition. Holt Rinehart & Winston, New York.

Snoo, G.R. de & A. Wegener Sleeswijk, 1993. Use of pesticides along field margins and ditch banks in The Netherlands. Med. Fac. Landbouww. Univ. Gent 58 (3a): 921-926.

Part 3

Ecological research

6 Arable flora in sprayed and unsprayed crop edges

G.R. de Snoo

Abstract

On 15 conventionally managed arable farms in an intensive arable farming district on marine clay in the Netherlands, the edges of winter wheat, sugar beet and potato fields were left unsprayed with herbicides and insecticides. In these edges the presence and abundance of farmland plant species was investigated (Braun-Blanquêt method) and compared with the situation in sprayed edges and in the field centre. The results show that in all 3 crops there was a marked increase in both the presence and abundance of farmland plants, by a factor of 4.8-12.1 and 1.5-2.7, respectively, particularly in the winter wheat crop. The increase was attributable mainly to dicotyledonous species. In sugar beet the dominant species were Thlaspi arvense, Chenopodum ficifolium *and* Chenopodium album, *in potatoes* Senecio vulgaris *and in winter wheat* Matricaria recutita, Polygonum convolvulus *and* Galium aparine. *Although the majority of the farmland plants were common species, there was a major enhancement of the floristic value of the unsprayed fields, and the increase of these species can be very important for the occurrence of animal species. In the centre of the field, the presence and abundance of farmland plants as well as the overall floristic value was consistently lower than along the edges. Leaving the crop edges unsprayed had a significant impact on crop cover in sugar beet fields only. If compatibility with farm management is also taken into account, the measures investigated appear to have the greatest potential in winter wheat.*

Introduction

Over the past few decades, there has been a dramatic change in the arable flora of the Netherlands. Although the flora of nutrient-rich arable fields has generally remained stable or even improved, the species of less nutrient-rich arable fields have undergone a sharp decline (see Table 1). This decline has been particularly marked for the species of calcareous arable farmland.

Table 1. Changes in Dutch arable flora over the period 1940-1990 (*cf.* Plate *et al.*, 1992). Percentage of species in decline, remaining constant and on the increase, on the basis of quadrant frequency classes

	decline	constant	increase
nutrient-rich fields (46 species)	7%	57%	37%
moderately nutrient-rich fields			
- calcareous fields (31 species)	74%	26%	0
- non-calcareous fields (37 species)	38%	46%	16%

In other European countries, too, such as Germany and England, the composition of arable flora has undergone a pronounced change in this period (Eggers, 1984a, 1984b; Wilson, 1993). This change is linked to a transition to new cropping patterns and an intensification of seed cleaning, soil tillage, fertilizer regimes and weed control (Plate, 1990; Schumacher, 1984; Eggers, 1984b). At the individual field level, most arable farmland species are found in the outer few metres of the crop (Hald *et al.*, 1988; Marshall, 1989; Wilson, 1989, 1993). By leaving the crop edge unsprayed with herbicides, farmland plant presence (cover and species diversity) can be greatly enhanced (Schumacher, 1984; Sotherton *et al.*, 1985; Hald *et al.*, 1988; 1994; Vieting, 1988; Smeding & Joenje, 1990; Chiverton & Sotherton, 1991; Storck-Weyhermüller & Welling, 1991; Wilson, 1993; Chiverton, 1994; Helenius 1994). This measure results, moreover, in a major reduction in drift deposition of pesticides on neighbouring biotopes such as hedgerows and ditches (Cuthbertson & Jepson, 1988; De Snoo, 1994a). Until now, studies on the arable flora of unsprayed crop edges have focused mainly on cereal production on light soils. In addition to cereal crops, the present study also considers unsprayed edges in potato and sugar beet crops on clay soils. The presence of farmland plants in the unsprayed edges has been compared with that in the sprayed edges and in the sprayed field centre. Consideration is given to the significance of unsprayed crop edges for biological diversity and the potential compatibility with farm management.

Materials and methods

Research area and spraying regime

The study was carried out in the Haarlemmermeerpolder from 1990 to 1994. In this polder, reclaimed about 150 years ago, most parcels are 1000 m long and 200 m wide and are bordered by ditches. Ditch bank vegetation consists mainly of perennial grasses such as *Elymus repens* and *Festuca rubra*. Two or three times a year ditch banks are mown or chopped, and the swath left lying. The most common rotation on the farms is: winter wheat followed by potatoes and a second winter wheat crop and finally sugar beet. The soil characteristics are given in Table 2. Along the field edges strips measuring 3 m wide and 100 m long and bordering on the ditches were not sprayed with herbicides and insecticides. Spraying of fungicides was allowed. Conventional fertilizing and tillage regimes were maintained in the fields studied (see Table 2). The unsprayed edges were compared with sprayed edges in the same field and with the sprayed centre of the field. In 1990 research was carried out in 6 fields each of sugar beet, potatoes and winter wheat, in 1991 in 8 sugar beet fields, 5 potato fields and 7 winter wheat fields, in 1992 in 7 potato fields and 7 winter wheat fields and in 1993, finally, in 5 winter wheat fields. In principle, these unsprayed edges had the same location over the years, with the crops rotating. In practice, though, this regime could not be strictly maintained, owing to changes in farmers' rotation schemes and the discontinuation of the experiment in sugar beet following excessive weed growth. In 1992 and 1993 also 6-metre wide unsprayed edges were also created in winter wheat in 10 and 9 fields, respectively. In total 15 farms participated in the experiment.

Table 2. Soil and nitrogen fertilizer data of the arable farms investigated in the Haarlemmermeerpolder, 1990-1993

Soil data (13 farms):		
- percentage of silt (0-16 μm diam.)		24.1 ± 9.1
- percentage of organic matter		2.7 ± 11.0
- percentage of lime		2.7 ± 2.2
- Pw index	(mg P_2O_5/l soil)	52.4 ± 15.6.
- K HCl	(mg K_2O_5/100 g dry soil)	15.2 ± 3.5
- pH		7.4 ± 0.3
Average nitrogen fertilizer input (in kg N):		
- sugar beet	(9 fields)	137.6 ± 22.3
- potatoes	(12 fields)	231.8 ± 60.5
- winter wheat	(28 fields)	173.0 ± 33.5

Table 3. Pesticides most frequently used in 1990-1993 in the sprayed edges of the various crops (sugar beet: 10 fields; potatoes: 13 fields; winter wheat: 27 fields)

	herbicides	insecticides	fungicides
sugar beet	ethofumesate	oxydemeton-methyl	-
	phenmedipham	pirimicarb	
	metamitron		
potatoes	metribuzin	parathion	maneb
		dimethoate	
winter wheat	MCPA	dimethoate	prochloraz
	metsulfuron-methyl		triadimenol
	fluroxypyr		propiconazole
	mecoprop		anilazin
	bentazone		

There were differences in the spraying regime on the farms involved, in terms of active ingredient, spraying time and frequency, for example. However, in winter wheat farmers generally use herbicides twice, once in April and once in May. Insecticides are used once or twice in June against aphids and a mixture of fungicides mostly in June against diseases causing premature senescence. In this crop a growth-regulator (CCC) is also generally applied. In sugar beet there are generally three herbicide sprayings (down the rows), from the end of March until mid-May, and one to three insecticide sprayings from April to July. Between the rows, weeds are also controlled with a mechanical grubber as well as by hand. In sugar beet no fungicides are used. In potatoes, finally, there is usually one herbicide spraying about mid-May, two insecticide sprayings in May and June, and about ten or eleven fungicide sprayings from the end of May until harvest, in September. The pesticides most frequently used on the various crops are summarized in Table 3.

Relevés

The effects on the flora were analysed using the Braun-Blanquêt method (*cf.* Barkman *et al.*, 1964), with both the presence and the abundance (in 9 classes) of arable farmland species being determined. The total cover as well as the maximum height of the plants were also established. While conducting these relevés, the impact on the sown crop (crop cover and average crop height) and on the occurrence of volunteer crop plants were also investigated. The relevés were carried out in an unsprayed margin, in a reference margin and in the centre of the field; each strip investigated was 75 m^2 (50 m long and 1.5 m wide). In the crop edge inventory, the strip was parallel to a ditch, at a distance of 0.75 m from the field edge. The relevés were conducted in the period mid June to mid July. In processing the results at the individual species level, it was decided for statistical reasons to apply a statistical test only if the species in question was found in at least 7 fields. In the fields where the species was found, the difference in cover between the sprayed and unsprayed strips was also determined. In 14 sugar beet and 18 potato fields, the biomass of the farmland plants was also measured at harvest (September), with the dry weight being determined over an area of at least 9 m^2 in the sugar beet strips and at least 12 m^2 in the potato strips. The biomass of the plants in winter wheat was not investigated.

To assess the floristic significance of the inventoried plants, species with a specific conservation value: species occurring on the Dutch 'Red List' (*cf.* Weeda *et al.*, 1990) were assessed. In addition, use was made of a quantitative yardstick used by the Zuid-Holland provincial authorities to assess the floristic importance of a given vegetation (*cf.* Clausman & Van Wijngaarden, 1984). This yardstick is based on the presence of individual species, with an integral value (IV) being assigned on the basis of regional (Zuid-Holland province), national and worldwide rarity, including the population trend of the species in question. Subsequently, this integral value was used together with the cover of the species, as determined in the relevé, to calculate the floristic significance of the vegetation (including Red List species) with the aid of the following formula (*cf.* Clausman & Van Wijngaarden, 1984):

$$\text{floristic valuation of the vegetation} = \Sigma i_{10} \left(IV \frac{\text{species i}}{10} \right) x \frac{1}{1 - \log 10 \text{ cover}}$$

Because the Haarlemmermeerpolder, although being part of the province of Noord-Holland, is bordering directly on the province of Zuid-Holland, it was assumed that the regional rarity of species in that province is also valid for this area.

In elaborating the results, no consideration has been given to the temporal aspect of the individual strips, for statistical testing showed that there was no difference in cover or in arable plant species diversity in strips that had been left unsprayed for one or for several years ($P > 0.05$, Mann-Whitney U-test).

Results

Total cover, biomass and height of farmland species

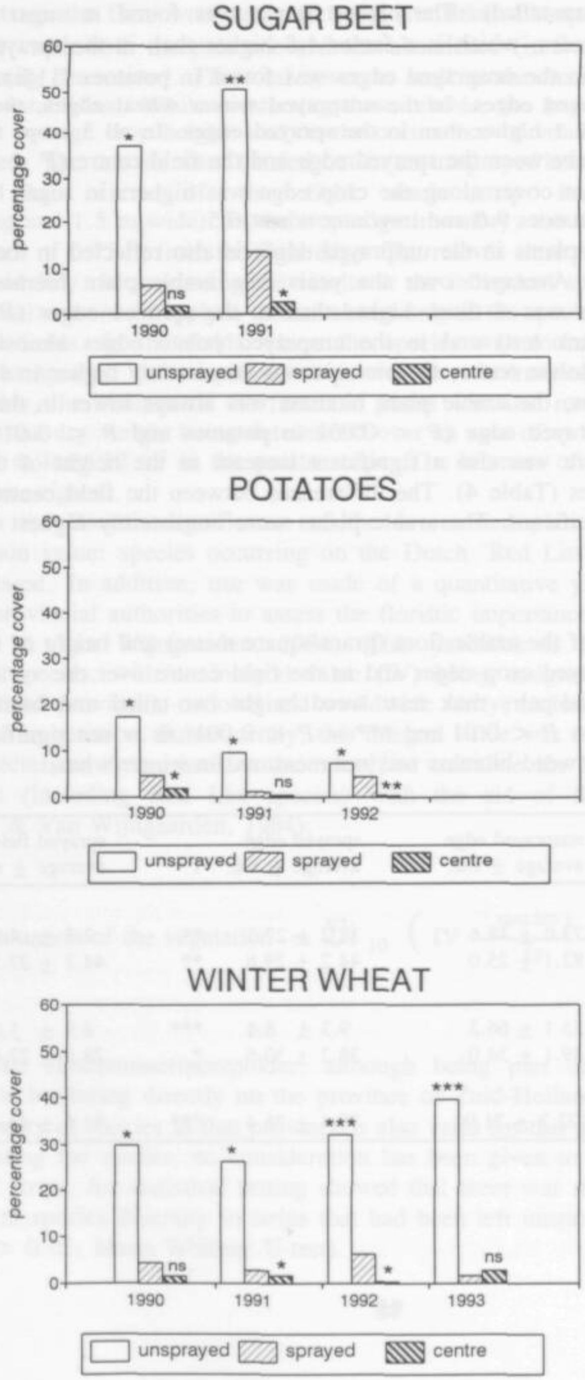
As can be seen in Figure 1, in all three crops the cover of farmland plants in the unsprayed edges was far higher than in the sprayed edges ($P < 0.001$, Wilcoxon matched-pairs rank test, one-tailed). The highest cover was found in sugar beet: an average of 44% over the years, which is a factor 4.8 higher than in the sprayed edges. The lowest average cover in the unsprayed edges was found in potatoes (11%), a factor 4.9 higher than in the sprayed edges. In the unsprayed winter wheat edges, the average cover was 32%, a factor 12.1 higher than in the sprayed edges. In all 3 crops there was also a significant difference between the sprayed edge and the field centre ($P < 0.01$). In each case the farmland plant cover along the crop edge was higher: in sugar beet by a factor 4.3 on average, in potatoes 9.0 and in winter wheat 6.5.

The higher cover of arable plants in the unsprayed edges is also reflected in the biomass of these plants (Table 4). Averaged over the years, the arable plant biomass in the unsprayed sugar beet edges was 4 times higher than in the sprayed edges ($P < 0.01$ Wilcoxon matched-pairs rank test) and in the unsprayed potato edges almost 6 times higher ($P < 0.001$). In absolute terms, the biomass was consistently higher in sugar beet edges. For both these crops, the arable plant biomass was always lower in the sprayed field centre than in the sprayed edge ($P < 0.001$ in potatoes and $P < 0.01$ in sugar beet). For all 3 crops, there was also a significant increase in the height of the arable flora in the unsprayed edges (Table 4). The differences between the field centre and the sprayed edge were not significant. The arable plants were consistently highest in winter wheat.

Table 4. Average biomass of the arable flora (gram/square metre) and height of the plants (cm) in unsprayed and sprayed crop edges and in the field centre over the various years of study. Wilcoxon matched-pairs rank test: weed height two-tailed and biomass one-tailed. * = $P < 0.05$, ** = $P < 0.01$ and *** = $P < 0.001$. ns = not significant. s.d. = standard deviation. N.B. weed biomass was not measured in winter wheat

	no. of fields	unsprayed edge average ± s.d.	sprayed edge average ± s.d.	T	sprayed field centre average ± s.d.	T
Sugar beet						
- biomass	10	73.0 ± 48.6	18.2 ± 27.2	**	2.5 ± 4.9	**
- height	12	82.1 ± 25.0	44.2 ± 29.6	**	44.2 ± 27.5	ns
Potatoes						
- biomass	18	53.1 ± 66.5	9.3 ± 8.4	***	0.9 ± 1.0	***
- height	11	49.1 ± 34.0	38.2 ± 30.6	*	28.6 ± 22.0	ns
Winter wheat						
- height	25	102.2 ± 21.9	70.4 ± 36.4	***	51.6 ± 44.4	ns

Figure 1. Average cover of the arable flora per relevé per year in sugar beet, potatoes and winter wheat in the unsprayed edges, sprayed edges and sprayed field centre. Wilcoxon matched-pairs rank test, unsprayed edge versus sprayed edge and centre versus sprayed edge: ns = not significant, * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$



Plant diversity

The average number of species is given in Figure 2. As this figure shows, each year, and for each crop, the number of species of arable land was significantly higher in the unsprayed edges than in the sprayed edges (Wilcoxon matched-pairs rank test, one-tailed): in sugar beet by a factor 1.5, averaged over the years, in potatoes by a factor 2.0 and in winter wheat by a factor 2.7. These differences are due mainly to an increase in the number of dicotyledonous arable species (significant in all crops, each year). The difference between the number of monocotyledons (including *Equisetum arvense*) in the unsprayed and sprayed edges is far smaller and was not significant in sugar beet or potatoes in 1990, nor in winter wheat in 1991 or 1993. Comparison of the sprayed edge with the field centre shows that the total number of arable species along the edges was always significantly higher than in the field centre (by factors of 1.6 in sugar beet, 2.1 in potatoes and 2.7 in winter wheat); the only exception was for potatoes, in 1991. These differences held both for dicotyledons (significantly higher each year and in each crop, except in potatoes in 1991) and for monocotyledons (although no significant difference in potatoes in 1992 nor in winter wheat in 1992 or 1993). Moreover, as Figure 2 shows, the average number of species in the various crops was relatively constant over the years. Surprisingly, however, in 1992 there were generally fewer species both in potatoes and in winter wheat. The fact that many species were found in sugar beet in 1991 may be due to the fact that in two of the eight fields inter-row mechanical grubbing was not carried out satisfactorily.

Presence and abundance of individual farmland species

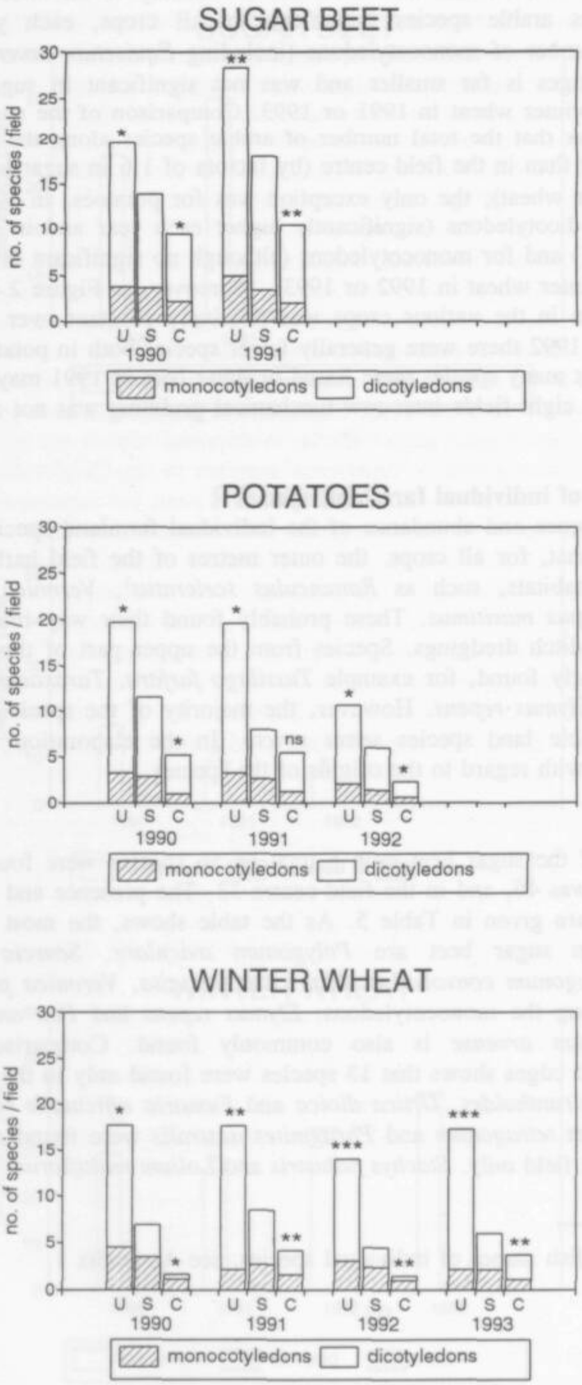
Before discussing the presence and abundance of the individual farmland species in each crop, it should be noted that, for all crops, the outer metres of the field harbour many pioneer species of wet habitats, such as *Ranunculus sceleratus*[1], *Veronica catenata*, *Glyceria fluitans* and *Scirpus maritimus*. These probably found their way into the crop edge via the dumping of ditch dredgings. Species from the upper part of the bordering ditch bank are also regularly found, for example *Tussilago farfara*, *Taraxacum vulgare*, *Plantago lanceolata* and *Elymus repens*. However, the majority of the species occurring in the crop edge are arable land species *sensu stricto*. In the elaboration below, no distinction has been made with regard to the origins of the species.

Sugar beet

In the unsprayed edges of the sugar beet crop a total of 56 species were found. In the sprayed edges this figure was 46, and in the field centre 33. The presence and abundance of the individual species are given in Table 5. As the table shows, the most frequently occurring dicotyledons in sugar beet are *Polygonum aviculare*, *Senecio vulgaris*, *Chenopodium album*, *Polygonum convolvulus*, *Matricaria recutita*, *Veronica persica* and *Lamium purpureum*. Among the monocotyledons, *Elymus repens* and *Poa annua* occur most frequently. *Equisetum arvense* is also commonly found. Comparison of the unsprayed with the sprayed edges shows that 13 species were found only in the unsprayed edges, with *Erysimum cheiranthoides*, *Urtica dioica* and *Fumaria officinalis* being found in several fields. *Epilobium tetragonum* and *Phragmites australis* were found only in the sprayed edges, both in one field only. *Stachys palustris* and *Lolium multiflorum* were

[1] For the English names of individual species, see Appendix 1.

Figure 2. Average number of species per relevé per year in sugar beet, potatoes and winter wheat in the unsprayed edges, sprayed edges and sprayed field centre. A distinction is made between dicotyledons and monocotyledons, the latter including *Equisetum arvense*. Legend see Figure 1



found exclusively in the field centre and not along the edges. In addition of the species being statistically tested (those occurring in more than 7 of the 14 fields) 5 were found significantly more often in the unsprayed edges, namely *Chenopodium ficifolium*, *Capsella bursa-pastoris*, *Euphorbia helioscopia*, *Cirsium arvense* and *Stellaria media*. Comparison of the sprayed edge with the field centre shows that *Polygonum convolvulus*, *Galium aparine*, *Sonchus arvensis*, *Veronica persica*, *Thlaspi arvense*, *Equisetum arvense* and *Elymus repens* are found more frequently along the edge. In the unsprayed edges, *Thlaspi arvense*, *Chenopodium album*, *Senecio vulgaris*, *Chenopodium ficifolium* and *Matricaria recutita* had the greatest cover. Of the species statistically tested, 17 had a significantly higher cover; of these, only 1 was a monocotyledon (*Poa annua*). For 11 species, the cover in the sprayed edges was higher than in the field centre. In the field centre, *Galium aparine* had a relatively high cover.

Potatoes

In potatoes (Table 6) a total of 43 species was found in the unsprayed edges. In the sprayed edges this figure was 37 and in the field centre 26. The species most frequently found were *Senecio vulgaris*, *Solanum nigrum nigrum*, *Polygonum convolvulus*, *Equisetum arvense* and *Elymus repens*. Nine species were found exclusively in the unsprayed edges; of these *Ranunculus sceleratus*, *Coronopus squamatus*, *Anagallis arvensis arvenis*, *Fumaria officinalis*, *Lamium amplexicaule* and *Matricaria discoidea* were found in more than one field. Three species were found only in the sprayed edges, namely *Alisma plantago-aquatica*, *Agrostis stolonifera* and *Viola arvensis*, all in one field. Three species were found only in the field centre (once each), namely *Stachys palustris*, *Trifolium dubium* and *Daucus carota*. Statistical testing showed that, of the species investigated, 11 were found significantly more often in the unsprayed edges. Three species were found more often in the sprayed edges than in the field centre. In the unsprayed edges *Senecio vulgaris*, *Equisetum arvense*, *Polygonum lapatifolium* and *Sonchus arvensis* had the highest cover. Of the species tested, 17 scored a significantly higher cover: 16 dicotyledons and *Poa annua*. In the sprayed edges the cover of *Senecio vulgaris*, *Equisetum arvense* and *Elymus repens* was significantly higher than in the field centre. Among the species found in the field centre, *Polygonum convolvulus* and *Galium aparine* had the highest cover.

Winter wheat

In winter wheat (Table 7) 70 species were found in the unsprayed edges, 39 in the sprayed edges and 29 in the field centre. The following species were frequently found: *Matricaria recutita*, *Polygonum aviculare*, *Polygonum convolvulus*, *Galium aparine*, *Equisetum arvense* and *Poa annua*. Thirty species were found only in the unsprayed edges and not in the sprayed edges. Of these, 17 were found in more than 1 field, namely *Epilobium parviflorum*, *Ranunculus sceleratus*, *Matricaria discoidea*, *Myosotis arvensis*, *Epilobium tetragonum*, *Sinapis arvensis*, *Sonchus asper*, *Epilobium hirsutum*, *Urtica urens*, *Sisymbrium officinale*, *Erysimum cheiranthoides*, *Veronica catenata*, *Geranium dissectum*, *Atriplex patula* and *Avena fatua*. Two monocotyledons, *Glyceria fluitans* and *Bromus sterilis*, were found only in the sprayed edges. Of the species occurring in at least 7 fields, 23 were found significantly more often in the unsprayed edges. Except for *Poa trivialis*, these were all dicotyledons. Comparison of the sprayed edges with the field centre shows that 4 species are found significantly more often in the sprayed edges,

Table 5. Presence and abundance of farmland flowers in sugar beet in 1990 and 1991 (total of 14 fields). Tests: frequency: Wilcoxon sign one-tailed, cover: Wilcoxon ranks one-tailed, ns = not significant, * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$. Species present at less than 7 fields not tested. u = unsprayed, s = sprayed and c = centre of the field

	frequency			test		cover						test	
	u	s	c	u/s	s/c	unsprayed x	sd.	sprayed x	sd.	centre x	sd.	u/s	s/c
DICOTYLEDONS													
Polygonum aviculare	14	13	11	ns	ns	2.14	± 5.20	0.21	± 0.11	0.12	± 0.11	*	*
Senecio vulgaris	14	11	11	ns	ns	5.91	± 9.74	2.91	± 5.40	0.20	± 0.26	*	**
Chenopodium album	14	11	9	ns	ns	6.19	±11.19	0.18	± 0.13	0.14	± 0.13	**	ns
Polygonum convolvulus	13	14	9	ns	*	4.64	± 6.80	0.27	± 0.07	0.19	± 0.15	*	*
Lamium purpureum	12	10	6	ns	ns	1.44	± 3.00	0.13	± 0.12	0.15	± 0.27	**	ns
Galium aparine	12	10	4	ns	*	1.97	± 3.54	1.34	± 3.03	1.24	± 3.08	ns	ns
Matricaria recutita	12	9	9	ns	ns	5.24	±10.04	0.16	± 0.14	0.11	± 0.11	**	*
Sonchus oleraceus	12	8	1	ns	*	0.21	± 0.25	0.11	± 0.13	0.01	± 0.03	ns	**
Veronica persica	11	12	5	ns	*	0.84	± 2.22	0.20	± 0.12	0.08	± 0.13	ns	*
Thlaspi arvense	11	7	1	ns	*	8.78	±15.72	2.09	± 5.23	0.01	± 0.03	*	**
Chenopodium ficifolium	11	4	4	*	ns	5.81	±16.59	0.07	± 0.13	0.06	± 0.11	**	ns
Capsella bursa-pastoris	11	3	5	**	ns	3.44	±10.05	0.04	± 0.08	0.05	± 0.09	**	ns
Euphorbia helioscopia	10	5	5	*		0.27	± 0.33	0.09	± 0.14	0.09	± 0.14	**	
Sonchus arvensis	9	6	1	ns	ns	3.41	± 6.76	0.10	± 0.14	0.01	± 0.03	*	*
Cirsium arvense	9	4	5	*		2.02	± 5.24	0.67	± 2.26	0.06	± 0.11	**	
Sonchus asper	9	4		ns		0.71	± 2.25	0.03	± 0.05			*	
Stellaria media	9	1	1	**		1.31	± 3.05	0.01	± 0.03	0.01	± 0.03	**	
Polygonum persica	8	4	3	ns		0.11	± 0.13	0.04	± 0.09	0.02	± 0.04	ns	
Veronica hederifolia	7	4	1	ns		0.09	± 0.12	0.06	± 0.11	0.01	± 0.03	*	
Polygonum lapathifolium	7	3	6	ns		3.39	±10.07	0.05	± 0.11	0.04	± 0.05	*	
Solanum nigrum nigrum	6	7	6	ns	ns	0.07	± 0.11	0.14	± 0.15	0.10	± 0.14	ns	ns
Matricaria discoidea	6	1				0.07	± 0.11	0.01	± 0.03				
Ranunculus sceleratus	5	6	1	ns	ns	0.06	± 0.11	0.06	± 0.09	0.01	± 0.03	ns	*
Lamium amplexicaule	5	3	1			0.08	± 0.13	0.02	± 0.04	0.01	± 0.03		
Anagallis arv. arvensis	5		1			0.06	± 0.11			0.01	± 0.03		
Erysimum cheiranthoides	5					0.05	± 0.09						
Atriplex patula	4	1				0.03	± 0.05	0.01	± 0.03				
Coronopus squamatus	3	2	1			0.04	± 0.08	0.03	± 0.08	0.01	± 0.03		
Tussilago farfara	3	2				0.65	± 2.26	0.03	± 0.08				
Urtica dioica	3					0.05	± 0.11						
Cardamine hirsuta	2	2				0.03	± 0.08	0.03	± 0.08				
Geranium molle	2	2				0.01	± 0.04	0.03	± 0.08				
Sinapis arvensis	2	2				0.61	± 2.27	0.01	± 0.04				
Myosotis arvensis	2	1				0.03	± 0.08	0.01	± 0.03				
Fumaria officinalis	2					0.01	± 0.04						
Rubus fruticosus	1	2				0.01	± 0.03	0.01	± 0.04				
Lapsana communis	1	1	1			0.01	± 0.03	0.01	± 0.03	0.01	± 0.03		
Plantago lanceolata	1	1				0.01	± 0.03	0.01	± 0.03				
Alisma plantago-aquatia	1					0.01	± 0.03						
Chenopodium rubrum	1					0.02	± 0.08						
Papaver dubium	1					0.01	± 0.03						
Ranunculus repens	1					0.01	± 0.03						
Stachys arvensis	1					0.01	± 0.03						
Trifolium dubium	1					0.01	± 0.03						
Vicia cracca	1					0.02	± 0.08						
Taraxacum vulgare		1	1					0.01	± 0.03	0.02	± 0.08		
Epilobium tetragonum		1						0.01	± 0.03				
Stachys palustris			2							0.04	± 0.11		
MONOCOTYLEDONS													
Equisetum arvense	14	13	6	ns	*	0.36	± 0.28	0.85	± 2.22	0.09	± 0.12	ns	*
Elymus repens	12	12	6	ns	*	1.41	± 3.00	0.81	± 2.22	0.09	± 0.12	ns	**
Poa annua.	11	7	7	ns	ns	0.22	± 0.13	0.11	± 0.13	0.09	± 0.12	**	ns
Agrostis stolonifera	7	4		ns		0.11	± 0.13	0.07	± 0.13			ns	
Glyceria fluitans	5	1				0.04	± 0.05	0.01	± 0.03				
Lolium perenne	4	2	6			0.06	± 0.11	0.03	± 0.08	0.10	± 0.14		
Alopecurus myosuroides	3	2	3			0.10	± 0.27	0.04	± 0.11	0.06	± 0.13		
Poa trivialis	3	2				0.04	± 0.08	0.01	± 0.04				
Scirpus maritimus	2	5				0.01	± 0.04	0.05	± 0.09				
Avena fatua	1					0.01	± 0.03						
Typha latifolia	1					0.01	± 0.03						
Phragmites australis		1						0.01	± 0.03				
Lolium multiflorum			1							0.01	± 0.03		

Table 6. Presence and abundance of farmland flowers in potatoes in 1991 and 1992 (total of 18 fields). Legend see Table 5

	frequency			test		cover			test	
	u	s	c	u/s	s/c	unsprayed	sprayed	centre	u/s	s/c
						x ± sd	x ± sd	x ± sd		
DICOTYLEDONS										
Senecio vulgaris	15	14	5	ns	**	2.25 ± 4.52	0.69 ± 0.93	0.05 ± 0.10	*	**
Solanum nigrum nigrum	14	7	8	*	ns	0.22 ± 0.23	0.11 ± 0.24	0.07 ± 0.10	*	ns
Polygonum convolvulus	13	12	7	ns	ns	0.89 ± 2.03	0.31 ± 0.69	0.55 ± 1.99	*	ns
Sonchus oleraceus	12	5	2	*		0.19 ± 0.24	0.06 ± 0.11	0.01 ± 0.03	*	
Chenopodium album	12	3	3	**		0.81 ± 2.04	0.07 ± 0.13	0.04 ± 0.10	**	
Thlaspi arvense	12	3	3	**		0.92 ± 2.11	0.04 ± 0.10	0.03 ± 0.08	**	
Capsella bursa-pastoris	12	2	1	**		0.22 ± 0.31	0.02 ± 0.07	0.01 ± 0.02	***	
Chenopodium ficifolium	12	2		**		0.32 ± 0.71	0.03 ± 0.10		*	
Polygonum aviculare	11	5	4	*		0.11 ± 0.12	0.05 ± 0.10	0.02 ± 0.04	*	
Euphorbia helioscopia	10	7	1	ns		0.30 ± 0.40	0.07 ± 0.11	0.01 ± 0.02	**	
Veronica persica	10	5	1	*		0.57 ± 1.98	0.05 ± 0.10	0.01 ± 0.02	**	
Galium aparine	9	7	3	ns		0.64 ± 1.99	0.69 ± 2.07	0.51 ± 2.00	ns	
Sonchus arvensis	9	5	3	ns		1.04 ± 2.72	0.06 ± 0.11	0.03 ± 0.08	*	
Cirsium arvense	8	6	2			0.11 ± 0.14	0.52 ± 1.99	0.02 ± 0.07		
Lamium purpureum	7	4	7	ns	ns	0.08 ± 0.12	0.03 ± 0.08	0.08 ± 0.12	ns	ns
Polygonum lapathifolium	7	4	2	ns		1.09 ± 4.35	0.03 ± 0.08	0.02 ± 0.07	*	
Matricaria recutitia	7	3	1	ns		0.24 ± 0.70	0.03 ± 0.08	0.02 ± 0.07	*	
Lapsana communis	7	2				0.07 ± 0.11	0.02 ± 0.07			
Stellaria media	7	1	1	*		0.08 ± 0.12	0.01 ± 0.02	0.01 ± 0.02	*	
Polygonum persica	7	1		*		0.54 ± 1.99	0.02 ± 0.07		*	
Ranunculus sceleratus	5					0.04 ± 0.08				
Sinapis arvensis	4	2	1			0.03 ± 0.08	0.02 ± 0.07	0.01 ± 0.02		
Veronica hederifolia	4	2				0.04 ± 0.10	0.02 ± 0.07			
Tussilago farfara	3	2				0.49 ± 2.00	0.02 ± 0.07			
Cardamine hirsuta	3	1				0.02 ± 0.04	0.01 ± 0.02			
Sonchus asper	3	1				0.02 ± 0.04	0.01 ± 0.02			
Anagallis arv. arvensis	3					0.04 ± 0.10				
Coronopus squamatus	3					0.02 ± 0.04				
Taraxacum vulgare	2	1				0.01 ± 0.03	0.01 ± 0.02			
Fumaria officinalis	2					0.01 ± 0.03				
Lamium amplexicaule	2					0.01 ± 0.03				
Matricaria discoidea	2					0.01 ± 0.03				
Geranium molle	1	2				0.02 ± 0.07	0.01 ± 0.03			
Atriplex patula	1					0.01 ± 0.02				
Myosotis arvensis	1					0.01 ± 0.02				
Alisma plantago-aquatica		1					0.01 ± 0.02			
Viola arvensis		1					0.01 ± 0.02			
Daucus carota			1					0.01 ± 0.02		
Trifolium dubium			1					0.01 ± 0.02		
Stachys palustris			1					0.02 ± 0.07		
MONOCOTYLEDONS										
Equisetum arvense	17	16	8	ns	*	1.91 ± 4.56	1.45 ± 2.59	0.09 ± 0.12	ns	***
Elymus repens	14	12	4	ns	*	0.63 ± 1.97	0.21 ± 0.31	0.04 ± 0.10	ns	*
Poa annua	9	3	2	*		0.12 ± 0.14	0.02 ± 0.04	0.02 ± 0.07	**	
Scirpus maritimus	3	3				0.05 ± 0.12	0.04 ± 0.10			
Lolium perenne	2	2	1			0.03 ± 0.10	0.01 ± 0.03	0.02 ± 0.07		
Phragmites australis	2	1				0.02 ± 0.07	0.02 ± 0.07			
Avena fatua	1	1	1			0.01 ± 0.02	0.02 ± 0.07	0.01 ± 0.02		
Alopecurus myosuroides	1					0.01 ± 0.2				
Agrostis stolonifera		1					0.01 ± 0.02			

Table 7. Presence and abundance of farmland flowers in winter wheat in 1990, 1991, 1992 and 1993 (total of 35 fields). Legend see Table 5

	frequency			test		cover						test
	u	s	c	u/s	s/c	unsprayed x	sd	sprayed x	sd	centre x	sd	u/s
DICOTHYLEDONS												
Polygonum convolvulus	32	18	11	***	*	3.59	± 7.44	0.15	± 0.20	0.36	± 1.50	***
Polygonum aviculare	32	13	7	***		1.42	± 3.44	0.08	± 0.12	0.06	± 0.18	***
Matricaria recutitia	32	11	5	***		14.87	±20.71	0.31	± 1.43	0.29	± 1.44	***
Galium aparine	28	15	2	**		3.39	± 6.08	0.13	± 0.20	0.02	± 0.07	***
Senecio vulgaris	24	5	2	***		0.24	± 0.50	0.02	± 0.06	0.01	± 0.05	***
Capsella bursa-pastoris	24	5	1	***		1.09	± 3.46	0.03	± 0.07	0.01	± 0.05	***
Veronica persica	21	8	4	**		0.23	± 0.52	0.03	± 0.08	0.01	± 0.03	**
Sonchus arvensis	21	4	1	***		0.79	± 2.29	0.03	± 0.09	0.00	± 0.02	***
Stellaria media	21	2	4	***		0.37	± 1.37	0.01	± 0.05	0.02	± 0.07	***
Sonchus oleraceus	20	2		***		0.81	± 3.25	0.01	± 0.05			***
Thlaspi arvense	20	1	1	***		0.20	± 0.50	0.00	± 0.02	0.00	± 0.02	***
Chenopodium album	17	2	2	***		0.55	± 1.91	0.02	± 0.07	0.01	± 0.02	**
Cirsium arvense	14	6	3	**	ns	0.09	± 0.14	0.03	± 0.08	0.01	± 0.03	**
Euphorbia helioscopia	14	6		*		0.12	± 0.24	0.03	± 0.08			**
Lamium purpureum	14	3	5	**		0.10	± 0.19	0.01	± 0.03	0.01	± 0.04	***
Polygonum lapathifolium	11	3	4	*		0.61	± 3.02	0.01	± 0.03	0.26	± 1.44	**
Epilobium parviflorum	11			**		0.07	± 0.18					**
Ranunculus sceleratus	10			**		0.04	± 0.09					**
Veronica hederifolia	8	10	3	ns		0.06	± 0.18	0.08	± 0.13	0.02	± 0.07	ns
Tussilago farfara	7	4		ns		0.04	± 0.09	0.26	± 1.44			ns
Anagallis arv. arvensis	7		1	*		0.03	± 0.07			0.00	± 0.02	**
Lamium amplexicaule	7		1	*		0.03	± 0.08			0.01	± 0.05	**
Matricaria discoidea	7			*		0.03	± 0.07					**
Myosotis arvensis	7			*		0.02	± 0.04					**
Epilobium tetragonum	6					0.10	± 0.49					
Solanum nigrum nigrum	4	2	2			0.02	± 0.05	0.01	± 0.05	0.01	± 0.05	
Lapsana communis	4	2				0.02	± 0.05	0.01	± 0.05			
Fumaria officinalis	4	1	1			0.01	± 0.03	0.00	± 0.02	0.01	± 0.05	
Polygonum persicaria	4	1	1			0.04	± 0.07	0.00	± 0.02	0.00	± 0.02	
Sinapis arvensis	4					0.01	± 0.03					
Geranium molle	3	1	1			0.02	± 0.07	0.00	± 0.02	0.00	± 0.02	
Ranunculus repens	3	1	1			0.01	± 0.03	0.01	± 0.05	0.01	± 0.05	
Papaver dubium	3	1				0.01	± 0.05	0.00	± 0.02			
Epilobium hirsutum	3					0.03	± 0.16					
Sonchus asper	3					0.02	± 0.07					
Urtica urens	3					0.01	± 0.05					
Cardamine hirsuta	2	1				0.01	± 0.05	0.00	± 0.02			
Atriplex patula	2					0.01	± 0.02					
Erysimum cheiranthoides	2					0.02	± 0.07					
Geranium dissectum	2					0.01	± 0.02					
Sisybrium officinale	2					0.01	± 0.02					
Veronica catenata	2					0.01	± 0.02					
Chenopodium ficifolium	1	1				0.01	± 0.05	0.00	± 0.02			
Veronica arvensis	1		1			0.00	± 0.02			0.01	± 0.05	
Achillea millefolium	1					0.00	± 0.02					
Barbara vulgaris	1					0.00	± 0.02					
Cerastium font. vulgare	1					0.00	± 0.02					
Coronopus squamatus	1					0.00	± 0.02					
Crepis capillaris	1					0.00	± 0.02					
Erigeron canadensis	1					0.00	± 0.02					
Matricaria maritima	1					0.02	± 0.07					
Medicago lupulina	1					0.00	± 0.02					
Papaver argemone	1					0.01	± 0.05					
Papaver rhoeas	1					0.22	± 1.38					
Rorippa palustris	1					0.00	± 0.02					
Rubus fruticosus	1					0.00	± 0.02					
Rumex obtusifolius	1					0.00	± 0.02					
Urtica dioica	1					0.00	± 0.02					
Viola arvensis	1					0.01	± 0.05					
MONOCOTYLEDONS												
Equisetum arvense	26	25	5	ns	***	0.30	± 0.51	0.29	± 0.51	0.02	± 0.07	ns
Poa annua	22	19	17	ns	ns	1.07	± 2.60	0.22	± 0.31	0.81	± 3.16	*
Poa trivialis	17	10	3	*	*	0.69	± 1.98	0.33	± 1.44	0.01	± 0.03	**
Elymus repens	12	13	5	ns	**	0.46	± 1.50	0.47	± 1.56	0.05	± 0.18	ns
Lolium perenne	6	5	7	ns	ns	0.04	± 0.09	0.04	± 0.11	0.04	± 0.09	ns
Lolium multiflorum	5	4				0.03	± 0.08	0.02	± 0.07			
Alopecurus myosuroides	4	4	3			1.08	± 6.09	0.13	± 0.53	0.33	± 1.51	
Avena fatua	2					0.01	± 0.02					
Festuca rubra	1	2				0.00	± 0.02	0.01	± 0.02			
Phragmites australis	1	2				0.00	± 0.02	0.01	± 0.02			
Scirpus maritimus	1	1				0.00	± 0.02	0.00	± 0.02			
Bromus sterilis		1						0.00	± 0.02			
Glyceria fluitans		1						0.00	± 0.02			

namely *Polygonum convolvulus*, *Equisetum arvense*, *Poa trivialis* and *Elymus repens*. In the unsprayed edges *Matricaria recutita* undoubtedly had the highest cover (14.9% on average), although *Alopecurus myosuroides*, *Polygonum convolvulus* and *Galium aparine* also showed high cover in these edges. Of the species tested, 24 (2 monocotyledons) had a significantly higher cover in the unsprayed edges. Compared with the field centre, the cover of *Equisetum arvense*, *Poa trivialis* and *Elymus repens* was significantly higher in the sprayed edge. Among the species found in the field centre, *Poa annua* had a relatively high cover.

Floristic value of the vegetation

Of the species on the Dutch 'Red List', only *Stachys arvensis* was found (once) in an unsprayed sugar beet edge. Figure 3 shows, for the 3 crops, the floristic value of the unsprayed edges, sprayed edges and field centre, based on the yardstick used by the Zuid-Holland provincial authorities (for assignment of floristic scores, see Appendix 1). As the figure shows, in all crops and in each year the floristic value of the unsprayed edges is significantly higher than that of the sprayed edge, with the exception of the sugar beet crop in 1990. On average, this value increases by a factor 5.2 in sugar beet, by a factor 2.8 in potatoes and by a factor 7.2 in winter wheat. The floristic value of the sprayed edges is also generally higher than that of the field centre (on average, by factors of 2.6, 3.6 and 2.0 in sugar beet, potatoes and winter wheat, respectively). There is a surprising degree of variation in the floristic value of the fields from year to year. This variation does not always correspond with the number of species found (Figure 2). The extremely high value scored by the unsprayed sugar beet edges in 1990 is due to *Stachys arvensis*, a 'Red List' species found only once and assigned a very high value (see Appendix 1).

Effects on crop and volunteer crop plants

Table 8 gives the crop cover in the sprayed and unsprayed edges and the field centre. With respect to crop cover, it can be seen that only with sugar beet this parameter was significantly lower than in the unsprayed edges ($P < 0.01$, Wilcoxon matched-pairs rank test, two-tailed). In all three crops, average crop cover seems to be highest in the field centre; however, only in winter wheat was this difference statistically significant ($P < 0.001$).

For all crops, crop height was significantly greater in the field centre than in the sprayed edges (Table 8). For potatoes and sugar beet, crop height in the unsprayed edges was not different from that in the sprayed edges; in winter wheat, however, crop height in the unsprayed edge was significantly greater than in the sprayed edge, owing to the absence of treatment with growth regulators such as CCC (Wilcoxon matched-pairs rank test, two-tailed, $P < 0.01$). In this case, the crop was in fact higher than in the field centre.

It was found that the number of agricultural crops growing spontaneously in the unsprayed edges (volunteer crop plants, e.g. potatoes, wheat and green-manure crops) was not significantly different from that in the sprayed edges ($P > 0.05$, Wilcoxon matched-pairs rank test; see Table 8). The volunteers most frequently found were potatoes, in sugar beet and winter wheat. Their presence was not greater in the unsprayed edges, and the cover of volunteer potatoes was also the same in the 2 types of edge: in sugar beet an average of 0.3% (14 fields) and in winter wheat 0.1% (25 fields).

Figure 3. Floristic value of arable flora per relevé per year in sugar beet, potatoes and winter wheat in the unsprayed edges, sprayed edges and sprayed field centre. Legend see Figure 1

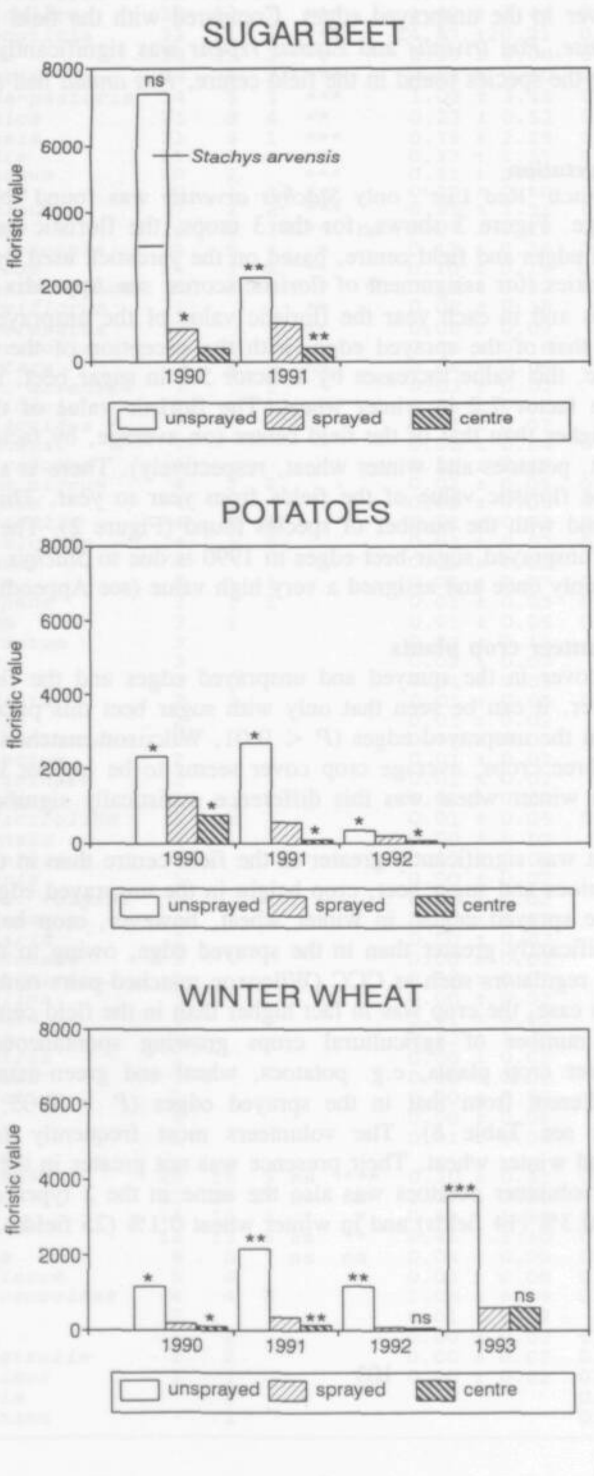


Table 8. Average crop cover (%), crop height (cm) and number of species of volunteer crop plants in unsprayed and sprayed crop edges and field centre over the various years of study. Wilcoxon matched-pairs rank test, two-tailed. * = $P < 0.05$, ** = $P < 0.01$ and *** = $P < 0.001$. ns = not significant. s.d. = standard deviation

	no. of fields	Unsprayed edge average ± s.d.	Sprayed edge average ± s.d.	T	Field centre average ± s.d.	T
Sugar beet						
- crop cover	14	46.8 ± 19.8	56.1 ± 18.1	**	61.4 ± 21.1	ns
- crop height	12	37.1 ± 11.0	37.9 ± 10.5	ns	42.5 ± 13.4	*
- no. of volunteer crop species	14	1.2 ± 0.7	0.9 ± 0.3	ns	1.0 ± 0.4	ns
Potatoes						
- crop cover	14	75.7 ± 14.5	77.1 ± 14.9	ns	82.5 ± 17.2	ns
- crop height	13	50.4 ± 8.0	49.2 ± 8.6	ns	55.0 ± 16.5	*
- no. of volunteer crop species	18	0.1 ± 0.3	0.1 ± 0.3	ns	0.1 ± 0.3	ns
Winter wheat						
- crop cover	30	76.3 ± 13.8	75.3 ± 12.0	ns	82.2 ± 11.2	***
- crop height	32	95.3 ± 20.5	85.9 ± 20.5	**	91.6 ± 21.8	*
- no. of volunteer crop species	35	0.5 ± 0.5	0.5 ± 0.5	ns	0.4 ± 0.5	ns

Discussion

The research results indicate that on Dutch clay soils in the intensively cultivated polder region the occurrence of farmland plants in unsprayed crop edges can be enhanced. In the three crops studied this held true for both the presence and the abundance of the species studied. The increase was particularly pronounced with the dicotyledenous farmland species, while monocotyledon occurrence remains virtually unchanged. The increase in the cover and the number of farmland plants is particularly marked in winter wheat edges. The results found in this crop confirm the data from studies carried out elsewhere in Europe (see introduction). In addition to other field margin projects in the present study also the data for sugar beet and potatoes were presented.

In the study it was found that there was major variation among the fields in the cover of farmland plants on the unsprayed edges. This variation has also been noted in other studies (e.g. Smeding & Joenje, 1990; Storck-Weyhermüller & Welling, 1991: factor 50 to 60). This inter-field variation is probably closely connected with the management regimes of the individual farmers. In this context, the following variables are likely to play a role: crop sowing date, choice of crop variety, sowing density, fertilizer regime, prevailing weather conditions for germination and pesticide use, including dosage and time of application. Field management in earlier years is also important and is reflected in the size and composition of the local seed bank. A final source of variation in the local arable flora is the interaction between the crop edge and the boundary vegetation, including the management of the latter. The frequent occurrence of species from the ditch and ditch banks observed in the present study is an illustration of this process. Despite the major variation in the occurrence of farmland plants, by consistently making a pairwise comparison within a single field, it was possible to draw general conclusions within the framework of this study.

Although (very) rare farmland species have been observed in unsprayed crop edges in some studies (e.g. Schumacher, 1984; Wilson, 1989), in the present study virtually no rare species were found. Nevertheless, the floristic value of the unsprayed edges, as measured with the yardstick employed in this study, certainly increased. In their inventory of unsprayed crop edges on sandy soils in the Netherlands, Joenje en Klein (1994), found virtually common species only. However, the increase in these more common species is of major importance for the occurrence of animal species. For example, the cover of species such as *Matricaria recutita*, *Papaver rhoeas* and *Veronica* spp. has been found to promote the abundance of flower-visiting insects such as hover-flies and butterflies (Moltan & Ruppert, 1988; Dover *et al.*, 1990; Ruppert & Molthan, 1991; De Snoo, 1994a). This enhanced abundance of insects in the edges in its form improves the survival chances of partridges and other birds (Rands, 1985; De Snoo *et al.*, 1994a). In this way the indirect effects of pesticide use, in the form of food shortages at higher trophic levels in agricultural regions, may be mitigated (*cf.* de Snoo *et al.*, 1994b). By leaving crop edges unsprayed, moreover, deleterious effects on the vegetation bordering on the field can be minimized, as has been demonstrated in bioassay studies (*cf.* Marrs *et al.*, 1989; -1991a; 1991b; 1993; Breeze *et al.*, 1992). The field studies carried out by Hald *et al.* (1994) also confirm this tendency for the boundary vegetation after some years along an unsprayed crop edge to show greater species diversity than that adjacent to a sprayed edge.
The compatibility of unsprayed crop edges with farm management is very different in each of the 3 crops investigated. In sugar beet the crop became in many cases overgrown with the arable plant vegetation. Here and there, major harvest losses were measured (about 30% on average) and in this crop unsprayed edges were consequently not economically compatible with farm management (De Snoo, 1994b). In the case of unsprayed potato edges, there is no change in crop cover and the farmland plants do not generally grow higher than the crop. In this crop, harvest losses are very limited (2% on average), making the measures certainly economically compatible. In the unsprayed winter wheat edges, there is sometimes abundant growth of farmland plants. In this crop the average harvest loss is 13%. If the costs and benefits (savings on pesticide use) are weighed up, however, the economic significance of this loss proves to be minimal (De Snoo, 1994b). Interviews with farmers have indicated that despite this greater abundance of weeds and the slightly higher costs, with this particular crop farmers generally show a preference for winter wheat unsprayed edges, instead of potatoes. In such an economically important crop as potatoes, every risk of pests and disease is to be avoided (Van der Meulen *et al.*, in prep.). In summary, then, it can be concluded that leaving crop edges unsprayed as a biological diversity measure offers greatest potential in winter wheat, in terms of both floristic value and practical feasibility.

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References

Barkman, J.J., H. Doing & S. Segal, 1964. Kritische Bemerkungen und Vorschläge zur quantitativen Vegetationsanalyse. Acta Bot. Neerl. 13: 394-419.

Breeze V., G. Thomas & R. Butler, 1992. Use of a model and toxicity data to predict the risks to some wild plant species from drift of four herbicides. Ann. Applied Biology 121: 667-677.

Chiverton, P.A., 1994. Large-scale field trials with conservation headlands in Sweden. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 185-190.

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

Clausman, P.H.M.A. & W. van Wijngaarden, 1984. Het vegetatie-onderzoek van de provincie Zuid-Holland. Deelrapport I: verspreiding en ecologie van wilde planten in Zuid-Holland. Deel A: waarderings-parameters. Provinciale Planologische Dienst Zuid-Holland.

Cuthbertson, P.S. & P.C. Jepson, 1988. Reducing pesticide drift into the hedgerow by inclusion of an unsprayed field margin. Proc. Brighton Crop Protection Conference, Pests and diseases: 747-751.

Dover, J.W., N.W. Sotherton & K. Gobbett, 1990. Reduced pesticide inputs on cereal field margins: the effects on butterfly abundance. Ecological Entomology 15: 17-24.

Eggers, Th., 1984a. Some remarks on endangered weed species in Germany. COLUMA/ EWRS, 7th International Symposium on Weed Biology and Systematics, Paris: 395-402.

Eggers, Th., 1984b. Wandel der Unkrautvegetation der Äcker. Schweiz. Landwirtsch. Forsch. 23 (1/2): 47-61.

Hald, A.B., B.O. Nielsen, L. Samsøe-Petersen, K. Hansen, N. Elmegaard & J. Kjøholt, 1988. Sprøjtefri randzoner i kornmarker. Miljøprojekt nr. 103. Miljøstyrelsen, København. 212 p.

Hald, A.B., H. Pontoppidan, J. Reddersen & H. Elbek-Pedersen, 1994. Sprøjtefri randzoner i saedskiftemarker. Plante- og insektliv samt udbytter: Landsforsøg 1987-1992. Bekaempelsesemiddelforskning fra Miljøstyrelsen nr. 6. Miljøministeriet Miljøstryrelsen, København 157 p.

Helenius, J., 1994. Adoption of conservation headlands to Finnish farming. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 191-196.

Joenje, W. & D. Klein, 1994. Plant distribution across arable field ecotones in the Netherlands. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 323-328.

Marrs, R.H., C.T. Williams, A.J. Frost & R.A. Plant, 1989. Assessment of the effects of herbicide spray drift on a range of plant species of conservation interest. Environmental Pollution 59: 71-86.

Marrs, R.H., A.J. Frost & R.A. Plant, 1991a. Effects of herbicide spray drift on selected species of nature conservation interest: the effects of plant age and surrounding vegetation structure. Environmental Pollution 69: 223-235.

Marrs, R.H., A.J. Frost & R.A. Plant, 1991b. Effect of mecoprop drift on some plant species of conservation interest when grown in standardized mixtures in microcosms. Environmental Pollution 73: 25-42.

Marrs, R.H., A.J. Frost, R.A. Plant & P. Lunnis, 1993. Determination of buffer zones to protect seedlings of non-target plants from the effects of glyphosate spray drift. Agriculture, Ecosystems and Environment 45: 283-293.

Marshall, E.J.P., 1989. Distribution patterns of plants associated with arable field edges. J. Applied Ecology 26: 247-257.

Meijden, R. van der, 1990. Heukels' Flora van Nederland. 21ste druk, Wolters-Noordhoff, Groningen.

Molthan, J. & V. Ruppert, 1988. Zur Bedeutung blühender Wildkrauter in feldrainen und Äckern für blütenbesuchenden Nutzinsekten. Mitt. BBA Land- und Forstwirtschaft Heft 247, 85-99.

Plate, C.L., R. Liefaard & L. van Duuren, 1992. Veranderingen in de Nederlandse flora op basis van de standaardlijst 1990. Gorteria 18 (2): 21-29.

Plate, C.L., 1990. Akkeronkruiden sterk bedreigd! Maandstatistiek Landbouw (CBS) 90/6: 29-34.

Rands, M.R.W., 1985. Pesticide use on cereals and the survival of grey partridge chicks: a field experiment. J. Applied Ecology 22: 49-54.

Ruppert, V. and J. Molthan, 1991. Augmentation of aphid antagonists by field margins rich in flowering plants. Behaviour and impact of Aphidophaga: 243-247.

Schumacher, W., 1984. Gefährdete Ackerwildkräuter können auf ungespritzten Feldrändern erhalten werden. Mitteilungen der LÖLF 9 (1): 14-20.

Smeding, F.W. & W. Joenje, 1990. Onbespoten en onbemeste perceelsranden in graanakkers. In: J.M. Groenendael, W. Joenje & K.V. Sykora: 10 jaar Zonderwijk & V.P.O. Wageningen 129-134.

Snoo, G.R. de, 1994a. Unsprayed field margins in arable land. Med. Fac. Landbouww. Univ. Gent 59 (2b): 549-559.

Snoo, G.R. de, 1994b. Cost-benefits of unsprayed crop edges in winter wheat, sugar beet and potatoes. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 197-201.

Snoo, G.R. de, R.T.J.M. Dobbelstein & S. Koelewijn, 1994a. Effects of unsprayed crop edges on farmland birds. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 221-226.

Snoo, G.R. de, K.J. Canters, F.M.W. de Jong & R. Cuperus, 1994b. Integral hazard assessment of side-effects of pesticides in the Netherlands - a proposal. J. Environmental Toxicology and Chemistry 13 (8): 1331-1340.

Sotherton, N.W., M.R.W. Rands & S.J. Moreby, 1995. Comparison of herbicide treated and untreated headlands for the survival of game and wildlife. British Crop Protection Conference - Weeds 1995: 991-998.

Stace, C.A., 1991. New Flora of the British Isles. Cambridge University Press, Cambridge.

Storck-Weyhermüller, S. & M. Welling, 1991. Regulationsmöglichkeiten von Schad- und Nutzarthropoden im Winterweizen durch Ackerschonstreifen. Mitt. BBA Land- und Forstwirtschaft Berlin-Dahlem, Heft 273.

Vieting, U.K., 1988. Untersuchungen in Hessen über Auswirkung und Bedeutung von Ackerschonstreifen. 1: Konzeption des Projektes und der Botanische Aspect. Mitt. BBA Land- und Forstwirtschaft Berlin-Dahlem, Heft 247: 29-41.

Weeda, E.J., R. van der Meijden & P.A. Bakker, 1990. FLORON-Rode lijst 1990. Gorteria 16: 1-2.

Wilson, P.J., 1989. The distribution of arable weed seedbanks and the implications for the conservation of endangered species and communities. Proc. Brighton Crop Protection Conference - Weeds, 1989: 1081-1086.

Wilson, P.J., 1993. Conserving Britain's cornfield flowers. Brighton Crop Protection Conference - Weeds, 1993: 411-416.

Appendix 1. Arable flora nomenclature (scientific names *cf.* Van der Meijden *et al.*, 1990, English names *cf.* Stace, 1991) with value of individual species according to Clausman *et al.* (1984)

SCIENTIFIC NAME	ENGLISH NAME	VALUE
Achillea millefolium	Yarrow	158
Agrostis stolonifera	Creeping bent	32
Alisma plantago-aquatica	Water plantain	1259
Alopecurus myosuroides	Black-grass	631
Anagallis arvensis arvensis	Scarlet pimpernel	3981
Atriplex patula	Common orache	158
Avena fatua	Wild-oat	12589
Barbarea vulgaris	Winter-cress	25119
Bromus sterilis	Barren brome	1259
Capsella bursa-pastoris	Shepherd's-purse	16
Cardamine hirsuta	Hairy bitter-cress	2512
Cerastium fontanum vulgare	Common mouse-ear	126
Chenopodium album	Fat-hen	25
Chenopodium ficifolium	Fig-leaved goosefoot	100
Chenopodium rubrum	Red goosefoot	316
Cirsium arvense	Creeping thistle	32
Coronopus squamatus	Swine-cress	1585
Crepis capillaris	Smooth hawk's-beard	1000
Daucus carota	Wild carrot	1585
Elymus repens	Common couch	4
Epilobium hirsutum	Great willowherb	126
Epilobium parviflorum	Hoary willowherb	316
Epilobium tetragonum	Square-stalked willowherb	1995
Equisetum arvense	Field horsetail	20
Erigeron canadensis	Canadian fleabane	398
Erysimum cheiranthoides	Treacle mustard	1259
Euphorbia helioscopia	Sun spurge	200
Festuca rubra	Red fescue	200
Fumaria officinalis	Common fumitory	19953
Galium aparine	Cleavers	32
Geranium dissectum	Cut-leaved cranesbill	7943
Geranium molle	Dove's-foot crane's-bill	1995
Glyceria fluitans	Floating sweet-grass	200
Lamium amplexicaule	Henbit dead-nettle	398
Lamium purpureum	Red dead-nettle	100
Lapsana communis	Nipplewort	251
Lolium multiflorum	Italian rye-grass	0
Lolium perenne	Perennial rye-grass	6
Matricaria discoidea	Pineapple-weed	8
Matricaria maritima	Scentless mayweed	316

Matricaria recutita	Scented mayweed	100
Medicago lupulina	Black medick	631
Myosotis arvensis	Field forget-me-not	794
Papaver argemone	Prickly poppy	31623
Papaver dubium	Long-headed poppy	1259
Papaver rhoeas	Common poppy	631
Phragmites australis	Common reed	40
Plantago lanceolata	Ribwort plantain	251
Poa annua	Annual meadow-grass	4
Poa trivialis	Rough meadow-grass	13
Polygonum aviculare	Knotgrass	16
Polygonum convolvulus	Black-bindweed	251
Polygonum lapathifolium	Pale persicaria	40
Polygonum persicaria	Redshank	25
Ranunculus repens	Creeping buttercup	20
Ranunculus sceleratus	Celery-leaved buttercup	251
Rorippa palustris	Marsh yellow-cress	501
Rubus fruticosus	Bramble	398
Rumex obtusifolius	Broad-leaved dock	79
Scirpus maritimus	Sea club-rush	2512
Senecio vulgaris	Groundsel	20
Sinapis arvensis	Charlock	126
Sisymbrium officinale	Hedge mustard	50
Solanum nigrum nigrum	Black nightshade	79
Sonchus arvensis	Perennial sow-thistle	32
Sonchus asper	Prickly cow-thistle	79
Sonchus oleraceus	Smooth sow-thistle	40
Stachys arvensis	Field woundwort	100000
Stachys palustris	Marsh woundwort	1000
Stellaria media	Common chickweed	5
Taraxacum vulgare	Dandelion	8
Thlaspi arvense	Field penny-cress	316
Trifolium dubium	Lesser trefoil	794
Tussilago farfara	Colt's-foot	32
Typha latifolia	Bulrush	316
Urtica dioica	Common nettle	25
Urtica urens	Small nettle	126
Veronica arvensis	Wall speedwell	1259
Veronica catenata	Pink water-speedwell	631
Veronica hederifolia	Ivy-leaved speedwell	316
Veronica persica	Common field-speedwell	316
Vicia cracca	Tufted vetch	398
Viola arvensis	Field pansy	1995

7 Non-target insects in unsprayed cereal edges and aphid dispersal to the adjacent crop

G.R. de Snoo & J. de Leeuw

Abstract

In 1992 and 1993 6-metre wide edges of a winter wheat crop were not sprayed with herbicides and insecticides to investigate the impact on the abundance of insects inhabiting the upper parts of the crop and on farmland flowers. To this end, a total of 18 fields were sampled using sweep nets. It was demonstrated that the number of insect groups as well as the insect density increases in the unsprayed edges, by a factor of 1.4 and 3.5, respectively. At the level of the 21 insect groups studied, too, a significant increase in numbers was found for most groups. This held true for aphid predators (mainly Coccinellidae), flower visitors (mainly adult Syrphidae) and insects that form the staple diet of the bird species Motacilla flava flava. *Although there was an increase in aphid abundance in most unsprayed edges, the aphids did not spread to the rest of the field, improving the compatibility of unsprayed edges with farm management.*

Introduction

The use of pesticides on arable fields can affect the abundance of non-target insects in both a direct and an indirect manner (*cf.* De Snoo *et al.*, 1994a). Direct effects are due to the toxic action of insecticides, in particular. Herbicides generally have an indirect impact on insect abundance, resulting from the loss of nectar and host plants. Fungicides are generally non-toxic to insects, although organophosphate fungicides such as pyrazophos form an exception (*cf.* Sotherton *et al.*, 1987). By not spraying herbicides or insecticides along the edges of cereal crops, biodiversity can be encouraged in arable areas, by promoting the abundance of flowering plants and many insect groups such as butterflies (Hald *et al.*, 1988; Schumacher, 1984; Dover *et al.*, 1990; De Snoo, 1994a). The presence of insects on arable fields can be a key factor for the survival of bird species. In England it has been shown that the population size of gamebirds such as the Partridge (*Perdix perdix)* is determined largely by the food supply available to the chicks. In areas where unsprayed cereal crop edges have been created, the decline in Partridge numbers can be halted and even reversed (Rands, 1985; Rands, 1986). The Blue-headed wagtail (*Motacilla flava flava*) also benefits from the presence of unsprayed crop edges; in the Haarlemmermeerpolder unsprayed edges are visited 3 to 4 times more frequently than sprayed edges (De Snoo *et al.*, 1994b).

Until now, research has focused mainly on arable regions on fairly light soils, where fields are often surrounded by hedgerows. In the present study, it has been investigated to what extent the abundance of non-target insects inhabiting the upper part of the crop and farmland flowers can be promoted by creating unsprayed crop edges in arable regions on heavier soils where hedgerows are lacking. The results were interpreted in relation to the food of the Blue-headed wagtail (*Motacilla flava flava*), a bird species that feeds on insects in the upper portions of plants. The study also investigated whether increased insect abundance has any negative impact on agricultural practice. In addition to direct losses of crop yield it was investigated to what extent potential insect pests such as aphids disperse from the unsprayed edges to the rest of the field.

Material and methods

Study area and insect sampling

The study was carried out in the Haarlemmermeerpolder, a region in the west of the Netherlands where large-scale arable farming is practised. In this clay region, insect abundance was investigated in winter wheat crop edges approx. 450 m long and 6 m wide on 10 farms in 1992 and 8 farms in 1993. No herbicides or insecticides were used on these crop edges. The unsprayed edges were compared with sprayed edges on the same field. Spraying of fungicides was allowed, but organophosphates were not applied. The fertilizer regime was left unchanged. All the edges, both unsprayed and sprayed, bordered on ditches.

Along the crop edges, insects in the upper part of the vegetation (crop and farmland flowers) were sampled at the end of June. Observation took place between 10.00 and 16.00 hours, at a temperature above 20°C. In 1992 all the edges were sampled twice, while in 1993 only a single sample was taken. In each 100-m strip, 10 subsamples were taken in 6 sweeps of a sweep net with a diameter of 35 cm. The total area sampled was 20 m^2 per 100 m. Sampling took place 1.5 m from the field edge. For mobile insects such as Syrphidae (Hover-flies), Stratiomyidae (Soldier flies), Tipulidae (Crane flies), Apidae (Bees and Bumble-bees) Crambinae (Grass moths) and Coccinellidae (Lady birds) additional visual observations were made. A total of 21 insect groups were distinguished. The Parasitica and several Diptera families were not included, because of the very small size of many representatives of these groups. The observed insects were identified at the family level or higher.

Impact on non-target insects

The impact of spraying on the abundance of insects was investigated in terms of the average number of insect groups and insect density on the strips. At the separate insect group level, a comparison was made between insect abundance in the sprayed and unsprayed strips for those groups found at more than 50% of the locations (Wilcoxon matched-pairs signed-ranks test). To allow for the 'overall effect' of spraying on the various groups, including those found at less than half the locations, the Liptak simultaneous test was carried out with a 'Lancaster generalization' based on the Wilcoxon test (Haccou & Meelis, 1992). To make due allowance for groups found at only a few locations, a weighting factor was used: $w_i = \sqrt{(m_i/f)}$, where w = weighting factor, m = no. of times group i is found, and f = total number of fields investigated (*cf.* Haccou & Meelis, 1992). The impact of spraying on the staple diet of the bird species *Motacilla flava flava* was determined by aggregating the various Diptera families (*cf.* Glutz von Blotzheim *et al.*, 1971/7; Cramp, 1988).

Aphids and aphid dispersal

In 1993 the spread of aphids from the unsprayed edges to the rest of the field was investigated on 5 of the 8 fields. In the period from 15-04-1993 to 08-07-1993, the number of aphids on 50 wheat plants (ear and flag leaf) was counted every two weeks. Aphid counts were carried out on both sprayed and unsprayed strips as well as at distances inwards of 2, 5, 16 and 38 m from these strips. The distance between the sprayed and unsprayed strips was at least 25 m. The number of aphids on the wheat plants was estimated in 4 classes: 0, 1-10, 11-100 and >100. Data processing consisted in converting these class scores into averages, *viz*. 0, 5, 50 and 200 aphids. The number of aphids at different distances from the sprayed and unsprayed edges were then compared. Spraying to control aphids took place prior to 23-06-1993.

Results

Impact on non-target insects

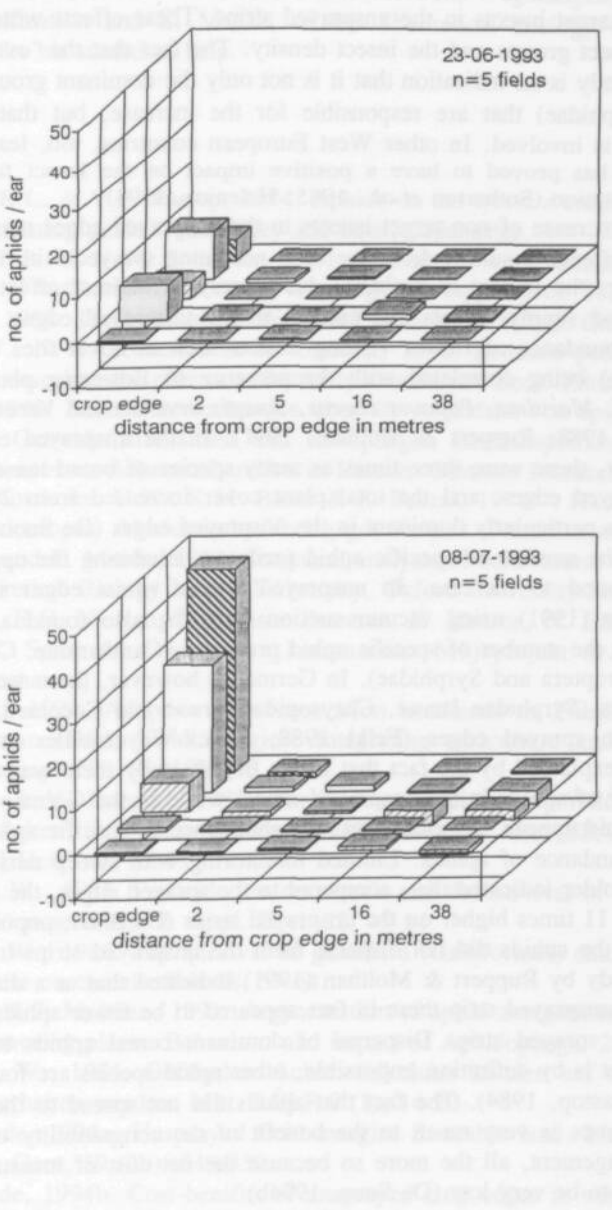
The impact of spraying on the abundance of non-target insects in the winter wheat crop edges is shown in Table 1. As can be seen from this table, in the two years the average number of insect groups caught in the unsprayed strips was 1.3 to 1.5 times higher than the number caught in the sprayed strips ($P < 0.01$ in both years, Wilcoxon matched-pairs test). Similarly, the average insect density in the unsprayed strips was 3 to 4 times higher than in the sprayed strips ($P < 0.01$ and < 0.05). At the level of individual insect groups, it was found that of the 21 groups investigated only the Dolichopodidae (both years) and the Tipulidae and Heterocera (moths) in 1993 were less abundant in the unsprayed strips. Of the 18 groups found on more than 50% of the sampling sites in 1992, 11 were significantly more abundant in the unsprayed strips. In 1993, 9 of the 18 groups were found to be significantly more abundant in the unsprayed strips.
In both years, the most noticeable impact was observed for flower-visiting insects (Syrphidae, Nitidulidae: Sap-beetles, Stratiomyidae, Apidae and Symphyta: Sawflies) and insect predators of aphids (Coccinellidae, Asilidae: Assassin flies, and Chrysopidae: Lacewings). In the unsprayed strips, flower visitors and aphid predators were found to constitute 62% (1992) and 73% (1993) of all the insects observed. In the sprayed strips these percentages were far lower, *viz*. 24% (1992) and 32% (1993). The absolute increase was significant for both insect groups and for both years (Wilcoxon matched-pairs test: flower visitors $P < 0.01$ and $P < 0.05$, respectively, and aphid predators $P < 0.05$ in both years). Each year, Coccinellidae (juveniles and adults) and Syrphidae (adults only) were particularly dominant in the unsprayed strips. The vast majority of the Coccinellidae were *Adalia bipunctata* and of the Syrphidae *Episyrphus balteatus*. Within several other groups, too, there was little diversity; for example, the Chrysomelidae were mainly *Lema melanopa*, the Asilidae *Leptogaster cilindrica* and the Carabidae representatives of the (herbivorous) genus *Amara*.
The staple diet of *Motacilla flava flava* is also significantly more abundant in unsprayed crop edges: in 1992, the total number of Diptera increased from 3.5 per 100 m in the sprayed strips to 13.4 per 100 m in the unsprayed strips; in 1993, the increase was from 3.8 to 11.4 Diptera per 100 m (Wilcoxon test, $P < 0.05$ in both years).
When the results (P-values) of the statistical analysis for all the individual insect groups are combined ('overall effect'), including those groups found at less than 50% of the sampling sites, there is found to be a significant positive effect in the unsprayed strips in both years (Liptak test $P < 0.001$).

Aphids and aphid dispersal
Figure 1 shows the difference in the degree of aphid infestation of the wheat plants during the 1993 growing season between the unsprayed and sprayed crop edges and adjacent field. Species composition consists of *Sitobion avenae* (grain aphid), *Metopolophium dirhodum* (rose-grain aphid) and *Rhopalosiphum padi* (bird cherry-oat aphid), the dominant aphid species in cereals. The first aphids in the cereal were counted on 8 June. From Figure 1 it can be seen that although in the course of time there was an increase in aphid abundance in 3 to 4 of the 5 strips, the aphids did not spread to the rest of the field. Even at a distance of 2 m from the unsprayed strip (*i.e.* 5 m from the field edge) no increase in aphid numbers was found in comparison with the situation adjacent to the sprayed strip.

Table 1. Abundance of non-target insects (adults) on sprayed and unsprayed field edges in 1992 and 1993. Average numbers per 100 m, including standard deviation, 1) = also including juveniles. T = Wilcoxon matched-pairs signed-ranks test, - = not tested (found at less than 50% of sampling sites); ns = not significant; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$. Number of strips in 1992 n = 10, in 1993 n = 8. For explanation of 'overall effect', see text

1992	sprayed	unsprayed	T	1993 sprayed	unsprayed	T
no. of groups	11.3 ± 2.9	14.2 ± 2.0	**	8.3± 3.8	12.4± 3.9	**
insect density	10.4 ± 7.8	30.6 ± 35.3	**	9.7± 7.1	40.5± 47.8	*
Coccinellidae 1)	1.7 ± 3.2	4.1 ± 4.8	*	1.3± 2.9	19.4 ± 34.5	*
Cantharidae	1.2 ± 2.0	2.0 ± 2.6	*	0.9± 1.1	1.0 ± 1.0	ns
Nitidulidae	0.1 ± 0.2	1.2 ± 1.4	*	0.1± 0.2	0.6 ± 1.5	ns
Elateridae	<0.1 ± 0.3	0.2 ± 0.3	*	0.1± 0.2	0.1 ± 0.2	ns
Chrysomelidae	0.8 ± 1.1	1.1 ± 1.2	ns	0.1± 0.2	0.7 ± 1.0	*
Curculionidae	<0.1 ± 0.1	0.9 ± 1.3	*	0	0.1 ± 0.2	-
Staphilinidae	<0.1 ± <0.1	0.1 ± 0.1	*	0	0.1 ± 0.1	-
Carabidae	0	<0.1 ± <0.1	-	0	0.1 ± 0.2	-
Syrphidae	0.4 ± 0.4	9.5 ± 22.3	**	0.5± 0.5	5.2 ± 10.4	*
Scatophagidae	1.5 ± 1.5	2.6 ± 2.1	**	0.4± 0.4	1.1 ± 1.8	ns
Dolichopodidae	1.1 ± 1.1	0.7 ± 0.8	ns	1.8± 2.5	1.2 ± 1.2	ns
Asilidae	<0.1 ± 0.1	0.3 ± 0.4	ns	0.1± 0.2	0.2 ± 0.3	ns
Empididae	0.1 ± 0.3	0.2 ± 0.2	ns	0.1± 0.2	1.1 ± 2.2	*
Stratiomyidae	<0.1 ± <0.1	0.2 ± 0.4	-	0.4± 0.7	2.2 ± 2.5	*
Tipulidae	0.3 ± 0.6	0.3 ± 0.4	ns	0.5± 0.8	0.4 ± 0.5	ns
Chrysopidae 1)	0.8 ± 1.4	2.0 ± 1.5	*	0.6± 0.7	1.4 ± 1.2	*
Apidae	0.1 ± 0.2	1.5 ± 3.7	-	0	0.2 ± 0.3	*
Symphyta 1)	0.2 ± 0.3	0.3 ± 0.5	ns	0.1± 0.2	0.5 ± 0.6	*
Heteroptera 1)	0.3 ± 0.3	1.6 ± 1.8	*	0.2± 0.3	2.4 ± 2.5	**
Cicadellidae 1)	0.3 ± 0.7	0.6 ± 1.1	**	0.5± 0.7	1.4 ± 2.2	ns
Heterocera 1)	2.8 ± 2.0	5.0 ± 3.7	ns	1.9± 1.6	1.1 ± 0.8	ns
Overall effect			***			***

Figure 1. Aphid dispersal during growing season (1993) in five cereal fields. Difference between aphid numbers in the unsprayed and sprayed crop edges and adjacent field (2 = number of aphids per ear at a distance of 2 m from the crop edge, etc.)



Discussion

The results demonstrate that, in the Dutch situation in arable regions on heavier soils where hedgerows are lacking, in both years of study there were clearly positive effects on the abundance of non-target insects in the unsprayed strips. These effects were found for both the number of insect groups and the insect density. The fact that the 'overall effect' also increases significantly is an indication that it is not only the dominant groups (such as Coccinellidae and Syrphidae) that are responsible for the increase, but that the entire range of entomofauna is involved. In other West European countries, too, leaving cereal crop edges unsprayed has proved to have a positive impact on the insect fauna in the upper parts of the vegetation (Sotherton *et al.*, 1985; Helenius, 1994).

On the one hand, the increase of non-target insects in the unsprayed edges may be due to the absence of direct effects, resulting from the crop not being sprayed with insecticides, in particular. However, the impact is probably due largely to indirect effects, resulting from the increased food supply (plants and aphids) in the unsprayed edges. Earlier research points to the abundance of flower visiting insects such as hover-flies (*Episyrphus balteatus*, for example) being correlated with the presence of flowering plants such as *Matricaria recutita, M. Maritima, Papaver rhoeas, Sinapis arvensis* and *Veronica persica* (Molthan & Ruppert, 1988; Ruppert & Molthan, 1991). In the unsprayed edges in the Haarlemmermeerpolder, there were three times as many species of broad-leaved farmland flowers as in the sprayed edges, and the total plant cover increased from 2% to 34%. *Matricaria recutita* was particularly dominant in the unsprayed edges (De Snoo, 1994a).

In the present study, the number of specific aphid predators inhabiting the upper parts of the vegetation was found to increase. In unsprayed winter wheat edges in England, Chiverton & Sotherton (1991) using vacuum-suction sampling also found a slight (not significant) increase in the number of specific aphid predators (Cantharidae, Coccinellidae and the larvae of Neuroptera and Syrphidae). In Germany, however, there were found to be less aphid predators (Syrphidae larvae, Chrysopidae larvae and Coccinellidae) in the unsprayed than in the sprayed edges (Felkl 1988; Storck-Weyermüller and Welling, 1991). This might be explained by the fact that in the British study there was also a slight increase in the number of aphids in the unsprayed strips, while in the German study there was a decrease. It would appear, therefore, that the abundance of specific aphid predators increases with the abundance of aphids. Limited monitoring with sweep nets in 1992 in the Haarlemmermeerpolder indicated that, compared to the sprayed edges, the number of aphids was 11 times higher on the unsprayed strips (De Snoo, unpublished).

The study shows that the aphids did not disperse from the unsprayed strips to the rest of the wheat field. A study by Ruppert & Molthan (1991) indicated that at a distance of 10 m from a flower-rich unsprayed strip there in fact appeared to be fewer aphids than at the same distance from a sprayed strip. Dispersal of dominant cereal aphids to crops like potatoes and sugar beet is by definition impossible; other aphid species are found on these crops (Blackman & Eastop, 1984). The fact that aphids did not spread to the rest of the field or to adjacent crops is very much to the benefit of the compatibility of unsprayed edges with farm management, all the more so because the net cost of measures taken in winter wheat is found to be very low (De Snoo, 1994b).

The fact that there is an increase in the supply of the staple food (Diptera) of *Motacilla flava flava* supports the observed higher frequency of visits to the unsprayed cereal crop edges by the Blue-headed wagtail (De Snoo *et al.*, 1994).

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References

Blackman, R.L. & V.F. Eastop, 1984. Aphids on the world's crops: an identification and information guide. John Wiley and Sons, Chichester.

Chiverton, P.A. & N.W. Sotherton, 1991. The effects on beneficial arthropods of exclusion of herbicides from cereal crop edges. J. Appl. Ecol. 28, 1027-1039.

Cramp, S., 1988. The birds of the Western Palaearctic. Oxford: Oxford University.

Dover, J.W., N.W. Sotherton & K. Gobbett, 1990. Reduced pesticide inputs on cereal field margins: the effects on butterfly abundance. Ecol. Entomol. 15, 17-24.

Felkl, G., 1988. Erste Untersuchungen über die Abundanz von epigaïschen Raubarthropoden, Getreide Blattläusen und stenophagen Blattlausprädatoren in herbizidfreien Winterweizen-Ackerrandstreifen in Hessen. Gesunde Pflanzen 40 (12), 483-491.

Glutz von Blotzheim, U.N., K.M. Bauer & E. Bezzel, 1971/7. Handbuch der Vögel Mitteleuropas. Akademische Verlagsgesellschaft, Frankfurt am Main.

Haccou, R. and E. Meelis, 1992. Statistical analysis of behavioural data. Institute of Theoretical Biology Leiden University, Oxford University Press.

Hald, A.B., B.O. Nielsen, L. Samsøe-Petersen, K. Hansen, N. Elmegaard & J. Kjoholt, 1988. Sprojtefri randzoner i kornmarker. Miljoprojekt nr. 103. Miljostyrelsen, Kobenhavn.

Helenius, J., 1994. Adoption of conservation headlands to Finnish farming. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58, 191-196.

Molthan, J. & V. Ruppert, 1988. Zur Bedeutung blühender Wildkrauter in Feldrainen und Äckern für blüten besuchenden Nutzinsekten. Mitt. BBA Land- und Forstwirtschaft Heft 247, 85-99.

Rands, M.R.W., 1985. Pesticide use on cereals and the survival of grey partridge chicks: a field experiment. J. Appl. Ecol. 22, 49-54.

Rands, M.R.W., 1986. The survival of gamebird (Galliformes) chicks in relation to pesticide use on cereals. Ibis 28, 57-64.

Ruppert, V. & J. Molthan, 1991. Augmentation of aphid antagonists by field margins rich in flowering plants. Behaviour and impact of Aphidophaga: 243-247.

Schumacher, W., 1984. Gefährdete Ackerwildkräuter können auf ungespritzten Feldrändern erhalten werden. Mitt. LÖLF 9 (1), 14-20.

Snoo, G.R. de, 1994a. Unsprayed field margins in arable land. Med. Fac. Landbouww. Univ. Gent, 59 (2b): 549-559.

Snoo, G.R. de, 1994b. Cost-benifits of unsprayed crop edges in winter wheat, sugar beet and potatoes. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58, 197-201.

Snoo, G.R. de, K.J. Canters, F.M.W. de Jong & R. Cuperus, 1994a. Integral hazard assessment of side effects of pesticides in the Netherlands - a proposal. J. Environm. Toxicol. Chem. 13 (8), 1331-1340.

Snoo, G.R. de, R.T.J.M. Dobbelstein & S. Koelewijn, 1994b. Effects of unsprayed crop edges on farmland birds. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58,, 221-226.

Sotherton, N.W., S.J. Moreby & M.G. Langley, 1987. The effects of the foliar fungicide pyrazophos on beneficial arthropods in barley fields. Ann. Appl. Biol. 111, 75-87.

Sotherton, N.W., M.R.W. Rands & S.J. Moreby, 1985. Comparison of herbicide treated and untreated headlands for the survival of game and wildlife. Proc. BCPC-Weeds 1985, 8B-3, 8p.

Storck-Weyhermüller, S. & M. Welling, 1991. Regulationsmöglichkeiten von Schad- und Nutzarthropoden im Winterweizen durch Ackerschonstreifen. Mitt. BBA Land- und Forstwirtschaft Berlin-Dahlem, Heft 273.

8 Butterflies in sprayed and unsprayed field margins

G.R. de Snoo, R.J. van der Poll & J. Bertels

Abstract

In the Dutch Field Margin Project in the Haarlemmermeerpolder a field study was carried out in 1990 and 1992 to investigate the extent to which unsprayed field margins offer scope for increasing butterfly abundance in agricultural areas. To this end the outer 3 to 6 metres of fields of winter wheat or potatoes were left unsprayed with herbicides or insecticides. In the unsprayed crop edges and adjacent field boundaries the number of butterflies was counted weekly and compared with numbers in sprayed field margins. Six species were found to be abundant: Maniola jurtina, Lasiommata megera, Coenonympha pamphilus, Pieris rapae, Pieris napi and Thymelicus lineola. The impact of spraying was investigated at two levels: the crop edge and the crop edge plus adjacent field boundary (ditch bank and field edge).

1) *Crop edge: In the unsprayed edges a total of 12 butterfly species were observed, in sprayed edges 10 species. In both years in the unsprayed winter wheat edges a significant increase was found in species number (about a factor 2.3) and the number of individuals (a factor 4.6-4.9). In the unsprayed potato edges only in 1992 the increase in species number and the number of individuals was significant (a factor 3.6 and 6.9 respectively). Compared to the unsprayed potato edges total butterfly abundance in unsprayed winter wheat edges was about 2 to 3 times higher. In winter wheat 5 butterfly species were more abundant in unsprayed edges and in potatoes 3 species.*
2) *Crop edge plus adjacent field boundary: the number of butterfly species along the unsprayed margins significantly increased in winter wheat by a factor 1.3-1.7 in the 2 years. Also a significant impact on the number of individuals was found in winter wheat in both years (factor 1.7-2.5). Only in 1992, the increase in species number and the number of individuals in the unsprayed potato margins was significant (a factor 2.0 and 3.2 respectively). At the species level, again in the winter wheat crop, spraying was found to have most impact.*

The ecological relevance of the results are discussed.

Introduction

In the Netherlands, as elsewhere in Europe, there has been a marked decline in the abundance of butterflies over the past 50 years. Of the 71 species of endemic butterflies, 15 are now extinct; of the remaining 56 species, 29 are vulnerable or threatened (Tax, 1989; Ministry of Agriculture & Fisheries, 1989). Moreover, 13 of the 56 species are found exclusively in nature reserves: only 4% of the area of the Netherlands. The decline has been most severe for locally occurring species and those with a modest breeding rate (Bink, 1992). In addition to the breeding butterflies, there are five summer migrants to the Netherlands: *Colias crocea* and *C. hyale* (Clouded yellow and Pale clouded yellow) and *Lysandra coridon* (Chalk-hill blue), all of which have suffered a decline, and *Vanessa atalanta* (Red admiral) and *Cynthia cardui* (Painted lady), numbers of which have remained approximately stable (Tax, 1989).

Today's arable fields are held to have little attraction for butterflies (Thomas, 1984; Ministry of Agriculture & Fisheries, 1989). The formerly traditional system of three-course rotation, with fields being left fallow every 3 years for at least 1 year, or sown to a green manure crop like lucerne, favoured such species as the Pale clouded yellow. The fallow field, with its profuse vegetation of arable weeds, will have attracted such species as *Papilio machaon* (Swallow tail) and *Issoria lathonia* (Queen of Spain fritillary; Bink, 1992).

Studies in the U.K. have shown that butterfly abundance in arable areas can be improved if the outer 6 m of fields are not treated with herbicides or insecticides (Rands & Sotherton, 1986; Dover *et al.*, 1990). These studies, carried out in cereal fields with adjacent hedgerows, woodland, roads or railways, have shown that in these 'Conservation Headlands' there is a sharp increase in the number of butterfly individuals. In most years, moreover, more species are also observed. A comparison between areas with and without Conservation Headlands indicates that for some species there is a positive impact at the population level, too (Dover *et al.*, 1990).

Throughout much of the arable acreage in the lowland areas of the Netherlands fields are typically bounded by ditches rather than hedgerows. In these areas potatoes, sugar beet and cereals are grown in rotation, with cereals often accounting for less than 50% of the overall crop. Compared with other European countries, extremely large quantities of pesticides are employed in Dutch agriculture: an average of 19 kg a.i./ha/yr (Meerjarenplan Gewasbescherming, MJP-G, 1991). Field edges and ditch banks are also regularly sprayed (De Snoo & Wegener Sleeswijk, 1993). The Dutch Field Margin Project being conducted by the Centre of Environmental Science of the Leiden University (CML) is investigating the extent to which nature conservation in arable regions can be improved by leaving field margins unsprayed with pesticides. The effects on arable weeds, invertebrates and songbirds are being studied, as well as the compatibility of the measures with agricultural management (De Snoo, 1994a). Butterfly abundance was monitored in 1990 and 1992.

Materials and methods

Study area and experimental design

The study was carried out in the Haarlemmermeerpolder, an arable region on marine clay in the west of the Netherlands. On 6 conventionally managed arable farms in this region, in 1990 strips 100 m long and 3 m wide were left unsprayed with herbicides and insecticides along the edges of winter wheat and potato crops. In 1992 such strips were created along 8 winter wheat and 6 potato fields. In addition, at 6 other farms 6 unsprayed strips with a length of approx. 400 m and a width of 6 m were created along winter wheat fields. The use of fungicides was permitted on these strips and the fertilizer regime was also left unchanged. The sprayed crop edges were compared with the unsprayed crop edges, almost always in the same field. All sprayed and unsprayed crop edges bordered on a ditch. Ditch bank vegetation consists mainly of perennial grasses such as *Elymus repens* and *Festuca rubra*. Two or 3 times a year ditch banks are mown or chopped, and the swath left lying (De Snoo & Wegener Sleeswijk, 1993). As an additional element, in

1992 a single, wide crop edge in winter wheat was studied with the sprayed and unsprayed strip bordering on a grass seed field.
Compared to the sprayed edges the abundance of farmland plants strongly increases in the winter wheat from 2% to 32% average in the unsprayed edges. Dominant species were *Matricaria recutita*, *Polygonum convolvulus* and *Galium aparine*. Also plant diversity increases from 5.7 to 15.9 species average. The increase is mainly due to dicotyledon species, which can be exploited by Lepidoptera. In potatoes cover of the farmland plants increases from 3.6 to 11.2%. Dominant species in this crop were *Senecio vulgaris*, *Polygonum lapathifolium* and *Sonchus arvensis*. Plant diversity increases from 8.7 to 15.2 species. (De Snoo, 1994a; De Snoo in prep.). Because of profuse weed growth on some crop edges, at the farmers' request, *Matricaria recutita* was partly removed by hand from 3 narrow unsprayed winter wheat margins in both years.

Sampling

A butterfly census was carried out according to the transect method of Pollard (1977). Censuses were performed between 11.00 and 16.30 h Central European Time at a wind speed of <10 m/s and a temperature of >17°C, or a temperature of 13-17°C and less than 40% cloud cover. Whenever possible, butterflies were recorded once a week. During the census rounds, a distinction was made between butterflies in the crop edge and butterflies on the bordering ditch bank (including the 35 cm wide field edge and half the ditch). In the case of narrow strips, the census area of the crop edge was 3 m wide, with wide strips 6 m. The farms were visited in random sequence. Each year, in every crop 9 census rounds were made from the middle of May to the end of July.

Data processing

Data were processed for 2 levels: 1) the crop edge, and 2) the crop edge including the adjacent ditch bank (with field edge). This procedure was chosen because of the potentially close relationship between the number of butterflies in the crop edge and that on the bordering ditch bank. All butterfly data were expressed as the average number of individuals per 100 m. For the statistical test at the species level, only those species at more than 50% of the fields were used (Wilcoxon matched-pairs ranks test). Based on the data for 1992, a comparison was made of the number of butterfly individuals and species in unsprayed crop edges 3 and 6 metres wide. After conversion to abundance per unit area, there proved to be no significant difference between the 3 and 6 m edges, whether sprayed or unsprayed (Mann-Whitney U-test). At the same time, though, spraying was found to have a significant effect in both the 3 and 6 m edges. The number of butterflies on the adjacent ditch bank was approximately the same in both cases. Therefore for 1992 the results of the 3 and 6-m wide edges have been pooled.

Results

In the 2 monitoring seasons a total of 2084 butterflies were observed, comprising 14 species (Table 1). Satyridae (Browns) were the most dominant family, followed by Pieridae (Whites) and Hesperiidae (Skippers). In these families 6 species were common: *Maniola jurtina* (Meadow brown), *Lasiommata megera* (Wall brown), *Coenonympha pamphilus* (Small heath), *Pieris rapae* (Small white), *P. napi* (Green-veined white) and *Thymelicus lineola* (Essex skipper). Consistently more butterflies were observed on the ditch banks than in the crop edges. The species *Issoria lathonia* and *Aricia agestis* (Brown argus) were found only on the ditch banks along fields of winter wheat.

Table 1. Number of individuals of butterfly species per 100 m in sprayed and unsprayed field margins (crop edges + adjacent ditch banks) in the Haarlemmermeerpolder in 1990 and 1992

Species		1990 2400m	1992 7800m
Satyridae:			
Maniola jurtina	Meadow brown	7.08	8.74
Lasiommata megera	Wall brown	4.21	1.23
Coenonympha pamphilus	Small heath	7.08	0.81
Hesperiidae:			
Thymelicus lineola	Essex skipper	2.42	3.27
Pieridae:			
Pieris rapae	Small white	0.42	2.58
Pieris napi	Green-veined white	1.13	1.40
Pieris brassicae	Large white	0	0.10
Nymphalidae:			
Aglais urticae	Small tortoiseshell	0.13	0.53
Cynthia cardui	Painted lady	0.04	0.56
Vanessa atalanta	Red admiral	0.13	0.12
Inachis io	Peacock butterfly	0.13	0.09
Issoria lathonia	Queen of Spain fritillary	0.17	0
Lycaenidae:			
Polyommatus icarus	Common blue	0	0.13
Aricia agestis	Brown argus	0.04	0.03
total no. of individuals per 100 m		23.21	19.58

Impact of spraying

Crop edge

In the unsprayed crop edges a total of 12 species were found, contrasting with 10 species in the sprayed edges; *Pieris brassicae* (Large white) and *Polyommatus icarus* (Common blue) were observed in unsprayed edges only. Compared with the sprayed crop edges, the average number of species per 100 m in the unsprayed edges was significantly higher in winter wheat in both years (a factor 2.3 to 2.4) and in potatoes in 1992 (a factor 3.6, see Table 2). The number of species in the sprayed potato edges was remarkably low in 1992, for example, no Satyridae at all were observed (Table 3). In both seasons in the unsprayed winter wheat edges there were significantly more butterfly individuals than in the sprayed edges. The difference varied from a factor 4.6 to 4.9 (Table 2). In potatoes only in 1992 there were significant more individuals in the unsprayed edges (factor 6.9). The absolute number of butterflies was highest in unsprayed winter wheat edges: approx. 10-12 individuals per 100 m. In unsprayed potato edges approx. 3 to 5 butterflies were recorded per 100 m. At the species level there was marked variation in butterfly abundance from year to year. Taking the data on an aggregate basis for the 2 years indicates that in winter wheat there is a significant impact for 5 species and in potatoes for 3 species (Table 3).

Table 2. Average number of butterflies (individuals and number of species, with standard error) per 100 m field margin. - = not tested (observed at <50% of locations). * = P <0.05; ** = P <0.01; *** = P <0.001; ns = not significant; Wilcoxon matched-pairs ranks test

	crop edge			crop edge + ditch bank		
	sprayed	unsprayed	T	sprayed	unsprayed	T
WINTER WHEAT						
1990						
no. of individuals	2.5 ± 1.1	12.2 ± 6.1	*	18.8 ± 3.9	32.2 ± 8.0	*
no. of species	1.3 ± 0.6	3.0 ± 0.3	*	4.5 ± 0.7	5.7 ± 0.8	*
1992						
no. of individuals	2.1 ± 0.8	9.7 ± 2.4	***	11.3 ± 2.3	28.1 ± 5.4	**
no. of species	1.7 ± 0.4	4.0 ± 0.5	***	4.8 ± 0.6	6.4 ± 0.6	*
POTATOES						
1990						
no. of individuals	2.2 ± 1.2	3.0 ± 1.2	ns	18.7 ± 6.9	23.5 ± 6.8	ns
no. of species	1.3 ± 0.6	2.2 ± 0.7	ns	3.7 ± 0.5	4.8 ± 0.7	ns
1992						
no. of individuals	0.7 ± 0.2	4.8 ± 1.7	*	9.7 ± 3.0	30.7 ± 12.8	*
no. of species	0.7 ± 0.2	2.5 ± 0.7	*	3.0 ± 0.3	6.0 ± 1.0	*

Table 3. Average number of butterflies individuals (with standard error) per 100 m field margin for 6 dominant species. - = not tested (observed at <50% of locations). * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$; ns = not significant; Wilcoxon matched-pairs ranks test

	crop edge			crop edge + ditch bank		
	sprayed	unsprayed	T	sprayed	unsprayed	T
WINTER WHEAT						
1990						
Maniola jurtina	1.0 ± 0.5	8.2 ± 5.2	*	4.7 ± 1.7	14.2 ± 6.2	*
Lasiommata megera	0.3 ± 0.3	0.5 ± 0.2	ns	4.7 ± 1.9	4.8 ± 1.2	ns
Coenonympha pamphilus	0.7 ± 0.5	2.5 ± 1.0	*	5.3 ± 1.4	7.7 ± 1.7	ns
Thymelicus lineola	0	0.3 ± 0.2	-	1.2 ± 0.7	2.5 ± 1.0	*
Pieris rapae	0.2 ± 0.2	0	-	0.8 ± 0.5	0.3 ± 0.2	ns
Pieris napi	0.2 ± 0.2	0.3 ± 0.2	ns	1.2 ± 0.6	1.5 ± 0.6	ns
1992						
Maniola jurtina	1.3 ± 0.8	5.5 ± 2.1	***	4.6 ± 2.0	12.6 ± 4.3	***
Lasiommata megera	0.1 ± 0.1	0.2 ± 0.1	-	1.2 ± 0.3	1.5 ± 0.5	ns
Coenonympha pamphilus	0.1 ± 0.1	0.3 ± 0.2	-	0.5 ± 0.2	1.7 ± 0.6	**
Thymelicus lineola	0.3 ± 0.2	1.2 ± 0.5	**	2.4 ± 0.8	5.5 ± 1.6	**
Pieris rapae	0.1 ± 0.1	1.0 ± 0.2	**	1.0 ± 0.2	3.2 ± 0.6	*
Pieris napi	0.1 ± 0.1	0.6 ± 0.2	**	1.2 ± 0.3	1.7 ± 0.5	ns
POTATOES						
1990						
Maniola jurtina	0	0.5 ± 0.3	-	4.3 ± 3.2	5.2 ± 2.3	ns
Lasiommata megera	0.3 ± 0.2	0.8 ± 0.3	*	2.8 ± 1.1	4.5 ± 0.8	*
Coenonympha pamphilus	1.0 ± 0.8	0.3 ± 0.2	ns	7.5 ± 3.4	7.9 ± 2.5	ns
Thymelicus lineola	0.5 ± 0.3	0.7 ± 0.7	-	2.7 ± 2.0	3.7 ± 2.5	ns
Pieris rapae	0.2 ± 0.2	0.3 ± 0.2	ns	0.5 ± 0.3	0.8 ± 0.5	ns
Pieris napi	0	0.2 ± 0.2	-	0.5 ± 0.3	1.2 ± 1.0	ns
1992						
Maniola jurtina	0	1.3 ± 0.7	*	4.3 ± 2.1	11.5 ± 5.7	*
Lasiommata megera	0	0.2 ± 0.2	-	0.7 ± 0.4	2.7 ± 0.8	*
Coenonympha pamphilus	0	0	-	0	0.7 ± 0.3	*
Thymelicus lineola	0.2 ± 0.2	0.5 ± 0.3	ns	2.2 ± 1.3	4.5 ± 2.8	ns
Pieris rapae	0.3 ± 0.2	1.5 ± 0.4	*	1.7 ± 0.4	5.2 ± 1.7	*
Pieris napi	0.2 ± 0.2	0.3 ± 0.2	-	0.8 ± 0.5	1.7 ± 0.8	ns

Crop edge plus adjacent ditch bank
Termination of spraying leads to an increase in the number of butterfly individuals not only in the crop edges but also on the adjacent ditch banks (including the field edge). However, the percentage increase in the number of individuals is far greater in the crop edge than on the ditch bank. If the crop edge is considered together with the adjacent ditch bank, it can be concluded that in winter wheat in both years and in potatoes in 1992, there is a significant increase in the number of butterfly individuals in the unsprayed regime (Table 2). For winter wheat the increase was a factor 1.7 to 2.5 and in potatoes in 1992 a factor 3.2. With the exception of the potato edges in 1990, there was always a significant increase in the number of butterfly species per 100 m in the unsprayed situation, in winter wheat by a factor 1.3-1.7 and in potatoes in 1992 by a factor 2.0. At the species level, combining the data for the 2 years, in winter wheat significant effects were found for 4 dominant species (Table 3). In this crop also a significant increase was found for *Aglais urticae* in 1992 (resp. 0.4 ± 0.2 and 1.0 ± 0.5; $P < 0.05$). In potatoes a significant increase was found for 4 species.
The influence of the location of the sprayed edge is illustrated by the data for the winter wheat edge bordering on a grass seed field rather than a ditch. Here, no butterflies were observed in the sprayed crop edge, with only 1.4 per 100 m in the unsprayed edge. This is far less than in comparable edges along a ditch bank (average: 9.7 ± 2.4).

Discussion

Of the 43 species found outside nature reserves in the Netherlands, 14 were observed in the field margins (33%). All of these were common species, the populations of which are not threatened (Tax, 1989). There was wide variation in the number of butterflies at each farm. To a large extent this can probably be explained by differences in the abundance and species composition of flowering herbs on the individual farms, in turn determined by variation in former and current management of the fields, ditch banks and field edge. Important parameters in this respect include crop sowing date, nature and intensity of spraying operations, and ditch bank mowing regime. There was also variation in the number of butterflies between the 2 monitoring seasons.

Leaving field margins unsprayed leads to a distinct increase in the number of butterfly individuals. The number of species observed in unsprayed edges is often also higher than that in sprayed edges. These effects are most pronounced in winter wheat. The increase in the number of individuals in this crop (in the crop edge by a factor 4.6-4.9 and in the crop edge plus ditch bank by a factor 1.7-2.5) is comparable with the results of the U.K. study, despite the differences in biotope (ditch banks versus hedgerows). There the number of individuals increased by a factor 1.8-2.9 in the various years of study (Dover *et al.*, 1990). This implies that unsprayed crop edges in Dutch fields without hedgerows could be even more valuable to conservation compared to the U.K. In the present study positive effects on butterfly abundance have now also been found in potatoes in 1 year.
The favourable effects on butterfly abundance in the unsprayed margins are due mainly to the greater supply of nectar from the flowering plants: in the winter wheat edges predominantly *Matricaria recutita*, although other species attractive for butterflies such as *Cirsium arvense* and *Sonchus* spp. were also often more abundant. It should be noted that *Matricaria recutita* was partly removed in some winter wheat edges. Dover (1989)

investigated the importance of various flowering herbs in unsprayed cereal edges for Satyridae and Pieridae. For these groups, composites such as *Cirsium arvense* and crucifers such as *Sinapis arvensis* and *Brassica napus* are important nectar plants. The composition of the herb layer may also explain the differences in the number of butterflies between the various crops: in contrast to the winter wheat crop edge, potato crop edges had fewer flowering nectar plants.

The increase in the number of butterflies in the unsprayed crop margins cannot be seen in isolation from abundance on the adjacent ditch bank and field edge. Butterfly numbers are far higher on the banks and there is regular movement between the bank and crop edge. Following creation of unsprayed crop edges Pieridae, for example, have been seen to shift their foraging activity from the field boundary (hedgerow) to the unsprayed crop edge (Dover, 1988). At the same time, moreover, leaving the crop edges unsprayed means a substantial decrease in pesticide emissions to the field edge and ditch bank. As a result, there is often an increase in the abundance of flowering herbs, especially on the field edge. Our results show that in most cases the number of butterflies also increases on the ditch bank and field edge bordering on the unsprayed crop edges. It is therefore not the case that the butterflies on unsprayed crop edges are 'drawn away' from the ditch bank: there is a substantial increase in the aggregate number found in the crop edge and on the ditch bank.

In particular, the unsprayed crop edge may serve as a summer habitat for butterflies (nectar supply). In the field itself there are few food plants and larvae, pupae and eggs have difficulty surviving because of autumn ploughing. Because of their perennial vegetation (particularly grasses), the ditch banks, in contrast, may be an important winter habitat for Satyridae and Hesperiidae and other groups. Pieridae and Nymphalidae are far more mobile and consequently not bound to the ditch bank. The potential of the ditch bank can probably be increased substantially by introducing a butterfly-friendly (mowing) regime.

At the landscape level, unsprayed field margins can help create 'green veins' in arable regions, often referred to as 'white areas' in Dutch conservation policy (Natuurbeleidsplan, NBP, 1990). It is, however, extremely important that the unsprayed edges border on a ditch or other landscape element. Butterflies fly almost exclusively along the edges of fields (Dover, 1990), and in this light - backed up by the results of the present study - there appears to be little point in creating unsprayed crop edges in the middle of other cropped land.

Finally, a cost-benefits analysis of the unsprayed winter wheat and potato edges in the Haarlemmermeerpolder with its very intensive land use shows that, balancing the yield losses against the benefits, *viz.* reduced pesticide costs, the measures can be economically well adopted in agricultural practice (De Snoo, 1994b).

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References

Bink, F.A., 1992. Ecologische atlas van de dagvlinders van Noordwest-Europa. Schuyt & Co Uitgevers en Importeurs bv, Haarlem.

Dover, J.W., 1988. Butterflies on farmland. Bulletin of the Amateur Entomologists So ciety London 47, 3-6.

Dover, J.W., 1989. The use of flowers by butterflies foraging in cereal field margins. Entomologist's Gazette 40, 283-291.

Dover, J.W., 1990. Butterflies and wildlife corridors. Annual Review of the Game Con servancy 1989 21, 62-64. The Game Conservancy, Fordingbridge.

Dover, J.W., N.W. Sotherton, & K. Gobbett, 1990. Reduced pesticide inputs on cereals field margins: the effects on butterfly abundance. Ecological Entomology 15, 17-24.

Ministry of Agriculture & Fisheries (NL), 1989. Beschermingsplan Dagvlinders. Ministry of Agriculture & Fisheries, The Hague.

Meerjarenplan Gewasbescherming (MJP-G), 1991. Regeringsbeslissing. Tweede Kamer, vergaderjaar 1990-1991, 21677, nrs. 3-4. SDU Uitgeverij, Den Haag.

Natuurbeleidsplan (NBP), 1990. Regeringsbeslissing. Tweede Kamer, vergaderjaar 1989-1990, 21149, nrs. 2-3. SDU uitgeverij, Den Haag.

Pollard, E., 1977. A method for assessing changes in the abundance of butterflies. Biolo gical Conservation 12, 115-134.

Rands, M.R.W. & N.W. Sotherton, 1986. Pesticide use on cereal crops and changes in the abundance of butterflies on arable farmland in England. Biological Conservation 36, 71-82.

Snoo, G.R. de & A. Wegener Sleeswijk, 1993. Use of pesticides along field margins and ditch banks in the Netherlands. Med. Fac. Landbouww. Univ. Gent 58/3a, 921-926.

Snoo, G.R. de, 1994a. Unsprayed field margins in arable land. Med. Fac. Landbouww. Univ. Gent, 59/2b, 549-559.

Snoo, G.R. de, 1994b. Cost-benifits of unsprayed crop edges in winter wheat, sugar beet and potatoes. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 197-201.

Snoo, G.R. de, Arable flora in sprayed and unsprayed crop edges. in prep.

Tax, M.H., 1989. Atlas van de Nederlandes dagvlinders. Vlinderstichting, Wageningen en Natuurmonumenten, 's-Graveland.

Thomas, J.A., 1984. The conservation of butterflies in temperate countries: past efforts and lessons for the future. In: Vane-Wright, R.I. & Ackery, P.R. (Ed.). The biology of butterflies. Symposium of the Royal Entomological Society of London 11, 334-353.

9 Carabids in sprayed and unsprayed crop edges of winter wheat, sugar beet and potatoes

G.R. de Snoo, R.J. van der Poll & J. de Leeuw

Abstract

In the Dutch Field Margin Project a management strategy is being developed to promote nature conservation in arable fields and reduce pesticide drift to non-target areas. In 1990 and 1991 carabids were sampled by pitfalls in sprayed and unsprayed crop edges 3 m wide and 100 m long in winter wheat, sugar beet and potatoes. The activity density of carabids in winter wheat (both 1990 and 1991) and in sugar beet (1991) was significantly higher in the unsprayed margins. In these crops the number of species was significantly higher in 1991. In potatoes there was only a significant difference in the number of species (1990). Species of the carabid genera Amara and Harpalus, both herbivorous, show the most marked increase. The relevance of the results is discussed.

Introduction

Carabids are among the most dominant epigeal soil invertebrates of arable fields. Most species are polyphagous predators with a preference for aphids and Collembola. Their main significance for agricultural practice is their role in preventing pest outbreaks (Luff, 1982). *Agonum dorsale* is particularly important in this respect because the species also preys very successfully on aphids when these are present in low densities (Sunderland & Vickerman, 1980). Adult carabids from the genera *Amara* and *Harpalus* are partly phytophagous, consuming weed seeds. The number of carabids in arable fields is important for the chick survival of some birds, such as pheasants (Hill, 1985).

One of the factors determining the presence of carabids in arable fields is pesticide use. Compared with other West European countries, pesticide use is very high in the Netherlands: on arable farmland 19 kg a.i./ha average per year (Meerjarenplan GEwasbescherming, MJP-G, 1991). The use of pesticides on a plot generally has an adverse impact on the number of carabid species and individuals found there, and there is consequently less aphid predation (Vickerman & Sunderland 1977; Edwards *et al.*, 1979; Sotherton *et al.*, 1987; Dritschilo & Wanner, 1990; Basedow *et al.*, 1991). At the same time certain species, such as *Trechus quadristriatus* and *Asaphidion flavipes*, appear to be more abundant under conditions of intensive cropping (Dritschilo & Wanner, 1990; Basedow *et al.*, 1991). The abundance of some species in arable fields is also influenced by the presence of distinct field boundary elements such as grass strips and hedges. So-called spring breeders such as *A. dorsale*, in particular, overwinter as adults in large numbers in perennial vegetation, from there colonizing fields in spring (Sotherton, 1984; Wallin, 1986; Coombes & Sotherton, 1986; Riedel, 1991; Basedow *et al.*, 1991).

Over the past 10 years there has been a growing interest in maintaining unsprayed crop edges. In 6-m wide unsprayed cereal crop edges Hassall *et al.* (1992) found significantly more carabids (individuals and species) than in sprayed edges. Storck-Weyhermüller & Welling (1991) found more carabids (activity density, species and diversity) and also less aphid predation in 3-5-m wide herbicide-free winter wheat crop edges. However, a study by Felkl (1988) in 2-5-m wide unsprayed cereal crop edges showed no increase in the number of carabid species and only a slight increase in the number of individuals. Using pitfall traps in 6-m wide cereal crop edges where no herbicides has been used, Chiverton & Sotherton (1991) found no increase in numbers of the studied species *Agonum dorsale* and *Pterostichus melanarius*. These studies focused solely on effects in the unsprayed edges of cereal crops. The Dutch Field Margin Project being undertaken in the Haarlemmermeerpolder is also concerned with unsprayed potato and sugar beet crop edges. The aim of this project is to develop a management strategy for promoting nature conservation in arable fields and reducing pesticide drift to non-target areas. The effects on weeds, invertebrates, vertebrates, yields and pesticide drift into ditches and ditch banks are being investigated.

Methods

Study area

The study was carried out on 7 farms in the Haarlemmermeerpolder in 1990 and 1991. In this polder, reclaimed about 150 years ago, most parcels are 1000 m long and 200 m wide and are bordered by ditches. Ditch bank vegetation consists mainly of perennial grasses such as *Elymus repens* and *Festuca rubra*. Two or 3 times a year ditch banks are mown or chopped, and the swath left lying. The most common rotation on the farms is: winter wheat followed by potatoes and a second winter wheat crop and finally sugar beet. The size of most of the fields investigated in this study was 500 x 100 m (average: 5.2 ha). The (clay) soil contains 22.8 $\pm$ 9.0% silt (0-16 μm diam.) and 2.5 $\pm$ 1.0% organic matter. In 1990 6 fields of each crop were investigated, in 1991 8 sugar beet fields, 6 winter wheat fields and 5 potato fields were studied. Along the field edges strips measuring 3 m wide and 100 m long and bordering on the ditches were not sprayed with herbicides or insecticides. Spraying of fungicides was allowed. These compounds are virtually non-toxic to carabids and no side effects on carabid abundance were found in the field. Organophosphate fungicides such as pyrazophos form an exception in this respect. (*cf.* Sotherton *et al.*, 1987), and this compound was not applied. Conventional fertilizing and tillage regimes were maintained in the fields studied.

There are differences in the spraying regime on the farms involved, for example active ingredient, spraying time, frequency etc. However, in winter wheat farmers generally use herbicides twice, once in April and once in May. Insecticides are used 1 or 2 in June against aphids and a mixture of fungicides mostly in June against diseases which cause premature senescence. In sugar beet there are generally 3 herbicide sprayings, from the end of March until mid-May, and 1 to 3 insecticide sprayings from April to July. In sugar beet no fungicides are used. In potatoes finally there is usually 1 herbicide spraying about mid-May, 2 insecticide sprayings in May and June, and about 10 fungicide sprayings from the end of May until harvest, in September. The pesticides most frequently used on the various crops are summarized in Table 1.

Table 1. Most used pesticides in 1990 and 1991 in the various crops in the sprayed edges

	herbicides	insecticides	fungicides
winter wheat	MCPA	dimethoate	propiconazole
	mecoprop	phosphamidon	maneb
	bentazone		prochloraz
	isoproturon		fenpropimorph
sugar beet	ethofumesate	oxydemeton-methyl	-
	phenmedipham	pirimicarb	
	metamitron		
potatoes	metribuzin	parathion	maneb
		dimethoate	

Sampling programme

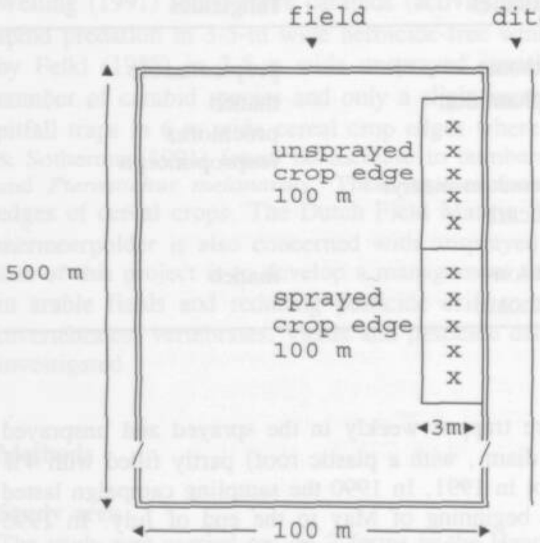
During the growing season carabids were trapped weekly in the sprayed and unsprayed crop edges, using pitfall traps (11.3 cm diam., with a plastic roof) partly filled with 4% formalin in 1990 and 50% ethylene glycol in 1991. In 1990 the sampling campaign lasted 13 weeks, in 1991 12 weeks, from the beginning of May to the end of July. In 1990 sampling in sugar beet and potato fields was continued from the beginning of June to the beginning of September. In 1990 and 1991, respectively 4 and 5 pitfalls were placed 15 m apart along crop edges, 1.5 m from the field edge (see Figure 1). To compare the results of the pitfalls filled with formalin with those filled with ethylene glycol a control experiment was carried out in 1991 in winter wheat and potatoes. At 3 farms a comparison was made between the 2 chemicals, with carabids being trapped for a total of 3 times in June and July: week no. 23, 26 and 29 (5 pitfalls per crop edge). The control experiment showed no significant difference in numbers trapped between the pitfalls with formalin and ethylene glycol ($P > 0.05$, two-tailed two-way ANOVA). However, fewer individuals seem to be caught with ethylene glycol in winter wheat. There was also no significant difference in the number of species trapped, but there appeared to be slightly fewer species in the pitfalls with ethylene glycol ($P = 0.08$). The taxonomy of the carabids follows Lindroth (1974).

To assess weed growth on the sprayed and unsprayed edges, weed coverage and species diversity was measured at the end of June (Braun-Blanquet, sample area 75 m^2). Because of abundant growth on a number of fields, weeds had to be partly removed by hand in some unsprayed edges: in 1990 on 4 crop edges in sugar beet and 3 in winter wheat (in June) and in 1991 on all edges in sugar beet (early July) and 3 in winter wheat (mid-July). In the winter wheat fields only *Matricaria recutita* was removed.

Statistical processing of results

The impact on the total number of individuals (activity density) and the total number of species was assessed by means of a two-tailed two-way ANOVA, summing the data for each pitfall over the entire sampling period. At the species level the number of carabids were averaged per crop edge and the results were processed using the Wilcoxon matched-pairs ranks test, for species found at half or more of the fields.

Figure 1. Sampling of carabids in sprayed and unsprayed crop edges on the fields, x = pitfall trap



Results

On unsprayed field edges average weed coverage was much higher than on sprayed edges (Table 2). In sugar beet crops weed coverage was particularly high. In winter wheat *Matricaria recutita*, *Polygonum aviculare* and *P. convolvulus* predominate, while in sugar beet and potato crops *Chenopodium album* and *P. persica* may also become dominant.

Table 2. Average weed coverage (percentage cover) on sprayed and unsprayed crop edges

	1990 unsprayed	1990 sprayed	1991 unsprayed	1991 sprayed
winter wheat	25	1	30	3
sugar beet	37	7	51	14
potatoes	17	5	9	2

In 1990 a total of 44,233 individuals of 68 carabid species were trapped; in 1991 these figures were 43,243 and 55, respectively. The lower number of species trapped in 1991, may have been due in part to the preservatives used in the pitfalls. Overall, 6 species predominated, together accounting for 82% of the total number of individuals: *Pterostichus melanarius* (31%), *Bembidion tetracolum* (16%), *Nebria brevicollis* (10%), *Trechus quadristriatus* (9%), *Harpalus rufipes* (8%) and *Agonum dorsale* (8%).

Because of the different length of the sampling programs in the 2 years, as well as for the various crops in 1990, due caution should be applied in comparing the 2 years and the 3 crops. Table 3 gives the results for the sprayed and unsprayed edges of the various crops. The greatest number of species and individuals were caught in winter wheat and sugar beet crops, with lower numbers in potatoes. In winter wheat in both years a significant increase was found in the number of individuals in unsprayed edges. In 1 year (1991) also the number of species increased significantly. In sugar beet, a significant increase was found in the number of individuals and the number of species, but only in 1991. In potatoes, finally, a significant effect was found only on the number of species in 1990. In all cases there were significant differences between the locations.

Table 3. Activity density (individuals) and number of species in the various crops in sprayed and unsprayed crop edges in 1990 and 1991. Mean numbers per pitfall ± standard deviation (per crop edge) using two-tailed two-way ANOVA: ** = $P < 0.01$, *** = $P < 0.001$, ns = not significant, n = number of pitfalls

	1990 unsprayed edge	1990 sprayed edge	1991 unsprayed edge	1991 sprayed edge
winter wheat	(n=24)		(n=30)	
individuals	333 ± 94	283 ± 98 **	252 ± 67	183 ± 58 ***
species	22.7 ± 2.5	21.5 ± 2.2 ns	16.5 ± 1.9	14.9 ± 2.9 **
sugar beet	(n=24)		(n=40)	
individuals	367 ± 214	345 ± 269 ns	318 ± 127	236 ± 115 ***
species	16.0 ± 2.5	15.7 ± 3.7 ns	16.1 ± 1.8	14.3 ± 2.7 ***
potatoes	(n=24)		(n=25)	
individuals	247 ± 104	268 ± 115 ns	164 ± 135	157 ± 121 ns
species	14.0 ± 2.4	11.8 ± 2.3 **	9.5 ± 1.8	9.4 ± 2.3 ns

Figure 2 shows the variation in time in the number of individuals trapped. The pattern of trappings was very different in the 2 years. In winter wheat in 1990 a large number of carabids was trapped at the beginning of the sampling campaign, in 1991 at the end. The peak in 1990 is due almost entirely to the number of *Nebria brevicollis* in the pitfalls. In 1991 there is similarity among the patterns for the various crops, in each crop there was a peak in the number of carabids trapped around mid-June and in the second week of July. In 1991 there was a difference in carabid activity density on sprayed and unsprayed strips throughout the season in sugar beet and winter wheat.

The impact on the different crops at species level is given in Tables 4, 5 and 6. These tables show the dominant species as well as the species present at at least half the sampling sites and with a significantly higher activity density on unsprayed crop edges.

Figure 2. Average number of carabids trapped per pitfall per week in sprayed and unsprayed edges of winter wheat, sugar beet and potatoes in 1990 and 1991. In 1990: 4 pitfalls per crop edge, in 1991: 5 pitfalls per crop edge. Dotted lines = unsprayed situation, continous lines = sprayed situation, n = number of fields

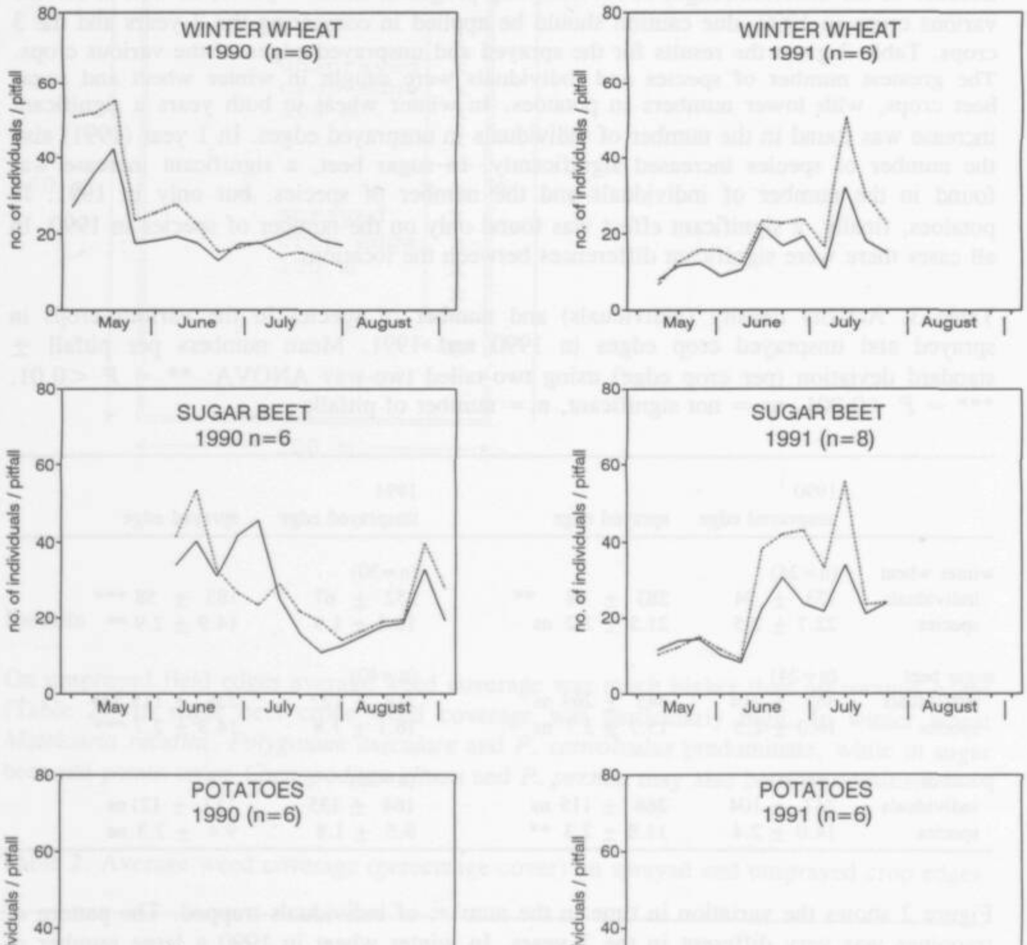


Table 4. Mean number of carabids per pitfall ± standard deviation (per crop edge) of dominant species, or species found at half or more the sampling sites with significant difference in sprayed and unsprayed *winter wheat* crop edges in 1990 and 1991. Two-tailed Wilcoxon matched-pairs ranks test: * = $P < 0.05$; ** = $P < 0.01$; ns = not significant; - = not tested: species present on less than 50% of the fields; n = no. of fields. Carabid taxonomy follows Lindroth (1974)

WINTER WHEAT	1990 (n=6)			1991 (n=6)		
	unsprayed	sprayed	test	unsprayed	sprayed	test
Nebria brevicollis	82.0 ± 74.8	37.3 ± 32.9	ns	35.3 ± 27.1	29.0 ± 26.2	ns
Loricera pilicornis	18.9 ± 15.1	22.8 ± 22.4	ns	4.9 ± 5.3	3.0 ± 3.7	ns
Trechus quadristriatus	6.2 ± 4.0	8.0 ± 7.4	ns	6.4 ± 4.0	11.5 ± 7.6	ns
Bembidion lampros	4.5 ± 3.8	6.4 ± 4.1	ns	2.0 ± 1.6	1.6 ± 1.7	ns
Bembidion tetracolum	56.4 ± 28.1	53.3 ± 25.3	ns	39.2 ± 31.2	31.1 ± 14.4	ns
Pterostichus melanarius	28.3 ± 20.9	43.7 ± 46.3	ns	68.1 ± 38.7	51.2 ± 43.9	ns
Pterostichus niger	2.5 ± 1.4	2.5 ± 1.9	ns	4.5 ± 5.0	5.1 ± 7.0	ns
Agonum dorsale	61.9 ± 30.3	46.3 ± 33.8	ns	40.5 ± 29.5	24.8 ± 26.0	ns
Amara aenea	10.3 ± 9.2	6.2 ± 7.4	ns	3.2 ± 5.1	0.4 ± 0.4	*
Amara apricaria	0.6 ± 0.5	0.2 ± 0.2	ns	0.4 ± 0.4	0.3 ± 0.4	ns
Amara bifrons	0.2 ± 0.2	<0.1 ± 0.1	*	0.2 ± 0.2	0	*
Amara familiaris	2.5 ± 3.7	0.4 ± 0.4	*	0	<0.1 ± 0.1	-
Amara similata	15.2 ± 11.7	3.3 ± 3.9	*	5.8 ± 7.0	0.9 ± 0.8	ns
Harpalus aeneus	11.3 ± 9.0	9.3 ± 2.9	ns	9.2 ± 10.0	2.6 ± 1.6	*
Harpalus rufipes	9.8 ± 7.8	14.3 ± 14.9	ns	15.9 ± 6.8	8.5 ± 3.5	*

Table 5. Mean number of carabids per pitfall ± standard deviation (per crop edge) of dominant species found at half or more the sampling sites with significant difference in sprayed and unsprayed *sugar beet* crop edges in 1990 and 1991. Legend see Table 4.

SUGAR BEET 1	990 (n=6)			1991 (n=8)		
	unsprayed	sprayed	test	unsprayed	sprayed	test
Nebria brevicollis	15.6 ± 20.6	11.5 ± 13.4	ns	34.2 ± 50.2	24.3 ± 41.9	ns
Loricera pilicornis	1.9 ± 1.5	1.6 ± 2.1	ns	0.1 ± 0.1	0.3 ± 0.4	ns
Trechus quadristriatus	32.1 ± 29.6	30.1 ± 25.5	ns	36.2 ± 44.2	36.9 ± 43.4	ns
Bembidion lampros	25.8 ± 41.9	15.4 ± 27.3	*	5.1 ± 2.9	4.4 ± 3.6	ns
Bembidion tetracolum	34.8 ± 32.4	84.0 ± 170.5	ns	48.5 ± 29.7	54.9 ± 43.9	ns
Pterostichus melanarius	129.1 ± 151.1	125.0 ± 155.6	ns	75.3 ± 86.1	49.0 ± 47.8	*
Pterostichus niger	11.3 ± 7.4	11.7 ± 8.1	ns	2.3 ± 2.5	1.4 ± 2.2	ns
Agonum dorsale	8.8 ± 8.3	2.8 ± 3.4	*	36.8 ± 33.9	17.6 ± 24.2	**
Amara aenea	0.2 ± 0.2	0.4 ± 0.6	ns	2.6 ± 3.4	0.9 ± 1.3	*
Amara apricaria	5.4 ± 6.1	2.5 ± 3.2	*	0.4 ± 0.2	0.1 ± 0.1	*
Amara bifrons	0.8 ± 0.6	0.7 ± 0.8	ns	0.4 ± 0.4	0.1 ± 0.2	*
Amara familiaris	0	0	-	0.1 ± 0.1	0	-
Amara similata	1.4 ± 1.6	0.8 ± 0.9	ns	9.7 ± 13.7	3.3 ± 4.9	**
Harpalus aeneus	19.4 ± 10.9	11.4 ± 8.1	*	24.1 ± 13.8	14.4 ± 6.7	*
Harpalus rufipes	66.2 ± 40.9	34.2 ± 18.9	*	25.7 ± 17.8	16.3 ± 16.2	*

Table 6. Mean number of carabids per pitfall ± standard deviation (per crop edge) of dominant species, or species found at half or more the sampling sites with significant difference in sprayed and unsprayed *potato* crop edges in 1990 and 1991. Legend see Table 4.

POTATOES	1990 (n=6) unsprayed	1990 sprayed	test	1991 (n=5) unsprayed	1991 sprayed	test
Nebria brevicollis	11.8 ± 14.9	7.4 ± 8.2	ns	5.0 ± 3.0	4.6 ± 1.5	ns
Loricera pilicornis	0.1 ± 0.1	0.3 ± 0.2	ns	<0.1 ± 0.1	0	-
Trechus quadristriatus	43.5 ± 40.7	39.1 ± 35.6	ns	19.5 ± 22.7	14.0 ± 14.2	ns
Bembidion lampros	1.3 ± 1.3	1.3 ± 1.8	ns	5.0 ± 9.8	3.0 ± 5.8	ns
Bembidion tetracolum	18.8 ± 31.5	15.1 ± 19.5	ns	29.1 ± 32.7	31.4 ± 40.8	ns
Pterostichus melanarius	100.1 ± 60.7	138.5 ± 92.9	ns	91.6 ± 139.6	91.9 ± 122.5	ns
Pterostichus niger	8.8 ± 9.2	12.0 ± 12.8	ns	1.2 ± 1.8	1.0 ± 0.6	ns
Agonum dorsale	2.5 ± 2.3	2.3 ± 4.3	ns	1.0 ± 1.1	0.8 ± 0.7	ns
Amara aenea	0.2 ± 0.2	0.1 ± 0.2	ns	0.1 ± 0.1	0.1 ± 0.1	ns
Amara apricaria	0.9 ± 0.9	<0.1 ± 0.1	*	0.3 ± 0.6	<0.1 ± 0.1	-
Amara bifrons	1.2 ± 1.6	0.6 ± 0.6	ns	0.1 ± 0.1	0.1 ± 0.3	-
Amara familiaris	0	0	-	0	<0.1 ± 0.1	-
Amara similata	0.8 ± 0.6	0.3 ± 0.3	ns	0.2 ± 0.3	0.2 ± 0.2	ns
Harpalus aeneus	9.5 ± 7.3	11.7 ± 11.6	ns	4.6 ± 6.4	4.2 ± 3.9	ns
Harpalus rufipes	38.8 ± 34.2	31.9 ± 38.3	ns	3.9 ± 5.4	3.1 ± 4.9	ns

Although there are major differences between the 2 years, it can still be concluded that some species show a preference for certain crops. In winter wheat relatively large numbers of *Loricera pilicornis*, *Agonum dorsale* and various *Amara* species were found, in potatoes and sugar beet large numbers of *Trechus quadristriatus* and *Pterostichus melanarius*. Compared to the sprayed edge, in winter wheat, a statistically significant increase in activity density was found 1990 for 3 carabid species and in 1991 for 4 species (Table 4). The effects were found only for species of the genera *Amara* and *Harpalus*. In sugar beet (Table 5) in 1990 there was a significant increase in 5 species and in 1991 in 8 species. Again most of these species belong to the genera *Amara* and *Harpalus*, but effects were also found on *Bembidion Lampros*, *Agonum dorsale* and *Pterostichus melanarius*. In potatoes (Table 6) only in 1990 was a statistically significant increase found in *Amara apricaria*. Some species were trapped much less frequently in the unsprayed margins, such as *Bembidion lampros* and *Trechus quadristriatus* in winter wheat, however, these effects were not statistically significant. Overall, of all 10 species showing a significant increase in one or more crops or years, there were 7 *Amara* or *Harpalus* species. It is interesting that the species in these genera are herbivorous, and that there seems to be a relation between the number of species showing significant effects and the percentage weed cover in the various crops and years (see also Table 2).

Discussion

The results of this study show that in unsprayed winter wheat crop edges more carabid individuals, and in one year more carabid species were caught than in the sprayed crop edges. Also in sugar beet in 1991 more individuals and species were caught in the unsprayed edges. With respect to individual species, too, the greatest impact was seen in these crops. In potatoes the average number of species was affected in 1990 only. It can be concluded that with all 3 crops unsprayed edges only 3 metres wide can have a positive effect on carabids.

The changes in the carabid fauna may be due to direct toxic pesticide effects, on the one hand, and indirect (ecological) effects such as the disappearance of prey or changes in habitat, on the other. Insecticides, in particular, may have a toxic impact on carabids. Sensitivity varies from species to species, however, and there is a very wide range of toxicity depending on the compound involved (Edwards & Thompson, 1975; Förster, 1991). Moreover, the degree of exposure depends on the habits of the species (Dixon & McKinlay, 1992). Because the weed vegetation becomes very dense in the unsprayed edges, the microclimate also changes. Felkl (1988) found a lower soil temperature and higher humidity in unsprayed field edges. This can have a major impact on species composition (Wallin, 1986; Quinn *et al.*, 1991). Because both direct and indirect effects may be involved, and because different pesticides were used at different times on the various farms, no attempt has been made to establish a direct relationship between spraying regimes and carabid activity density. But it should be remarked that in some crops there was already a difference in activity density before insecticide spraying, due possibly to herbicides applied earlier in the season. It is also noteworthy that it was above all the numbers of *Amara* and *Harpalus* species that increased. The abundance of these species correlates with the weed density (Kokta & Niemann, 1990; Basedow *et al.*, 1991; Welling *et al.*, 1988). Prevalence of *Agonum dorsale* is likewise positively influenced by the presence of weeds (Coombes & Sotherton, 1986). It is possible that the high activity density of phytophagous carabids could play a role in the natural control of weed seeds in the unsprayed edges (*cf.* Welling *et al.*, 1988; Kokta, 1988). The variation in weed cover may possibly also explain the differences in carabid activity density among the various crops or within a given crop (sugar beet, for example). The significance of the higher activity density of carabids in unsprayed crop edges in relation to aphid predation is not entirely clear. Although Storck-Weyhermüller & Welling (1991) found generally less aphid predation in the sprayed cereal edges, as a result of all predators, Chiverton & Sotherton (1991) demonstrated that carabids in the unsprayed cereal edges consumed less aphids, because of greater variation in prey.

Because pitfall traps were used in the study, trapping success was also determined by carabid activity and species trappability (*cf.* Sunderland *et al.*, 1995). This may in turn be affected by pesticide application, with more carabids being caught post-spraying due to greater activity resulting from food shortages or a more open habitat in sprayed fields (Chiverton, 1984; Basedow *et al.*, 1991; Dixon & Mckinlay, 1992). It is therefore possible that the use of pitfalls has under-estimated the differences in density between the sprayed and unsprayed edges. Although in the present study a higher activity density was generally measured in the unsprayed crop edges, the results should be interpreted with due care.

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References

Basedow, Th., C. Braun, A. Lühr, J. Naumann, T. Norgall & G. Yanes Yanes, 1991. Abundanz, Biomassa und Artenzahl epigaïscher Raubarthropoden auf unterscheidlich intensiv bewirtschafteten Weizen- und Rübenfeldern: Unterschied und ihre Ursachen. Ergebnisse eines dreistufigen Vergleichs in Hessen, 1985 bis 1988. Zool. Jb. Syst 118: 87-116.

Chiverton, P.A., & N.W. Sotherton, 1991. The effects on beneficial arthropods of ex clusion of herbicides from cereal crop edges. J. Appl. Ecol. 28: 1027-1039.

Chiverton, P.A., 1984. Pitfall catches of the carabid beetle *Pterostichus melanarius*, in relation to gut content and prey densities, in insecticide treated and untreated spring barley. Entomol. Exp. Appl. 36: 23-30.

Coombes, D.S. & N.W. Sotherton, 1986. The dispersal and distribution of polyphagous predatory Coleoptera in cereals. Ann. Appl. Biol. 108: 461-474.

Dixon, P.L. & R.G. McKinlay, 1992. Pitfall catches of and aphid predation by *Pterostichus melanarius* and *Pterostichus madidus* in insecticide treated and untreated potatoes. Entomol. Exp. Appl. 64: 63-72.

Dritschilo, W. & D. Wanner, 1980. Ground beetle abundance in organic and conventio nal corn fields. Environm. Entomol. 9 (5): 629-631.

Edwards, C.A. & A.R. Thompson, 1975. Some effects of insecticides on predatory beetles. Proc. Ass. Appl. Biol. 80: 132-135.

Edwards, C.A., K.D. Sunderland & K.S. George, 1979. Studies on polyphagous predators of cereal aphids. J. Appl. Ecol. 16: 811-823.

Felkl, G., 1988. Erste Untersuchungen über die Abundanz von epigaïschen Raubarthropo den, Getreide Blattläusen und stenophagen Blattlausprädatoren in herbizidfreien Winterweizen-Ackerrandstreifen in Hessen. Gesunde Pflanzen 40 (12): 483-491.

Förster, P., 1991. Einfluss von Pflanzenschutzmitteln auf Larven und Adulte von *Platynus dorsalis* (Pont.) (Col., Carabidae) und Adulte von *Tachyporus hypnorum* (L.) (Col., Staphylinidae) in Labor- und Halbfreilandversuchen. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz 98 (5): 457-463.

Haccou, R. & E. Meelis, 1992. Statistical analysis of behavioural data. Institute of Theoretical Biology Leiden University, Oxford University Press.

Hassall, M., A. Hawthorne, M. Maudsley, P. White & C. Cardwell, 1992. Effects of headland management on invertebrate communities in cereal fields. Agriculture, Ecosystems and Environment 40: 155-178.

Hill, D.A., 1985. The feeding ecology and survival of pheasant chicks on arable farmland. J. Appl. Ecol. 22: 645-654.

Kokta, Ch., 1988. Beziehungen zwischen der Verunkrautung und Phytophagen Laufkäfern der Gattung *Amara*. Mitt. Biol. Bundesanst. Land- und Forstwirtschaft 247: 139-145.

Kokta, Ch. & P. Niemann, 1990. Wechselwirkungen zwischen Produktionsintensität und Aktivitätsdichte von Laufkäfern in einer dreiliedrigen Fruchtfolge. DFG-Forschungsbericht "Integrierte Pflanzenproduktion": Weinheim: 126-139.

Lindroth, C.H., 1974. Handbooks for identification of British insects: Coleoptora, Carabidae. Vol. IV part 2, Royal Entomological Society of London, London, 148 pp.
Luff, M.L., 1982. Population dynamics of Carabidae. Ann. Appl. Biol. 101:164-170.
Meerjarenplan Gewasbescherming (MJP-G), 1991. Regeringsbeslissing. Tweede Kamer, vergaderjaar 1990-1991, 21 677, nrs. 3-4. SDU uitgeverij, Den Haag.
Quinn, M.A., R.L. Kepner, D.D. Walgenbach, R. Nelson Foster, R.A. Bohls, P.D. Pooler, K.C. Reuter & J.L. Swain, 1991. Effect of habitat characteristics and perturbation from insecticides on the community dynamics of groud beetles (Coleoptera: Carabidae) on mixed-grass rangeland. Environ. Entomol. 20 (5): 1285-1294.
Riedel, W., 1991. Overwintering and spring dispersal of *Bembidion lampros* (Coleoptera: Carabidae) from established hibernation sites in a winter wheat field in Denmark. In: Behaviour and Impact of Aphidophaga: 235-241. Ed. L. Polgár, R.J. Chambers, A.F.G. Dixon & I. Hodek. Academic Publishing bv, The Hague, The Netherlands.
Sotherton, N.W., 1984. The distribution and abundance of predatory arthropods overwin tering on farmland. Ann. Appl. Biol. 105: 423-429.
Sotherton, N.W., S.J. Moreby & M.G. Langley, 1987. The effects of the foliar fungicide pyrazophos on beneficial arthropods in barley fields. Ann. Appl. Biol. 111: 75-87.
Storck-Weyhermüller S. & M. Welling, 1991. Regulationsmöglichkeiten von Schad- und Nutzarthropoden im Winterweizen durch Ackerschonstreifen. Mitt. Biol. Bundesanst. Land-Forstwirtschaft. Berlin-Dahlem. Heft 273 Berlin.
Sunderland, K.D. & G.P. Vickerman, 1980. Aphid feeding by some polyphagous predators in relation to aphid density in cereal fields. J. Appl. Ecol. 17: 389-396.
Sunderland, K.D, G.R. de Snoo, A. Dinter, T. Hance, J. Helinius, P. Jepson, D. Kromp, F. Samu, N.W. Sotherton, S. Toft, B. Ulber, 1995
Density estimation for benificial predators in agro-ecosystems. Acta Jutlandica 1995, in press.
Vickerman, G.P. & K.D. Sunderland, 1977. Some effects of dimethoate on arthropods in winter wheat. J. Appl. Ecol. 14: 767-777.
Wallin, H., 1986. Habitat choice of some field-inhabiting carabid beetles (Coleoptera: Carabidae) studied by recapture of marked individuals. Ecol. Entomol. 11: 457-466.
Welling, M., R.A. Pötzl & D. Jürgens, 1988. Untersuchungen in Hessen über Auswir kung und Bedeutung von Ackerschonstreifen. 3: Epigäische Raubarthropoden. Mitt. Biol. Bundesanst. Land- und Forstwirtschaft 247: 55-63.

10 Effects of unsprayed crop edges on farmland birds

G.R. de Snoo, R.T.J.M. Dobbelstein & S. Koelewijn

Abstract

In 1992 and 1993 the abundance of three farmland bird species, Motacilla flava flava, Alauda arvensis and Anthus pratensis in sprayed and unsprayed edges of winter wheat fields was investigated. Compared with the sprayed crop edges, the number of visits of Motacilla flava flava was significantly 3 - 4.5 times higher on the unsprayed edges. There was no difference in the frequency of visits for the other two species. The number of territories of Motacilla flava flava per hectare correlates with the percentage area of winter wheat on the farms.

Introduction

Over the past few decades there has been a substantial decline in the number of farmland birds in the Netherlands (Kwak *et al.*, 1988). This may be due in part to the use of herbicides and insecticides on arable land. In addition to direct effects there may also be indirect effects, for example resulting from changes in food abundance (*cf.* De Snoo & Canters, 1990). It has been demonstrated that leaving the edges of cereal fields unsprayed benefits populations of gamebirds such as *Perdix perdix* (Partridge) and *Phasianus colchicus* (Pheasant), because the greater abundance of insects in the unsprayed crop edges benefits chick survival (Rands, 1985; 1996). In the present study it was investigated whether unsprayed crop edges also attract small songbirds such as *Motacilla flava flava* (Blue-headed wagtail), *Alauda arvensis* (Skylark) and *Anthus pratensis* (Meadow pipit). *Motacilla flava flava* and *Anthus pratensis* are both insectivores, while *Alauda arvensis* is also partly herbivorous eating weed seeds, seedling cotyledons and leaves from weeds and crop (Cramp, 1988; Green, 1978; 1980). The research is part of the Dutch Field Margin Project being undertaken in the Haarlemmermeerpolder. The aim of this project is to develop a management strategy for promoting nature conservation in arable fields and reducing pesticide drift to non-target areas. Effects on weeds, invertebrates, vertebrates, pesticide drift and costs to the farmer are being studied.

Methods

The research was conducted in the Haarlemmermeerpolder (clay soil) in 1992 and 1993. In this polder most parcels of land are 1000 m long and 200 m wide and are bordered by ditches. The most common rotation on the farms was: winter wheat, followed by potatoes, a second winter wheat crop, and finally sugar beet. The study was carried out on 8 farms in 1992 and on 7 farms in 1993. In 1 winter wheat field at each farm a 6-metre wide crop edge bordering on a ditch was left unsprayed; these crop edges had a mean length of 424 ± 116 m. The total length of unsprayed crop edge was 3790 m in

1992 and 2560 m in 1993. No herbicides or insecticides were used on these margins. Spraying with fungicides was allowed, but no organophosphate fungicides were used. The unsprayed edges were compared with sprayed edges which were generally in the same field. On the unsprayed crop edges weed coverage increased substantially, as did the overall number of weed species. Dominant species include *Matricaria recutita*, *Polygonum aviculare* and *P. convolvulus*.

The number of farmland birds frequenting the crop edges was determined in a linear transect census (strip census; Hustings *et al.*, 1989), with all birds visiting a sprayed or unsprayed edge being recorded (ground contact). In 1993 a census was also made of the number of birds visiting an imaginary strip in the centre of each field and visiting the other side of the field. A census was additionally carried out of the number of birds sighted across the ditch on the adjacent field, where in most cases the crop was potatoes or sugar beet rather than winter wheat. All the strips recorded had the same area. In 1992 10 census sessions were performed on each farm between 08.30 h and 14.30 h in the period from 26 May to 7 July. In 1993 a weekly census was undertaken between 15 April and 15 July, with 5 sessions being held at each farm between 06.00 h and 09.00 h and 7 sessions between 09.00 h and 16.15 h Central European Time.

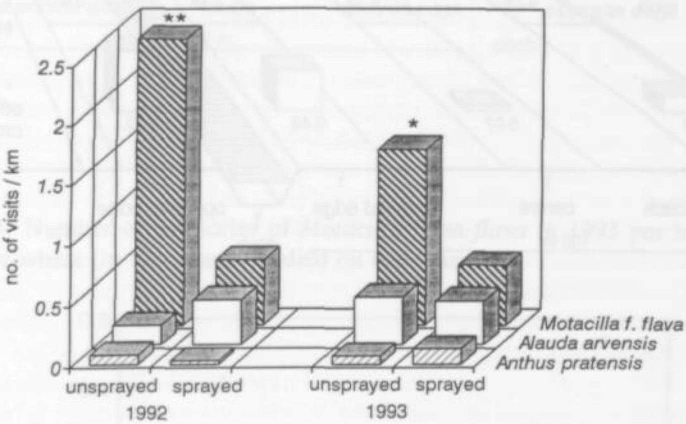
In 1993, at the same time as the strip census, for each species of bird the number of territories was determined in the entire winter wheat field as well as in the first 100 m of each adjacent field. The area recorded on each farm had an average size of 27.8 $\pm$ 6.9 ha. In preparing the territory maps, both territory-indicative and nest-indicative sightings were used (SOVON, 1985). A positive territory indication was recorded only for conclusive observations or concentrations of very widely distributed observations that fell within the valid date limits for the species in question. Finally, in 1993 a number of individuals of *Motacilla flava flava*, *Alauda arvensis* and *Anthus pratensis* was observed in order to study differences in feeding behaviour in sprayed and unsprayed crop edges. To this end, between 08.00 h and 14.45 h from 4 June to 16 July a total of 15 birds were observed for more than 1 hour on 6 farms from an observation post camouflages with a net. A record was made of the time spent by the birds on the following activities; flying, singing, feeding, resting and 'unseen field presence' (= bird present in the field but not visible).

Results

Major differences were found in the presence of the 3 species on the crop edges. *Motacilla flava flava* was most frequently observed. In 1992 a total of 110 visits by this species to sprayed and unsprayed edges was recorded; in 1993 this figure was 60. *Alauda arvensis* was recorded 20 and 23 times in these 2 years, respectively, and *Anthus pratensis* only 4 and 6 times. In the 2 years of study the total number of visits by *Motacilla flava flava* (Figure 1) to the unsprayed crop edges was significantly higher than in the sprayed edges (significant difference P = 0.007 in 1992 and P = 0.03 in 1993; Wilcoxon paired sample test). The difference was greater by a factor of 3 to 4.5 in the unsprayed edges. In the 2 years the average number of visits by *Motacilla flava flava* per km crop edge was 2.37 and 1.46, respectively, in the unsprayed margins as compared with 0.53 and 0.49 in the sprayed margins. Throughout the census period of both years the number of visits by *Motacilla flava flava* was consistently higher in unsprayed edges, with the exception of 1 census session in 1993.

In the case of *Alauda arvensis* and *Anthus pratensis*, in neither year there was a significant difference in species abundance in sprayed and unsprayed edges. The greatest number of visits to crop edges was 0.39 per km for *Alauda arvensis* and 0.13 per km for *Anthus pratensis*. It is noteworthy that 3 of the 6 sightings of *Anthus pratensis* were during the first census session and that 4 birds were observed on just 1 farm.

Figure 1. Number of visits by bird species per km in sprayed and unsprayed winter wheat edges in 1992 and 1993 (* = $P < 0.05$; ** = $P < 0.01$; Wilcoxon paired sample test)

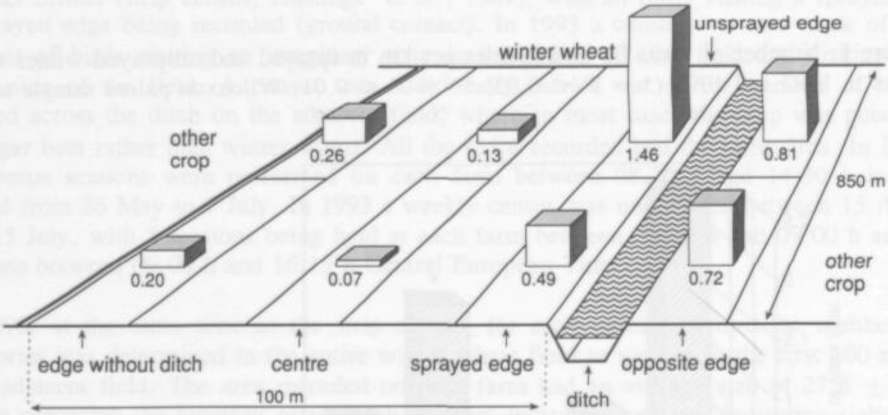


An analysis of species abundance over the entire plot indicated that the number of visits by *Motacilla flava flava* and *Alauda arvensis* to field edges was greater than that to the plot centre (Figure 2). This also seemed to be the case for *Anthus pratensis* but the number of observations was very small. The count was also higher for visits to sprayed edges bordering on a ditch than to sprayed edges directly adjacent to a second plot.

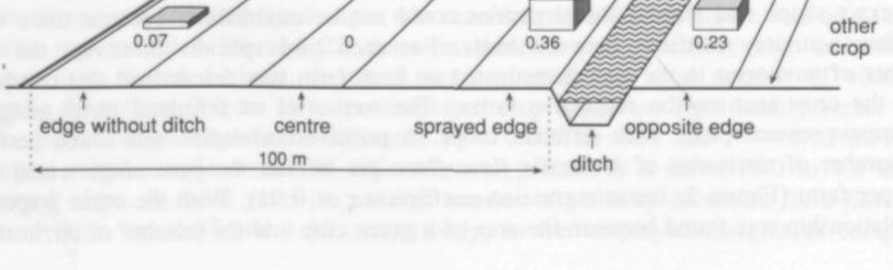
The exact shape and size of the territories could not be established, because there were too few boundary conflicts between birds. For each bird species, however, the total number of territories in the area investigated on each farm was determined and compared with the crop area on the respective farms. The territories of farmland birds generally encompass several plots, with different crops. A positive correlation was found between the number of territories of *Motacilla flava flava* per ha and the percentage wheat crop area per farm (Figure 3; linear regression coefficient r = 0.91). With the other 2 species, no relationship was found between the area of a given crop and the number of territories.

Figure 2. Total number of visits of bird species per km during the 1993 season in the various parts of the fields; 2A = *Motacilla flava flava*, 2B = *Alauda arvensis* and 2C = *Anthus pratensis*

2a. *Motacilla flava flava*



2b. *Alauda arvensis*



2c. *Anthus pratensis*

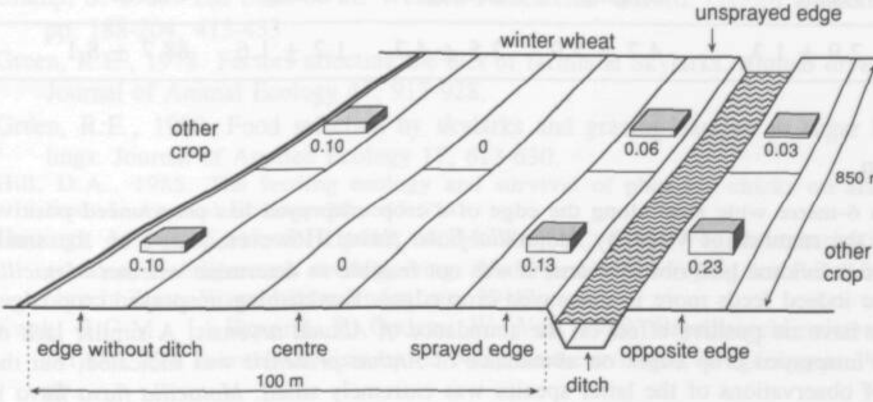
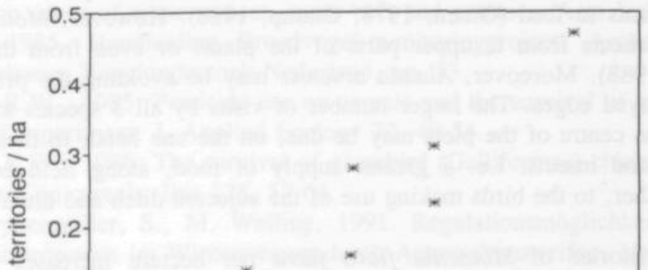


Figure 3. Number of territories of *Motacilla flava flava* in 1993 per ha compared to area of winter wheat (in %) in area studied on each farm



The results of the observations of individuals of *Motacilla flava flava* are shown in Table 1. For the larger part of the observation period this species had an 'unseen field presence', and consequently during this period no definite conclusions could be drawn as to activities. Feeding could be observed during a number of brief periods only. *Motacilla flava flava* was observed to feed both on the ground and on the crop itself. Because of the limited number of observations, no difference could be observed in the length of time spent feeding in sprayed versus unsprayed crop edges. Neither *Alauda arvensis* nor *Anthus pratensis* were observed to feed.

Table 1. Mean percentage of total time spent on each activity by *Motacilla flava flava*

Activity	Flying	Singing	Resting	Feeding	Unseen
% time	2.9 ± 1.3	4.7 ± 5.9	2.5 ± 4.2	1.2 ± 1.6	88.7 ± 8.1

Discussion

Leaving a 6-metre wide strip along the edge of a crop unsprayed has pronounced positive effect on the number of visits by *Motacilla flava flava*. However, based on the small number of individual bird observations, it was not feasible to determine whether *Motacilla flava flava* indeed feeds more in unsprayed crop edges. Establishing unsprayed crop edges seemed to have no positive effect on the abundance of *Alauda arvensis*. A similar lack of effects of unsprayed crop edges on abundance of *Anthus pratensis* was indicated, but the number of observations of the latter species was extremely small. *Motacilla flava flava* is insectivorous, and insects such as Heteroptera, Chrysomelidae, Curculionidae and Carabidae are generally more abundant in unsprayed winter wheat edges (Rands, 1985; Storck-Weyhermüller & Welling, 1991 *etc.*). In our study area the most marked effects in the unsprayed edges were found on invertebrates which live on plants. The effects on soil invertebrates were only small (De Snoo, 1993; De Snoo *et al.*, 1995). The difference between *Motacilla flava flava* and *Alauda arvensis* may be explained since the latter species is partly herbivorous and threre is a difference in feeding strategy: *Alauda arvensis* walks the ground feeding from the soil surface and the lower parts of plants, but never perches on plants to feed (Green, 1978; Cramp, 1988). However, *Motacilla flava flava* will also eat insects from te upper parts of the plants or even from the air (fly-catching) (Cramp, 1988). Moreover, *Alauda arvensis* may be avoiding the profuse weed growth in the unsprayed edges. The larger number of visits by all 3 species to the edges as compared with the centre of the plots may be due, on the one hand, to there naturally being more weeds and insects, i.e. a greater supply of food, along field edges (Hill, 1985) and, on the other, to the birds making use of the adjacent ditch and ditch banks.

The number of territories of *Motacilla flava flava* per hectare increases more than proportionally with the area of wheat per ha, a doubling of the percentage area of wheat giving 2.6 times more territories (Figure 4). The fact that this species benefits greatly from cultivation of this particular crop and, moreover, shows far greater abundance after establishing unsprayed crop edges makes it attractive to opt for this crop if the aim is to increase nature conservation of arable land. In addition leaving the winter wheat crop edge unsprayed is economically viable (De Snoo, 1994).

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References

Cramp, S. 1988. The birds of the Western Palaearctic. Oxford: Oxford University Press, pp. 188-204, 413-433.

Green, R.E., 1978. Factors affecting the diet of farmland Skylarks, *Alauda arvensis*. Journal of Animal Ecology 47, 913-928.

Green, R.E., 1980. Food selection by skylarks and grazing damage to sugar beet seedlings. Journal of Applied Ecology 17, 613-630.

Hill, D.A., 1985. The feeding ecology and survival of pheasant chicks on arable farmland. J. Applied Ecology 22, 645-654.

Hustings, M., R. Kwak, P. Opdam, & M. Reijnen, 1989. Vogelinventarisatie. Achtergronden, richtlijnen en verslaggeving. Nederlandse Vereniging tot Bescherming van Vogels Zeist, Wageningen: Pudoc, pp. 39-43.

Kwak, R.G.M., L. Reyrink, P. Opdam, W. Vos, 1988. Broedvogeldistricten van Nederland. Een ruimtelijke visie op de Nederlandse avifauna. Wageningen: Pudoc, 143 pp.

Snoo, G.R. de, 1993. Onbespoten akkerranden in de Haarlemmermeerpolder. Landinrichting 33 (4), 31-34.

Snoo, G.R. de, 1994. Cost-benefits of unsprayed crop edges in winter wheat, sugar beet and potatoes. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 197-201.

Snoo, G.R. de, K.J. Canters, 1990. Side-effects of pesticides on terrestrial vertebrates. CML reports 35, Centre of Environmental Science, Leiden University, pp. 147.

Snoo, G.R. de, R.J. van der Poll & J. de Leeuw, 1995. Carabids in sprayed and unsprayed crop edges of winter wheat, sugar beet and potatoes. Acta Jutlandica in press.

SOVON, 1985. Handleiding Broedvogel-monitoringproject. Arnhem: Samenwerkende Organisaties Vogelonderzoek Nederland, pp. 73.

Rands, M.R.W., 1985. Pesticide use on cereals and the survival of grey partridge chicks: a field experiment. J. Applied Ecology 22, 49-54.

Rands, M.R.W., 1986. The survival of gamebird (Galliformes) chicks in relation to pesticide use on cereals. Ibis 128, 57-64.

Storck-Weyhermüller, S., M. Welling, 1991. Regulationsmöglichkeiten von Schad- und Nutzarthropoden im Winterweizen durch Ackerschonstreifen. Mitt. Biol. Bundesanst. Land-Forstwirtschaft. Berlin-Dahlem. Heft 273 Berlin.

11 Additional observations: epigeïc soil-invertebrates and small mammals

Epigeic soil invertebrates

In Chapter 9 a comparison was made between the abundance and diversity of Carabidae in sprayed and unsprayed crop edges. As a follow-on study it was investigated to what extent there were differences in the occurrence of other groups of epigeic soil invertebrates in the two types of margin. To this end, all the invertebrates caught in the pitfalls were identified at the order level and counted. For the experimental design, see Chapter 9. In this case, however, only 4 pitfalls per margin were studied, over a period of only 9 weeks: in 1992 from 29-05 to 31-07 and in 1991 from 01-05 to 24-07.
The invertebrates trapped were from 14 groups, *viz.:* Oligochaeta, Isopoda, Chilopoda, Diplopoda, Araneida, Opilionida, Heteroptera, Homoptera, Neuroptera, Lepidoptera, Diptera, Hymenoptera, Coleoptera and Stylommatophora.

The pitfall observations indicated that 95% of all individuals caught belonged to the following groups: Coleoptera (mainly Carabidae and Staphiliidae), Araneida (mainly Liniphidae), Diptera and Hymenoptera. For these groups, the effects of spraying were investigated. The results are shown in Figure 1.

It was found that in virtually no case there was a significant difference between the number of individuals trapped in sprayed and unsprayed edges. Only in 1991 were Araneida found more frequently in the unsprayed winter wheat edges and Coleoptera in the unsprayed sugarbeet edges. The difference relative to the sprayed edges was only small, however: by a factor of about 1.2.

Small mammals

To a limited extent, the abundance of small mammals in sprayed and unsprayed crop edges was also investigated in the study. In the period 1990-1992 rodents were regularly found in the pitfalls used for inventorying the epigeic soil invertebrates (for experimental design, see Chapter 9). In 1993 rodents were captured intentionally on a minor scale using live traps in winter wheat (3 farms; 10 live traps per edge; trapping period 09-07 to 15-07-1993; 3 nights pre-baiting, 3 12-hour trapping nights; bait: apple, winter carrot, oatmeal and hay).
The vast majority of the rodents were identified as Common voles (*Microtus arvalis*). Only in 1990, in the unsprayed winter wheat, were 2 Long-tailed field mice (*Apodemus sylvaticus*) also trapped. In 1993 1 Common shrew (*Sorex araneus*) was captured in a live trap, in both the sprayed and unsprayed edges. In that year 2 Long-tailed field mice and 1 Common vole were also captured in the unsprayed edges. The results of the rodent trappings are shown in Table 1.

Figure 1. Numbers of Coleoptera (Coleopt.), Araneida, Diptera and Hymenoptera (Hymenopt.) in 1990 and 1991 trapped in pitfalls in sprayed and unsprayed edges. * = $P < 0.05$, Wilcoxon matched-pairs signed ranks test

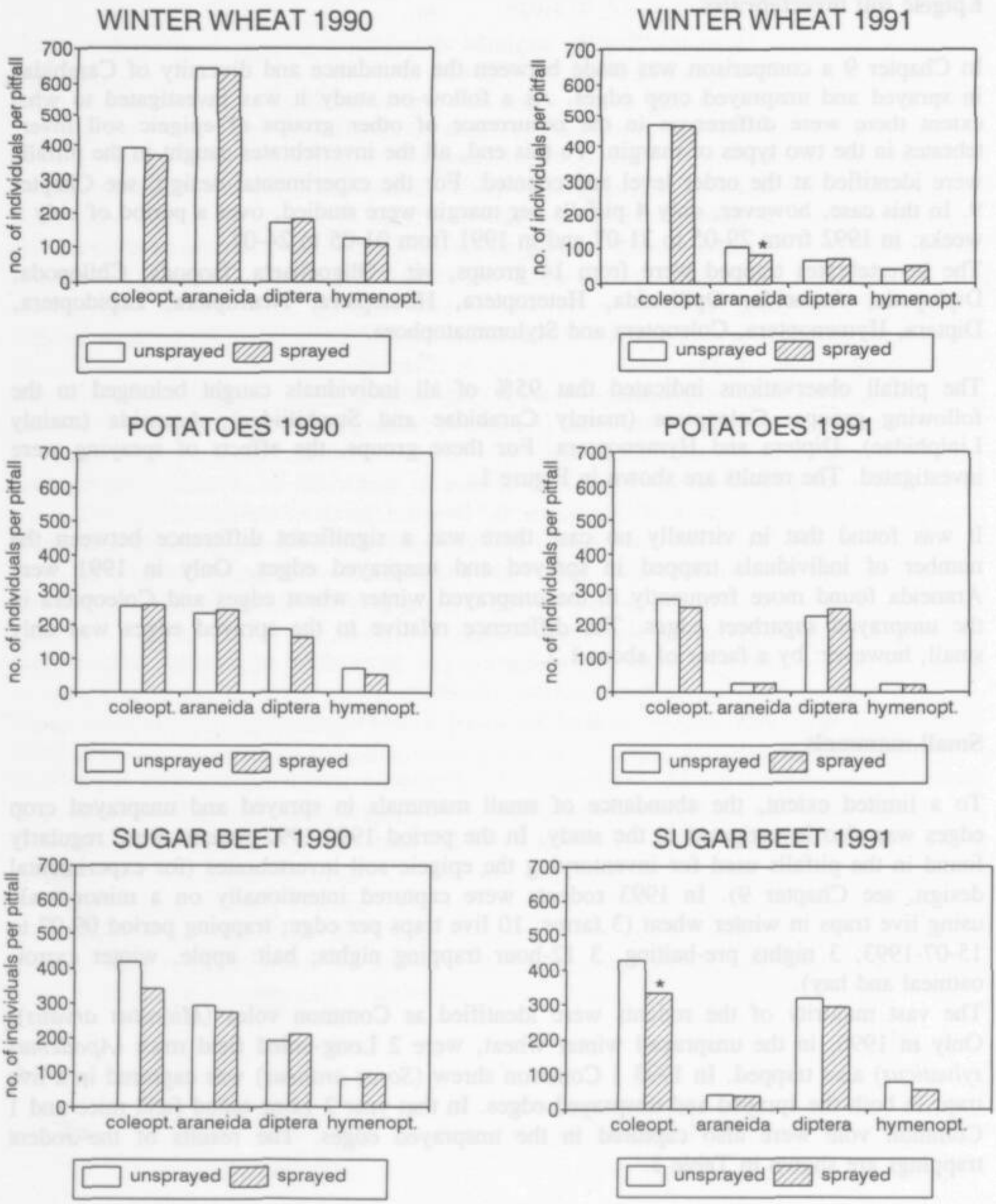


Table 1. Number of rodents captured in sprayed and unsprayed crop margins

	no. of fields	sprayed edges	unsprayed edges
1990			
winter wheat	7	7	13
potatoes	6	1	3
sugar beet	6	1	2
1991			
winter wheat	6	13	15
potatoes	5	0	0
sugar beet	8	0	0
1992			
winter wheat	8	6	6
potatoes	5	0	0
1993			
winter wheat	3	1	4

As Table 1 shows, most of the rodents were trapped in the cereal edges, with hardly any being caught in in the edges of potato and sugar beet fields. Of the 65 rodents caught in cereal edges, 27 were in sprayed edges and 38 in unsprayed edges. There thus appear to be slightly more rodents in the unsprayed edges ($P < 0.05$, Mann-Whitney U-test, one-tailed). In view of the sampling method used and the limited scope of the study, however, these results should be interpreted with due caution.

12 Enhancement of non-target insects: indications about dimensions of unsprayed crop edges

G.R. de Snoo

Abstract

In the Haarlemmermeer field margin project, 3 m x 100 m and 6 m x 450 m strips along the edge of a cereal crop were left unsprayed with herbicides and insecticides. By comparing these 2 types of unsprayed edges, an indication can be obtained of the dimensions of unsprayed crop edges required for enhancing the natural values of arable farmland. This study considers the non-target insects on the vegetation, including Butterflies, Hover-flies and Lady birds. Because of its intermediate role, the vegetation was also investigated. The results show that the abundance and presence of farmland plants is greatest in the outer 3 metres of the field and that there is no significant difference between a 3-metre wide edge and the outer 3 metres of a 6-metre wide edge. There is no extra increase in the density of insects and a number of selected insect groups in the 6-metre wide unsprayed edges compared with the 3-metre wide edges. Although the experimental set-up was limited in scope, it therefore appears that for these insect groups it is sufficient to leave a relatively narrow strip unsprayed.

Introduction

Spray drift of pesticides to field surroundings can be markedly reduced by leaving the outer metres of the crop unsprayed (Cuthbertson & Jepson, 1988). Obviously, the width of the unsprayed strip is important. At low wind speeds (3 m/s) a buffer zone of 3 metres wide is found to be sufficient to achieve a 98% reduction in the loading of the adjacent ditch (De Snoo, 1994a). At these wind speeds, an unsprayed strip of 6 m width reduces pesticide deposition in the ditch by about 100%.

By abandoning pesticide treatment on crop edges, biodiversity in farmland can also be promoted (Boatman, 1994). Notable results include the return of rare species of farmland plants and the recovery of partridge populations (Schumacher, 1984; Rands, 1985). In addition to the question of where such unsprayed crop edges can best be realized, in terms of (landscape) ecology, it is also obviously important to find out how different dimensions contribute to benefits for nature. The width of the unsprayed strip is of great importance here, because of the pesticide input to this strip from the adjacent sprayed crop.

In the Dutch Field Margin Project in the Haarlemmermeerpolder (1990-1994) it has been investigated to which extent it is possible to enhance the natural values of arable farmland by creating unsprayed crop edges. For this purpose, both short, 3-m wide and long, 6-m wide unsprayed cereal crop edges were established and compared with the sprayed reference situation. By comparing the 2 types of unsprayed strips, an *indication* can be obtained of what dimensions unsprayed crop edges should have from the perspective of promoting biodiversity. This article discusses the impact of unsprayed crop edges on the presence and abundance of non-target insect groups (no pest-insects). Because of its intermediate role, the vegetation was also investigated. The article does not primary consider the benefits to nature of unsprayed relative to sprayed crop edges; for a review of this topic, the reader is referred to Boatman (1994) and De Snoo & Udo de Haes (1994).

Methods

The study was carried out in the Haarlemmermeerpolder in 1992. In this polder, reclaimed about 150 years ago, most parcels are 1000 m long and 200 m wide and bordered by ditches. The clay soil contains about 23% silt (0-16 μm diam.) and 3% organic matter. The most common rotation on the farms is winter wheat followed by potatoes and a second winter wheat crop and finally sugar beet. To investigate the consequences for non-target insects, 3- and 6-m wide strips were left unsprayed with herbicides and insecticides in winter wheat. Widths of 3 and 6 m were chosen because this frequently corresponds to the length of the field sprayer boom, which can be switched off independently, permitting ready implementation of the measures in farming operations. The unsprayed 3-m wide strips were 100 m long and have remained unsprayed since 1-1-1990 (see Figure 1). The 6-m wide strips were 450 m long and have been left unsprayed since 1-1-1992. The 6-m wide strips are mostly situated on different fields from the 3-m strips. All crop edges are parallel to a ditch.
It was investigated whether the presence and abundance of farmland plants were comparable in the various fields. First a comparison was made between farmland plants presence in the inner and outer 3 m of the 6-m unsprayed strip (10 fields). Next the presence of farmland plants in the outer 3 m of a 6-m strip was compared with that in a 3-m crop edge (established on 9 fields). To this end, at the end of June vegetation inventories were made in both the unsprayed and the sprayed edges (in the same field) at a distance of 1-2 and 4-5 m from the field edge (Braun-Blanquet method, inventory area 75 m^2 in all cases).

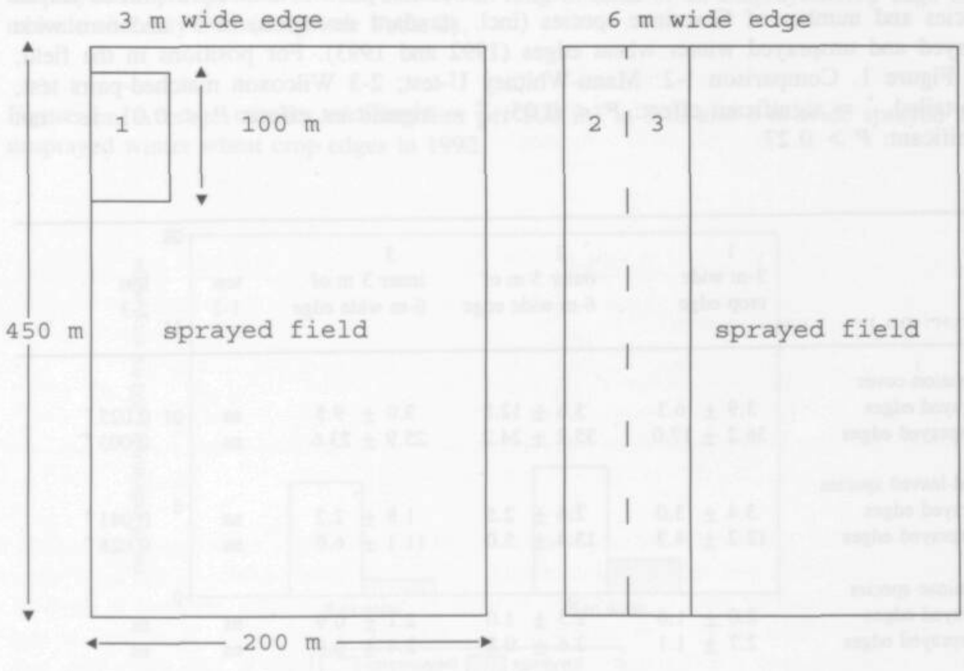
Impact on non-target insects

A butterfly census was carried out according to the transect method of Pollard (1977). Censuses were performed between 11.00 and 16.30 h at a wind speed of <10 m/s and a temperature of >17°C, or a temperature of 13-17°C and less than 40% cloud cover. Whenever possible, butterflies were inventoried once a week from 8 May to 22 July. A total of 11 census rounds was made. The censuses were carried out on 8 farms with a 3-m unsprayed crop edge and on 6 farms with a 6-m unsprayed edge. In each field, butterflies were also inventoried in a sprayed edge of similar width. The farms were visited in random sequence. The census areas of the crop edges were the same width as the unsprayed edges, i.e. 3 m for the 3-m edges and 6 m for the 6-m edges. To compare the number of butterflies in the 3- and 6-m unsprayed crop edges, the number of individuals in the 6-m edges was divided by 2, afterwhich the differences between both edges were tested with the Mann-Whitney U-test.
Along the crop edges, other insect groups in the upper part of the vegetation (crop and farmland plants) were sampled at the end of June. Observation took place between 10.00 and 16.00 h, at a temperature above 20°C. All the edges were sampled twice. Per 100 m edge, 60 sweeps were taken, with a sweep net with a diameter of 35 cm, during the same

timelength and by the same person. The total area sampled was approx. 20 m² per 100 m. Sampling took place 1.5 m from the field edge. For mobile insect groups such as Syrphidae (Hover-flies), Stratiomyidae (Soldier flies), Tipulidae (Crane flies), Apidae (Bees and Bumble-bees), Crambinae (Grass moths) and Coccinellidae (Lady birds), additional visual observations were made. A total of 21 insect groups were distinguished. The Parasitica and several Diptera families were not included, because of the very small size of many representatives of these groups. The observed insects were identified at the family level or higher. A comparison was made between the presence of these insects on 7 fields with a 3-m unsprayed strip and their presence in the outer 3 m of 6-m unsprayed strips (10 fields) (Mann-Whitney U-test). For the sprayed situation, too, these fields were similarly compared.

Figure 1. Comparison of crop edges 3 m wide and 100 m long and crop edges 6 m wide and 450 m long

1 = unsprayed crop edge 100 m long, 3 m wide
2 = unsprayed crop edge 450 m long, 6 m wide, outer 3 m
3 = unsprayed crop edge 450 m long, 6 m wide, inner 3 m



Results

Vegetation

In the outer 3 m of the 6-m wide unsprayed crop edges, the average cover of farmland plants is 35.2%, significantly higher than in the inner 3 m of the strip (25.9%; Table 1). This is also true in the sprayed situation, where these figures are 5.6 and 3.0%, respectively. A comparison between fields with unsprayed edges 3- and 6-m wide shows that the vegetation cover of the outer 3 m of the 6-m strips is very similar to that of the 3-m strips (36.2). Comparison of the presence of a number of broad-leaved species of arable land in the various parts of the crop edges gives a similar picture: in both the sprayed and unsprayed situation, the average number of such species is greater in the outer 3 m than in the inner 3 m of the 6-m wide edge, and also greater (but not significant) than in the 3-m unsprayed strip (Table 1). There is no difference between the 3-m wide edges and the outer 3 m of the 6-m wide edges. In the unsprayed crop edges, species such as *Matricaria recutita, Polygonum aviculare* and *Polygonum convulvulus* predominate. For Graminae (e.g. *Poa annua*), finally, no significant difference was found in the presence of selected species in the outer and inner 3 m of 6-m unsprayed crop edges. Similarly, there was no difference between the 3-m crop edge and the outer 3 m of the 6-m edge (Table 1).

Table 1. Comparison of average cover of farmland plants, number of broad-leaved species and number of Graminae species (incl. standard deviation) in 3- and 6-m wide sprayed and unsprayed winter wheat edges (1992 and 1993). For positions in the field, see Figure 1. Comparison 1-2: Mann-Whitney U-test; 2-3 Wilcoxon matched-pairs test, two-tailed. * = significant effect: $P < 0.05$; ** = significant effect: $P < 0.01$; ns - not significant: $P > 0.27$

	1 3-m wide crop edge	2 outer 3 m of 6-m wide edge	3 inner 3 m of 6-m wide edge	test 1-2	test 2-3
vegetation cover					
sprayed edges	3.9 ± 6.3	5.6 ± 12.8	3.0 ± 9.5	ns	0.025 *
unsprayed edges	36.2 ± 17.0	35.2 ± 24.2	25.9 ± 23.6	ns	0.003 **
broad-leaved species					
sprayed edges	3.4 ± 3.0	2.6 ± 2.5	1.8 ± 2.2	ns	0.041 *
unsprayed edges	12.2 ± 4.3	13.4 ± 5.0	11.1 ± 6.0	ns	0.028 *
Graminae species					
sprayed edges	2.0 ± 1.6	2.3 ± 1.0	2.1 ± 0.9	ns	ns
unsprayed edges	2.7 ± 1.1	2.6 ± 0.8	2.4 ± 0.9	ns	ns

Non-target insects

Comparing the unsprayed with the sprayed crop edges, the number of butterflies, the total number of other non-target insects as well as the number of insect groups increased significantly in both the 3-m wide unsprayed edges and the 6-m wide unsprayed edges, compared with the sprayed ones. However, there was great variation in insect abundance and insect species composition among the fields. Among the butterflies, Satyridae (Browns) were the most dominant family, followed by Pieridae (Whites) and Hesperiidae (Skippers). In these families, 6 species were common: *Maniola jurtina* (Meadow brown), *Lasiommata megera* (Wall brown), *Coenonymphha pamphilus* (Small heath), *Pieris rapae* (Small white), *Pieris napi* (Green-veined white) and *Thymelicus lineola* (Essex skipper). In the 6-m edges the average number of butterfly individuals (per 100 m length) is found to be about twice as high as in the 3-m edges. After conversion to abundance per unit area, however, there proves to be no significant ($P > 0.05$) difference between the 3- and 6-m edges, whether sprayed or unsprayed. Neither is the relative increase in the number of butterflies in the 6-m edges greater than that in the 3-m edges (Figure 2a). On adjacent ditch banks, too, the number of butterflies (per 100 m length) is virtually the same for the 3- and 6-m wide unsprayed crop edges, and here again there is no additional increase in presence adjacent to an unsprayed 6-m edge (Figure 2b). Moreover, because of the greater abundance of butterflies on the ditch banks in stead of the crop edges, the absolute butterfly increase will be much higher (per unit area unsprayed crop edge) by creating an unsprayed crop edge of 3 m wide and 100 m long in stead of an unsprayed crop edge of 6 m wide and only 50 m long (see Table 2).

Figure 2a. Average number of butterflies per 300 m² in 3-m and 6-m wide sprayed and unsprayed winter wheat crop edges in 1992

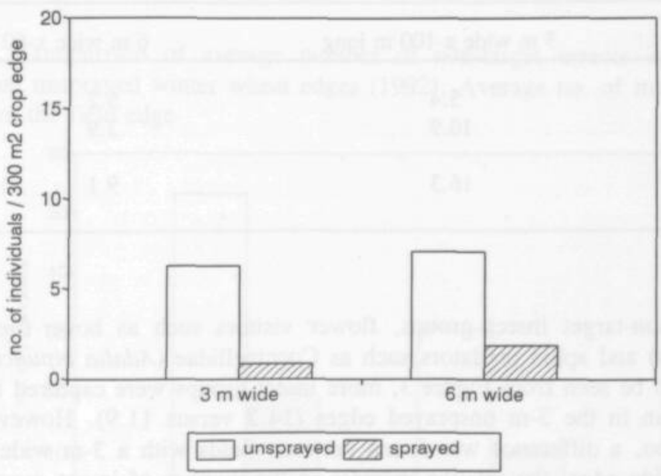


Figure 2b. Average number of butterflies per 100 m ditch bank adjacent to 3-m and 6-m wide sprayed and unsprayed winter wheat crop edges in 1992

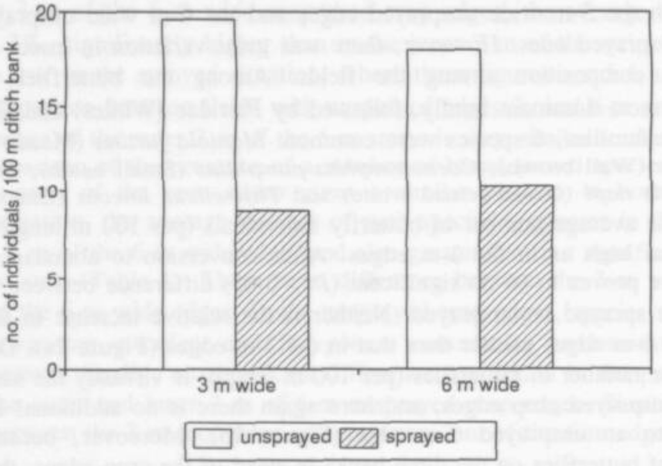


Table 2. Absolute increase of butterflies per 300 m² unsprayed crop edge plus adjacent ditch bank, in relation to the sprayed situation, by creating a unsprayed strip of 3 m wide and 100 m long or 6 m wide and 50 m long

	3 m wide x 100 m long	6 m wide x 50 m long
crop edge	5.4	5.2
adjacent ditch bank	10.9	3.9
total	16.3	9.1

Among the other non-target insect groups, flower visitors such as hover-flies (mainly *Episyrphus balteatus*) and aphid predators such as Coccinellidae (*Adalia bipunctata*) were predominant. As can be seen from Figure 3, more insect groups were captured in the 6-m unsprayed edges than in the 3-m unsprayed edges (14.2 versus 11.9). However, in the sprayed situation, too, a difference was found between fields with a 3-m wide edge and those with a 6-m wide edge; the relative increase in the number of insect groups in 6-m edges was no greater than that in 3-m edges ($P > 0.05$, Mann-Whitney U-test). In the unsprayed 6-m edges the average number of individuals is 30.6 per 100 m investigated crop edge and lower than in the 3-m edges (average: 53.2 individuals per 100 m), but this trend was also found in the sprayed situation, and here again the relative increase in the wide strips was no greater than in the narrow strips (Figure 4). At the level of the individual insect groups, too, the relative increase in insects in the 6-m wide edges was not significantly different from that in the 3-m wide edges (Table 3).

Figure 3. Comparison of average number of insect groups in 3- and 6-m wide sprayed and unsprayed winter wheat edges (1992). Average no. of insect groups per 100 m, 1.5 m from the field edge

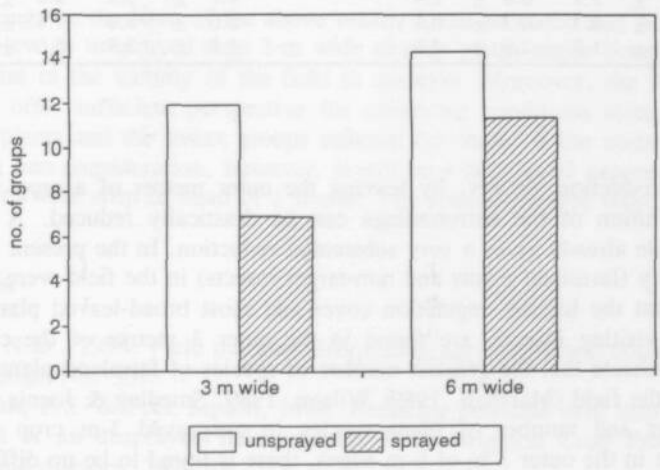


Figure 4. Comparison of average number of non-target insects in 3- and 6-m wide sprayed and unsprayed winter wheat edges (1992). Average no. of individuals per 100 m, 1.5 m from the field edge

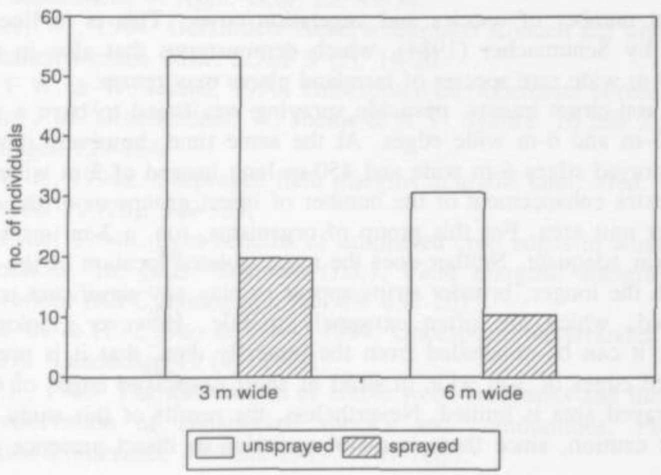


Table 3. Comparison of dominant non-target insect groups in 3- and 6-m wide sprayed and unsprayed winter wheat edges (1992). Average no. of individuals per 100 m ± standard deviation, 1.5 m from the field edge

	sprayed fields		unsprayed fields	
	3 m wide	6 m wide	3 m wide	6 m wide
Coccinellidae	5.8 ± 14.2	1.7 ± 3.2	19.0 ± 23.8	4.1 ± 4.8
Chrysomelidae	0.7 ± 0.7	0.8 ± 1.1	4.2 ± 5.5	1.1 ± 1.2
Syrphidae	0.1 ± 0.2	0.4 ± 0.4	1.7 ± 2.7	9.5 ± 22.3
Chrysopidae	3.3 ± 5.3	0.8 ± 1.4	4.7 ± 3.3	2.0 ± 1.5
Heteroptera	0.2 ± 0.3	0.3 ± 0.3	5.0 ± 8.0	1.6 ± 1.8
Heterocera	2.3 ± 1.5	2.8 ± 2.0	4.3 ± 3.9	5.0 ± 3.7

Discussion

As stated in the introduction already, by leaving the outer metres of a crop unsprayed with pesticides, pollution of the surroundings can be drastically reduced. A relatively narrow strip 3-m wide already gives a very substantial reduction. In the present study, the effects on biodiversity (farmland plants and non-target insects) in the field were investigated. It was found that the highest vegetation cover and most broad-leaved plant species, relevant for flower-visiting insects, are found in the outer 3 metres of the crop edge. Other studies also indicate that the greatest number of species of farmland plants occur in the outer metres of the field (Marshall, 1989; Wilson, 1989; Smeding & Joenje, 1990). If the vegetation cover and number of plant species in unsprayed 3-m crop edges are compared with those in the outer 3 m of 6-m edges, there is found to be no difference. In the 3-m wide edge, therefore, drift deposition does not seem to be a limiting factor. Moreover, in the sprayed situation, too, there is a difference in farmland plant abundance between the inner and outer 3 m. It is thus likely that the greater abundance of farmland plants in the outer 3 m is a natural phenomenon, due to reduced competition from the crop and species exchange with the field boundary. It can therefore be concluded that, with respect to the abundance of farmland plants, a strip 3-m wide is probably sufficient to achieve maximum number of species and vegetation cover. This is in line with the results of the work by Schumacher (1984), which demonstrates that also in unsprayed crop edges of only 3-m wide rare species of farmland plants may return.

With respect to the non-target insects, pesticide spraying was found to have a significant impact in both the 3-m and 6-m wide edges. At the same time, however, it was found that by creating unsprayed edges 6-m wide and 450-m long instead of 3-m wide and 100-m long there is no extra enhancement of the number of insect groups or of the density of non-target insects per unit area. For this group of organisms, too, a 3-m unsprayed strip would therefore appear adequate. Neither does the more isolated location of the short 3-m edges compared with the longer, broader strips appear to play any significant role for the insect groups studied, which are often extremely mobile. However, looking to the adjacent ditch bank, it can be concluded from the butterfly data, that it is preferable to create long unsprayed edges of 3-m wide in stead of short unsprayed edges of 6-m wide, when the total unsprayed area is limited. Nevertheless, the results of this study should be interpreted with due caution, since there is major variation in insect presence and abun-

dance among the fields and because the comparison is not entirely sound owing to the fact that the 3-m edges had been left unsprayed for a longer period of time. Insects are unlikely to suffer any time-related effects, though, because for overwintering they are frequently dependent on the area outside the field.
Naturally, the dimensions of an unsprayed crop edge are not only of relevance for the potential benefits to nature and the environment; due consideration must also be given to the cost of the measures in terms of harvest losses for the farmer. In an unsprayed strip 6-m wide harvest losses seems to be relatively high in the outer 3 metres of the field probably because of the intensive competition from the farmland plants here. In the inner 3 metres of the strip, more towards the field centre, harvest losses seem to be lower (De Snoo, 1994b).
Summarizing, on the basis of the above results it can be stated that from an environmental point of view an unsprayed strip 3-m wide already yields major benefits to nature and the environment in the vicinity of the field in question. Moreover, the 3-m wide crop edges appear to offer sufficient perspective for enhancing conditions along the edges for both farmland plants and the insect groups selected for study. If the costs of the measures are also taken into consideration, however, it will be a little more expensive to create a twice as long 3-m wide strip in stead of a shorter 6-m wide unsprayed strip.

References

Boatman, N.D., 1994. Field margins: Integrating agriculture and conservation, BCPC monograph No. 58.

Cuthbertson, P.S. & P.C. Jepson, 1988. Reducing pesticide drift into the hedgerow by in clusion of an unsprayed field margin. Proc. Brighton Crop Protection Conference, Pests and diseases: 747-751.

Marshall, E.J.P., 1989. Distribution patterns of plant associated with arable field edges. J. Applied Ecology 26: 247-257.

Pollard, E., 1977. A method for assessing changes in the abundance of butterflies. Biological Conservation 12, 115-134.

Rands, M.R.W., 1985. Pesticide use on cereals and the survival of grey partridge chicks: a field experiment. J. Appl. Ecol. 22: 49-54.

Schumacher, W., 1984. Gefährdete Ackerwildkräuter können auf ungespritzten Feldrändern erhalten werden. Mitt. LÖLF 9 (1): 14-20.

Smeding, F.W. & W. Joenje, 1990. Onbespoten en onbemeste perceelsranden in graanakkers. In: J.M. Groenendael, W. Joenje & K.V. Sykora: 10 jaar Zonderwijk & V.P.O. Wageningen 129-134.

Snoo, G.R. de, 1994a. Unsprayed field margins in arable land. Med. Fac. Landbouww. Univ. Gent 59 (2b): 549-559.

Snoo, G.R. de, 1994b. Cost-benefits of unsprayed crop edges in winter wheat, sugar beet and potatoes. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 197-201.

Snoo, G.R. de & H.A. Udo de Haes, 1994. Onbespoten akkerranden voor natuur, milieu en bedrijf. Landschap 11 (4): 17-31.

Wilson, P.J., 1989. The distribution of arable weed seedbanks and the implications for the conservation of endangered species and communities. Proc. Brighton Crop Protection Conference - Weeds 1989: 1081-1086.

Part 4

Socio-agronomic research

13 Cost-benefits of unsprayed crop edges in winter wheat, sugar beet and potatoes

G.R. de Snoo

Abstract

In winter wheat, potatoes and sugar beet unsprayed crop edges were established on which no herbicides or insecticides were used. The yield (quantity and quality) from the unsprayed crop edges was compared with that from the sprayed edges and the centre of the field. In every crop the yield at the field centre was much greater (by 14%) than at the sprayed field edge. Relative to the sprayed crop edges the reduction in yield on the unsprayed edges (3 metres wide) was about 30% in sugar beet and 2% in potatoes. In winter wheat the reduction in yield was 13% average for the outer 3 metres and 11% for the outer 6 metres of the unsprayed crop edge. The quality of the harvests was unchanged, with the exception of potato size in one year. Balancing the yield losses against the benefits, viz. reduced pesticide costs, it is concluded that with winter wheat and potatoes, unsprayed field margins can be well adopted in agricultural practice. In sugar beet, however, the cost is too high.

Introduction

From an agricultural point of view field margins are economically less valuable than field centres. Management of crop edges often requires additional effort - in the case of wedge-shaped fields, for example - which does not benefit operational efficiency. The yield from crop edges is also often lower, for a variety of reasons (*cf.* Boatman & Sotherton, 1988): less favourable crop site factors (e.g. fertilizer and water regime, soil structure), competition from off-plot vegetation (tree shade, infestation by perennial weeds), increased feeding damage by pheasants, wild boars, mice and other animals and finally, direct crop damage due to more intensive machinery use on field margins (turning tracks on headlands, and tracks resulting from ditch bank management).
Over the past 10 years, in many West European countries there has been a growing interest in establishing unsprayed crop edges for the purpose of nature conservation, biological pest control or reducing pesticide drift to surrounding areas. It has been demonstrated that the creation of unsprayed crop edges has a positive impact on the abundance of rare weed species, invertebrates, birds and mammals (Schumacher, 1984; Rands, 1985; Hald *et al.*, 1988; Tew *et al.*, 1992; De Snoo *et al.*, 1994). This practice has also been shown to help reduce pesticide drift to surrounding areas (Cuthbertson & Jepson, 1988). There is still little research data available on the costs associated with establishment of unsprayed field margins, however. Boatman & Sotherton (1988) have calculated the cost of maintaining unsprayed cereal crop edges. In the present study the cost has also been calculated for potato and sugar beet crops. The study forms part of the Dutch Field Margin Project being undertaken in the Haarlemmermeerpolder. The aim of this project is to develop a management strategy for promoting nature conservation in

arable fields and reducing pesticide drift to non-target areas. Effects on weeds, invertebrates, vertebrates, pesticide drift and costs to the farmer are being studied.

Methods

Research area

The study was carried out in the Haarlemmermeerpolder (clay soil) during the period 1990-1993 in winter wheat, sugar beet and potato fields (Table 1). Yields were determined on crop edges 100 m long and 3 m wide left unsprayed with herbicides or insecticides and these were compared with yields from sprayed crop edges in the same fields as well as from the field centres. In 1992 and 1993 yields were also measured on 6-m unsprayed edges in winter wheat fields. Because of proliferous weed growth in some plots, in 1990 weeds were cleared by hand on 4 and in 1991 on all sugar beet field margins over a length of 85 m. In the winter wheat crop, too, some of the weeds (*Matricaria recutita* only) were cleared on several farms to prevent seeding; in 1991 on 3 edges, and in 1992 and 1993 on 2 edges. Because of rampant weed growth in the sugar beet crop, in 1991 the scope for differentiated spraying of this crop was considered on a limited scale (strips 25 m long), varying from 0 to 3 herbicide treatments.

Table 1. Number of fields investigated. In every field an unsprayed crop edge, a sprayed crop edge and the field centre were investigated

	winter wheat 3 m wide	winter wheat 6 m wide	potatoes	sugar beet	sugar beet 0-3 sprayings
1990	-	-	5	6	-
1991	6	-	5	8	4
1992	7	5*	7	-	-
1993	5	4**	-	-	-

* = no field centre investigated; ** = incl. 2 spring wheat fields

Yield measurements

In the potato plots, in 1990 the crop was dug up by hand along the crop edge and in the field centre over an area measuring 12 m^2 (4 x 3 m^2), and in 1991 and 1992 over 18 m^2 (6 x 3 m^2). On the edges the samples were taken alternately on the 2nd and 3rd potato ridges and in the centre on the 21st and 22nd ridges. The potatoes were sorted into three size classes: <40 mm, 40-50 mm and >50 mm. In processing the data for the class <40 mm, half of the aggregate weight was taken, as machine harvesting leaves a large proportion of these potatoes behind on the land. The dry-matter content was calculated by determining, for each sample, the underwater weight of the potatoes in the >40 mm fraction (Ludwig, 1972).

In the sugar beet plots, in both years an area measuring 12 m² was manually harvested on each strip (in 1990 4 x 3 m², in 1991 6 x 2 m², including the trial with differentiated spraying). Along the field edges the samples were taken on the 2nd, 3rd and 4th beet rows, and in the centre on the 21st and 22nd rows. In 1990, in the unsprayed, uncleared section (15 m long) an area of only 1 x 3 m² was harvested. In 1990 and 1991 the sugar content as well as the potassium, sodium and alpha-aminonitrogen content of respectively 2 and 4 samples were determined by the Dutch Institute for Rational Sugar Production and the results employed to calculate the sugar extractability index using Van Geyn's formula.

In the winter wheat plots, in 1991 a reed mower was employed to reap a swath 50 m long and 1.20 m wide along the edges and at the centre of the fields, and the harvest was removed and then threshed using a plot combine (Deutz-Fahr M660, type 2116). In 1992 and 1993 a plot combine (Claas, type Cosmos) was used to combine (reap and thresh) a single swath 100 m long and 2.20 m wide. On the 6-m wide strips the outer 3 m and inner 3 m of the crop edges were combined separately. Data on the strips partly cleared of weeds were also processed, and there was found to be no difference in crop yield. On each strip the dry crop weight was determined by drying a 5 x 1 kg sample at 100 °C and reweighing.

Results

Potatoes

Table 2 shows the yields from the various strips for potatoes. Comparison of the sprayed and unsprayed edges indicates a lower yield on the unsprayed edges in 1990 and 1992 (by 3.5% and 8.6%, respectively). This yield loss was significant in 1992 only. In that year there was a lower yield of large potatoes (>50 mm), especially. In 1991, however, on 4 of the 5 farms the yield from the unsprayed crop edges was higher than from the sprayed edges (by 5.8% on average). In 1990 and 1991 no significant effects on potato size were found. In all 3 years there were significant differences, of about 10.0-12.6%, between yields from the field centre and from the sprayed crop edge. In the field centre the yield of large potatoes (>50 mm), particularly, was significantly higher than on the edges. At the field centre there were fewer potatoes in the class <50 mm. No difference in dry weight was found between potatoes from sprayed and unsprayed crop edges (Table 3). In 1992 potatoes from the field centre generally contained more water.

Sugar beet

Because by many of the farmers the unsprayed strip is partly weeded, which meant that in the worst case (1990) only one sample could be taken per plot, it was decided to test the average yields from the individual plots non-parametrically. Compared with the sprayed crop edges, the average sugar beet yield from the unsprayed edges was 20.6% lower in 1990 and 39.1% lower in 1991 (Table 4). This reduction in yield was significant in 1991 only. In both years there was found to be a significant difference between the sprayed edges and the field centre (16.4 and 16.0% average yield reduction on the edges).

Table 2. Potato yield (kg/m²)

	sprayed edge		unsprayed edge			field centre		
	av.	s.d.	av.	s.d.	T	av.	s.d.	T
1990 (n=5)								
<40 mm	0.44	± 0.12	0.50	± 0.24	n.s.	0.32	± 0.11	***
40-50 mm	1.56	± 0.18	1.51	± 0.29	n.s.	1.47	± 0.40	n.s.
>50 mm	1.95	± 1.33	1.81	± 1.51	n.s.	2.70	± 1.59	***
total	3.96	± 1.22	3.82	± 1.28	n.s.	4.49	± 1.12	**
1991 (n=5)								
<40 mm	0.57	± 0.15	0.54	± 0.10	n.s.	0.46	± 0.12	***
40-50 mm	1.98	± 0.46	2.14	± 0.38	n.s.	1.59	± 0.24	***
>50 mm	1.79	± 1.03	1.92	± 0.64	n.s.	2.77	± 1.02	***
total	4.34	± 0.93	4.59	± 0.67	n.s.	4.82	± 0.75	**
1992 (n=7)								
<40 mm	0.27	± 0.09	0.31	± 0.12	*	0.24	± 0.10	*
40-50 mm	1.71	± 0.32	1.74	± 0.39	n.s.	1.59	± 0.49	n.s.
>50 mm	2.64	± 1.25	2.18	± 1.04	**	3.45	± 1.31	***
total	4.62	± 0.92	4.22	± 0.68	**	5.28	± 0.85	***

Legend: av. = average; s.d. = standard deviation between fields; n = no. of fields; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$; n.s. = not significant; T = two-way, two-tailed ANOVA

Table 3. Percentage dry matter in potatoes (>40 mm)

	sprayed edge		unsprayed edge			field centre		
	av.	s.d.	av.	s.d.	T	av.	s.d.	T
1990 (n=5)	21.8	± 0.6	21.8	± 0.8	n.s.	21.0	± 1.2	n.s.
1991 (n=5)	22.4	± 1.2	22.3	± 0.9	n.s.	21.6	± 2.1	n.s.
1992 (n=7)	19.4	± 2.1	19.3	± 1.9	n.s.	18.2	± 2.3	*

Legend: see Table 2; T = one-way, two-tailed ANOVA

No significant differences in sugar content were found between beets from the sprayed and unsprayed crop edges, nor between beets from the sprayed edges and the field centre. Although the sugar content in the field centre was slightly lower than on the sprayed edges (Table 5), the difference was not significant ($P = 0.054$, Wilcoxon matched pairs, in 1991). There was also no difference in sugar extractability index between beets from the sprayed and unsprayed edges. This index was much lower for beets from the field centre than for those from the sprayed edges ($P = <0.05$, Wilcoxon matched pairs).

The results of the experiment with differentiated spraying are shown in Table 6. There was a significant difference in yield between the unsprayed (36.3% loss) or once-sprayed strip (9.6% loss) and the fully-sprayed strip (3 treatments). Although there was little difference the double spraying gave a significant increase in yield (8.5% loss).

Table 4. Sugar beet yield (kg/m²)

	sprayed edge		unsprayed edge			field centre		
	av.	s.d.	av.	s.d.	T	av.	s.d.	T
1990 (n=6)	7.34	± 1.57	5.83	± 2.26	n.s.	8.78	± 0.52	*
1991 (n=8)	5.97	± 1.32	3.63	± 1.74	**	7.11	± 0.94	*

Legend: see Table 2; T = one-tailed Wilcoxon matched pairs

Table 5. Sugar content (%) and extractability index (%) of sugar beet

	sprayed edge		unsprayed edge			field centre		
	av.	s.d.	av.	s.d.	T	av.	s.d.	T
sugar content								
1990	17.15	± 1.07	17.03	± 0.98	n.s.	16.47	± 1.29	n.s.
1991	15.82	± 0.78	15.47	± 1.42	n.s.	15.16	± 0.77	n.s.
winning index								
1990	91.90	± 2.41	92.22	± 3.35	n.s.	87.96	± 6.61	*
1991	92.54	± 2.19	93.13	± 3.86	n.s.	88.26	± 4.74	*

Legend: see Table 2; T = two-tailed Wilcoxon matched pairs

Table 6. Sugar beet yield (kg/m²) with various spraying regimes (n=4)

	av.	sd.	T	
unsprayed	4.05	± 1.21	***	(0 vs 3 sprayings)
1 spraying	5.74	± 0.70	**	(1 vs 3 sprayings)
2 sprayings	5.82	± 0.56	*	(2 vs 3 sprayings)
3 sprayings	6.35	± 1.43		

Legend: see Table 2: T = two-way, one-tailed ANOVA

Winter wheat

The yield losses on the unsprayed crop edges are presented in Table 7. The average losses are significant each year: 11.0% in 1991, 11.1% in 1992 and 17.2% in 1993 for the outer 3 m of the strips. In the inner 3 m of the unsprayed 6-m strips, yield losses were 2.7% in 1992 and 7.4% in 1993. In neither year was this difference significant. Over the full 6 m of the strip, the average yield loss was 6.2% in 1992 and 15.2% in 1993, giving a combined loss of 10.7% for the 2 years. Each year the yield from the sprayed edge was significantly less than at the plot centre; in 1991 this loss was 17.5%, in 1992 11.3% and in 1993 12.1%. There was no significant difference in the moisture content of the grain between the sprayed crop edge, the unsprayed edge and the plot centre.

Table 7. Winter wheat yield (kg/m²; 16% grain moisture)

	sprayed edge		unsprayed edge			field centre		
	av.	s.d.	av.	s.d.	T	av.	s.d.	T
1991 0-3 m (n= 6)	0.729	± 0.079	0.649	± 0.076	*	0.883	± 0.087	* 1)
1992 0-3 m (n=12)	0.808	± 0.139	0.718	± 0.120	**	0.952	± 0.154	* 1)
4-6 m (n= 5)	0.872	± 0.093	0.848	± 0.073	n.s.	----		
1993 0-3 m (n= 9)	0.805	± 0.102	0.667	± 0.112	**	0.916	± 0.171	**
4-6 m (n= 4)	0.971	± 0.054	0.899	± 0.091	n.s.	1.054	± 0.056	*

Legend: see Table 2; T = one-tailed Wilcoxon matched pairs; 1) n = 5

Discussion

In making an economic cost-benefit analysis of the unsprayed field margins, yield losses must be offset against savings in pesticide use. In the potato crop, yield losses were only minor (average 2%). The cost of this crop is average Dfl. 0.02 per m² (based on potato price over last 6 years of Dfl. 0.17 per kg, *cf.* IKC, 1993). Savings on pesticide use (*cf.* IKC, 1993) amount to Dfl. 0.02 per m², giving no nett extra expenditure. In the case of sugar beet, the direct loss of yield is rather greater (average 30%), at a cost of about Dfl. 0.24 per m² (based on 'mixture price' sugar beet of Dfl. 0.11 per kg, adjusted for sugar content and extractability index, *cf.* IKC, 1993). Savings on pesticide use total Dfl. 0.03, giving average Dfl. 0.21 nett extra expenditure per m². The experiment with differentiated spraying shows that the first, pre-emergence treatment is most important for limiting these yield losses. In winter wheat, finally, yield losses are 13% average for the outer 3 m, i.e. Dfl. 0.03 per m² (based on EC price of Dfl. 0.26 per kg). Savings on pesticide use are approximately Dfl. 0.02 per m², giving about Dfl. 0.01 nett extra expenditure per m². For a strip 6 m wide this means about Dfl. 0.005 per m². In England yield losses on 6-m wide unsprayed crop edges have been found to be only 3% for winter wheat and 6% for spring barley. The cost of yield losses in that country, including the cost of separate harvesting, threshing, drying, storage and possibly extra spraying of edges, is about Dfl. 0.04 per m² (Boatman & Sotherton, 1988; Boatman, 1990). As a general conclusion it can be said that maintaining unsprayed crop edges is economically viable for crops of potatoes and winter wheat. In sugar beet, however, the cost appeared to be too high.

Besides savings on pesticide use, benefits from establishing unsprayed field margins may also be accrued in the form of extra income from huntsmen, for example. In England the cost of maintaining unsprayed cereal edges is found to be compensated by the increase in revenue resulting from larger populations of partridges and pheasants (Boatman, 1990). This might be tied in with payment for 'nature production'.

The differences in yield between 3-m wide crop edges and field centres are in reasonable agreement for the various years and crops: for potatoes 11% difference, for sugar beet 16% and for winter wheat 15%. Boatman & Sotherton (1988) found that the yield from the edges of cereal fields (6-m wide) was 18% less, on average, than that from the field centre. In establishing compensation measures for arable farmers, therefore, it is important not to base payments on the average yield per hectare but on a yield loss of say 10% to 15% from the field edge.

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References

Boatman, N.D., 1990. Conservation headlands and the economics of wild game produc tion. In: De toekomst van de wilde hoenderachtigen in Nederland. Lumeij, J.T; Hoogeveen, Y.R. Elinkwijk B.V., Utrecht, 198-206.

Boatman, N.D. & N.W. Sotherton, 1988. The agronomic consequences and costs of managing field margins for game and wildlife conservation. Aspects of Applied Biology 17, 47-55.

Cuthbertson, P.S. & P.C. Jepson, 1988. Reducing pesticide drift into the hedgerow by inclusion of an unsprayed field margin. Brighton Crop Protection Conference - Pests and diseases 1988, 747-751.

Hald, A.B., B.O. Nielsen, L. Samsøe-Petersen, K. Hansen, N. Elmegaard & J. Kjoholt, 1988. Sprojtefri randzoner i kornmarker. Miljoprojekt nr. 103. Miljostyrelsen, Kobenhavn.

IKC, 1993. Kwantitatieve informatie voor de Akkerbouw en de Groenteteelt in de Vollegrond. Bedrijfssynthese 1993-1994. Informatie- en Kenniscentrum voor de Akkerbouw en de Groenteteelt in de Vollegrond (IKC) Lelystad. Publikatie 69, 212 p.

Ludwig, J.W., 1972. Bepaling van het droge-stofgehalte van aardappelen via onderwater weging Instituut voor Bewaring en Verwerking van Landbouwprodukten Wageningen. IBVL publikatie 247, 12 pp.

Rands, M.R.W., 1985. Pesticide use on cereals and the survival of grey partridge chicks: a field experiment. Journal of Applied Ecology 22, 49-54.

Schumacher, W., 1984. Gefährdete Ackerwildkräuter können auf ungespritzten Feldrändern erhalten werden. Mitteilungen der LÖLF 9 (1), 14-20.

Snoo, G.R. de, R.T.J.M. Dobbelstein & S. Koelewijn, 1994. Effects of unsprayed crop edges on farmland birds. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 221-226.

Tew, T.E., D.W. MacDonald, M.R.W. Rands, 1992. Herbicide application affects mi crohabitat use by arable wood mice (*Apodemus sylvaticus*). Journal of Applied Ecology 29, 532-539.

14 Farmers' perception of unsprayed crop edges in the Netherlands

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Abstract

This article argues that in developing nature conservation policies at the farm level not only should environmental and ecological benefits and economic costs be considered but farmers' perceptions as well. Statistical analysis of survey data demonstrates the relevance of these behavioural aspects. Arable farmers with experience of unsprayed crop edges indicated that of several types they preferred unsprayed edges in cereals or grass strips, for agronomical, farming equipment related and socio-psychological reasons. The study also focused on the 'ideal' unsprayed crop edge from the farmers' perspective. It appeared that a flexible width is most important for acceptance in farming practice, since it is above all the width that determines compatibility with existing farming organization and parcel lay-out. In this respect there are significant differences between regions. With regard to the payment system, farmers prefer a guaranteed reward instead of a payment for nature result, irrespective of the region considered.

Introduction

Over the last ten years, it has been demonstrated that the creation of unsprayed crop edges has a positive impact on the abundance of arable flora and fauna (Schumacher, 1984; Rands, 1985; Hald *et al.*, 1988; Tew *et al.*, 1992; Boatman, 1994). In the Netherlands since 1990 the Centre of Environmental Science of Leiden University has carried out a field study on conventional arable farms (CML project). The aim of this study is to develop a management strategy for promoting nature conservation in arable fields and reducing pesticide emissions to non-target areas (De Snoo, 1994a). The research is being undertaken in the Haarlemmermeerpolder. In winter wheat, potatoes and sugar beet unsprayed crop edges were established on which no herbicides or insecticides were used. The effects of unsprayed crop edges on nature, the environment and on farm economics were established by means of empirical analyses based on experiments on farms (De Snoo & De Wit, 1993; De Snoo, 1994a; De Snoo, 1994b; De Snoo *et al.*, 1994). These studies have shown that unsprayed crop edges have: (1) a positive impact on the abundance of wildflowers, invertebrates and birds; (2) ample scope for reducing pesticide emissions to adjacent areas; (3) in terms of cost, feasibility in winter wheat and potato crops. Elsewhere in the Netherlands, too, unsprayed crop edges are being developed (Meijer, 1991; Maris, 1993; Melman, 1994).

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In the process of adoption of innovations, such as unsprayed crop edges, apart from the economic aspects, behavioural and informational aspects are important (Hooks *et al.*, 1983; Van der Meulen *et al.*, 1995). In an approach that advocates such close involvement of farmers with the management of nature, it is important that the acceptability of these measures to farmers is carefully considered (Deane, 1989). Survey analysis can provide insight into the influences of additional behavioural attributes. This article studies the additional behavioural attributes for unsprayed crop edges. Five types of unsprayed crop edges used in Dutch arable farming were evaluated: (1) unsprayed crop edges in cereals; (2) unsprayed crop edges in potatoes; (3) unsprayed cereal edges along other crops; (4) grass strips; and (5) set-aside (or uncropped wildlife) strips.
The present article focuses on 2 subjects. First, farmers' preferences for one of the types of unsprayed crop edges are established and explained by a perception analysis. Second, the question is addressed which attributes are seen by the farmers as important preconditions for the 'ideal' unsprayed crop edge from their own perspective. Also the motivation for participation in field margin research projects is part of the study.

Data use and methods

The results presented in this article are based on an interview study among conventional arable farmers, mostly on clay soil, who have at least one year's experience with unsprayed crop edges. The clay soil was chosen because the CML project in the Haarlemmermeerpolder was our starting point. Besides the farmers from the CML project, we also included farmers from the project being implemented by the Gelderland provincial authorities and from the SBNL project (Foundation for Conservation of Nature and Environment) in the provinces of Zeeland and Groningen. In total, the Netherlands has some 90 farmers with experience with unsprayed crop edges, of which only 40 can be typified as conventional arable farmers on clay soil, however. Of these, 35 suitable farmers were approached, of whom 31 were willing to participate. The other 4 were interested but were too busy with harvesting activities. The average length of the interviews with the farmers was 45 minutes. In the interviews the motivation for participation, preferences and preconditions for unsprayed crop edges were discussed. The data gathered were analysed by means of SPSS (SPSS inc., Chicago).

Katona (1975) was one of the first authors to emphasize the relevance of the psychological variables behind economic behaviour: motives, perceptions, attitudes and expectations. Approaches starting from behavioural aspects are common in marketing research and analysis of consumer behaviour. In behavioural economics it is not the objective character of goods/actions that matter but the subjective characteristics as perceived by the decision maker. Perception analysis and conjoint analysis are well known procedures for determining the perceptions and preferences of individual decision makers, respectively (Churchill, 1991).
In this study, perception analysis is used to assessed the importance to the farmer of a number of prespecified features of the 5 types of unsprayed crop edges. These features relate to agronomy, farm equipment and the social environment of the farmer. For the five types of unsprayed crop edges the individual scores of the features were measured on the Likert scale. Respondents were asked to indicate on a 5-point scale their degree of agreement or disagreement with each of the various features. The perception scores were

used to explain the farmers' preference for one of the types of unsprayed crop edges. The difference between the average scores of the 5 types of unsprayed crop edges per feature was tested by means of the paired-samples t-test. To measure the preference the 5 types of unsprayed crop edges were ranked by the respondents from 1 (greatest preference) to 5 (lowest preference).

To obtain an insight into which attributes are seen by the farmers as important preconditions for unsprayed crop edges, we have made use of conjoint analysis. In conjoint analysis respondents are asked to give a rank or a score to each of a number of profiles, where a profile stands for a specific combination of attributes (or attribute levels). By using regression analysis the utility scores for each attribute level can be estimated. These utility scores indicate the influence of each attribute (or attribute level) on the respondents' preference for a particular profile (see e.g. Hair *et al.*, 1990; Horst *et al.*, 1995). The higher the utility score, the greater the influence of that attribute level on the overall preference. We distinguished 4 attributes which were presumed to be relevant for the compatibility of unsprayed crop edges with farming business organization. The attributes and their levels were:

1. the width of the margin (3 metres, 6 metres, defined by the farmer);
2. the location of the margin in the field (fixed, rotation);
3. the payment system (conditional, result);
4. the guidance (frequent, infrequent).

For the width a multiple of 3 metres was chosen, determined by considerations of machinery efficiency. The location of the margin can be a fixed location in the field or a location that shifts from year to year (rotation). In the current system, payment is assured independent of the resulting nature (conditional payment or 'standard' payment). In an experimental project under the auspices of DBL (the governmental service for Land Management of the Ministry of Agriculture, Nature Conservation and Fisheries) the concept of nature result payment has been introduced for arable field margins (Melman, 1994). Farmers are paid for positive results only, whether or not these are a consequence of their efforts. They are free to choose the way in which they achieve nature benefits on their fields. There are no prescriptions as to how to reach them. In the last attribute 'guidance' refers to the amount of support the farmer receives from the extension officer or from study groups, etc. This could be frequent or infrequent.
These attributes with their levels make a total of 3*2*2*2 = 24 possible profiles. With this number of profiles we cannot reasonably expect the respondent to provide meaningful judgements. The number of profiles can be reduced by using fraction factorial designs. The basic plan of Addelman enables the researcher in this case to use only 9 profiles to estimate the utility scores, assuming no interaction among the attributes (Addelman, 1962). Each of the 9 selected profiles was ranked by the respondents from 1 (greatest preference) to 9 (lowest preference). Besides their reaction to the profiles, the respondents were asked to indicate on a 5-point scale their degree of agreement or disagreement with a number of statements with regard to the compatibility of unsprayed crop edges with their business organization. The statements were related to the width of the margin, the location of the margin in the field, the payment system, the guidance, the amount of payment and the length of the agreement.

As mentioned above, the 31 respondents were from 3 different projects. The projects differ in the aim pursued, in the choices of types of unsprayed crop edges and in the region. In this article we will discuss the influence of the projects on the farmers' perception and preference. Besides, there might be a difference between respondents with or without experience with one of the types of unsprayed crop edges. This effect will also be discussed. For each feature the influence of experience and of the projects on the farmers' perception was tested by means of ANOVA. First, though, a short outline of the projects is given.

The aim of the *project* in *Gelderland province* is to improve the nature value of the arable land by restricting the use of herbicides, insecticides and fertiliser. The goal is a permanent increase in species of arable flora. The province of Gelderland is not well-known as a purely arable farming area. The arable farms are surrounded by dairy farms and in some cases by a stretch of woodland. The farmers could make a choice from among all 5 types of unsprayed crop edges. They have experience with 6-metre wide strips. Most of the strips were established under trees or along hedgerows.

The aim of the *SBNL project* is to restore the number of Partridges in the Netherlands. Our respondents were from 2 areas, one in Poortvliet (province of Zeeland, with 4 respondents) and one in Muntendam/Zuidlaardermeer (province of Groningen, with 8 respondents). Both regions can be typified as arable farming areas with large-scale farms. An important crop for the farms in Groningen are potatoes for processing. In both areas the respondents could make a choice between unsprayed crop edges in cereals, unsprayed cereal edges along other crops, grass strips and set-aside strips. They have experience with more than 6-m wide edges. Most of the strips were established on locations less efficient for production due to wedge-shaped fields. In view of the small sample of Poortvliet, the areas were taken together and analyzed as one SBNL project.

The aim of the *CML project* has already been mentioned in the introduction. The Haarlemmermeerpolder is known as an arable farming area. Most parcels of land are 1000 metres long and 200 metres wide and are bordered by ditches. The most common rotation on the farms is winter wheat followed by potatoes and a second winter wheat crop and finally sugar beet. The farmers have experience with 3- or 6-m wide unsprayed crop edges.

Table 1 presents the experience of the respondents with different types of unsprayed crop edges. Most respondents have experience with unsprayed crop edges in cereals. Only 7 respondents have experience with set-aside strips (type 5). Except for one all these respondents are participants in the SBNL project. Measured in number of years, the respondents have most experience with grass strips and unsprayed crop edges in cereals.

Table 1. Number of respondents with experience with different types of unsprayed crop edges, including average number of years of experience with specific types (overall and per project)

	overall (n=31)			Gelderland province (n=9)	SBNL (n=12)	CML (n=10)
	ne	av.	s.d.	ne	ne	ne
type 1: unsprayed crop edges in cereals	23	2.17	± 1.27	8	5	10
type 2: unsprayed crop edges in potatoes	10	1.80	± 1.40	4	0	6
type 3: unsprayed cereal edges along other crops	9	1.56	± 0.72	6	3	0
type 4: grass strips	15	2.27	± 0.96	5	10	0
type 5: set-aside strips	7	1.28	± 0.49	1	6	0

Legend: av. = average score; n = number of respondents; ne = number of respondents with specific experience; s.d. = standard deviation

Results

Motivation for participation in field margin research projects

Table 2 shows the ranking list of the importance of different aspects for taking part in the unsprayed crop edge projects. This ranking list is based on the average scores on a five-point scale. The two most important aspects for participation were the interest in the research on unsprayed crop edges and the role of the person who made the first contact with the farmers. The other aspects have an average score above 3.0, which indicates their unimportance. The lowest ranking for the aspect 'positive impressions of colleagues' is due to the fact that impressions of colleagues were not available because most of the respondents have participated in the research from the start.

Table 2 also shows the average scores for the importance of different aspects for the 3 projects and the significant differences between the projects. In the Gelderland project confidence in the contact person is a less important aspect than in the other projects. For respondents from the SBNL project financial attractiveness was an important aspect for taking part in the unsprayed crop edge project. In contrast, this aspect was of no importance for respondents from the CML project. The importance of the increase in the number of birds in the SBNL project can be explained by the goal of the project.

Table 2. Ranking list of importance of different aspects for participating in the unsprayed crop edge projects, based on average scores overall and for the three projects (1 = very important; 5 = not important)

	overall (n = 31)		Gelderland province (n = 9)		SBNL (n = 12)		CML (n = 10)		test
	av.	s.d.	av.	s.d.	av.	s.d.	av.	s.d.	T
confidence in contact person	1.90 ±	1.08	2.77 ±	1.39	1.50 ±	0.67	1.60 ±	0.70	*
interest in the research	1.97 ±	1.05	1.89 ±	1.05	2.08 ±	1.16	1.90 ±	0.99	
financial attractiveness	3.23 ±	1.50	3.11 ±	1.54	2.25 ±	1.29	4.50 ±	0.53	**
less pesticides in the ditch	3.29 ±	1.19	3.00 ±	1.12	3.67 ±	1.23	3.10 ±	1.20	
increase in the number of birds	3.39 ±	1.36	3.67 ±	1.12	2.58 ±	1.51	4.10 ±	0.88	*
increase in the number of insects	3.77 ±	1.02	3.22 ±	0.97	4.17 ±	1.11	3.80 ±	0.79	
increase in the number of arable flora species	3.77 ±	1.15	3.11 ±	0.78	4.25 ±	1.06	3.80 ±	1.32	
benefits for game shooting	4.06 ±	1.18	4.22 ±	1.09	3.75 ±	1.48	4.30 ±	0.82	
positive impressions of colleagues	4.19 ±	1.17	4.44 ±	1.01	4.17 ±	1.40	4.00 ±	1.05	

Legend: n = number of respondents; av. = average score; s.d. = standard deviation; statistical test: T = significant difference between the project tested with one-way analysis of variance; * = $P < 0.05$; ** = $P < 0.01$

Preference for types of unsprayed crop edges

Table 3 shows the preference of the respondents with and without experience for the types of unsprayed crop edges. The preference for each type is based on the mean score of the rank numbers, which varies from 1 to 5. Besides the overall mean score, we make a distinction between the scores of respondents with or without experience with the different types of unsprayed crop edges.

All respondents prefer unsprayed crop edges in cereals (type 1) and grass strips (type 4). Looking at the first preference, 12 respondents indicate type 1 as their first preference. In most cases these respondents rank unsprayed crop edges in potatoes or unsprayed cereal edges along other crops as second and third and grass strips and set-aside as fourth and fifth. 14 respondents indicate type 4 as their first preference. Of these, 8 respondents rank unsprayed crop edges in cereals as second and 6 respondents prefer a set-aside strip after grass strips. Apparently 2 groups of respondents exist. There is one group that wants to achieve a certain yield from the unsprayed crop edge. They opt for a crop in the edge or prefer a crop after a grass strip. The second group is smaller and prefers a set-aside strip after a grass strip or vice versa because these strips require no maintenance. This group is situated primarily in the province of Groningen (SBNL project). The yield of the strip is unimportant here. Unsprayed cereal edges along other crops (type 3) are often ranked as number three. The set-aside strips (type 5) and unsprayed crop edges in potatoes (type 2) have the lowest preference.

The relative preference of the respondents with or without experience for the types of unsprayed crop edges is equal (Table 3). For both groups the ranking is the same[2]. For all the types of unsprayed crop edges the lower average score of the respondents with experience in comparison with the group without experience indicates that in most cases the types they have experience with are ranked first and second. The differences in the relative preference of the respondents among the projects are small. Respondents from the SBNL project prefer grass strips to unsprayed crop edges in cereals, while respondents from the Gelderland and CML project show a higher preference for unsprayed crop edges in potatoes than for set-aside strips. These small differences in preference can be explained by the differences in experience with the types of unsprayed crop edges between the projects.

Table 3. Preferences for different types of unsprayed crop edges (overall and with or without experience) (1 = greatest preference; 5 = lowest preference)

	overall (n = 31)		with experience			without experience		
	av.	s.d.	ne	av.	s.d.	nw	av.	s.d.
type 1: unsprayed crop edges in cereals	2.06	± 1.03	23	1.83	± 1.03	8	2.75	± 0.71
type 2: unsprayed crop edges in potatoes	3.77	± 1.38	10	2.60	± 1.58	21	4.33	± 0.86
type 3: unsprayed cereal edges along other crops	3.06	± 1.03	9	2.33	± 1.32	22	3.36	± 0.73
type 4: grass strips	2.13	± 1.26	15	1.80	± 1.01	16	2.44	± 1.41
type 5: set-aside strips	3.71	± 1.47	7	2.43	± 1.51	24	4.08	± 1.25

Legend: n = number of respondents; av. = average score; s.d. = standard deviation; ne = number of respondents with experience; nw = number of respondents without experience

On the basis of Table 4 and some complaints mentioned spontaneously by the farmers we will try to explain the differences in the respondents' preference for a given type of unsprayed crop edges. Table 4 presents the average scores on a 5-point scale of 12 features distinguished for the 5 types of unsprayed crop edges. The features of the farmers were based on judgements and are concerned with agronomy, farm equipment and the social environment of the farmer. For each feature the number of respondents, average score, standard deviation and significant differences are given. Significant differences between the average scores of the five types of unsprayed crop edges were tested by means of a paired-samples t-test. Table 4 only shows the results of this test in cases where the average score of a feature for one type differs significantly from the average scores of the other 4 types. For each variable ANOVA is used to test whether

[2] The fact that the overall ranking of the different types does not correspond with the preference of the respondents in the groups with and without experience, is due to the different group sizes.

there is a significant difference between respondents with or without experience and among the respondents from the 3 projects. A short interpretation of the features which can explain the preference for one of the types is given.

Agronomy

With regard to crop aspects, the respondents expect weed density along the edge to increase with time for all types of unsprayed crop edges except grass strips (type 4). The respondents characterize the grass strip as a type with no pronounced increase in weed density with time on the edge or in other parts of the crop and insensitive to diseases and pests. On the other hand, apart from an increase in weeds the respondents also expect an increase in diseases through the application of unsprayed crop edges in potatoes (type 2) despite the fact that fungicide use is permitted. The greater fear of increased pest infestation in other parts of the crops in unsprayed crop edges in potatoes is caused by respondents from the province of Gelderland. With the unsprayed cereal edges (type 1 and 3) respondents from the CML project expect a stronger increase in weed density in other parts of the crop than respondents from the other 2 projects. A complaint mentioned spontaneously by the farmers with regard to unsprayed cereal edges along other crops is the interference with crop rotation due to the fixed location of the unsprayed edge in the field.

Farm equipment

The score for the purchase of machinery for grass strips is due entirely to the respondents from the CML project, who do not have a mowing machine at their disposal. Compared with unsprayed crop edges in cereals the respondents expect that more labour is required for unsprayed crop edges in potatoes (type 2) and in unsprayed cereal edges along other crops (type 3). Irrespective of the type of crop edge, respondents from the CML project are of the opinion that the labour required for the unsprayed edges does not match the available labour supply. Furthermore, they expect that set-aside strips cannot be managed with the available machinery and that they require considerable labour. Also in contrast with the other projects, respondents from the CML project expect that for unsprayed cereal edges along other crops additional knowledge is required.

Social environment of the farmer

As can be seen in Table 4, the questions about the features regarding the social environment of the farmer were not answered by all respondents. In most cases the farmer is not well informed about the attitude of the extension officer and the pesticide supplier or he expresses no opinion on the matter. The respondents characterize the grass strip as the type eliciting the most positive attitude on the part of colleague farmers, despite the significantly higher score of the respondents from the CML project. Farmers lacking experience with unsprayed crop edges in potatoes mention a more negative attitude of the extension officer and the herbicide supplier than those with such experience. According to the respondents unsprayed crop edges in potatoes are relatively less interesting for game hunters. Also, it appears that the preferences of the hunters for the various types of unsprayed crop edges differ from the attitudes of colleague farmers, the extension officer and the pesticide supplier.

Table 4. Average scores of features that can be distinguished for 5 types of unsprayed crop edges (1 = totally agree; 2 = agree; 3 = neutral; 4 = disagree; 5 = totally disagree)

	type 1		type 2		type 3		type 4		type 5	
	av. s.d.	T	av. s.d.	T	av. s.d.	T	av. s.d.	T	av. s.d.	T
I: agronomy										
increasing weed density in the edge with time (n=31)	2.00 ± 0.93		2.13 ± 1.23		2.13 ± 0.99		3.48 ± 1.18	***	2.16 ± 1.24	
increasing weed density in other parts of the crop (n=31)	2.74 ± 1.24	b	2.48 ± 1.26		2.65 ± 1.25	b	3.71 ± 1.00	***	2.55 ± 1.39	
increase in diseases in other parts of the crop (n=31)	3.35 ± 1.05	c	2.65 ± 1.40	**	3.61 ± 1.02		4.23 ± 0.85		3.84 ± 1.13	
increase in pests in other parts of the crop (n=30)	3.30 ± 1.26		3.07 ± 1.39	b	3.67 ± 1.16		4.13 ± 1.00		3.70 ± 1.42	
II: farm equipment										
purchase new or other machines (n=31)	4.71 ± 0.78	c	4.71 ± 0.78		4.65 ± 0.84		3.68 ± 1.80	**b	4.29 ± 1.24	b
much labour required (n=31)	3.23 ± 1.45		2.71 ± 1.66		2.61 ± 1.48		3.00 ± 1.46		3.16 ± 1.53	b
required labour does not match labour supply (n=31)	3.81 ± 1.45	c	3.52 ± 1.57	b	3.48 ± 1.61	b	3.55 ± 1.63	b	3.74 ± 1.46	b
additional knowledge required (n=31)	3.23 ± 1.26		3.00 ± 1.34		3.35 ± 1.25	b	3.39 ± 1.26		3.32 ± 1.28	
III: social environment of the farmer										
positive attitude of colleague farmers (n=27)	3.30 ± 1.10		3.56 ± 1.12		3.44 ± 1.09		3.11 ± 1.16	b	3.67 ± 1.14	
positive attitude of extension officer (n=15)	2.67 ± 0.98		3.20 ±1.15	a	2.80 ± 1.01		2.80 ± 1.08		2.93 ± 1.16	
positive attitude of pesticide supplier (n=13)	3.31 ± 1.32		3.46 ± 1.39	a	3.38 ± 1.39		3.38 ± 1.33		3.62 ± 1.26	
positive attitude of game hunters (n=25)	1.96 ± 1.02		2.20 ± 1.08	*	1.76 ± 0.93		1.80 ± 1.04		1.76 ± 0.97	b

Legend: see Table 2; T = significant difference between the average scores of the 5 types tested by paired-sample t-test (* = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$); T = significant difference ($P < 0.05$) tested by ANOVA for difference between with or without experience (a), difference between the 3 projects (b) and interaction between a and b (c)

From the above it appears that the greatest differences among the types of unsprayed crop edges concern features related to agronomy. The preference for *grass strips* can be explained by the relatively minor problems with weeds, diseases and pests and the relatively positive attitude of colleague farmers. Despite the absence of a mowing machine on farms in the Haarlemmermeerpolder, 4 respondents give a grass strip as their first preference. This indicates that for these farmers this problem is solvable. The low preference for *unsprayed crop edges in potatoes* can be explained by the fear of an increase in diseases and pests in other parts of the crop. Besides, this type of strip is relatively less interesting for game hunters. The preference for *unsprayed cereal edges along other crops* is strongly influenced by the extra labour requirements. This type of strip is seen by the respondents as an extra crop activity. The low preference for *set-aside strips* is difficult to explain on the basis of Table 4. Many farmers view set-aside as an obligation resulting from the MacSharry adjustment. A few respondents spontaneously mention emotional complaints about set-aside. Farmers do not take part of the field out of production for no reason. As pointed out below Table 3, most of the respondents wish to achieve a yield from the unsprayed crop, and this is not possible with set-aside strips. Of all the types with a crop along the edge *unsprayed crop edges in cereals* have the best average scores despite the weed problems. This option is manageable with existing farm equipment.

Farmers' preconditions for unsprayed crop edges

In the second part of this article we look at which attributes the farmers see as important preconditions for the compatibility of unsprayed crop edges with the organization of their business. Stated differently: which attributes enhance the attractiveness of unsprayed crop edges?

From the statements made regarding compatibility with business organization it appears that besides the 4 attributes we distinguished there is one other aspect of particular importance. The respondents make it clear that it should be possible to terminate an agreement regarding unsprayed crop edges every year.

Table 5 presents the results of the conjoint analysis for the 31 respondents and the 3 projects. The degree of relative importance is given as a percentage. As Wierenga & Van Raaij (1987) point out, an attribute with small ranges between the utility scores of the different levels of the attribute is less important for the overall preference than an attribute with major variance in utility scores. Following this line of thought, the range of an attribute can be used as an indicator of the importance of that attribute for the overall preference. With the utility scores is it possible to calculate the personal utilities of a random product at the different levels of the attributes.

According to the respondents, the most important attribute is the width of the unsprayed crop edges. Their choice is 46% dependent on this attribute. They indicate a preference for a margin width defined by the farmer himself (highest utility score), as fitting best into his business organization. The payment system is the second attribute of importance (23%). The farmers prefer a conditional payment. This type of payment gives the farmers assurance about the amount received. The payment should compensate for yield losses and is not viewed as additional income. The attribute guidance has a 17% contribution to the total utility. Farmers prefer an infrequent rather than frequent form of guidance. This suggests they can manage the situation using their own knowledge. The least important attribute is the location of the margin in the field (13%). From the point of view of management a margin that can be rotated in the field gives the best results. In contrast, from the point of view of nature the farmers expect that the best results will be obtained with a fixed location in the field.

As can be seen in Table 5, the conjoint analysis results differ from project to project. The respondents in Gelderland prefer a margin width of 6 metres, the width with which they have experience in their project. The second attribute of importance in Gelderland is guidance (31%). The location in the field is of no importance here (2%). The respondents from the SBNL project have a high preference for a flexible width and conditional payment. In view of their experience with strips more than 6 metres wide the farmers interpret a flexible width as exceeding 6 metres. For the respondents from the CML project the width of the strip is by far the most important attribute (66%). They prefer a flexible width, which gives scope for a strip less than 3 metres wide. The location of the margin makes a 24% contribution and is of more importance than is the case in the other projects. The payment system and guidance are of little importance. These farmers have a slight preference for conditional payment and frequent guidance. The need for frequent guidance also appeared from the statements in which the respondents indicated that unsprayed crop edges as a means of nature conservation should be supported by farmer study groups and the extension officer.

Table 5. Results of conjoint analysis

	overall (n=31)		Gelderland province (n=9)		SBNL (n=12)		CML (n=10)	
	import. (in %)	utility	import. (in %)	utility	import. (in %)	utility	import. (in %)	utility
Width:	46.15		45.90		40.00		66.20	
* 3 metres		-0.84		-1.70		-0.83		0.00
* 6 metres		-0.21		0.89		0.11		-1.74
* defined by the farmer		1.05		0.81		0.72		1.74
Payment system:	23.48		20.66		35.36		4.23	
* conditional		0.48		0.58		0.69		0.11
* result		-0.48		-0.58		-0.69		-0.11
Guidance:	17.00		31.48		16.07		5.28	
* frequent		-0.35		-0.89		-0.31		0.14
* infrequent		0.35		0.89		0.31		-0.14
Location in the field:	13.36		1.97		8.57		24.30	
* fixed		-0.28		-0.06		-0.17		-0.64
* rotation		0.28		0.06		0.17		0.64

Legend: see Table 1; import. = importance of attribute

Discussion

This article considers the acceptability of different types of unsprayed crop edges by farmers with at least one year's experience with such edges. Two types of crop edges are given preference by the 31 farmers interviewed, namely unsprayed crop edges in cereals and grass strips, since these are most compatible with the existing farm organization and cropping patterns. The preference for unsprayed crop edges in cereals depends largely on the farmers' desire to produce a crop along the edge. The farmers' choice for cereals in the edge strip instead of potatoes is remarkable from an economic point of view. The nett cost, after deducting savings on pesticides, is approx. Dfl. 0.01 per square metre in winter wheat and zero in potatoes (De Snoo, 1994b). There is apparently a major fear of an increased incidence of diseases and pests in other parts of the crop, despite the fact that the use of fungicides is permitted. It should be noted that the gross margin for potatoes is considerably higher than that for cereals. With a potato crop the farmers' perception of risk is too high to experiment with unsprayed crop edges. The preference for grass strips is rooted in the associated avoidance of agricultural hazards (i.e. weeds, diseases and pests). A small group of respondents (primarily in the province of Groningen, SBNL project) prefer this type in combination with set-aside strips because of the lack of a need for maintenance. According to a number of respondents (primarily from the CML project) the attractiveness of set-aside strips would be improved if these could be made to fit in with existing Common Agricultural Policy (CAP) set-aside regulations.
Relative preferences differ only slightly among the 3 groups of respondents. It appears that respondents from the CML project are less satisfied with the compatibility of unsprayed crop edges with business organization because of labour requirements that do not match the available labour supply. This might be explained by the intensive nature of arable farming in the Haarlemmermeerpolder.

With respect to the 'ideal' unsprayed crop edge, significant insights were gained in this study. The most important factor for farmers is that the crop edge should be of flexible width. Furthermore, it should be possible to rotate the strip and there should be infrequent guidance and advice. In addition, they prefer the assurance embodied in conditional payment to payment for nature results. This is in accordance with the results of the DBL experiment (Melman, 1994). Melman points out that this choice may be a strategic one: first financial assurance via conditional payment and later greater income via a payment for nature results. Among the 3 groups of respondents there are differences in these preconditions, relating to differences in the intensity of farming and existing parcel structures in the region concerned. Hence, in the Haarlemmermeerpolder farmers prefer small, rotating margins to minimize the loss of cultivated land. Arable farming in the two other regions is far more extensive. Here, the strips are consciously located in field sections that are less productive (due to trees, hedgerows or inefficiency of machinery use) and where rotation is less relevant.

Given the differences in the compatibility of unsprayed crop edges with the farmers' business organization among the projects, a regional approach is to be preferred. This is in line with the policy of the Ministry of Agriculture, Nature Conservation and Fisheries (Ministry of LNV), which aims to stimulate regional initiatives by farmers and policy makers with regard to nature development by farmers. To achieve the policy targets for protecting Dutch surface waters (*cf.* Meerjarenplan Gewasbescherming, MJP-G, 1991) the unsprayed margin should be at least 3 metres wide (De Snoo, 1994a). If this unsprayed edge is established for the purpose of achieving nature conservation objectives, farmers could be given a specific reimbursement geared to local nature goals. In the DBL experiment concrete participation by farmers has so far been moderate on average. According to Melman (1994) one of the reasons is that the farmers are approached using written materials and public meetings only. The results of this study show that confidence in the contact person is indicated as the most important aspect for participating in unsprayed crop edge projects (Table 2). The interest of farmers might therefore be increased by making use of a local contact person who visits the farmers and liaises with government agencies. The magnitude of the payment is not discussed in this study. From discussions with farmers it appears that the reimbursement should at least cover the loss in the yield of the crop edge.

As shown in this paper, decision making in nature conservation is not just concerned with the monetary values of yields and input reduction but also with the goals and behaviour of those who make the farm management decisions. When research and extension programmes in nature conservation are being developed, it is important that an early attempt is made to obtain information on farmers' perceptions and on constraints affecting certain combinations of attributes (profiles). This analysis should be conducted at the regional or subregional level to account for differences in farm situations and farmers' objectives. By talking to and interviewing farmers and their advisors, it is possible to gain a better appreciation of the nature of the problem: whether farmers' perceptions or a certain combination of attributes are the major bottleneck, whether improved profiles can be developed or whether farmers' objectives can be met in some other way. We suggest that obtaining such background information to identify key features of nature conservation management decisions is a primary consideration if appropriate biological, environmental and economic research is to follow (see also Mumford & Norton, 1984).

Furthermore, following groups of farmers over a number of years could yield interesting information on how perceptions and preferences change with time. This would also give greater insight into whether adoption of nature management is positively related to the level of expertise and/or the level and manner of extension assistance. In further research attention should also be focused on the combination of normative biological-economic analysis with positive analysis of both producers' and consumers' attitudes towards nature conservation. This would provide policy makers with very valuable information concerning the trade-offs between the ecologically desirable and socially acceptable changes (see also Hodge, 1991).

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References

Addelman, S., 1962. Orthogonal main-effects plan for asymmetrical factorial experiments. Technometrics 4: 21-46.

Boatman, N.D. (Ed.), 1994. Field margins: Integrating agriculture and conservation, BCPC Monograph No. 58. Farnham.

Churchill, G.A., 1991. Marketing Research: methodological foundations. Chicago: the Dryden Press, 5th edition.

Deane, R.J.L., 1989. Expanded field margins; their costs to the farmer and the benefit to wildlife. A report to the Nature Conservancy Council. Glos: Kemerton Court.

Hair, J.F., R.E. Anderson & R.L. Tatham, 1990. Multivariate data analysis with read ings. New York: Macmillan Publishing Company, second edition.

Hald, A.B., B.O. Nielsen, L. Samsøe-Petersen, K. Hansen, N. Elmegaard & J. Kjoholt, 1988. Sprojtefri randzoner i kornmarker. Miljoprojekt nr. 103. Kobenhavn: Miljostyrelsen.

Hodge, I., 1991. The provison of public goods in the country side: how should it be arranged? In Farming and the countryside: an economic analysis of costs and benefits (N. Hanley, Ed.), pp. 179-196. Wallingford: CAB International.

Hooks, G.M., T.L. Napier & M.V. Carter, 1983. Correlates of adoption behaviors: The case of farm technologies. Rural Sociology 48 (2): 308-323.

Horst, H.S., A.A. Dijkhuizen & R.B.M. Huirne, 1995. Eliciting the relative importance of risk factors using conjoint analysis. In prep.

Katona, G., 1975. Psychological economics. New York: Elsevier.

Maris, W., 1993. 'Demonstratieproject Beheersmaatregelen t.b.v. de patrijs'. Jaarverslag 1992. Stichting Behoud Natuur en Leefmilieu, Wijk bij Duurstede.

Meerjarenplan Gewasbescherming (MJP-G), 1991. Regeringsbeslissing. Tweede Kamer, vergaderjaar 1990-1991, 21677, nrs. 3-4. SDU uitgeverij, Den Haag.

Meijer, W., 1991. Handleiding Akkerrandenbeheer provincie Gelderland. Arnhem.

Melman, Th.C.P., 1994. Field margins as a nature conservation objective in the Netherlands and Germany for nature conservation; policy, practise and innovative research. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 367-376.

Meulen, H.A.B. van der, G.A.A. Wossink & J.H. van Niejenhuis, 1995. Analysis of costs and perceptions of sustainable techniques in arable farming: the case of sugarbeet. In: M.F. Hofreither & S. Vogel (Eds.), The role of Agricultural Externalities in High Income Countries, Proceedings of the 37th Seminar of the European Association of Agricultural Economists, September 14-17, 1994, Vienna, Austria: Kiel: Wissenschaftsverlag Vauk: 143-160.

Mumford, J.D. & G.A. Norton, 1984. Economics in decisionmaking in pest management. Annual Review of Entomology 29: 157-174.

Rands, M.R.W., 1985. Pesticide use on cereals and the survival of grey patridge chicks: a field experiment. Journal of Applied Ecology 22: 49-54.

Schumacher, W., 1984. Gefährdete Ackerwildkräuter können auf ungespritzten Feldrän dern erhalten werden. Mitteilungen der LÖLF 9 (1): 14-20.

Snoo, G.R. de & P.J. de Wit, 1993. Pesticide drift from knapsack sprayer to ditches and ditch banks. Proceedings Brighton Crop Protection Conference - Weeds - 1993 (2), 879-884.

Snoo, G.R. de, 1994a. Unsprayed field margins in arable land. Med. Fac. Landbouww.

Univ. Gent 59/2b, 549-559.
Snoo, G.R. de, 1994b. Cost-benefits of unsprayed crop edges in winter wheat, sugarbeet and potatoes. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 197-201.
Snoo, G.R. de, R.T.J.M. Dobbelstein & S. Koelewijn, 1994. Effects of unsprayed crop edges on farmland birds. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 221-226.
Tew, T.E., D.W. MacDonald & M.R.W. Rands, 1992. Herbicide application effects mi crohabitat use by arable wood mice (*Apodemus sylvaticus*). Journal of Applied Ecology 29, 532-539.
Wierenga, B. & W.F. van Raaij, 1987. Consumentengedrag, Theorie, Analyse en Toe passing. Leiden/Antwerpen: Stenfert Kroese.

Part 5

Conclusions, recommendations and perspectives

15 Conclusions, recommendations and perspectives

The key issue pursued in this study is whether it is possible, by not spraying the margins of arable fields with herbicides and insecticides, to reduce pesticide emissions to the field surroundings and to what extent biodiversity in arable farming areas can be enhanced in a manner compatible with general farm management. These 3 aspects are elaborated in the various sections of this dissertation. Below, the main results of the study are summarized, in the form of conclusions and recommendations, making use of the literature data employed in Chapter 2.

Conclusions and recommendations

Environmental research

1 The margins of fields in the Haarlemmermeerpolder are sprayed intensively with pesticides (Chapter 3). This holds for the crop edge, the sterile strip, the ditch bank and the ditch bed. The sterile strip is sprayed by approx. 85% of farmers, simultaneously with spraying of the field. Approx. 95% of farmers also spray the sterile strip separately. The ditch bank is sprayed by approx. 60% of farmers, using a wide range of chemicals. The majority of these have not been approved for this application, however. Approx. 30% of farmers spray the ditch bed. In many cases the dosage employed is higher than recommended and varies by a factor 60 among the farmers interviewed.

2 During spraying of the crop with a field spraying unit, there is approx. 2% pesticide deposition in the adjacent ditch at low (<3 m/s) wind speeds (see Chapter 4). Deposition on the target crop is assumed to be 100%. Deposition on the ditch bank may be as high as 25%. At a wind speed of 3 m/s the ditch loading is equivalent to the dosage used to assess the risks of pesticides to aquatic organisms during the registration procedure (1-2%). With increasing wind speed, the ditch loading also increases. At 5 m/s, a wind speed at which spraying still regularly occurs in practice, deposition in the ditch is approx. 7%. Risk analysis indicates that at this wind speed 8 of the 17 pesticides investigated pose a risk to algae, water fleas and fishes. For 4 pesticides the risk is even high to very high. With current spraying technology, then, it is strongly recommended to postpone spraying if the wind speed exceeds 3 m/s.

3 At a wind speed of 5 m/s, buffer zones 3 metres wide reduce spray drift to adjacent ditches by more than 95% (Chapter 4). The targets for reducing emissions to surface waters laid down in the Multi-year Crop Protection Plan (MJP-G, 1991) can thus be achieved. The emission reduction to be achieved with smaller buffer strips was not investigated and deserves further study. Risk analysis indicates that with a 3-metre buffer strip only 4 of the 17 pesticides investigated pose a (minor) risk. With unsprayed strips 0.5 or 1.5 metres wide, more pesticides are anticipated to pose a risk.

4 Under practical conditions, during spraying of the sterile strip with a knapsack sprayer less than 1% of the pesticide ends up in the ditch and approx. 9% on the ditch bank (wind speed: max. 3.5 m/s; Chapter 5). With this mode of application, pesticide spray drift can be readily prevented by technical means, by using a spray nozzle with a tip angle of less than 60 degrees.
Practice shows that there are good mechanical alternatives for managing the sterile strip, ditch bank and ditch bed.

Ecological research

5 In all 3 crops investigated, the cover of plant species of arable land increases in the absence of spraying: in sugarbeet from an average of 10% to 44%, in potatoes from 4% to 11% and in winter wheat from 2% to 32% (Chapter 6). There is also an increase in the number of species of such plants: in sugarbeet from an average of 6 to 24 species, in potatoes from 8 to 17 species and in winter wheat from 6 to 17 species. The increase is due mainly to an increase in dicotyledonous species, which is relevant for the occurrence of other organisms in the agro-ecosystem, such as flower-visiting insects. Many species, such as *Papaver* spp., *Anagallis arvensis* and *Fumaria officinalis*, were found almost exclusively in the unsprayed margins and nowhere else in the fields.

6 The increase in the number of plant species of arable land is due almost entirely to common species. On the basis of a conservation value yardstick, whereby the rarity of a given species is combined with the population trend of that species, it can be concluded that there is also an increase in the conservation value of the vegetation in the unsprayed strips: in sugarbeet by a factor 5.2, in potatoes by a factor 2.8 and in winter wheat by a factor 7.2 (Chapter 6).

7 In unsprayed winter wheat margins the insect density in the upper parts of the vegetation is 3 to 4 times greater than in sprayed margins (Chapter 7). This increase is due to flower-visiting insects such as Syrphidae and also to natural predators of aphids such as Coccinellidae. The number of insect groups also increases in the unsprayed margins, by a factor 1.4.
The number of butterflies (Chapter 8) in unsprayed winter wheat margins is 4 to 5 times higher than in sprayed margins (from 2.3 to 11.0 individuals per 300 m^2). The number of butterfly species also increases, from 1.5 to 3.5 species per 100 m. In 1 of the 2 years that butterflies were inventoried there was also a significant increase in the number of butterfly individuals in the unsprayed potato margins.

8 The interaction with the ditch bank adjacent to the unsprayed margin has an important influence on the presence of insects. Butterflies naturally occur in greater numbers along the ditch banks than along the crop margins. On the ditch bank adjacent to the unsprayed margin, the number of butterflies increases by a factor 1.6: on average, from 12.8 to 19.2 individuals per 100 m (Chapter 8). There are indications that creation of an unsprayed strip at the centre of the field, unconnected to an outside landscape element such as a ditch bank, is of virtually no benefit to this species group.
From the perspective of the conservation effectiveness of the measures, it is important that this be further studied.

9 The number of epigeic soil invertebrates (activity density) in the unsprayed margins is found to be only slightly higher than in the sprayed margins (Chapters 9 and 11). Of the 4 dominant invertebrate groups, *viz.* Coleoptera, Araneida, Hymenoptera and Diptera, only the Araneida in winter wheat and the Coleoptera in sugarbeet were trapped slightly more frequently in 1 the 2 years of study (by a factor of approx. 1.2).
Carabidae constituted the bulk of the biomass of the epigeic soil invertebrates. In the unsprayed margins of winter wheat (in both years of study) and in those of sugarbeet (one year) the activity density of this family was greater than in the sprayed margins, by a factor 1.3. In one of the years of study a positive effect was found on the number of carabid species in all 3 crops. At the species level, the only clear effects were on herbivorous Carabidae in the genera *Harpalus* and *Amara*.

10 The unsprayed winter wheat margins were visited 3 to 4 times more frequently by the Blue-headed Wagtail than the sprayed margins (Chapter 10). No effect was found on the abundance of the Skylark. The different results for these two species are probably due to differences in diet and foraging strategy: the Blue-headed Wagtail forages in the upper parts of the vegetation, where there is a major impact on insect abundance (Chapter 7), while the Skylark forages exclusively on the ground. It is to be anticipated that leaving cereal margins unsprayed, will have a positive impact on the survival of Partridge chicks and consequently on the population of this species, as is the case in England (Chapter 2).

11 The limited inventory of small mammals undertaken indicates that it is above all cereal margins that are visited by (field) mice (Chapter 11). In the margins of sugarbeet and potato fields far fewer mice were caught. The unsprayed cereal margins appear to be more attractive to mice than the sprayed margins, as reflected in 38 compared with 27 mice caught.

12 A comparison of cereal field margins 3 and 6 metres wide indicates that it is above all the outermost metres of the field that are important for the vegetation and the insects living there (Chapter 12). The outer 3 metres originally harbour the greatest number of species. In the unsprayed situation there is no extra increase in the abundance of arable plant species or insects in the 6-metre-wide strips relative to the 3-metre-wide strips. This argues for the creation of long unsprayed margins 3 metres wide rather than 6-metre-wide strips of shorter length. By creating longer margins, moreover, there is greater benefit to nature and the environment along the ditch bank and in the ditch itself. There are insufficient data available on the abundance of field birds in narrow and wide margins. Further research is recommended to establish the relationship between the dimensions of the unsprayed margins and the occurrence of vertebrates.

13 The biodiversity-enhancement potential of other crop margin management options such as grass, wildflower or set-aside strips is highly dependent on the plant species sown and on the vegetation management regime (Chapter 2). If a grass or wildflower strip is sown, there is little scope for naturally occurring arable plant species. On the other hand, a grass strip has major significance for fauna, especi-

ally in winter when the rest of the field is bare. For many animal species, the presence of a summer and winter habitat in farmland is a precondition for long-term survival.

Compatibility with farm management

14 In all the unsprayed margins the crop yield was lower than in the sprayed margins (Chapter 13). On average over the various farms and years of study, the loss in yield amounted to about 30% in sugarbeet, 2% in potatoes and 13% in winter wheat. There was substantial variation from plot to plot and from year to year, however. The considerable loss in sugarbeet yield was due to the crop becoming overgrown with arable weeds. Both the cover and the height of the sugarbeet were lower in the unsprayed situation (Chapter 6). In this crop it was above all the absence of the first herbicide spraying session of the year that had a negative impact on the yield. In winter wheat and potatoes no negative impact on crop cover or height was observed in the unsprayed margins.

15 The harvest from the unsprayed margins was almost of the same quality as that from the sprayed margins (Chapter 13). No difference was found in the sugar content of the sugarbeet, sugar extractability, dry-matter content of the potatoes or moisture content of the cereal grains. In one year only was there slightly less variety in potato size in the unsprayed margins. In general, the harvest from the unsprayed margins could be processed together with that from the rest of the plot. Because of the possible dispersal of seeds of arable weeds, however, it does not seem advisable to create unsprayed margins along the margins of fields in use for seed and seedling production.

16 On the basis of this study, the unsprayed margins appear to create only minor indirect agricultural problems (Chapters 6 and 7). No increase in the abundance of arable plant species was observed on the unsprayed margins during the course of the study. Neither was there any indication that such plants spread to the rest of the field. Although there was an increase in the abundance of aphids in many of the unsprayed strips, the experiments in winter wheat crops demonstrated that the aphids did not spread to the rest of the crop.

17 A comparison of the costs of harvest losses with the savings on pesticide use achieved in the unsprayed margins indicates that the nett costs are high in sugarbeet: approx. Dfl. 0.21 per m² (Chapter 13). This type of field margin management is thus impractical. In a potato crop the costs of harvest losses are offset by the savings on pesticide use; with this crop there are zero nett costs. In winter wheat, finally, the nett costs are low: approx. Dfl. 0.01 per m². The costs of other margin management options, such as grass, wildflower and set-aside strips, are far higher than an unsprayed cereal or potato margin, taking an outer strip out of production.

Yield measurements indicate, furthermore, that in the sprayed situation the crop margin always yields 10-15% less than the plot centre. As a yardstick for possible financial reimbursement of arable farmers for leaving crop margins unsprayed, therefore, specific data on the margins should be employed.

18 If various different management packages are proposed to arable farmers experienced in field margin management, the farmers are found to show a preference for unsprayed cereal margins or unsprayed grass strips (Chapter 14). Unsprayed margins in potato crops and set-aside strips score substantially lower. Cereal margins around other crops occupy an intermediate position. This choice is found to be based mainly on crop protection arguments, such as the increase in the abundance of arable plant species and in the occurrence of diseases and pests on the margins and in the rest of the field. In the case of grass-sown strips the lack of suitable farm machinery, particularly in the Dutch lowlands, was quoted as the main argument. In their attitudes, the actors in the environment of the arable farmers differentiated little between the various management options. It is surprising that unsprayed potato margins score so low, despite the low costs they entail. This is probably due to a desire to avoid all risks in this high-profit crop. Educational activities concerning field margin management should therefore focus mainly on crop protection aspects. In addition, the creation of grass-sown strips can be encouraged by subsidizing certain types of farm machinery.

19 Interviews with arable farmers indicate that the most important aspect determining the compatibility of field margin management with overall farm management is the width of the unsprayed margins (Chapter 14). In this context there is a preference for a flexible width. On the basis of environmental and ecological study a minimum width of 3 metres appears to be adequate. In addition, arable farmers show a preference for a guaranteed payment rather than a system of reimbursement based on the conservation results achieved. Margin management need not be supported by an intensive support programme. The location of the unsprayed margins can rotate within a given farm.

20 The motives of arable farmers for participating in field margin projects are highly dependent on the degree of trust in the project liaison officer (Chapter 14). An additional factor of importance is the farmer's interest in the research. Prevention of spray drift to the field surroundings and/or enhancement of biodiversity in agricultural regions were found to play only a subordinate role.

Perspectives

Summarizing, it can be concluded that on the clay soils of the West of the Netherlands field margin management offers promising perspectives. By creating a relatively narrow strip 3 metres wide, the emission targets pertaining to pesticide spray drift to surface waters can be achieved. This is of major importance - on the one hand because of the high level of pesticide use in the Netherlands, and on the other because of the fact that so many fields are bordered by ditches.

As a means of enhancing biodiversity in farming regions, the creation of unsprayed margins in winter wheat offers the most promising perspectives. With this crop, there is certainly no less scope than in neighbouring countries. In addition, cereals are an important element in the rotation scheme of arable farmers in the West of the Netherlands. With winter wheat the costs of these measures are low. Arable farmers have a positive attitude towards unsprayed cereal margins, moreover.

In comparison with winter wheat, in potatoes the creation of unsprayed margins yields less conservation benefit. Although the costs in potatoes are extremely low on average, in this crop unsprayed margins are not popular with farmers. From the viewpoint of environmental protection, too, the creation of unsprayed margins serves less purpose in this crop, because with many varieties of potato it is scarcely possible to discontinue the use of fungicides (which were not included in the present study). Through use of these chemicals aquatic organisms remain at risk. In sugarbeet, finally, the costs of the measures are so high as to make unsprayed margins impracticable in this crop. In the case of potatoes and sugarbeet a better option is to create an unsprayed cereal margin or unsprayed grass-sown strip around the crop, for example. The scope for the flora and fauna of arable land in an unsprayed cereal margin around a second crop is probably no different from that in the unsprayed margin of a cereal plot. A margin sown to grass is particularly beneficial to the fauna, especially in winter, and is considered compatible with farm management by farmers. Based on the above, there appear to be at least two management packages with good perspectives for the Netherlands: unsprayed cereal margins and unsprayed grass-sown strips. As a variant on the latter, wildflowers may also be sown together with the grass.

An important question is how field margin management can be encouraged in the Netherlands. The creation of unsprayed margins will almost always involve extra costs, due to a depressed harvest or a decrease in productive area. In the Netherlands there is at present no general system of reimbursement in force for arable field margin management. However, there are at least 3 potential links to current policy.

Environmental policy
A strong incentive for creating unsprayed field margins can be found in current environmental policy in the field of pesticide use, as laid down *inter alia* in the Multi-Year Crop Protection Plan (MJP-G, 1991). Reduction of pesticide emissions to surface waters constitutes one of the key objectives of this policy and field margin management has been proven to be an effective instrument in achieving this aim. In the light of future technical developments aimed at limiting off-field pesticide emissions, with time it may prove sufficient to apply a narrower unsprayed margin. An important question is whether annually recurring costs connected with the prevention of surface water pollution, for example, should be reimbursed by the government. If farmers operate according to Good Agricultural Practice, there should be no loading of surface waters. For arable farmers the creation of unsprayed cereal margins is one way of operating in accordance with the criteria of environmental protection, with only little added expense. Cultivation of other unsprayed arable crops in the margins, with limited additional expenditure, is another option. This implies a certain degree of modification of current crop rotation schemes. In principle, the margin still provides part of the farmer's income, with the costs being borne by the farmer himself.

Agricultural policy
In principle, it is feasible to link up with European agricultural policy, and in particular with the EU's set-aside scheme, by not growing a non-agricultural crop in the field margin, but grass and/or a wildflower mixture. In this way some of the land is taken out of production and the overproduction of arable crops reduced. However, the current set-aside scheme should then be adapted and declared applicable to narrow margins only 3

metres wide. At the same time there must also be no pesticide use in these margins. In this context flora and fauna abundance in agricultural areas can be encouraged by gearing margin design and management as far as possible to these objectives.

Nature policy

Leaving the margins of arable fields unsprayed can also be directly encouraged within the context of nature policy, particularly in the framework of the so-called Relation Paper (a government paper on the relation between agriculture and nature and landscape conservation) or policy on species (protection of the Partridge, for example). Reimbursement for arable farmers will then always have to be linked to the pursuit of specific conservation objectives, such as the promotion of plants of arable land or protected animal species. This approach can in turn be linked to specific supplementary measures for achieving the set conservation targets, such as applying less fertilizer to cereal margins, or sowing them less densely, discontinuing mechanical weed control, or not harvesting the margin.

In the first 2 policy perspectives, promotion of biodiversity does not constitute an objective in its own right: in both cases, its 'co-option' will prove to be of a temporary nature. The third policy perspective does involve an independent objective geared to the promotion of biodiversity, but it is relatively expensive. It is to be anticipated that reimbursement in the framework of the Relation Paper or species policy will be given in some places only. Taking this into account, it is here recommended that it should be taken as a general principle of Good Agricultural Practice that cultivation should no longer be practised up to the edge of the ditch, but that, as standard practice, a strip about 1.5 metres wide should be left free of pesticides. In this way the environmental risks of pesticide residues can be pro-actively restricted. In addition, a certain degree of 'basic nature quality' (as laid down in government conservation policy) can be achieved in farming areas. Last but not least, with poppies and mayweed flowering round fields and improved chances being given to fauna, the public's perception of the Dutch agricultural sector will be improved.

In conclusion

In the course of a 4-year study, it was obviously not possible to answer all the questions concerning field margin management in the Netherlands. Agronomical questions regarding the consequences in the medium term, and differentiation among various regions and types of crop management could not be answered within this span of time. The ecological boundary conditions and their consequences for the long-term survival of species populations at the landscape level also need to be studied as an issue in its own right. However, the present study indicates that on clay soils specific field margin management in terms of pesticide use offers substantial scope for nature and the environment at the farm level and that a number of measures can be well integrated in overall farm management.

References

Meerjarenplan Gewasbescherming (MJP-G), 1991. Tweede Kamer, vergaderjaar 1990-1991, 21677, nrs. 3-4, SDU uitgeverij, Den Haag.

Curriculum vitae

Geert de Snoo werd op 12 januari 1961 te Zeist geboren. In 1979 behaalde hij het VWO-diploma aan de Christelijke Scholengemeenschap Amsterdam-Oost in Amsterdam. In hetzelfde jaar begon hij met de studie Biologie aan de Vrije Universiteit te Amsterdam. Tijdens de doctoraalfase waren de hoofdvakken Ecotoxicologie en Plantenecologie (prof.dr. E.N.G. Joosse en prof.dr. W.H.O. Ernst). Bijvakken waren Beleid en Bestuur aan de VU (prof.dr. E.J. Tuininga) en Natuurbeheer aan de Landbouwuniversiteit Wageningen (prof.dr. C.W. Stortenbeker). Naast deze wetenschappelijke opleiding werd de eerstegraads onderwijsbevoegdheid behaald. Tijdens zijn studie werkte hij als student-assistent voor de onderzoeksgroep Biologie en Samenleving (dr. J. Bunders). In 1986 werd de studie Biologie afgerond.
In de periode 1986-1990 was hij als projectmedewerker werkzaam bij het Centrum voor Milieukunde van de Rijksuniversiteit Leiden (CML). Hij was met name betrokken bij onderzoek op het gebied van de neveneffecten van bestrijdingsmiddelen op de Nederlandse flora en fauna. Van 1990 tot medio 1994 werkte hij als gekwalificeerd onderzoeker in dienst van de Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO) en werkte hij aan dit proefschrift. De werkzaamheden vonden plaats bij het Centrum voor Milieukunde, onder leiding van prof.dr. H.A. Udo de Haes. Vanaf medio 1994 trad hij wederom bij het Centrum voor Milieukunde in dienst, deels als projectleider en deels als universitair docent op het gebied van de ecotoxicologie. Sinds augustus 1995 is hij binnen de Onderzoekschool Milieuwetenschappen (SENSE) belast met het ontwikkelen van preventiestrategieën om de neveneffecten van bestrijdingsmiddelen te voorkomen.

Publikatielijst

Snoo, G.R. de, 1986. Effecten van dithiocarbamaten op vogels. Rapport Wetenschapswin kel VU, 30 p.

Capelleveen, H.E. van, G.R. de Snoo, J.E.M. Beurskens & J.G.A. van Zoest, 1987. The availability of lead in a terrestrial food chain. 91-101. In: H.E. van Capelleveen: Ecotoxicity of heavy metals for terrestrial isopoda. Free University Press Amsterdam.

Groot, G.M & G.R. de Snoo, 1988. Schimmeldodende middelen schadelijk voor vogels. Het Vogeljaar 36 (3) 128-130.

Snoo, G.R. de, 1989. Ontwikkeling risico-analysemethodiek voor bodemverontreiniging door systeemvreemde stoffen. Symposiumverslag tweede PCBB symposium, november 1989, Lunteren, 2 p.

Snoo, G.R. de & K.J. Canters, 1990. Side effects of pesticides on terrestrial vertebrates. CML report 35, Leiden, 147 p.

Canters, K.J., G.R. de Snoo, F,M.W. de Jong & J. van der Linden, 1990. Side effects of pesticides on terrestrial invertebrates and aquatic fauna. CML report 46, Leiden, 130 p + ann.

Jong, F.M.W. de, G.R. de Snoo & K.J. Canters 1990. Field trials for side effects of pesticides. CML report 60. Leiden, 76 p. + ann.

Snoo, G.R. de, 1991. Unsprayed field margins in the Haarlemmermeerpolder. EWRS-MSA Interactions, Wageningen, 2p.

Snoo, G.R. de & K.J. Canters, 1991. Vogels en zoogdieren chemisch onder druk. In: G.P. Hekstra & F.J.M van Linden (ed.), Flora en fauna chemisch onder druk. Pudoc, Wageningen: 149-173.

Snoo, G.R. de, 1993. Onbespoten akkerranden in de Haarlemmermeerpolder. Landinrich ting 33 (4): 31-34.

Snoo G.R. de & A. Wegener Sleeswijk, 1993. Use of pesticides along ditch banks and field margins. Med. Fac. Landbouww. Univ. Gent 58 (3a): 921-926.

Snoo, G.R. de & P.J. de Wit, 1993. Pesticide drift from knapsack sprayers to ditches and ditch banks. Proc. Brighton Crop Protection Conference - Weeds 1993 Vol. 2: 879-884.

Snoo, G.R. de & H.A. Udo de Haes, 1993. Unsprayed field margins in agro-ecosystems. Poster SETAC Lissabon 1993.

Snoo, G.R. de & F.M.W. de Jong, 1993. Ecological side effects of pesticides, another silent spring? lezing SETAC Houston USA 1993.

Canters, K.J. & G.R. de Snoo, 1993. Chemical threat to birds and mammals in The Netherlands. Reviews of Environmental Contamination and Toxicology 130: 1-29.

Canters, K.J., G.R. de Snoo, F.M.W. de Jong, R. Cuperus, 1993. Indirect side effects of pesticides. Poster SETAC Lissabon 1993.

Luttik, R. & G.R. de Snoo, 1993. Environmental hazard assessment of the use of pesti cides for seed treatment: The Dutch concept. Poster SETAC Lissabon 1993.

Jong, F.M.W. de & G.R. de Snoo, 1993. Field validation of the side effects of pestici des. Lezing SETAC Houston USA 1993.

Udo de Haes, H.A., W.L.M. Tamis, G.R. de Snoo & K.J. Canters, 1993. Algemene Natuurkwaliteit: een prima idee, maar het moet eenvoudig blijven. Landschap 10 (4): 53-58.

Snoo, G.R. de, 1994. Cost-benifits of unsprayed crop edges in winter wheat, sugar beet and potatoes. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 197-201.

Snoo, G.R. de, 1994. Een strookje minder, een vlinder meer. Onbespoten randen goed voor milieu, natuur en bedrijf. Boerderij 26 april 1994, nr. 30: 42-45.

Snoo, G.R. de, 1994. Unsprayed field margins in arable land. Proc. International Sympo sium on Crop Protection 4-5-1994. Med. Fac. Landbouww. Univ. Gent, 59/2b: 549-559.

Snoo, G.R. de, K.J. Canters, F.M.W. de Jong, R. Cuperus, 1994. Integral hazard assessment of side-effects of pesticides in the Netherlands - a proposal. J. Environmental Toxicology and Chemistry 13 (8): 1331-1340

Snoo, G.R. de, R.T.J.M. Dobbelstein & S. Koelewijn, 1994. Effects of unsprayed crop edges on farmland birds. In: N.D. Boatman (Ed.), Field margins: Integrating agriculture and conservation, BCPC monograph No. 58: 221-226.

Snoo, G.R. de & H.A. Udo de Haes, 1994. Onbespoten akkerranden voor natuur, milieu en bedrijf. Landschap, 11 (4): 17-32.

Aldershof, S., G.R. de Snoo, R. Cuperus, 1994. Een nieuw landbouwprodukt: vlinders! Vlinders 9 (5): 7-11.

Luttik, R. & G.R. de Snoo, 1994. Environmental hazard assessment of the use of pesti cides for seed treatment: The Dutch concept. BCPC Monograph no. 57: Seedtreatment: progress and prospects: 477-482.

Tamis, W.L.M., M. Gorree, J. de Leeuw, G.R. de Snoo & R. Luttik, 1994. The number of exposed dressed seeds in the field: an outline for field research. BCPC Monograph no. 57: Seedtreatment: progress and prospects: 471-476.

Snoo, G.R. de & J. de Leeuw, 1995. Non-target insects in unspraed cereal crop edges and aphid dispersal to the adjacent crop. Accepted: J. Appl. Entomology

Snoo, G.R. de, R.J. van der Poll & J. de Leeuw, 1995. Carabids in sprayed and unspray ed crop edges of winter wheat, sugar beet and potatoes. Acta Jutlandica 1995, in press.

Snoo, G.R. de, 1995. Enhancement of non-target insects: indications about dimensions of unsprayed crop edges. accepted Acta Jutlandia

Snoo, G.R. de & A. Wegener Sleeswijk, 1995. Gebruik van bestrijdingsmiddelen langs akkerranden en slootkanten in de Haarlemmermeer. H_20: 28 (14): 430-431.

Snoo, G.R. de, 1995. Cost-benefits analysis and farmer's perception of crop edge mana gement. Lezing IPPC, Congres, Den Haag.

Leeuw, J. de, M., Gorree, G.R. de Snoo, R.J. van der Poll & R. Luttik, 1995. Risks of granules and treated seeds to birds on arable fields. CML report 118, Leiden, 131 p.

Meulen, H.A.B. van der, G.R. de Snoo & G.A.A. Wossink, 1995. Perspectieven voor akkerrandenbeheer. Landinrichting 35 (5): 11-16.

Meulen, H.A.B. van der, G.R. de Snoo & G.A.A. Wossink, 1995. Natuurproduktie door Gelderse akkerbouwers. ZMO-krant 1995 nr. 20: 6.

Sunderland, K.D, G.R. de Snoo, A. Dinter, T. Hance, J. Helinius, P. Jepson, D. Kromp, F. Samu, N.W. Sotherton, S. Toft, B. Ulber, 1995. Density estimation for benificial predators in agro-ecosystems. Acta Jutlandica 1995, in press.

Nawoord

Op 8 mei 1987 hield Nick Sotherton van The Game Conservancy Trust een inspirerende lezing tijdens de workshop 'Neveneffecten Bestrijdingsmiddelen' in Utrecht, waarin hij de resultaten presenteerde van het 'Cereals and Gamebirds Research Project' in Engeland. Dit was de aanleiding om het onderzoek te starten waarvan in dit proefschrift verslag wordt gedaan.

Door de grote bereidheid van een aantal akkerbouwers in de Haarlemmermeerpolder kon het onderzoek ook daadwerkelijk worden uitgevoerd. Op hun bedrijven werden experimenten verricht waarvan de afloop moeilijk was in te schatten. Helaas doet dit proefschrift geen verslag van de enorme gastvrijheid die ik heb mogen ervaren en de intensieve contacten die ontstonden. Ik noem daarbij met name de heren M. van Nieuwenhuyzen, M. Maat, J.C.A. Buitenhuis, Ph. Blom, N.J.W. Koeckhoven, K. Roodenburg, G.J. Nieuwenhuis, O. de Kok, D. de Kok, E. de Groot, M.T.S.D. de Groot, J.W. Bus, gebroeders Nieuwenhuis, D.C. Molenaar, dhr. A.C. van Nieuwenhuyzen, gebroeders Verbeek, R. Stokman en medewerkers van het loonbedrijf RVR te Hoofddorp.

Het zal duidelijk zijn dat dit onderzoek niet door één persoon is uitgevoerd. Een groot aantal mensen heeft zich uitermate ingezet om het tot een goed einde te brengen. Allereerst wil ik de collega's, studenten en stagiaires noemen die hiervoor van grote betekenis zijn geweest, te weten: Rob van der Poll, Joop de Leeuw, Mark van der Wal, Paul de Wit, Hans Donner, Anneke Wegener Sleeswijk, Harold van der Meulen, Steven Koelewijn, Frank Mugge, Robert Dobbelstein, Joeri Bertels, Annet Muller, Edwin Koning, Sasja van Doorn, Pauline Hartsuyker en Saskia Aldershof.

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