RISKS OF GRANULES AND TREATED SEEDS TO BIRDS ON ARABLE FIELDS

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Supplemental research for the risk-assessment scheme for birds

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PREFACE

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The authors Leiden, June 1995

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SUMMARY

Before a pesticide is approved for use in the Dutch market, an assessment must be made of the risk of its use to non-target organisms. This study considers the extent to which use of pesticides, in the form of granules or seed-treatment agents, constitutes a potential risk to birds. If treated seeds or granules remain on the field surface during drilling, they may be picked up by birds for two reasons: seeds may be taken for food, or granules and pelleted seeds may be taken for potential grit (small stones used by birds to grind down their food). There are presently a number of gaps in the knowledge required to assess the risk of using such granules and seed-treatment agents. First of all, nothing is known about the grit consumption of farmland birds in the Netherlands. In addition, it is unknown what proportion of seeds remains on the surface after drilling. This study therefore has a twofold aim:

1. to describe the grit particles consumed by farmland birds, establish their resemblance to granules and pelleted seeds, and assess the resulting risk to these birds, and
2. to estimate the number of treated seeds remaining available to birds at the soil surface after drilling various crops, establish factors of influence and incorporate these in a risk assessment procedure.

Part 1: Resemblance between grit and granules/pelleted seeds

In order to describe the grit in bird gizzards, the gizzard content of some 200 birds of varying size and diet (e.g. granivores and non-granivores) was examined. The grit particles in the gizzards were counted and the size, shape and colour of those particles larger than 0.5 mm were determined. The results show that the grit particles recovered from granivores differ in size from those recovered from all other groups. This group of birds have comparatively more grit particles in their gizzards. Small granivores such as sparrows and finches mainly consume particles somewhat larger than 1 mm. Large granivores such as woodpigeons and pheasants have particles of 2-3 mm in their gizzards. In the non-granivores large numbers of very small particles (< 0.5 mm) were found. Particles this size cannot possibly have been picked up individually. The shape of the grit particles was virtually the same for all bird groups: about 1.4 times longer than wide. No correlation was found between the colour (chroma) of the grit and the bird groups. However, large granivores were found to pick up lighter particles than the other bird groups. This may indicate selectivity in the case of these birds, or, alternatively, a correlation between grit size and the nature of the parent material.

The size, shape and colour of the grit found in bird's gizzards were compared with a

number of granules and pelleted seeds in common use in the Netherlands. It was found that, in terms of size, small granules show a strong resemblance to the grit consumed by non-granivores and small granivores. The larger granules (pellets used to control slugs) show a stronger resemblance in size to the grit picked up by large granivores. The pelleted seeds investigated show only a slight overlap in size with the grit used by large granivores.

On the basis of the resemblance between bird grit on the one hand and granules and pelleted seeds on the other, an estimate has been made of the potential risk to birds foraging on drilled fields. In doing so, the following factors were also given due consideration: dose and toxicity of the pesticides employed, availability of granules and pelleted seeds, number of particles consumed daily and foraging strategy employed. It was found that small granivores run the greatest risk. Of the pesticides, the small granules (approx. 1 mm) appear to be pose the greatest risk to small granivores, and the larger granules (slug pellets) to large granivores. The pelleted seeds also appear to pose a risk to large granivores, although to a lesser degree.

Part 2: Availability of treated seeds resembling natural food

Field research to establish the number of seeds remaining on the field surface was undertaken in nine arable crops in various districts of the Netherlands. These crops were drilled using various techniques (standard and precision) and the seeds were of various size. Sampling to establish the number of surface seeds post-drilling was performed at field centres and on headlands. Depending on the crop, counts were carried out in the spring or autumn. At a number of sites it was also investigated how long the seeds remain on the surface post-drilling.

The research results indicate that the greatest number of seeds remains on the field surface after drilling of a winter wheat crop (autumn sowing). Even after correcting for seed density, it is in this crop that the highest proportion of seeds remains on the surface. The main factors of influence on the number of surface seeds are drilling technique, soil condition (seed-bed quality) and position in the field: headland or field centre. In standard-drilled fields 4 times more surface seeds were found on average than in precision-drilled fields. In cereal crops an average of 13 times more surface seeds were found in the autumn than in spring, probably as a result of soil condition. On headlands, finally, an average of 4 times more surface seeds were found than at the field centre. The study also investigated the number of seed spill spots in fields, at places where drilling machines are filled, for example. It was found that in some fields the total number of seeds at such spill spots is comparable with the number of seeds remaining on the surface post-drilling. The number of surface seeds declines in the period post-drilling. In the autumn of 1994 it was found that 50% of the surface seeds had disappeared after about 6 days (in winter wheat). In the autumn of 1993 this period was more than 14 days, however. The results of the field study have been used to arrive at a risk estimate for several crop protection agents, crops and bird species. In doing so, optimal foraging theory has also been taken into consideration.

SAMENVATTING

Voordat een bestrijdingsmiddel op de Nederlandse markt wordt toegelaten, wordt onderzocht in hoeverre het gebruik van de stof risico's kan opleveren voor niet-doelwit organismen. In dit onderzoek is nagegaan in hoeverre het gebruik van bestrijdingsmidelen, in de vorm van granulaten of zaaizaadbehandelingsmiddelen, mogelijke risico's met zich meebrengt voor vogels. Als bij toepassing behandelde zaden of granulaten aan het oppervlak van een akker blijven liggen, kunnen ze om twee redenen door vogels worden opgepikt: zaden kunnen worden gezien als voedsel of granulaten en gepilleerde zaden kunnen worden gezien als potentieel grit (maalsteentjes die helpen bij de voedselvertering). Voor het bepalen van de risico's van het gebruik van granulaten en zaaizaadbehandelsmiddelen bestaan bij de risico-evaluatie een aantal kennislacunes. Allereerst is niet bekend wat het gritgebruik is van akkervogels in Nederland en daarnaast is onbekend hoeveel zaden na het zaaien aan het oppervlak blijven liggen. Het doel van dit onderzoek is dan ook tweeledig:

1. het beschrijven van grit bij akkervogels en het vaststellen van de gelijkenis van grit met granulaten en gepilleerde zaden, en een schatting van het hieruit resulterende risico en
2. het verkrijgen van een beeld van het aantal zaden dat achterblijft aan het oppervlak na zaaien van verschillende gewassen, factoren die dit aantal beïnvloeden en de verwerking hiervan in een risicoschatting.

Deel 1: Overeenkomt tussen grit en granulaten/gepilleerde zaden.
Voor de beschrijving van het grit in vogelmagen is de maaginhoud van ca. 200 vogels van diverse grootte en met verschillende dieeten (zoals zaadeters, niet-zaadeters) onderzocht. De steentjes in de vogelmagen zijn geteld en van de steenjes groter dan 0.5 mm is de grootte, vorm en kleur bepaald. Uit de resultaten blijkt dat de grootte van gritdeeltjes bij zaadetende vogels zich onderscheid van alle andere vogels. Deze vogelgroep heeft naar verhouding veel meer grote steentjes in de maag. Kleine zaadeters zoals mussen en vinken verzamelen hoofdzakelijk steentjes van ruim 1 mm. Grote zaadeters zoals houtduiven en fazanten hebben steentjes van ca 2-3 mm in hun maag. Bij de niet-zaadeters zijn grote hoeveelheden zeer kleine deeltjes (<0.5 mm) aangetroffen. Dergelijke deeltjes kunnen onmogelijk afzonderlijk opgepikt worden. De vorm van de gritdeeltjes blijkt voor alle vogelgroepen nagenoeg hetzelfde te zijn: ca 1,4 maal zo lang als breed. Er is geen verband gevonden tussen de kleur (chroma) van het grit en de vogelgroepen. Bij grote zaadeters zijn de grit deeltjes evenwel lichter van aard dan bij de andere vogelgroepen. Dit kan duiden op eventuele selectiviteit van deze vogels, maar ook op een correlatie tussen de grootte van steentjes en de aard van het moedermateriaal.

De grootte, vorm en kleur van grit in de vogelmagen is vergeleken met een aantal in Nederland veel gebruikte granulaten en gepilleerde zaden. Het blijkt dat kleine granulaten voor wat betreft hun grootte sterk overeenkomen met het grit van niet-zaadeters en kleine zaadeters. De grotere granulaten (slakkenkorrels) vertonen qua grootte meer overeenkomst met het grit van grote zaadeters. De onderzochte gepilleerde zaden vertonen alleen een (geringe) overlap met het grit van grote zaadeters voor wat betreft hun grootte.

Op basis van de overeenkomst tussen het vogelgrit enerzijds en granulaten en gepilleerde zaden anderzijds is een schatting gemaakt van de potentiële risico's voor vogels die op de akker fourageren. Hierbij is tevens de dosering en toxiciteit van de gebruikte bestrijdingsmiddelen, de beschikbaarheid van granulaten en gepilleerde zaden, het aantal deeltjes dat dagelijks wordt opgepikt en de manier waarop deze worden verzameld, beschouwd. Hieruit volgt dat zaadeters de meeste risico's lijken te lopen. Van de bestrijdingsmiddelen lijken de kleine granulaten (ca. 1 mm) vooral riskant voor kleine zaadeters en de grotere granulaten (slakkenkorrels) voor grote zaadeters. De gepilleerde zaden lijken in mindere mate ook voor grote zaadeters risico's te kunnen opleveren.

Deel 2: Beschikbaarheid van op bruikbaar voedsel gelijkende, behandelde zaden.

Het veldonderzoek naar het aantal bovenliggende zaden op akkers is verricht in negen akkerbouwgewassen in verschillende gebieden in Nederland. Deze gewassen worden met verschillende zaaitechnieken gezaaid (standaard en precisie) en de zaden zijn van verschillende grootte. De bemonstering van het aantal bovenliggende zaden na het zaaien heeft plaatsgevonden in het centrum van de percelen en op de wendakkers. De tellingen zijn afhankelijk van het gewas in het voor- en najaar verricht. Op een aantal locaties is tevens nagegaan hoelang de zaden na het zaaien aan het oppervlak blijven liggen.

De resultaten van het onderzoek tonen aan dat in het gewas wintertarwe (inzaai in het najaar) het grootste aantal zaden bovengronds blijft liggen. Ook na correctie voor de zaaidichtheid blijven in dit gewas relatief de meeste zaden bovengronds liggen. De belangrijkste factoren die van invloed zijn op het aantal bovenliggende zaden zijn de zaaitechniek, de bodemconditie (kwaliteit van het zaaibed) en de plaats op het veld: wendakker of centrum van het perceel. Bij standaard gezaaide percelen zijn gemiddeld 4 maal zoveel bovenliggende zaden gevonden als bij precisie gezaaide percelen. In het najaar zijn bij granen gemiddeld 13 keer zoveel zaden aangetroffen als in het voorjaar, waarschijnlijk als gevolg van verschil in bodemconditie. Op wendakkers tenslotte zijn gemiddeld 4 keer zoveel zaden gevonden als op de centra van de velden. In het onderzoek is ook gekeken in hoeverre op de akker spilplaatsen van zaden aanwezig zijn, bijvoorbeeld op plaatsen waar de zaaimachines worden gevuld. Het blijkt dat op sommige velden het totaal aantal zaden op de spilplekken vergelijkbaar is met het aantal zaden dat bij het zaaien boven blijft liggen. In de periode na het zaaien neemt het aantal bovenliggende zaden op de akker af. In het najaar van 1994 bleek 50% van de bovenliggende zaden na ca. 6 dagen te zijn verdwenen (wintertarwe). In het najaar van 1993 duurde deze periode echter meer dan 14 dagen. De resultaten van het veldonderzoek zijn verwerkt in een risicoschatting voor enkele stoffen, gewassen en vogelssoorten. Hierbij is ook de optimal foraging theory beschouwd.

GENERAL INTRODUCTION

1 The risk-assessment scheme

An enormous variety of pesticides are used in agriculture today, and every year many new agents are developed. Before these new pesticides are approved for use in the Netherlands, their behaviour and effects must be evaluated. One of the aspects of this evaluation procedure is an assessment of adverse side-effects. In the Netherlands a stepwise assessment procedure has been developed to assess the hazards of pesticides to birds and mammals in the field (Luttik, 1992). This procedure is based on a risk-assessment scheme that can be used for pesticides used as a spray, for seed treatment or as granules. The general structure of this risk-assessment scheme is shown in Figure 1. The scheme helps to decide which module should be used for the mode of use of a particular pesticide. Luttik (1992): "In the risk-assessment scheme 3 different types of boxes and two different types of arrows are used:

- boxes with a single line are steps in the scheme where a choice has to be made;
- boxes with a double line are boxes where a statement is made or a reference to another module is given;
- boxes with a double vertical line and a single horizontal line are boxes with conclusions about the degree of risk,
- double lined arrows are indicating the route which has to be followed in the scheme,
- single lined arrows are indicating that one has to go back to the general module to look for other exposure possibilities."

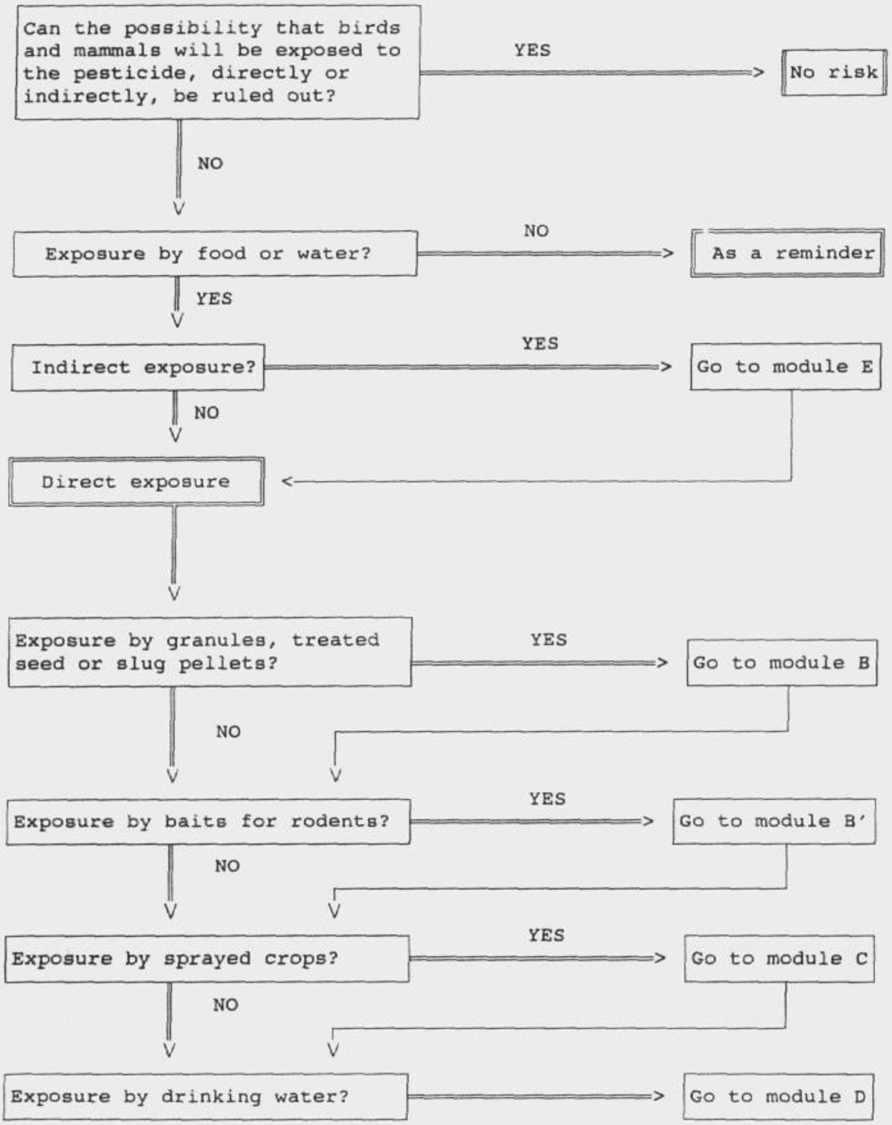

Figure 1. The general module of the risk-assessment scheme

The general scheme is referred to as module A. There are 4 modules dealing with possible exposure routes for birds or mammals:

module B:	exposure by granules, treated seed and pellets
module B':	exposure by baits for rodents;
module C:	exposure by pesticides used for spraying crops;
module D:	exposure by drinking water;
module E:	exposure by secondary poisoning.

2 Risks of treated seeds, granules and pellets

This report is focused on module B, dealing with exposure to granules, treated seed and pellets. These pesticide applications may pose a risk to birds and small mammals. These applications and their possible risks to wildlife are described below.

Seed treatment involves the direct addition of pesticides and other substances such as nutrients and beneficial microorganisms to the seed. Seed can be treated in different ways:

- Conventional treatment: the pesticides are added to the seed by mixing the seed with a powder, liquid or slurry formulation (Jeffs & Tuppen, 1986).
- Film-coating: the seed is coated with a film containing pesticides. This is achieved by adding film-forming binders to the liquids used in conventional seed treatment or in a more sophisticated way, e.g. by spraying relatively large volumes of pesticide and polymer binders on the seeds, with simultaneous drying. Film-coating results in a film around the seed that is usually coloured. The differences with the conventionally treated seed are: absence of dust, uniform coverage between and on individual seeds, and improved flow through the drill (Jeffs & Tuppen, 1986; Halmer, 1994).
- pelleted seeds: Small or irregular seeds are built up into spherical capsules so they can be sown with the required precision. Pesticides are added to the capsule coatings (Jeffs & Tuppen, 1986).

Seed treatment is used in many crops, e.g. sugar beet (pelleted), cereals, onion and pea (Mandersloot, 1993). By adding the pesticide directly to the seed instead of spraying after sowing, less pesticide can be used. Seed treatment is therefore generally considered to be relatively environmentally friendly.

Granules are small inert carriers (length: aprox. 1 mm) to which the pesticide is added. These granules are lightly incorporated into the soil and then slowly release the pesticide to the soil. A variety of carriers are used, including silica, clay, corncob, gypsum or cellulose (Best & Gionfriddo, 1994). They are used to control insects, nematodes and molluscs ((Mandersloot, 1993). Pellets are particles larger than granules (length: between 3 and 6 mm) that are used for controlling slugs. They are incorporated in the soil in the same way as granules. In this report they are treated as (large) granules.

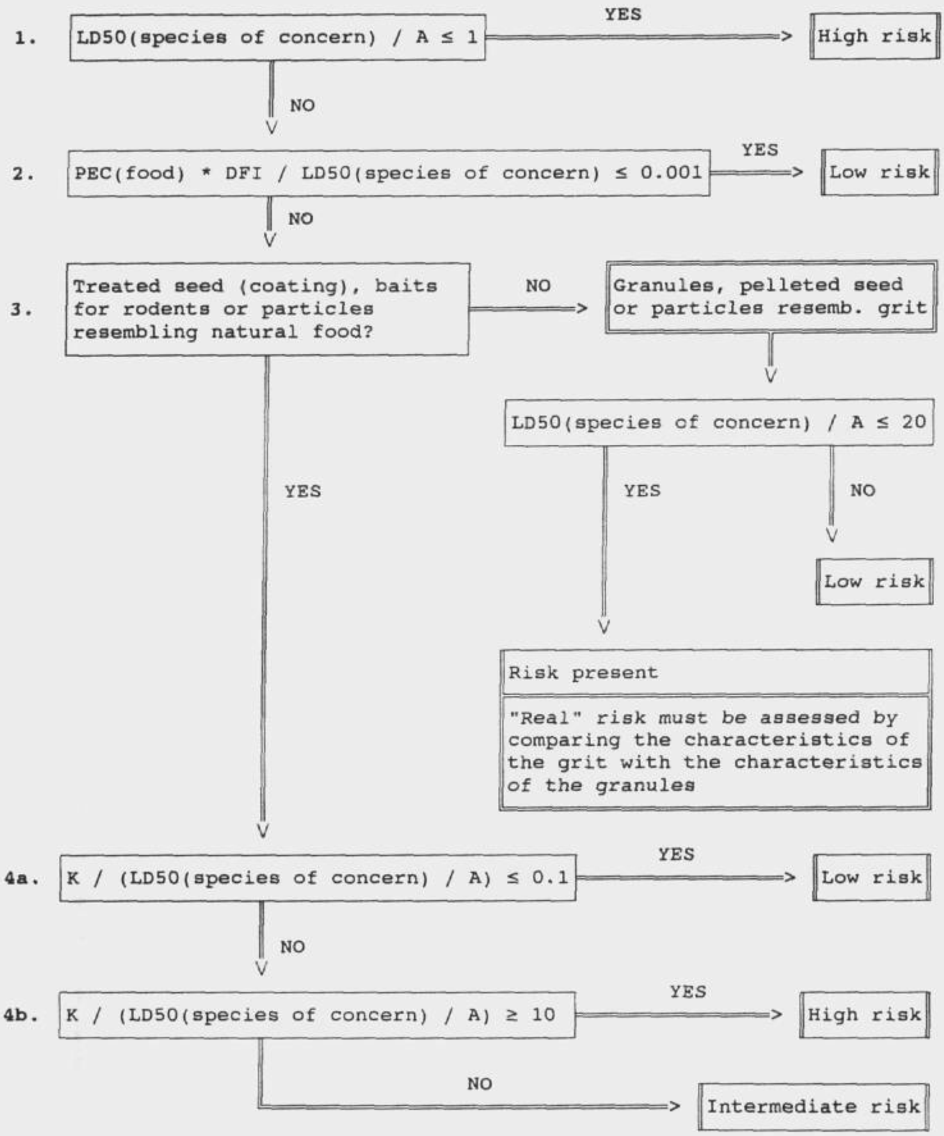

Figure 2. Module B: exposure by granules, treated seed and pellets. A: Amount of pesticide on one particle, K: number of particles available on the soil surface per m^2, DFI: Daily Food Intake, PEC(food): Predicted Environmental Concentration of pesticide on food.

Both granules and treated seeds may pose a risk to birds. The treated seeds can be picked up as food, while granules can be picked up by birds mistaking them for stones that can be used as grit (i.e. stones in a bird's stomach; see Part A of this report). Pelleted seeds may likewise be picked up as grit because pelleting changes the appearance of the seeds and birds can mistake the pelleted seed for stones. Even though the most hazardous pesticides have now been banned, there are still pesticide applications allowed that have been associated with poisoning incidents: lindane, chlorfenvinphos, methiocarb and fonofos for seed treatment and carbofuran for granules (Hart & Clook, 1994; Cooke, 1988).

The risk to birds of granules and treated seeds is assessed in module B. This module is shown in Figure 2. The risk assessment in this module is based on the LD50 of the species concerned. The LD50 is the dose at which 50% of the individuals of a species die. In the first step (1 in Fig. 1) the amount of pesticide on one granule or seed is compared with the LD50 of the species concerned. In the second step (2 in Fig. 1) the amount of pesticide ingested if the daily food intake consists completely of the particles containing the pesticide is compared with the LD50. In the third step (3 in Fig. 1) it is decided if the particles resemble food or grit. The risk assessment for particles resembling grit is still to be elaborated. The risk assessment for particles resembling food is based on the amount of pesticide (on the particles) per surface area. In this last step (4a and 4b in Fig. 1) the amount of pesticide available per m^2 is compared to the LD50.

However, the risk assessment using module B is hampered by a lack of information at two points. The first is step three of the risk-assessment scheme. This step requires characterization of the appearance of grit used by birds. Moreover, the method to assess the degree of risk for particles resembling grit has yet to be developed. The second point where the risk-assessment scheme is hampered is step four. To calculate the amount of pesticide per surface area, it is necessary to know the number of particles available on the soil surface. In addition, the risk measure used in step four has to be evaluated from the point of view of optimal foraging theories.

3 Aim of the research

Information on the above-mentioned subjects is necessary for further development of the risk-assessment scheme. Therefore the aim of the research described in this report was to gather information on the following subjects:

A. The appearance and number of grit particles consumed by bird species in the Netherlands, their resemblance to granules and pelleted seeds and the resulting risk to these birds.

B. The number of treated seeds available to birds at the soil surface and the risk of these seeds to birds.

The two subject were studied separately and are therefore described in two separate parts of the report; Part A describes the research focused on grit and its resemblance to granules and pelleted seeds, while Part B focuses on the availability of treated seeds resembling natural food and on the evaluation of the risk assessment of these treated seeds, based on optimal foraging theories. The research focused on birds, but most of the results can also be used for the assessment of the hazards posed to small mammals.

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Part A:

Resemblance between grit and granules/pelleted seeds

PART A: CONTENTS

CHAPTER 1: INTRODUCTION

1.1 Granules, pelleted seeds and the risk to birds

Many bird species ingest small stones (grit) in order to grind their food (Farner & King, 1972) and to obtain minerals, especially calcium in the egg-laying period (Vance, 1971; Moksness, 1988; Sadler, 1960). For most of the European species, however, it is unknown how much and what kind of grit they have in their gizzards. Many pesticides used in arable fields are formulated as granules, or are added to pelleted seeds. Fig. 1.1 shows a granule applicator used in the Netherlands. When granules or pelleted seeds are left on the surface of the soil, they may look like normal grit to birds, which may therefore pick them up intentionally (see step 4 in the decision scheme on p. xvii). Granular pesticides can be extremely hazardous to birds this way. In a laboratory experiment Balcomb *et al.* (1984) found that of the 16 granular insecticides tested, 6 resulted in mortality in House sparrows or Red-winged blackbirds when these birds were given a single particle (for the scientific name of the species mentioned, see Appendix 1). Most avian mortality incidents reported in the field as a result of granule ingestion are caused by carbofuran. Mineau (1988) mentions kills of large numbers of waterfowl and granivorous songbirds. Greig-Smith (1987) lists 30 incidents with pellets (large granules used for controlling slugs) and granules in England and Wales in the period 1980-87. Most incidents mentioned here involved the pesticides metaldehyde and carbofuran. Balcomb *et al.* (1984) systematically searched 195 ha of corn fields on which granular carbofuran was applied and found 7 poisoned songbirds. Although pelleted seeds are applied in much lower densities than granules, they may also look like grit to birds and thus constitute an avian hazard.

Reported kills highly underestimate the true mortality rate. Balcomb *et al.* (1984) point out that few people search for wildlife on agricultural land. Mineau (1988) has doubts about the willingness of farmers to report kills to the authorities. He also concludes that the carcass search efficiency is often in the 50% range, that many birds die outside the treated fields, and that the majority of fresh carcasses can be removed in one night by scavengers.

The aim of this research is to describe the grit that birds use on arable fields in the Netherlands, and to establish the resemblance of this grit to some widely used granules and pelleted seeds. Secondly, the study assesses the resultant hazards to these birds.

Figure 1.1 A granule applicator used in the Netherlands.

1.2 Mechanisms of exposure

In this study we concentrate on two potential mechanisms of avian exposure to granules mentioned by Best & Fisher (1992), and the same reasoning is applied here to pelleted seeds.

1. Granules or pelleted seeds may be picked up *intentionally* as a source of grit to birds. According to Farner & King (1972), one of the functions of the muscular stomach or gizzard is grinding food. Many species also make use of small stones (grit), especially graminivores, herbivores and some omnivores. The theory of the grinding ability of grit has been made acceptable by Norris *et al.*, 1975; Porkert & Höglund, 1984; Lifjeld, 1984; Norman & Mumford, 1985; Alonso, 1985; Högland & Porkert, 1983; Moksnes,

1988; Soler *et al.*, 1993; Norman & Brown, 1985; Hogstad, 1988. Grit is also mentioned as a source of minerals, especially calcium (Walton, 1984; Sadler,1960).

2. Birds may also pick up granules or pelleted seeds *inadvertently* as they forage on the ground. This can happen if they probe the soil for seeds or seedlings, or if granules adhere to selected food items like earthworms. In addition, we mention the possibility of birds ingesting small heaps of soil that function as grit without selection of separate particles. In such cases, birds may ingest granules along with small soil particles.

1.3 Grit use and characteristics of grit

1.3.1 Grit use

Whether selectively or randomly picked up, the **number** of particles ingested is very important in assessing the hazards to birds, and so are the factors that influence this number. From the literature on this subject, two factors seem to play an important role:

Diet: Best and Gionfriddo (1991a) found that all individuals of granivorous species like Pheasants and House sparrows have grit in their gizzards, whereas less than 50% of the examined Starlings, omnivores, appear to have grit in their gizzards. Also, Walton (1984) found that only 33% of adult Meadow pipits, which are mainly insectivorous, use grit. Only the juveniles (78%) use grit to a large extent. Norman & Brown (1985) examined ten species of Australian waterfowl and found that carnivorous species had less grit in their gizzard than herbivores. Soler *et al.* (1993) reported that Ravens normally eat carrion and small invertebrates, and grit use is almost never recorded in this species. In contrast, they found that Ravens in their agricultural research area are mainly granivorous and use large quantities of grit. Alonso (1985), Porkert *et al.* (1984), Mathiasson (1972), Norris *et al.* (1975) and Hogstad (1988) have shown that the number of grit stones also varies in relation to seasonal changes in diet.

Bird size: Lifjeld (1984) examined five species of waders and found that the amount of grit is positively correlated with the body size of the waders.

1.3.2 Characteristics of grit

If birds ingest stones selectively, one might expect them to ingest stones with features best suited to performing both the functions (grinding and mineral source) mentioned in paragraph 1.2. However, how birds select their grit is still largely unknown. A number of characteristics mentioned in literature will de discussed below.

Grit size

Högland & Porkert (1983) found that among the stones they offered to Capercaillie, Black grouse and Willow grouse, only those with certain dimensions were ingested. Norris *et* *al.* (1975) found that Willow grouse, when offered stones of various sizes, rarely consumed stones smaller than 2 mm. Trost (1981) concludes that grit consumption in captive Mallards is also affected by the size of the particles offered. Spanish sparrows ingest larger numbers of small particles in winter, when their diet consists mainly of small seeds, than in summer, when the birds ingest larger food items (Alonso, 1985). Lifjeld (1984) records that the size of grit particles in the gizzards of five species of waders is positively correlated with the body size of the birds. Best & Gionfriddo (1991a) characterized the grit use by 22 bird species with all kind of dietary habits in a cornfield area. According to the authors all kinds of stones were available in this area, but of all the characteristics examined, the birds differed most in the size of the grit they used. They found that grit size increases with the body mass of the examined species, including less selective birds. Resuming, the size of the particles appears to play an important role in grit uptake, and the size of the ingested particles seems related to body size (mass) and diet.

Grit colour

Colour has proven to be an important factor in the search for food by birds. Pank (1976) proposed using this fact by colouring seeds of the Douglas fir (*Pseudotsuga menziesii*) black or green, colours that proved to have a negative effect on the acceptance of the seeds. When granules based on crushed corncob as a carrier were coloured black, Pheasants were found to reduce their intake by 80-90% compared to their intake of uncoloured, yellowish white granules (Spittler, 1978). Best & Gionfriddo (1993), referring to unpublished data, have found an avoidance of black grit by House sparrows, too. In the grit of wild cornfield birds a variety of grit colours can be observed: from colourless to opaque. Most grit is opaque, and predominant hues are whites, grays and light browns. Blues and greens are rare (Best, 1992). It seems likely that birds select grit colours, and they seem to demonstrate an aversion to black and green and a preference for light colours. However, the dominance of opaque grit found by Best (1992) in wild birds suggests that availability might be equally important.

Shape of grit

'Shape' is defined here as the ratio of particle width to length. Unfortunately, there is very little information on possible selectiveness regarding this characteristic. Best & Gionfriddo (1991a) examined the shape of the grit of cornfield birds in the U.S., and they also investigated the preferences of two granivorous bird species in captivity with respect to these characteristics (Best & Gionfriddo, 1994). They found that shape does affect grit selection.

Grit composition

Soils in the Netherlands consist mainly of sediment (clay and sand). Clay particles are much too small to serve as grit for birds. Sand (quartz) would be more suitable. It is probably difficult to erode in the gizzard. Best & Gionfriddo (1991b) show that silica particles remain the same size after 72 hours in the House sparrow gizzard. Therefore, the reduction of grit size found by Vance (1971) after passage through the intestine-colon is probably due to the high percentage of calcareous grit in the examined Pheasants. Walton (1984) and Moksnes (1988) report a predominance of quartz in the gizzard of birds, and they presume that the most calcareous particles are not recorded because they dissolve very quickly in the acid environment of the stomach. The amount of calcium fragments ingested by birds is unknown. Sadler (1961) mentions that cereal grains are almost devoid of calcium, and he shows that Pheasants are able to compensate this deficiency by selecting calcareous grit. Kopischke (1965) and Harper (1964) have shown that hen Pheasants increase their intake of calcareous grit in the egg-laying period. Females of Ringed plovers and Temminck's stints have more calcareous grit in their stomachs than the males (Moksnes, 1988). Trost (1981) showed the same in captive Mallards. Soler *et al.* (1993) found, in 5 corvid species, that ingestion of calcareous grit increased during the egg-forming period. Composition is clearly an important factor in the selection of grit by birds, especially for females in the reproduction phase.

Grit taste

Birds are well capable of tasting (Duncan, 1960). The effect of repellency that some ingredients, like methiocarb, have on birds has been investigated as a means of reducing bird damage to various crops (Yusufu *et al.*, 1992; Conover, 1989; Duncan, 1963; Greig-Smith & Rowney, 1987). However, it is unknown whether birds refuse or accept soil particles as grit on the basis of their sense of taste.

1.4 Research questions

From the above we conclude that the size and diet of birds influence the number and size of ingested grit particles, and that their diet and sex affect the portion of calcareous grit. As a result, the birds considered in this study will be investigated according to their size and diet. The factor sex will be excluded, because the portion of calcareous grit will probably be severely underestimated when examining the contents of gizzards. Furthermore, our research is not designed to draw any conclusions about taste as a factor determining avian selection of grit. Consequently, grit, granules and pelleted seeds will be described on the basis of 1. size, 2. colour and 3. shape.

The following questions are thus investigated in this study:

- What is the amount and appearance in terms of size, colour and shape of grit used by avian species of varying size and dietary habit, and which forage on arable fields?
- How does this grit resemble the granules and pelleted seeds that are frequently applied on arable fields, and how can this resemblance be applied in assessing the resultant hazard to birds?

CHAPTER 2: MATERIALS AND METHODS

2.1 Sampling of grit, granules and pelleted seeds

2.1.1 Sampling of grit

The main factor determining our selection of bird species is their occurrence on arable fields in the Netherlands. We searched for birds that forage on these fields at least part of the year. The species sampled varied in their dietary habits and size. Most birds obtained were from game hunters, taxidermists or from the National Natural History Museum in Leiden. Their cause of death varied and remnants of granules or pelleted seeds were never found in their gizzards. Birds that probably died as a result of poor health (weakened thorax muscles, dirt around the anus) were excluded. In order to obtain representative samples of the bird species in question, the birds were collected throughout the year and at different locations. In Appendix 1 the scientific names of the birds investigated are listed along with their English names. The complete list of birds and the cause, place and time of death are presented in Appendix 2. The list comprises 12 granivorous species ($n=100$) and 15 species with other diets (i.e. fructivores and insectivores; $n=98$). The birds are divided into 3 groups according to their diet: granivores and non-granivores. Anatidae (ducks and geese) are considered separately from the non-granivores because of their 'sieving' mode of foraging (Kooloos, 1986). The granivores and non-granivores are subdivided into small and large species. Most results below are presented at the level of these species groups, allowing for more ready extrapolation of the results to species that are not investigated here but that fit into a given species group. Table 2.1 presents the groups with the numbers of individuals collected.

Table 2.1. Birds examined. n = number of birds. See Appendix 1 for scientific names.

size	diet/taxon/weight	n	size	diet/taxon/weight	n
Ia: granivores, 10-50 g		**39**	**IIa: non-granivores, 15-100 g**		**45**
	Skylark	6		Starling	10
	House sparrow	11		White wagtail	3
	Tree sparrow	1		Meadow pipit	9
	Brambling	1		Reed bunting	3
	Chaffinch	8		Blackbird	10
	Greenfinch	8		Song thrush	10
	Linnet	2	**IIb: non-granivores, 200-500 g**		**35**
	Twite	1		Carrion crow	13
	Goldfinch	1		Jackdaw	1
Ib: granivores, 350-1500 g		**61**		Magpie	11
	Pheasant	16		Black-headed gull	8
	Grey partridge	25		Lapwing	2
	Woodpigeon	20			
III: ducks and geese, 1000-3500 g		**18**			
	Bean goose	1			
	White-fronted goose	1			
	Greylag goose	5			
	Mallard	11			

In selecting the bird species various literature sources were used. De Snoo & Canters (1990) list a number of breeding birds in the Netherlands that regularly forage on arable fields. Breeding birds not mentioned by De Snoo & Canters (1990) as foragers on arable land are: Greenfinch, Reed bunting, Greylag goose and Mallard. These species have been included here because the literature shows that they forage on arable fields at least part of the time (Watson, 1992; Hänisch & Gemmeke, 1992; SOVON, 1987). Bramblings, Twites, Bean geese and White-fronted geese are mainly migratory species in the Netherlands, but are also regularly seen on arable fields (SOVON, 1987). Bird weights have been derived from Cramp *et al.* (1977-1993), Glutz von Blotzheim *et al.* (1971-1991), and our own data.

The gizzards of the birds were removed, sliced open and the contents flushed into a jar. The contents were then transferred into a test tube. This tube was centrifuged 2-3 times for 30 seconds and each time the (light) organic matter was poured out of the tube until there were only non-organic particles left. The particles and remaining water were poured back into the jar. The method was found to be very reliable: the organic matter was checked 3 times for the presence of non-organic particles and it was found that no more than 1% of the particles were lost in this way. The jar was then kept at a temperature of 80 °C for about 12 hours until the particles were completely dry.

It was found that many birds had huge numbers of very small particles in their gizzard. These particles were smaller than 0.5 mm and were presumably swallowed by accident along with food items, because it seems very unlikely that such small particles are actively selected by birds. Particles smaller than 0.5 mm were excluded by screening.

In our study the size of the particles was measured in terms of their length. However, if particles are screened the particles remaining on the screen will have been selected by their smallest diameter, i.e. their width. This means that if particles are to be described on the basis of their length, and if a screen is to be used to obtain a minimum size, a certain percentage of the particles falling through the screen will have lengths exceeding this minimum. We assumed that this effect will become stronger as the particles become more oblong. We quantified this effect by counting all particles with a diameter (i.e. length) exceeding 0.5 mm in the 0.25 - 0.5 mm screen fraction from one representative of the omnivorous birds and one of the granivorous birds. The results are summarized in Table 2.2. The derived average percentage of particles that were out of place in the screen fraction has been used to correct the size distributions of all examined species.

The number of particles smaller than 0.5 mm was estimated as follows. The samples were screened with screens with a mesh of 0.25 mm and 0.50 mm. Approximately 50 particles from both size classes (0 - 0.25 mm and 0.25 - 0.5 mm) were taken, and these subsamples weighed. In addition, whole samples of the two size classes were weighed. The number of particles in these classes was determined by extrapolation.

Table 2.2. The portion of grit longer than 0.5 mm found in the 0.25 - 0.5 mm screen fraction of a Magpie and a Grey partridge.

	Partridge	Magpie	average
grit length between 0.5 - 0.75 mm	15.8 %	12.8 %	14.3 %
grit length between 0.75 - 1 mm	0.6 %	1.3 %	0.95 %

The gizzards of geese and mallards contain huge numbers of particles larger than 0.5 mm. Therefore, only a subsample of several hundred particles was examined. The total number of grit particles was estimated by counting and weighing this subsample and extrapolating.

2.1.2 Sampling of granules and pelleted seeds

All the granules investigated in this study are used regularly on Dutch arable fields. For their full names, see Appendix 8. Vydate, Mocap and Temik are the granules most frequently used (pers. comm. Van Velde, Informatie en Kennis Centrum). Pelleted seeds of three widely grown crops were collected: sugar beet, carrot and onion. The granules and pelleted seeds examined are summarized in Table 2.3.

Table 2.3. Granules and pelleted seeds examined. A.I. = active ingredient, n = number of particles analyzed, pot = potatoes, beet = sugar beet, rape s = rape seed, cult = cultivation, veg = vegetables. The active ingredients mentioned for sugar beet are potentially used, i.e. not all at once.

trade name	A.I.	perc. A.I.	n	application	effect:
Granules					
Mocap 20GS	ethoprofos	20%	199	pot,veg,tree cult,flowers	nematicide,insecticide
Vydate 10G	oxamyl	10%	123	pot,beet,tree cult,veg,flowers	insecticide,acaricide
Curater granules	carbofuran	5%	108	rape s., maize,beet,onion,veg,tree cult	insecticide
Temik 10G Gypsum	aldicarb	10%	158	veg,pot,flowers,tree cult	nematicide,insecticide
Nemacur 10G	fenamifos	10%	263	pot,flowers	nematicide
Dursban pellets	chloorpyrifos	2%	100	veg,flowers,tree cult	insecticide
Mesurol pellets	methiocarb	4%	113	all crops	molluscicide,insecticide
Asef Slakkendood	metaldehyde	6%	119	all crops	molluscicide
Luxan pellets	metaldehyde	6.4%	126	all crops	molluscicide
Pelleted seeds					
Sugar beet	benfuracarb	1.6%	70		insecticide
	furathiocarb	2.2%			insecticide
	tefluthrin	0.4%			insecticide
	thiram	0.2%			fungicide
	hymexazool	0.9%			fungicide
Carrot	chlorfenvinphos	0.1%	98		insecticide
Onion	furathiocarb	0.5%	91		insecticide

2.2 Analysis of grit, granules and pelleted seeds

All grit, granules and pelleted seeds were laid in squares on a drawing-table and photographed. Small particles were laid in a square measuring 2.5 by 2.5 cm, larger particles in a square 5.5 by 5.5 cm. The particles were spread regularly in these squares and did not touch one another. They were illuminated from beneath and thus contrasted strongly against the white background. Some particles appeared transparent and later had to be filled in with a black pen on the photographs. On the photographs small particles are enlarged 3.6 times and large particles 1.7 times. The photographs were then taken to a Quantimet 570 image analyzer, consisting of a camera that scans images (usually photographs) and a computer that analyses the resulting (digital) information. Images are divided into 512 by 512 pixels and the resolution of an image is thus determined by the size of one pixel, i.e. the size of the image divided by 512. Consequently, the resolution of a photograph of large particles is about 0.1 mm, and of a photograph of small particles 0.05 mm. The computer determines the diameter of each particle in 64 directions. The largest diameter is defined to be the length and the smallest diameter the width of a particle. In this study the length is chosen to represent the size of the particles, and the length of a particle divided by its width is called the shape index.

The colours of the particles > 0.5 mm were determined for 6 bird species. We selected 3 species, with 5 individuals each, as representatives of the small and large granivores (small: House Sparrow, Chaffinch and Greenfinch; large: Woodpigeon, Partridge and Pheasant). In addition, particle colours were also analyzed for 2 non-granivorous species (Carrion crow and Black-headed gull, represented by 5 and 4 individuals, respectively). From each individual about 30 particles > 0.5 mm were aselectively taken for examination. As a result, a total of 1128 grit particles were classified. In addition, 10 samples of granules and 3 samples of pelleted seeds, all of different manufacture, were classified according to the Munsell soil colour system (Munsell, 1988). The Munsell system describes colours by three attributes: hue, representing the dominant spectral wavelength; value, representing the brightness of colour; and chroma, representing the strength of the colour. Each grit particle from the aforementioned birds was compared with colour chips on charts. The codes were then translated to colour names. A number of grit particles appeared to have no colour at all and were classified as transparent. Some particles (6.1%) had very bright colours, and their values exceeded the range of soil colours in the Munsell system. Of these particles, 5.9% had yellow hues according to the Munsell system and were therefore called yellow, but perhaps should have been called white instead because of their high values. Consequently, about one third of the so-called yellow grit particles is classified with uncertainty. The granules caused more problems: the translation from Munsell codes to Munsell soil colour names was found to be impossible because the colours of 10 granules were far beyond the range of soil colour names. As a result, we had to name these colours ourselves on the basis of their Munsell codes.

Colour classes were established on the basis of the last colour mentioned in the Munsell soil colour name (e.g. yellow in 'olive yellow'). This gave 5 colour classes: yellow, red, olive, brown, grey (including white and black), and transparent. The classes were subdivided into light and dark colours, on the basis of the Munsell values. Colours with a value higher than 6 were called light, the others dark, except for yellows, which always have values higher than 6.

All differences in the above characteristics between species groups were statistically, non-parametrically tested at the species level, except for grit colours, which were tested at the level of individuals. In all cases the Mann-Whitney U-test for the comparison of two independent samples was used.

CHAPTER 3: RESULTS

3.1. Grit

Separation of grit from 'soil'

The total number of particles found in the 198 birds examined was estimated to be 3.31 million. The vast majority of these particles was smaller than 0.5 mm (93%), and were found mainly in non-granivores and ducks and geese (91% of the total number of particles). The numbers of particles smaller than 0.5 mm found in the average non-granivore and average duck or goose species are thus enormous: 9,268 and 128,286 particles, respectively. With so many particles that small, it would seem impossible for birds to pick them up individually. It therefore seems likely that these birds ingest most particles in heaps, or that they are ingested along with food items. Moreover, these particles are out of the size range of granules and pelleted seeds, and from the viewpoint of assessing the hazard of granules and pelleted seeds on the basis of their appearance they are therefore irrelevant. We name particles smaller than 0.5 mm 'soil particles' and larger particles 'grit'. Examination of the birds clearly indicated that non-granivores and ducks and geese also ingest relatively few grit particles, compared to the amount of soil in their gizzards. Table 3.1 summarizes the ratio of soil to grit particles for the various species groups. This ratio reflects the difference in grit ingestion behaviour between the granivores and the non-granivores, including ducks and geese.

From Table 3.1 we conclude that granivores use relatively more grit than non-granivores, with the ducks and geese occupying an intermediate position. In the rest of this section, we ignore soil particles (<0.5 mm) and focus only on grit particles (>0.5 mm). The number, size, colour and shape of the grit particles are presented for each species group; the results for individual species can be found in the appendices.

*Table 3.1. Quotient of number of particles < 0.5 mm ('soil') and particles > 0.5 mm ('grit'), determined at species level and averaged per species group. The subgroups of small and large birds are combined here. Test: Mann-Whitney U-test, two-tailed. * = $P<0.05$, ** = $P<0.01$, *** = $P<0.001$. n = number of species examined, sd = standard deviation.*

species group	n	ratio (soil/grit) ± sd
a: granivores	12	1.9 ± 2.7
b: non-granivores	11	32.9 ± 21.4
c: ducks & geese	4	12.9 ± 3.1

Differences between groups:
a-b: ***
a-c: **
b-c: *

Number of grit particles

The total number of grit particles (>0.5 mm) retrieved from the sampled birds was 245,788. Table 3.3 shows that all the granivores, ducks and geese examined had grit in their gizzards. Grit use is less frequent in non-granivores, especially the small non-granivores like Starlings and Meadow pipits (in both species, 22% of the individuals examined had grit). It was found, furthermore, that 80% of the grit is found in less than 10% of the birds: the ducks and geese.

In Table 3.2 the mean number of grit particles found in the gizzard is listed per species group (species averaged, individuals with no grit excluded).

Table 3.2. Percentage of individuals per species group in which grit was found, and mean number of grit particles per group (species averaged, individuals with no grit excluded). n = number of species, sd = standard deviation.

species group	n	perc. with grit	mean ± sd
small granivores	9	100%	120.5 ± 60.7
large granivores	3	100%	365.7 ± 268.5
small non-granivores	6	46%	146.2 ± 232.4
large non-granivores	5	86%	495.6 ± 530.2
ducks & geese	4	100%	11041.5 ± 7377.8

The average duck or goose uses more grit than the average granivore (P=0.004, n=16) or non-granivore (P=0.005, n=15, both Mann-Whitney U-test). There is no difference in the amount of gizzard grit between an average granivore and an average non-granivore ($P=0.78$, Mann-Whitney U-test, $n=23$).

Fig. 3.1 shows that the body weight of the birds is positively correlated with the number of grit particles found in the gizzard.

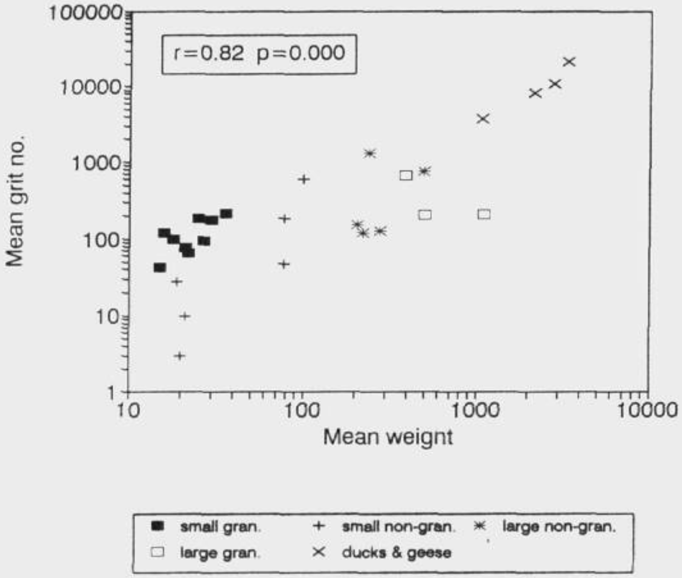

Figure 3.1. Average body weight of birds vs. number of grit particles per gizzard.

Size of grit particles

The average size of grit particles found in the various species groups is listed in Table 3.3. It can be concluded that non-granivores have smaller grit particles than granivores, with ducks and geese occupying an intermediate position. Also, small birds have smaller grit particles than large birds. The differences in grit size between the species groups are all significant (see Table 3.3), which supports the formation of such groups. Histograms of the relative frequencies of grit size in each species are presented in Appendix 4. Fig. 3.2 shows the histograms of the species groups.

Table 3.3. Average grit number and size for the various species groups. The frequencies shown in Fig. 3.2 were analyzed with the Mann-Whitney U-test, two-tailed. * = $P<0.05$, ** = $P<0.01$, *** = $P<0.001$.

species group	no. of species	average no. of grit particles	average size of grit particles (mm) ± sd
a: small granivores	9	121	1.2 ± 0.3
b: large granivores	3	366	2.4 ± 1.1
c: small non-granivores	6	146	0.7 ± 0.2
d: large non-granivores	5	496	1.0 ± 0.7
e: ducks & geese	4	11042	1.0 ± 0.5

Differences in grit size between groups:

a-b	***	b-c	***	c-e	***
a-c	***	b-d	***	d-e	**
a-d	***	b-e	***		
a-e	***	c-d	***		

Colour of grit

Fig. 3.3 presents pie charts of the grit colours. The top two pie charts show the relative occurrence of 10 colour classes in the small and large granivores, respectively. The bottom pie chart, for the large, probably less selective non-granivores, 'might' represent the composition of soil colours. Differences between the pie charts for the granivores and for the non-granivores indicate a possible preference of the former group. The pie charts for individual species are presented in Appendix 5; it is found that the proportions of many colours are very variable, and do not appear to depend of the species group in question, except for the proportions of white/light grey and black/dark grey in the large granivores. Table 3.4 shows the test results of the differences between the three groups in terms of the proportions of light and dark coloured grit, and the proportion of the remaining, transparent particles.

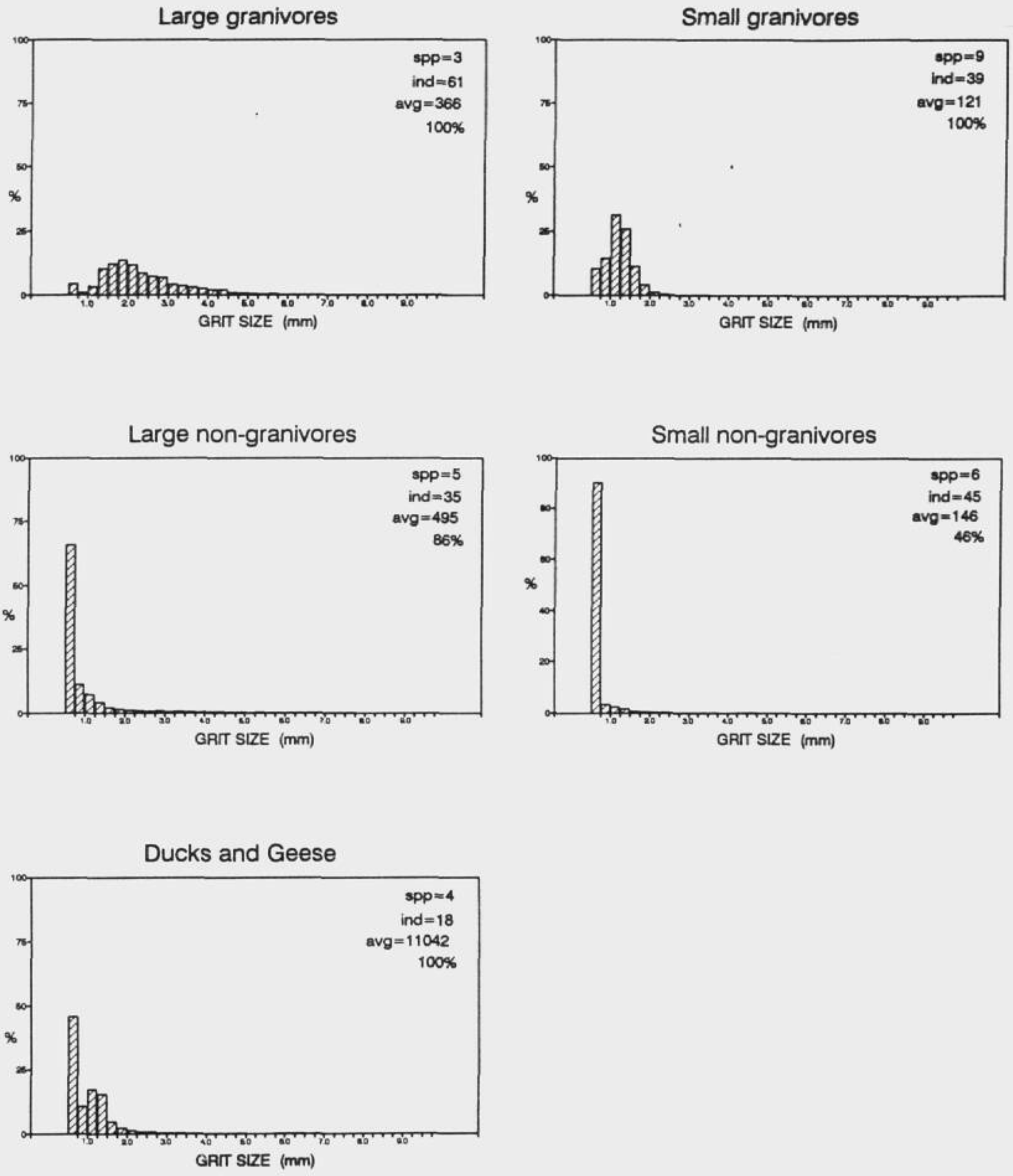

Figure 3.2. Grit size distributions in species groups. ind. = no. of individuals, spp. = no. of species, avg = average number of grit particles, percentage = percentage of birds with grit in their gizzard.

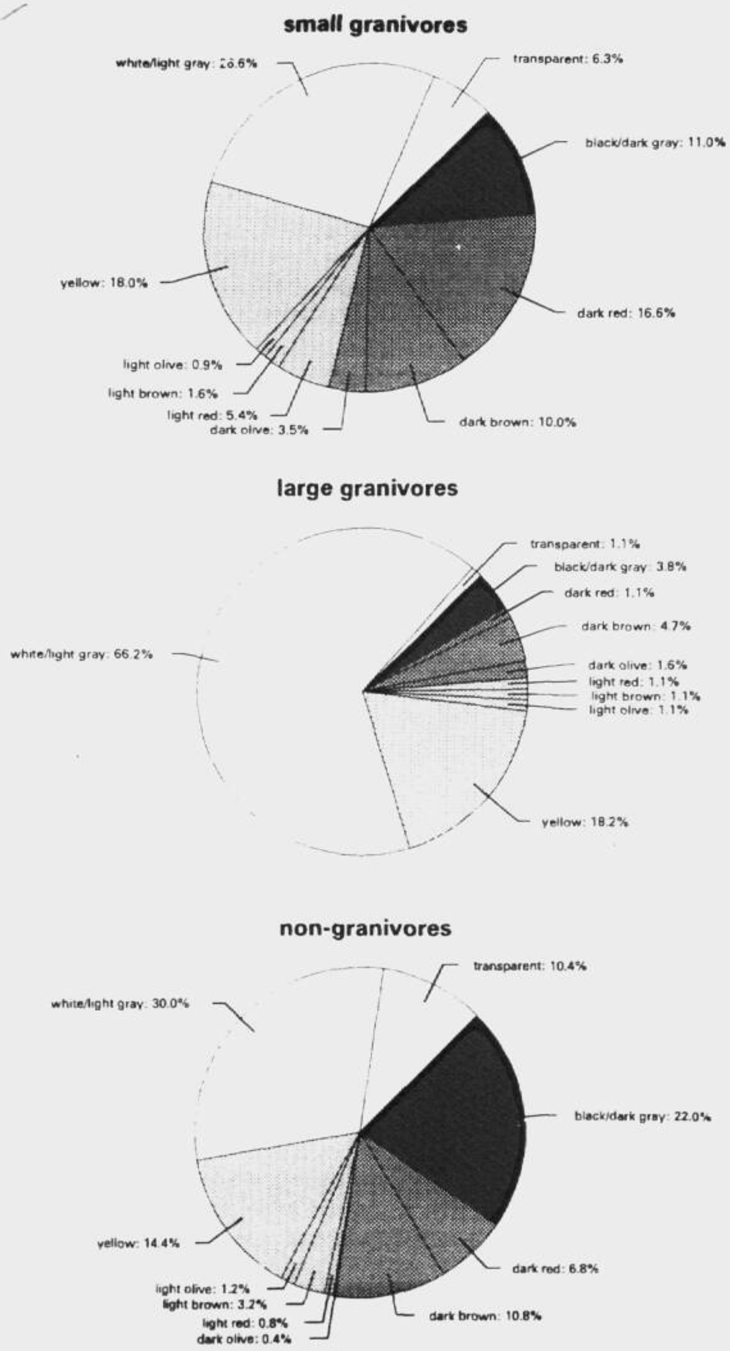

Figure 3.3. Proportions of grit colours in three species groups. White and light shading represent light colours (excluding transparent), heavy shading and black dark colours.

*Table 3.4. Mean proportions of transparent, dark and light coloured grit in small granivores, large granivores and non-granivores. Differences analyzed with Mann-Whitney U-test, two-tailed. ns = not significant. * = P<0.05, ** = P<0.01, *** = P<0.001. n = number of individuals.*

	transparent	light	dark
a: Small granivores (n=15)	6.0%	52.7%	41.3%
b: Large granivores (n=15)	1.1%	87.8%	11.1%
c: Non-granivores (n=9)	12.6%	49.6%	37.8%

Differences in proportion of light-coloured grit between groups:

a-c	ns
b-c	***
a-b	***

From Table 3.4 the large proportion of light-coloured grit in large granivores compared to non-granivores and small granivores is clearly evident. Two conclusions are possible: 1. large granivores use large grit, which is light coloured because large sand particles generally contain relatively pure silica, which is hard to erode (Pannekoek, 1976), or 2. large granivores prefer light coloured grit and avoid transparent and dark coloured grit.

Shape index of grit particles

The mean shape index of the grit found in each species examined is presented in Appendix 6. These indices range from 1.3 to 1.4, with very little variation. Table 3.5 presents the mean shape indices of the various species groups.

*Table 3.5. Average grit shape index (s.i., = length/breadth) of species in three species groups. Test: Mann-Whitney U-test, n=23, two-tailed. ns = not significant. * = P<0.05. sd = standard deviation.*

	mean ± sd
a: Granivores	1.37 ± 0.03
b: Non-granivores	1.37 ± 0.03
c: Ducks & Geese	1.34 ± 0.02

Differences between species groups:

a-b:	ns
a-c:	ns
b-c:	*

The ducks and geese had somewhat more spherical grit than the non-granivores. This could be due to the 'sieving' mode of ingestion of the ducks and geese. Since there is no difference in grit shape between the granivores and the presumably non-selective non-granivores, it seems unlikely that shape is used by these birds to select grit.

3.2 Granules and pelleted seeds

Size

The size distributions of the granules and pelleted seeds are shown in Appendix 7. The granules are found to form two groups in terms of size: the insecticides/nematicides Mocap, Curater, Temik and Nemacur are small granules measuring about 1 mm with small (± 1 mm) ranges, while the granules (pellets) used as molluscicides are considerably larger (median: 3.5 - 5.5 mm) with large ranges (4.25 - 7.75 mm); the insecticide Vydate has an intermediate size (1.5 mm) and range (2 mm). The median size of pelleted seeds is between 3.5 - 4.75 mm with a range of 1.25 - 2.25 mm.

Colour

Table 3.6 presents the colours of the granules and the pelleted seeds. Seven types of granules and pelleted seeds have light colours. The colours of most types of granules and pelleted seeds are strong, and cannot be assigned to one of the 11 colour classes used to determine the grit colours.

Shape

The grit shape index is also presented in Table 3.6. The small granules generally have mean shape indices ranging from 1.3 to 1.4, with only the Temik granules being somewhat more spherical. The larger granules (pellets) are more oblong: they are 1.5 - 2 times longer than wide. Pelleted seeds are designed for accurate sowing, and are found to be almost spherical, as expected.

Table 3.6. Colours and shapes of granules and pelleted seeds. For sugar beet 5 different pellet colours were examined.

	colour	light/dark	shape index mean ± sd
granules			
Mocap 20GS	reddish violet	light	1.31 ± 0.19
Vydate 10G	green	light	1.41 ± 0.24
Curater granules	greyish blue	dark	1.27 ± 0.12
Temik 10G Gypsum	strong black	dark	1.23 ± 0.16
Nemacur 10G	white	light	1.32 ± 0.15
Dursban pellets	yellowish green	light	1.38 ± 0.25
Mesurol pellets	blue/violet blue	dark	1.47 ± 0.17
Asef Slakkendood	blue	dark	2.08 ± 0.35
Luxan pellets	blue	dark	2.13 ± 0.55
pelleted seeds			
Sugar beet no. 1	red	dark	1.14 ± 0.07
Sugar beet no. 2	strong brown	dark	
Sugar beet no. 3	yellow	light	
Sugar beet no. 4	green	light	
Sugar beet no. 5	strong blue	dark	
Carrot	yellow	light	1.18 ± 0.05
Onion	red	dark	1.20 ± 0.21

CHAPTER 4:
HAZARDS TO BIRDS

4.1 Introduction

In this chapter we attempt to assess the hazard to birds, based on the resemblance between grit and granules or pelleted seeds, the difference in grit consumption between granivores and non-granivores, the availability of granules and pelleted seeds, and the consumption rate of birds.

4.2 Grit compared to granules and pelleted seeds

Below, grit is compared to granules and pelleted seeds in terms of size, colour (light/dark) and shape index.

Size

In order to establish the resemblance in size between grit and granules or pelleted seeds, histograms were compared, as follows: the 90% range of the size histograms of granules and pelleted seeds (5% subtracted at both tails) was placed over the grit histograms of the species groups, and the portion of grit within this size range was termed the 'overlap' between the grit of a certain bird species or group and a certain granule or pelleted seed. Thus, the overlap can be considered as the percentage of grit having the same size as granules.

This means that the shape of the size distribution of granules or pelleted seeds was not taken into account, only the size range of 90% of these particles. The reason for this is that 90% of granules and pelleted seeds are assumed to be present in unlimited quantities to birds. The value of 90% was chosen to eliminate the effect of small, isolated bars on the range of the size histograms of granules and pelleted seeds (see Appendix 7). In contrast, the shape of the grit size histograms is relevant for determining the size overlap, because the number of grit particles is limited by the intake of the birds. In Fig. 4.1 this is visualized. The shaded area in this figure shows the fraction of grit particles that can potentially be granules or pelleted seeds.

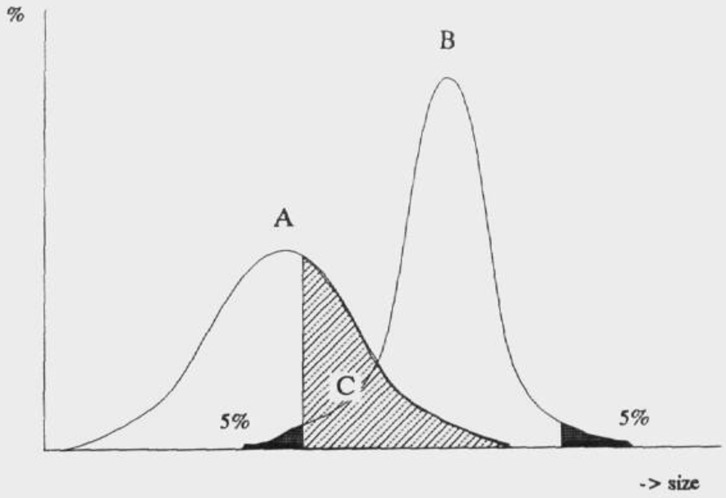

Figure 4.1. Determination of 'overlap' in size between grit of a given species (group) and certain granules or pelleted seeds. A = size distribution of grit. B = size distribution of granules or pelleted seeds. C = 'overlap'.

Table 4.1 shows the portion of grit of the various species groups within 90% of the size range of the granules and pelleted seeds. The small granules (Mocap, Vydate, Curater, Temik and Nemacur) are found to show the greatest resemblance to the grit of granivores (small and large), large non-granivores and ducks and geese. The very small Mocap granules also match the grit of small non-granivores. The large granules or pellets (Dursban, Asef, Mesurol, Luxan) most resemble the grit of large granivores, and the pelleted seeds show some resemblance to the grit of large granivores.

Colour

Since the hue of grit colours is very variable, and no preference was found among the birds examined, a comparison of grit to granules or pelleted seeds appears to have little point. Light colours (value > 6, see Chapter 2) might be preferred by large granivores, and these are found in the small granules of Nemacur, Mocap and Vydate, the pellets of Dursban, the pelleted carrot seeds, and 2 out of 5 kinds of pelleted sugar beet seeds.

Table 4.1. Percentage size overlap between grit and granules or pelleted seeds. For explanation of overlap determination, see text. gr. = granivores.

	90% range(mm)	small gr.	large gr.	small non-gr.	large non-gr.	ducks & geese
granules						
Mocap 20GS	0.50-1.50	86.7	18.6	97.7	88.2	89.0
Vydate 10G	1.00-1.25	65.7	50.7	5.7	16.0	40.8
Curater granules	0.75-1.50	75.1	14.8	7.3	22.4	43.1
Temik 10G Gypsum	1.00-1.75	61.8	25.3	4.8	13.3	37.2
Nemacur 10G	0.75-1.50	75.1	14.3	7.3	22.4	43.1
Dursban pellets	2.50-5.00	0.4	32.9	0.4	5.3	1.9
Mesurol pellets	2.75-5.00	0.2	25.7	0.3	4.5	1.0
Asef Slakkendood	2.75-5.50	0.2	26.8	0.3	4.9	1.0
Luxan pellets	3.25-8.25	0.1	17.3	0.1	3.9	0.6
pelleted seeds						
Sugar beet	4.25-5.75	0.0	5.6	0.0	1.6	0.1
Carrot	3.75-4.50	0.0	6.5	0.0	1.3	0.1
Onion	3.25-4.25	0.1	10.8	0.1	1.9	0.5

Shape index

There was no preference found in terms of shape index. The mean shape index of grit is between 1.3 - 1.4. All the granules have shape indices that are comparable with those of grit, except for the pellets of Mesurol, Luxan and Asef, which are more oblong. The small Temik granules and pelleted seeds are more spherical than grit.

4.3 Amount and size of grit

The resemblance of granules or pelleted seeds to grit was demonstrated in the previous chapter. However, equal percentage size overlaps in granivores and non-granivores (see Table 4.1) do not necessarily lead to equal hazards. Granivores are likely to search for particles of a certain size (or colour, shape index) and if large numbers of granule particles or pelleted seeds are exposed that look very similar to the grit they prefer, these particles might also be expected in large numbers in the gizzards of these birds. In contrast, if there is a strong resemblance between the grit of non-granivores and granules, this does not necessarily result in a large number of granules in their gizzard. It is assumed that the number of granules or pelleted seeds in the gizzards of these (non-selective) birds reflects, within a certain size range, their number among soil particles.

Granules may be present in large quantities on the soil surface after sowing: Erbach & Tollefson (1983) tested three brands of planters used on corn fields in the US, and found that 14.7% of the granules were left exposed. Mineau (1988) combined this result with the recommended rate of application in Canada, and estimated that on corn fields in Ontario (Canada) at least 5 to 17 granules per row centimetre are probably left exposed. Maze *et al.* (1991) evaluated the soil incorporation of rapeseed, combined with a substitute for Furadan granules, sown by four types of seeding equipment in Canada, and found that 2.18% of the granules remained on the surface. The number of pelleted seeds on the surface may be high if spillage occurs (see Part B of this report). We consequently assume that granules and pelleted seeds are available to birds *ad libitum*.

On the basis of the information on grit use and the toxicity of granules and pelleted seeds, the hazard of the latter to birds can be assessed. Because of a number of uncertainties about the foraging behaviour of birds in the field and the retention rate of grit in gizzards, the assessment should be regarded as a first approximation.

Hazard assessment:

Given the concentration of a certain active ingredient in one granule or pelleted seed, we can determine the number of granules or pelleted seeds that will add up to the LD50 dose for birds. This is presented in Appendix 9. The number of granules or pelleted seeds that would cause lethal effects in 50% of the average birds of the species groups is listed in parentheses for each type of granule or pelleted seed and each species group in Appendix 10. For example, when a number of individuals of the average small granivore ingest 4.97 Curater granules, 50% will die.

On the basis of the amount of grit in a bird's gizzard and the retention rate, we also can estimate the number of grit particles ingested daily. We term this number 'E' (expected). Fig. 3.2 shows the average number of grit particles found in the species groups. For a small granivore the number is 121. How many particles it has to ingest to maintain this number, in other words the retention time of grit, is largely unknown. Mathiasson (1972) has shown that Woodpigeons excrete half their grit in 2 days. From this, we derive that a bird substitutes a quarter of its gizzard grit each day. In our example this means that a small granivore consumes 30.3 grit particles per day.

We now propose that:

1. *x*% of the grit ingested by granivores will consist of granules or pelleted seeds.
2. *y*% of the grit ingested by non-granivores and Anatidae will consist of granules or pelleted seeds.

The value of x is determined mainly by the ratio between granules and soil particles of the same size. In the Netherlands many arable fields have soils of clay and fine sand with particles smaller than 0.2 mm (Pannekoek, 1976). Small and large granivores appear to prefer particles of about 1.25 mm and 2 mm, respectively. It is assumed, as a worst-case approach, that birds searching for grit on an arable field will ingest granules or pelleted seeds exclusively, rather than soil particles; we therefore take x to be 100%. The value of y is determined by the ratio between granules and all soil particles > 0.5 mm in a field. Although there is no information on the actual number of granules or pelleted seeds on the surface compared to surrounding soil particles, we expect that the value of y is very small.

In the example of an average small granivore, the size overlap of its grit with Curater is 75.1% (see Table 4.1). This means that, of the 30.3 particles it ingests daily, 22.8 particles are within the size range of Curater. If all 22.8 particles are granules ($x=100\%$), the number of Curater granules that would add up to the LD50 value for this average small granivore is exceeded 4.6 times.

We now define the quotient of the number of granules causing lethal effects in 50% of the birds in question ('LN50') and the expected number of granules ingested daily ('E') as the risk to these birds. Like Luttik & De Snoo (1994) in their decision scheme, we choose cut-off criteria: if $E/LN50 < 0.01$, a low risk is presumed. If $0.01 < E/LN50 < 1$ we assume an intermediate risk, and if $E/LN50 > 1$ we assume a high risk. In our example $E/LN50 = 4.61$, and Curater is therefore considered to pose a high risk to an average small granivorous bird.

In Appendix 8 the ingested numbers expected per day (=E) and the lethal numbers of granules and pelleted seeds (=LN50) are presented for the average species of each species group. E exceeds LN50 about 5 times in the small granivores, with Mocap, Vydate and Curater. E/LN50 is also about 5 in the large granivores, with Mesurol. However, the most hazardous granules for (small) birds appear to be Temik and Nemacur: $E/LN50 = 12.7$ and 10, respectively. It appears that granivores (small and large) are always more vulnerable to granules and pelleted seeds than non-granivores and ducks and geese. Even if $y = 100\%$ (which is very unlikely), the highest E/LN50 value for every type of granule or pelleted seed is found in the small or large granivores. In the risk assessment, it therefore seems sufficient to focus on small and large granivores. In Table 4.2 the E/LN50 values are translated into hazards, following the described procedure.

4.4 Other characteristics

Since large granivores in the Netherlands ingest more light coloured grit than dark coloured grit, Mocap, Dursban, Vydate, Nemacur, the light coloured pelleted seeds of carrot and sugar beet (partially) are suspected of being extra-hazardous to these birds. As far as the shape index is concerned, Mocap, Vydate, Curater, Nemacur and Dursban are the most similar to the grit that the majority of the birds use. Therefore, these granules and pelleted seeds are suspected of being extra hazardous to birds.

4.5 Conclusions

From Table 4.2 it can be seen that Mesurol and especially Dursban (because of its light colour and shape index) are suspected of being hazardous to large granivores. The small granules (Mocap, Vydate, Curater, Temik and Nemacur) appear to be very hazardous to small granivores, especially Temik and Nemacur.

Table 4.2. Hazards of granules to granivorous birds in relation to their grit use. If the hazard is considered 'low', information on colour and shape index is omitted.

	SMALL GRANIVORES		LARGE GRANIVORES		
	hazard (E/LN50)	similar shape index	hazard (E/LN50)	similar shape index	coloured light
granules					
Mocap 20GS	high	+	intermediate	+	+
Vydate 10G	high	+	intermediate	+	+
Curater gran.	high	+	low		
Temik 10G	high	-	intermediate	-	-
Nemacur 10G	high	+	intermediate	+	+
Dursban	intermediate	+	high	+	+
Mesurol	intermediate	-	high	-	-
Asef Sl.dood	low		intermediate	-	-
Luxan	low		intermediate	-	-
pelleted seeds					
sugar beet	low		intermediate	-	+/-
carrot	low		low		
onion	low		intermediate	-	-

CHAPTER 5:
DISCUSSION

5.1 Introduction

The first aim of this study was to describe the grit use of Dutch birds in terms of quantity, and particle size, colour and shape, making due allowance for the fact that birds differ in selectiveness. The second aim was to assess the resemblance of the grit particles to a number of granules and pelleted seeds used in the Netherlands, and in addition, to propose a method for quantitatively assessing the hazard to birds.
Below, the results concerning grit use description are compared with the literature on this subject. The results concerning the resemblance of grit to granules and pelleted seeds and the associated hazards are specific to the Netherlands, since only granules and pelleted seeds used in that country were investigated. However, the method of comparing grit and granules or pelleted seeds and the hazard assessment can be applied anywhere.

5.2 Results compared to literature

Mechanisms of grit ingestion

In this study a clear difference in grit use was found between granivorous birds and birds with other diets. The vast numbers of very small particles found in non-granivores seems typical in our research. It appears that most of the grit of non-granivores is smaller than 0.5 mm, with numbers decreasing exponentially as grit size increases. In fact, the grit distributions of non-granivores shown in Appendix 4 are only tails of the total distribution obtained if 'soil' particles are included. Therefore, the distributions of the small and large non-granivores show no selectiveness, unless these birds search for the smallest soil particles available. In that case, it is very unlikely that they select the particles individually, because of the vast numbers in which these particles occur. This 'tail' of particles probably ingested non-selectively can also be seen in the smallest classes of many granivores (see Appendix 4). A second peak dominates their grit size distribution, however, which strongly suggests selectivity. As with the ratio of soil particles to grit, the ducks and geese occupy an intermediate position: a large first peak and a very modest second one, suggesting some sort of selectivity. Bearing in mind that ducks and geese are able to select food items according to size (Kooloos, 1986), their grit size distribution might be the result of taking large amounts of sand into their bills, and ingesting a relatively high number of large particles by 'sieving'.

This difference is less pronounced in the literature. Comparing the histograms of the corvid species we examined (Jackdaw, Carrion crow, Magpie) to those of the five corvid species in Soler *et al.* (1993), there seems to be some similarity. Best & Gionfriddo (1991a) discarded collected gizzards with "hundreds of particles < 0.2 mm" in their research. This occurred in less than 2% of the gizzards they examined. If the same criterion had been used in our study, we would have had to discard 33% of the granivores and 80% of the other birds examined. Best & Gionfriddo (1991a) define the selectiveness of a bird as the number of size classes needed to comprise 80% of its grit particles. However, they do not take into account the shape of the distribution. Moreover, this shape could be affected by the number of particles they did not count (<0.1 mm). The grit size distributions they present for some omnivorous species such as the Starling and American robin resemble the distributions we found in Starlings and *Turdus* species (Blackbird and Song thrush). Also, the size distributions of the granivorous (selective) Pheasant are similar in each study.

Number and size of grit particles

In Table 5.1 the number and size of grit particles of species found in the literature are compared to similar species in our research. The species mentioned in this table are covered by literature from all over Europe, and some (Pheasant, House sparrow and Starling) even from the United States. The species studied by Best & Gionfriddo (1991a) use a larger amount of grit than found in our research area. The cause of this difference is unknown. Hogstad (1988) also finds a smaller number of particles in the Brambling. However, the Bramblings we examined were collected in winter, while Hogstad (1988) examined individuals during the breeding season. Moreover, he demonstrates variable grit use in Bramblings during the breeding season. We cannot explain why Soler *et al.* (1993) find smaller grit in the Carrion crow and the Jackdaw. Like us, Best & Gionfriddo (1991a) find that mean grit size increases with body mass.

Grit colour and shape

In Chapter 1 it was concluded that birds seem to prefer light coloured and avoid dark coloured grit (Pank, 1976; Spittler, 1978; Best & Gionfriddo, 1993). It is difficult to support this statement using the findings of our own research. Light colours prove to be

predominant in the grit we examined in all species groups, but only the large granivores might exhibit a preference for light colours.
The grit Best and Gionfriddo (1991a) found is more oblong that found in our study: their mean shape index, for all species, was 1.86 ± 0.31, while ours is 1.37 ± 0.03. They also found little differentiation among the species, which supports the idea that the shape index of grit primarily reflects availability. However, if captive House sparrows or Northern bobwhites are given a choice between spherical or oblong, they select oblong grit (Best & Gionfriddo, 1994).

Table 5.1. Grit described in this study (in parentheses) compared to other studies of similar bird species. The length of grit particles in Best & Gionfriddo (1991a) is derived by correcting it with the mean shape index. Also, only the number of particles > 0.5 mm in that article are listed here. Superscripts: 1 = Best & Gionfriddo (1991a), 2 = Mathiasson (1972), 3 = Hogstad (1988), 4 = Soler et al. (1993) 5 = Walton (1984); a = median, b = mean,; # = end of May.

species	number		perc. of birds with grit		size (mm) (=length)	
Pheasant[1]	6^{a}	(214^{b})	100%	(100%)	2.6^{b}	(2.9^{b})
Woodpigeon[2]	296^{b}	(208^{b})	99%	(100%)	-	
House sparrow[1]	60^{a}	(179^{b})	99%	(100%)	0.9^{b}	(1.2^{b})
Brambling[3]	$80^{\#}$	(188^{b})	100%	(100%)	-	
Carrion crow[4]	-		-		2.9^{b}	(1.0^{b})
Magpie[4]	-		-		1.1^{b}	(0.9^{b})
Jackdaw[4]	-		-		2.2^{b}	(1.0^{b})
Starling[1]	0^{a}	(38^{b})	38%	(20%)	1.4^{b}	(0.6^{b})
Meadow pipit[5]	2.8^{b}	(6^{b})	33%	(22%)	-	

5.3 The hazard assessment

The results of the hazard assessment are very much dependent on the values of x and y (see Section 4.3). What is determined is thus a first approximation of the hazard to birds. Nevertheless, even if the difference in mode of grit uptake between these species groups is less pronounced than assumed, the granivores are likely to run the highest risks. The hazards shown in Table 4.3 do not have absolute reliability. The value of Table 4.3 is that it reflects the relative hazards of the pesticides examined. Cage experiments with birds, or reports on incidents with granules or pelleted seeds, would be useful for calibrating these hazards.

5.4 Recommendations

Decision scheme

In order to incorporate the results of this study in module B of the discussion scheme (see Fig. 2, General Introduction), some alterations must be made to the scheme. We assume that only granivorous species are included in this assessment. Furthermore, we discuss only average representatives of small and large granivores. If it is decided that the particles resemble grit, the following steps are suggested.

1. An estimate must be made of how many particles of the granules or pelleted seeds of concern might be expected (=E) in the small granivore (sg) or large granivore (lg) of concern. (E_{sg} = 121/4 * size overlap, E_{lg} = 366/4 * size overlap). The numbers are explained in Chapter 4.
2. Next, the number of particles causing lethal effects (LN50) in the small or large granivore of concern must be established (see also Chapter 4).
3. The value of E/LN50 determines whether a low, intermediate or high risk is posed to the small or large granivore.

Only the size of the particles are included here, because a possible preference of birds regarding the characteristics shape and colour are still uncertain.

How can we reduce the hazards to birds?

Incorporation of every granule or pelleted seed in the soil is the most obvious strategy to prevent poisoning of foraging birds on the fields. Although this is possible in theory only, of course, there seems to be a large difference between granule application under test conditions (Hummel *et al.*, 1992): less than 1% on the surface, and normal agricultural practice in the U.S.A.: about 15%. Research on ways to reduce this difference would be advisable.

Assuming that soil incorporation is never fully effective, the question remains what appearance the granules or pelleted seeds should have to avoid being ingested by birds. The characteristic that seems most important for grit selection by birds is size. If the size of granules were to be altered, the attendant risk would also consequently change. There are two possible answers to this question.

1. The granules should be made smaller. To avoid being ingested by small granivores, the granules should be 0.5 mm at most.
2. The granules should be made larger. They would have to be at least 4 mm to minimize ingestion by large granivores. At the same time, though, the enlarging the granules should not mean that the amount of pesticide per particle is also increased, for otherwise the risk would not be effective reduced.

Which solution is preferable depends on compatibility with agricultural practice, which is beyond the subject of this study.

Light colours should be avoided in granules.

Adding repellant ingredients to granules, in combination with a dye, is another way of reducing the risk to birds. Birds are able to develop food aversions if the food items are treated with a repellant like quinine sulphate or tannic acid, in combination with a dye, like blue (Greig-Smith & Rowney, 1987). Perhaps the same is possible in granules, assuming that the birds do not ingest a lethal dose by consuming one granule.

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Appendix A1. Scientific and popular names of birds.

popular name	scientific name
American robin	*Turdus migratorius*
Bean goose	*Anser fabalis*
Black grouse	*Tetrao tetrix*
Black-headed gull	*Larus ridibundus*
Blackbird	*Turdus merula*
Brambling	*Fringilla montifringilla*
Capercaillie	*Tetrao urogallus*
Carrion crow	*Corvus corone corone*
Chaffinch	*Fringilla coelebs*
Goldfinch	*Carduelis carduelis*
Greenfinch	*Chloris chloris*
Grey partridge	*Perdix perdix*
Greylag goose	*Anser anser*
House sparrow	*Passer domesticus*
Jackdaw	*Corvus monedula*
Lapwing	*Vanellus vanellus*
Linnet	*Carduelis cannabina*
Magpie	*Pica pica*
Mallard	*Anas platyrhynchos*
Meadow pipit	*Anthus pratensis*
Northern bobwhite	*Colinus virginianus*
Raven	*Corvus corax*
Red-winged blackbird	*Agelaius phoenicus*
Reed bunting	*Emberiza schoeniclus*
Ring-necked pheasant	*Phasianus colchicus*
Ringed plover	*Charadrius hiaticula*
Skylark	*Alauda arvensis*
Song thrush	*Turdus philomelos*
Spanish sparrow	*Passer hispaniolensis*
Starling	*Sturnus vulgaris*
Temminck's stint	*Caladris temminckii*
Tree sparrow	*Passer montanus*
Twite	*Carduelis flavirostris*
White wagtail	*Motacilla alba*
White-fronted goose	*Anser albifrons*
Willow grouse	*Lagopus lagopus*
Woodpigeon	*Columba palumbus*

Appendix A2. List of collected birds. n = number of individuals.

Species	n	Collected in:	Collection date:
Small granivores			
Goldfinch	1	Netherlands	--
Greenfinch	1	Ierseke	09/01/1984
Greenfinch	1	Netherlands	09/18/1991
Greenfinch	3	Netherlands	--
Greenfinch	1	Oostvoorne	10/01/1987
Greenfinch	3	Heteren	11/02/1994
Chaffinch	1	Flevopolder	12/17/1992
Chaffinch	1	Kronenberg	05/26/1991
Chaffinch	1	Swalmen	08/19/1993
Chaffinch	1	Middelburg	02/04/1989
Chaffinch	1	Netherlands	--
Chaffinch	1	Steijl	03/26/1991
Chaffinch	1	Horst	March 1994
Chaffinch	1	Westenschouwen	10/06/1994
Chaffinch	1	Westenschouwen	10/08/1994
Brambling	1	Westenschouwen	10/10/1994
Linnet	1	Meterik	March 1992
Linnet	1	Maasvlakte	04/26/1988
Twite	1	Netherlands	--
Skylark	1	Oppenhuizen	October 1994
Skylark	5	Baarlo	Sept.- Nov. 1994
House sparrow	9	Obbicht	November 1993
House sparrow	1	Rijnsburg	01/02/1992
House sparrow	1	Ierseke	09/01/1984
House sparrow	1	Netherlands	08/11/1990
Tree sparrow	1	Netherlands	08/11/1993
Large granivores			
Grey partridge	3	Stein	10/16/1993
Grey partridge	1	Netherlands	02/12/1992
Grey partridge	2	Netherlands	--
Grey partridge	15	Netherlands	November 1994
Grey partridge	5	Apeldoorn	November 1994
Pheasant	12	Haarlemmermeer	12/06/1993
Pheasant	3	Flevopolder	12/01/1993
Pheasant	1	Wassenaar	12/20/1993
Woodpigeon	12	Voerendaal	November 1993
Woodpigeon	6	Haarlemmermeer	08/02/1993
Small non-granivores			
Starling	6	Haarlemmermeer	08/10/1993
Starling	1	Obbicht	November 1993
Starling	1	Netherlands	--
Starling	1	Deurne	11/12/1992
Starling	1	Zoetermeer	November 1993
White wagtail	1	Koudekerk	04/04/1989
White wagtail	1	Netherlands	--
White wagtail	1	Koudekerk	04/04/1989

Appendix A2. (continued).

Reed bunting	2	Flevopolder	07/09/1992
Reed bunting	1	Flevopolder	07/03/1993
Meadow pipit	1	Kennemer duinen	October 1993
Meadow pipit	1	Westenschouwen	10/07/1994
Meadow pipit	1	Westenschouwen	10/11/1994
Meadow pipit	1	Westenschouwen	10/02/1994
Meadow pipit	2	Westenschouwen	10/09/1994
Meadow pipit	1	Westenschouwen	10/02/1994
Meadow pipit	1	Baarlo	sept.- nov. 1994
Blackbird	5	Netherlands	--
Blackbird	1	Lisse	11/26/1993
Blackbird	2	Maasvlakte	10/24/1988
Blackbird	1	Leiden	11/25/1993
Blackbird	1	Hoeze	07/01/1992
Song thrush	1	Hexthuysen	--
Song thrush	1	Maasvlakte	10/13/1987
Song thrush	1	Oostvoorne	09/09/1987
Song thrush	1	Netherlands	--
Song thrush	1	Maasvlakte	10/27/1987
Song thrush	1	Maasvlakte	10/31/1987
Song thrush	1	Katwijk	September 1993
Song thrush	1	Zeist	10/28/1993
Song thrush	1	Roermond	--
Large non-granivores			
Jackdaw	1	Den Helder	10/13/1992
Carrion crow	3	Maasvallei	November 1993
Carrion crow	10	Stein	November 1993
Magpie	3	Maasvallei	November 1993
Magpie	2	Abbenes	November 1993
Magpie	1	Horst	01/31/1994
Magpie	1	Rijnsburg	11/06/1993
Magpie	4	Brunssum	November 1993
Black-headed gull	1	Tilburg	--
Black-headed gull	5	Stein	November 1993
Black-headed gull	1	Voorschoten	02/12/1993
Black-headed gull	1	Maasvlakte	12/01/1987
Lapwing	1	Netherlands	--
Lapwing	1	Eindhoven	02/01/1993
Geese & ducks			
Grey-lag goose	5	Oostvaardersplassen	--
White-fronted goose	1	Hellegatsplaten	03/08/1989
Bean goose	1	Uithoorn	12/01/1993
Mallard	3	Haarlemmermeer	08/26/1993
Mallard	8	Haarlemmermeer	09/14/1993

Appendix A3. Number of grit particles per size class (mm). n = number of individuals, x = average number of particles, sd = standard deviation.

SPECIES	N	<0.25		0.25-0.5		>0.5	
		X	SD	X	SD	X	SD
LARGE GRANIVORES	61	662.3	807.4	160.2	194.3	365.7	268.5
Grey Partridge	25	1566.2	3557.9	378.0	158.5	675.7	37.0
Woodpigeon	20	12.7	2.8	4.9	0.6	207.7	8.4
Pheasant	16	407.9	1103.0	97.6	67.3	213.7	6.4
SMALL GRANIVORES	39	254.4	535.8	88.6	141.7	120.5	60.7
House Sparrow	11	519.1	613.6	217.5	102.9	179.3	12.1
Greenfinch	8	14.2	30.0	46.6	43.1	94.7	6.4
Chaffinch	8	18.8	37.4	26.3	27.0	64.9	4.2
Skylark	6	1610.3	1356.0	422.7	76.1	217.0	13.3
Linnet	2	0.0	0.0	11.4	16.2	99.5	7.8
Twite	1	0.0	0.0	0.0	0.0	122.0	10.4
Brambling	1	0.0	0.0	8.5	0.0	187.5	18.2
Goldfinch	1	0.0	0.0	20.3	0.0	42.6	2.9
Tree Sparrow	1	127.1	0.0	44.3	0.0	76.6	5.9
LARGE NON-GRANIVORES	35	9133.5	10288.2	2729.2	3062.0	465.9	537.4
Carrion Crow	13	13348.1	16482.5	4268.3	3376.2	710.5	80.8
Magpie	11	1968.5	3112.0	614.8	464.0	97.1	11.5
Black-headed Gull	8	1133.5	1882.1	419.3	317.9	96.2	9.0
Lapwing	2	3877.3	5063.9	918.6	236.1	121.1	14.3
Jackdaw	1	25340.3	0.0	7425.0	0.0	1304.7	134.9
SMALL NON-GRANIVORES	45	5175.6	12555.8	970.8	2262.8	82.6	175.9
Blackbird	10	33628.8	89250.9	6094.2	472.8	479.6	72.6
Starling	10	1300.9	2143.4	341.6	236.8	37.8	5.7
Song Thrush	10	833.3	737.3	235.5	100.0	42.7	4.3
Meadow Pipet	9	105.9	219.6	37.5	33.2	6.2	0.8
Reed Bunting	3	42.4	73.4	10.5	5.9	1.0	0.2
White Wagtail	3	0.0	0.0	7.6	13.2	3.4	0.3
DUCKS & GEESE	18	89443.4	39886.3	38842.2	25568.1	11041.5	7377.8
Mallard	11	50249.8	50191.3	15903.3	7282.3	3785.9	304.6
Greylag Goose	5	144888.6	44833.6	73931.3	18502.2	21201.2	1750.5
White-fronted Goose	1	77419.1	0.0	24706.9	0.0	8322.0	633.3
Bean Goose	1	85216.1	0.0	40827.4	0.0	10856.9	1006.9

Appendix A3. (continued)

SPECIES	0.5-0.75		0.75-1.0		1.0-1.25		1.25-1.50		1.5-1.75		1.75-2.0	
	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
LARGE GRANIVORES	16.0	18.8	3.7	3.3	11.6	13.5	37.2	53.8	43.9	68.1	49.8	72.4
Grey Partridge	37.1	1.1	7.0	5.5	26.8	28.6	99.1	83.1	122.5	101.3	133.2	88.3
Woodpigeon	1.0	0.6	0.4	0.8	1.1	2.3	1.7	2.6	2.1	2.3	3.6	3.6
Pheasant	10.0	1.3	3.6	3.9	6.9	7.2	10.8	10.4	7.3	6.8	12.5	14.1
SMALL GRANIVORES	12.5	15.2	17.5	9.8	37.9	25.1	31.2	16.7	13.6	9.5	5.0	4.3
House Sparrow	31.5	2.7	32.0	25.8	51.1	34.6	35.3	19.8	18.5	12.1	7.9	4.8
Greenfinch	10.0	3.2	18.4	14.5	28.0	18.5	20.6	14.1	9.9	7.7	4.6	3.7
Chaffinch	4.4	0.7	8.4	7.7	15.4	12.6	16.8	15.7	10.8	8.8	6.6	5.1
Skylark	45.0	1.9	28.5	22.8	43.5	37.9	42.5	32.8	31.5	24.3	14.7	12.7
Linnet	6.9	4.2	26.6	10.6	36.0	15.6	20.5	12.0	8.0	1.4	1.5	0.7
Twite	1.0	-	6.0	-	34.0	-	51.0	-	25.0	-	3.0	-
Brambling	1.4	-	19.1	-	96.0	-	59.0	-	10.0	-	1.0	-
Goldfinch	6.4	-	8.2	-	12.0	-	10.0	-	2.0	-	3.0	-
Tree Sparrow	6.3	-	10.3	-	25.0	-	25.0	-	7.0	-	3.0	-
LARGE NON-GRANIVORES	306.6	342.9	51.4	64.1	33.5	40.5	19.4	23.6	9.2	11.6	7.0	9.4
Carrion Crow	496.7	9.8	70.0	72.3	41.9	51.6	28.5	32.0	13.0	16.3	7.8	6.5
Magpie	70.5	1.0	8.1	12.4	6.1	15.4	4.1	10.0	2.2	5.6	1.5	3.9
Black-headed Gull	53.7	4.3	14.7	15.4	10.5	12.1	6.1	5.6	2.9	3.2	2.5	3.0
Lapwing	88.6	0.7	8.0	5.7	8.0	9.9	1.5	2.1	0.0	-	0.0	-
Jackdaw	823.4	-	156.3	-	101.0	-	57.0	-	28.0	-	23.0	-
SMALL NON-GRANIVORES	74.7	165.1	2.7	3.8	2.0	3.3	1.4	2.4	0.6	0.7	0.5	0.9
Blackbird	447.9	0.3	10.7	7.3	8.7	9.5	5.9	6.8	1.0	1.3	2.1	3.8
Starling	35.3	0.3	2.2	1.9	0.3	0.9	0.0	-	0.0	-	0.0	-
Song Thrush	25.8	0.7	3.9	3.2	4.1	3.5	3.4	3.3	2.0	2.7	1.3	2.1
Meadow Pipet	4.6	0.4	0.7	1.4	0.0	-	0.4	0.7	0.4	0.7	0.1	0.4
Reed Bunting	1.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
White Wagtail	2.0	1.2	0.4	0.6	0.3	0.6	0.0	0.0	0.3	0.6	0.0	0.0
DUCKS & GEESE	5065.4	3622.1	1174.0	721.3	1891.9	1211.9	1695.6	1170.6	521.9	555.6	250.4	295.8
Mallard	1827.4	13.5	250.5	124.4	343.8	152.0	336.3	129.7	265.9	112.8	218.5	89.9
Greylag Goose	9999.0	45.5	1750.7	835.5	3261.9	1785.9	3017.1	2133.9	1288.8	1016.7	673.4	567.5
White-fronted Goose	2973.5	-	1744.5	-	1739.3	-	1206.6	-	532.8	-	109.7	-
Bean Goose	5461.6	-	950.2	-	2222.6	-	2222.6	-	0.0	-	0.0	-

Appendix A3. (continued)

SPECIES	2.0-2.25		2.25-2.5		2.5-2.75		2.75-3.0		3.0-3.25		3.25-3.5	
	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
LARGE GRANIVORES	42.9	55.7	30.8	29.5	26.4	15.2	24.7	9.4	15.3	8.4	13.1	9.6
Grey Partridge	107.0	64.9	64.6	45.6	44.0	34.4	15.2	12.7	7.7	6.3	3.6	3.4
Woodpigeon	6.7	6.7	10.4	11.4	17.2	17.8	34.1	33.9	24.4	23.0	22.8	20.3
Pheasant	14.9	23.4	17.3	25.7	17.9	25.8	24.9	37.4	13.9	15.2	12.9	15.6
SMALL GRANIVORES	1.6	2.1	0.6	0.8	0.2	0.6	0.1	0.1	0.0	0.1	0.1	0.3
House Sparrow	1.7	2.0	1.1	1.6	0.0	0.3	0.3	0.5	0.0	-	0.0	-
Greenfinch	2.3	3.0	0.7	0.9	0.2	0.4	0.1	0.3	0.0	-	0.0	-
Chaffinch	1.9	2.1	0.6	1.1	0.0	-	0.1	0.3	0.0	-	0.0	-
Skylark	6.7	5.0	2.5	1.5	1.8	1.5	0.0	-	0.2	0.4	0.2	0.4
Linnet	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Twite	2.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Brambling	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	1.0	-
Goldfinch	0.0	-	1.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Tree Sparrow	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
LARGE NON-GRANIVORES	5.3	7.1	4.2	5.4	3.8	5.9	4.6	6.8	2.5	3.8	3.4	4.4
Carrion Crow	7.0	6.8	6.2	6.4	3.9	3.5	5.9	6.1	2.8	3.0	3.4	3.0
Magpie	1.2	3.3	0.8	2.4	0.3	0.6	0.6	1.3	0.4	1.2	0.1	0.3
Black-headed Gull	0.9	1.1	0.8	1.2	0.8	1.2	0.6	1.4	0.5	0.8	0.5	1.1
Lapwing	0.5	0.7	0.5	0.7	0.0	-	0.0	-	0.0	-	2.0	1.4
Jackdaw	17.0	-	13.0	-	14.0	-	16.0	-	9.0	-	11.0	-
SMALL NON-GRANIVORES	0.2	0.4	0.2	0.5	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1
Blackbird	0.8	1.3	1.3	1.7	0.3	0.7	0.2	0.4	0.2	0.4	0.1	0.3
Starling	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Song Thrush	0.9	1.3	0.3	1.0	0.2	0.7	0.1	0.3	0.2	0.4	0.1	0.3
Meadow Pipet	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Reed Bunting	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
White Wagtail	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.0	-
DUCKS & GEESE	146.4	179.8	86.0	110.8	92.9	138.1	31.2	37.6	21.1	25.0	23.3	28.6
Mallard	184.6	71.1	112.0	61.7	79.5	49.1	48.9	32.6	35.7	21.4	34.4	35.2
Greylag Goose	365.1	342.7	232.1	144.2	292.2	292.3	75.8	74.9	48.9	22.4	58.6	62.9
White-fronted Goose	15.7	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Bean Goose	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-

Appendix A3. (continued)

SPECIES	3.5-3.75		3.75-4.0		4.0-4.25		4.25-4.5		4.5-4.75		4.75-5.0	
	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
LARGE GRANIVORES	10.6	8.3	8.7	6.7	7.3	5.4	7.8	6.4	3.5	2.7	3.2	2.4
Grey Partridge	2.7	3.2	1.6	2.1	1.4	2.4	0.7	1.3	0.6	1.0	0.4	0.8
Woodpigeon	19.2	16.7	14.9	12.3	12.0	9.2	13.4	9.2	5.9	5.0	4.9	3.2
Pheasant	9.9	10.4	9.6	10.3	8.4	8.1	9.3	10.7	3.9	3.9	4.3	5.3
SMALL GRANIVORES	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
House Sparrow	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Greenfinch	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Chaffinch	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Skylark	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Linnet	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Twite	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Brambling	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Goldfinch	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Tree Sparrow	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
LARGE NON-GRANIVORES	1.8	2.4	1.2	1.6	2.3	2.0	2.6	3.3	1.4	1.2	1.2	1.3
Carrion Crow	1.8	1.6	2.9	2.9	2.8	2.4	3.4	2.9	1.8	2.2	1.8	2.0
Magpie	0.2	0.6	0.0	-	0.1	0.3	0.0	-	0.3	0.9	0.0	-
Black-headed Gull	0.4	0.7	0.1	0.4	0.5	0.8	0.4	0.5	0.1	0.4	0.0	-
Lapwing	0.5	0.7	0.0	-	3.0	4.2	1.0	0.0	2.0	1.4	1.0	0.0
Jackdaw	6.0	-	3.0	-	5.0	-	8.0	-	3.0	-	3.0	-
SMALL NON-GRANIVORES	0.1	0.1	0.0	-	0.0	-	0.0	0.0	0.0	0.0	0.0	-
Blackbird	0.3	0.7	0.0	-	0.0	-	0.0	-	0.1	0.3	0.0	-
Starling	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Song Thrush	0.1	0.3	0.0	-	0.0	-	0.1	0.3	0.0	-	0.0	-
Meadow Pipet	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Reed Bunting	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
White Wagtail	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
DUCKS & GEESE	18.8	27.0	8.7	11.8	4.7	5.8	2.0	2.5	2.0	2.5	2.6	3.0
Mallard	17.9	20.8	9.7	14.2	6.6	8.6	2.6	5.8	2.6	6.0	5.3	12.0
Greylag Goose	57.3	80.8	25.0	23.9	12.0	16.6	5.3	11.9	5.2	11.7	5.2	11.7
White-fronted Goose	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Bean Goose	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-

Appendix A3. (continued)

SPECIES	5.0-5.25		5.25-5.5		5.5-5.75		5.75-6.0		6.0-6.25		6.25-6.5	
	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
LARGE GRANIVORES	2.0	1.7	1.9	1.6	2.1	1.9	0.8	0.7	0.6	0.4	0.5	0.4
Grey Partridge	0.0	0.2	0.0	0.2	0.0	-	0.0	-	0.1	0.4	0.0	-
Woodpigeon	2.8	2.5	3.1	2.7	2.6	2.5	1.2	1.4	0.9	1.1	0.7	0.7
Pheasant	3.1	3.8	2.6	3.1	3.7	4.7	1.3	1.6	0.9	1.1	0.8	1.1
SMALL GRANIVORES	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
House Sparrow	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Greenfinch	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Chaffinch	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Skylark	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Linnet	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Twite	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Brambling	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Goldfinch	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Tree Sparrow	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
LARGE NON-GRANIVORES	0.6	0.8	1.2	2.2	0.4	0.6	0.7	0.8	0.3	0.3	0.4	0.5
Carrion Crow	1.3	1.8	0.9	1.3	1.5	2.0	0.5	0.9	0.8	0.9	0.8	1.2
Magpie	0.1	0.3	0.1	0.3	0.2	0.6	0.0	-	0.0	-	0.0	-
Black-headed Gull	0.0	-	0.0	-	0.0	-	0.0	-	0.1	0.4	0.0	-
Lapwing	1.5	2.1	0.0	-	0.5	0.7	1.0	1.4	0.5	0.7	0.0	-
Jackdaw	0.0	-	5.0	-	0.0	-	2.0	-	0.0	-	1.0	-
SMALL NON-GRANIVORES	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Blackbird	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Starling	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Song Thrush	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Meadow Pipet	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Reed Bunting	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
White Wagtail	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
DUCKS & GEESE	0.0	-	0.0	-	0.0	-	0.6	1.1	0.3	0.5	1.6	2.5
Mallard	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3.4	1.1	3.5
Greylag Goose	0.0	0.0	0.0	0.0	0.0	0.0	2.2	5.0	0.0	0.0	5.2	11.7
White-fronted Goose	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Bean Goose	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-

Appendix A3. (continued)

SPECIES	6.5-6.75		6.75-7.0		7.0-7.25		7.25-7.5		7.5-7.75		7.75-8.0	
	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
LARGE GRANIVORES	0.5	0.5	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.0	0.0
Grey Partridge	0.1	0.3	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Woodpigeon	0.3	0.5	0.2	0.4	0.3	0.5	0.2	0.5	0.1	0.2	0.1	0.2
Pheasant	1.1	1.5	0.4	0.9	0.3	0.6	0.3	0.4	0.4	0.6	0.1	0.3
SMALL GRANIVORES	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
House Sparrow	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Greenfinch	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Chaffinch	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Skylark	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Linnet	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Twite	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Brambling	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Goldfinch	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Tree Sparrow	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
LARGE NON-GRANIVORES	0.1	0.2	0.2	0.4	0.1	0.2	0.3	0.4	0.1	0.1	0.0	-
Carrion Crow	0.5	0.9	0.8	1.1	0.5	1.0	0.4	0.7	0.3	0.6	0.0	-
Magpie	0.1	0.3	0.1	0.3	0.0	-	0.1	0.3	0.0	-	0.0	-
Black-headed Gull	0.0	-	0.0	-	0.0	-	0.0	-	0.1	0.4	0.0	-
Lapwing	0.0	-	0.0	-	0.0	-	1.0	0.0	0.0	-	0.0	-
Jackdaw	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
SMALL NON-GRANIVORES	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Blackbird	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Starling	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Song Thrush	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Meadow Pipet	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Reed Bunting	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
White Wagtail	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
DUCKS & GEESE	0.0	-	0.4	0.8	0.0	-	0.0	-	0.0	-	0.0	-
Mallard	0.0	0.0	1.5	5.1	0.0	-	0.0	-	0.0	-	0.0	-
Greylag Goose	0.0	0.0	0.0	0.0	0.0	-	0.0	-	0.0	-	0.0	-
White-fronted Goose	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Bean Goose	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-

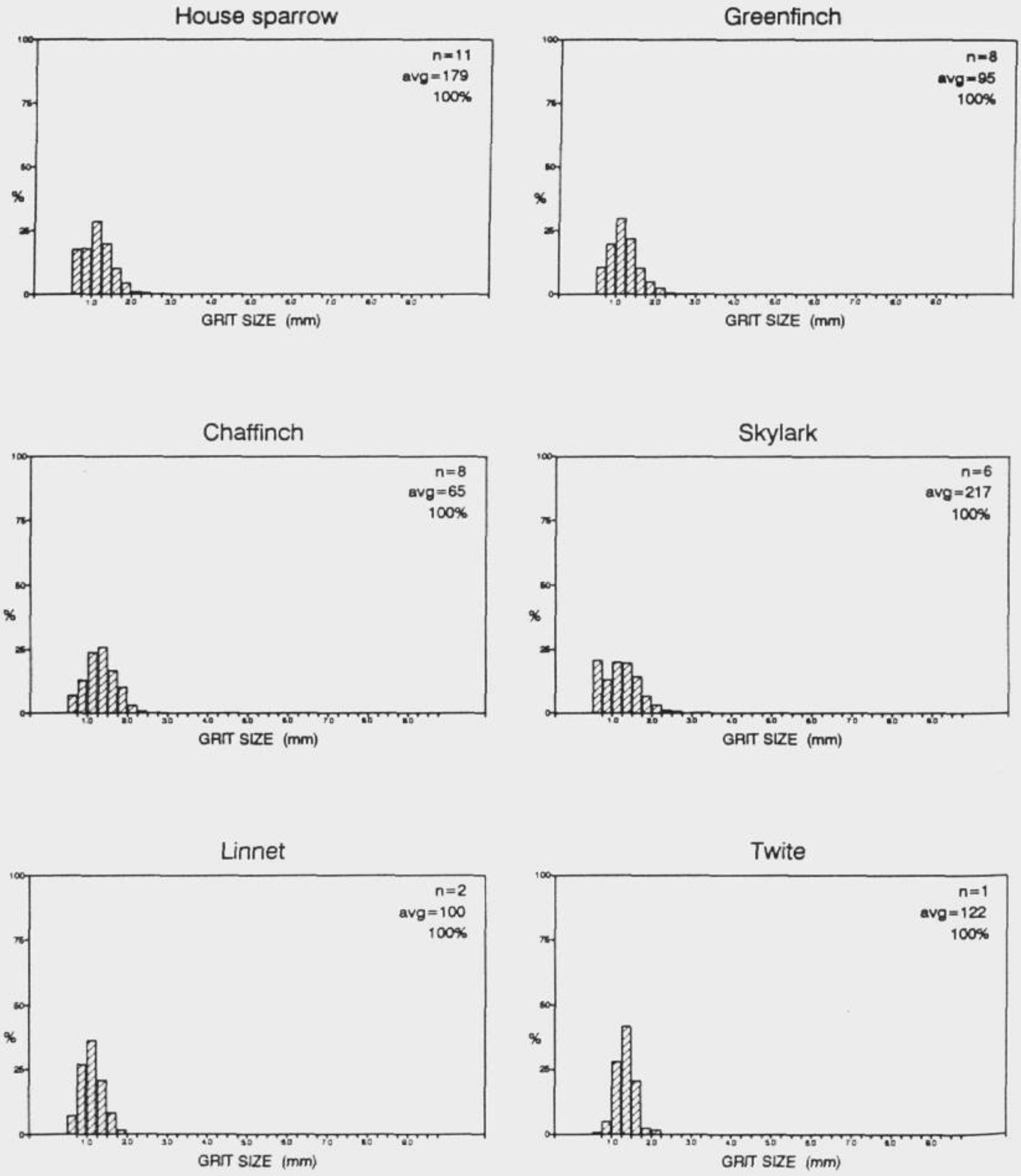
Appendix A3. (continued)

SPECIES	8.0-8.25		8.25-8.5		8.5-8.75		8.75-9.0		9.0-9.25		9.25-9.5	
	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
LARGE GRANIVORES	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0
Grey Partridge	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Woodpigeon	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Pheasant	0.1	0.3	0.2	0.4	0.1	0.3	0.1	0.5	0.3	0.8	0.1	0.3
SMALL GRANIVORES	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
House Sparrow	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Greenfinch	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Chaffinch	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Skylark	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Linnet	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Twite	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Brambling	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Goldfinch	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Tree Sparrow	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
LARGE NON-GRANIVORES	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Carrion Crow	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Magpie	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Black-headed Gull	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Lapwing	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Jackdaw	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
SMALL NON-GRANIVORES	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Blackbird	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Starling	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Song Thrush	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Meadow Pipet	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Reed Bunting	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
White Wagtail	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
DUCKS & GEESE	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Mallard	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Greylag Goose	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
White-fronted Goose	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
Bean Goose	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-

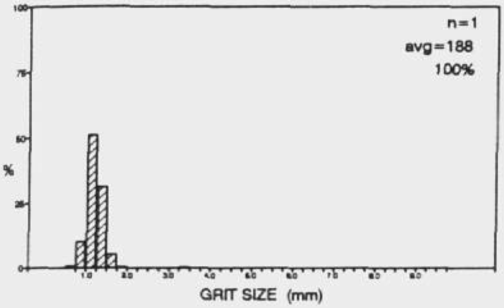
Appendix A3. (continued)

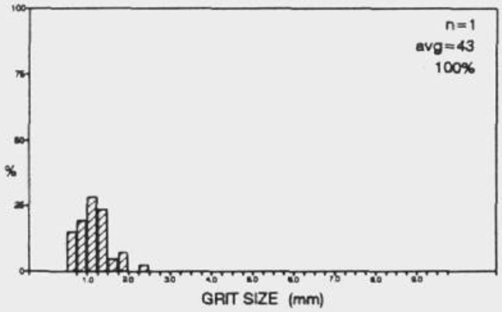
SPECIES	9.5-9.75		9.75-10.0	
	X	SD	X	SD
LARGE GRANIVORES	0.1	0.1	0.0	0.0
Grey Partridge	0.0	0.2	0.0	-
Woodpigeon	0.0	-	0.0	-
Pheasant	0.1	0.3	0.1	0.3
SMALL GRANIVORES	0.0	-	0.0	-
House Sparrow	0.0	-	0.0	-
Greenfinch	0.0	-	0.0	-
Chaffinch	0.0	-	0.0	-
Skylark	0.0	-	0.0	-
Linnet	0.0	-	0.0	-
Twite	0.0	-	0.0	-
Brambling	0.0	-	0.0	-
Goldfinch	0.0	-	0.0	-
Tree Sparrow	0.0	-	0.0	-
LARGE NON-GRANIVORES	0.0	-	0.0	-
Carrion Crow	0.0	-	0.0	-
Magpie	0.0	-	0.0	-
Black-headed Gull	0.0	-	0.0	-
Lapwing	0.0	-	0.0	-
Jackdaw	0.0	-	0.0	-
SMALL NON-GRANIVORES	0.0	-	0.0	-
Blackbird	0.0	-	0.0	-
Starling	0.0	-	0.0	-
Song Thrush	0.0	-	0.0	-
Meadow Pipet	0.0	-	0.0	-
Reed Bunting	0.0	-	0.0	-
White Wagtail	0.0	-	0.0	-
DUCKS & GEESE	0.0	-	0.0	-
Mallard	0.0	-	0.0	-
Greylag Goose	0.0	-	0.0	-
White-fronted Goose	0.0	-	0.0	-
Bean Goose	0.0	-	0.0	-

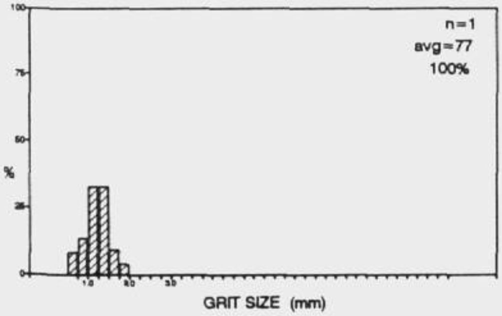
Appendix A4. Size histograms of the grit of small granivores. n = number of individuals, avg = average, percentage is portion of individuals with grit in their gizzard.



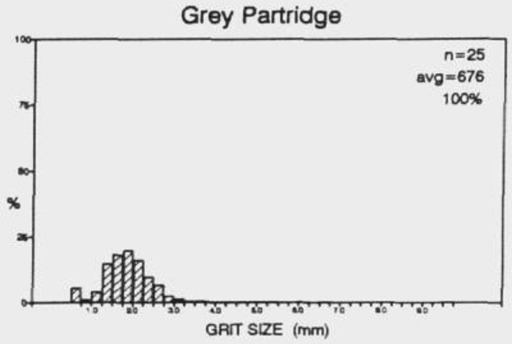
Appendix A4. Size histograms of grit: small granivores (continued)

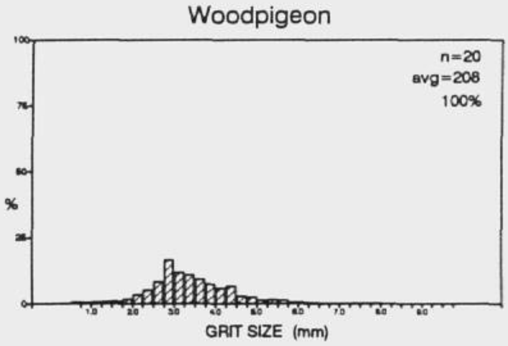

Brambling

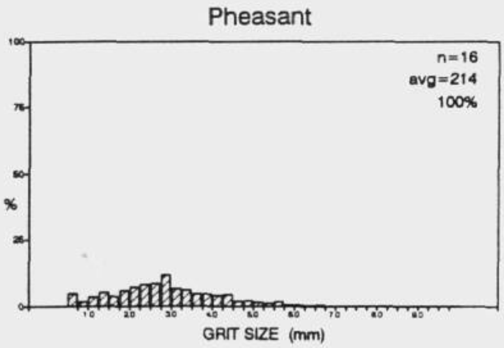

Goldfinch


Tree Sparrow

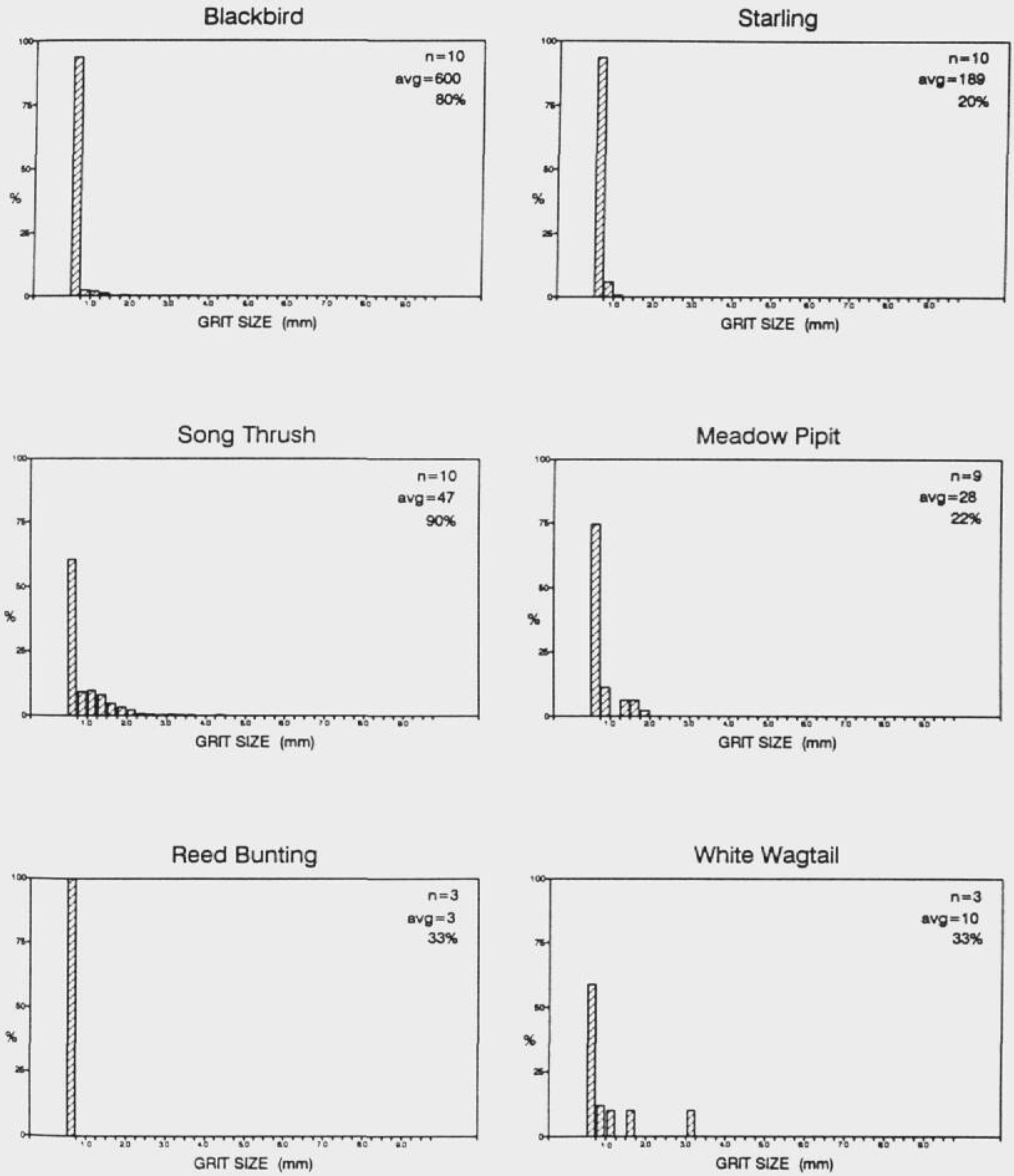
Appendix A4. Size histograms of grit: large granivores. n = number of individuals, avg = average, percentage is portion of individuals with grit in their gizzard.





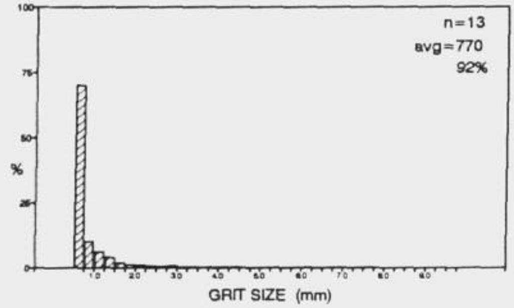


Appendix A4. Size histograms of grit: small non-granivores. n = number of individuals, avg = average, percentage is portion of individuals with grit in their gizzard.

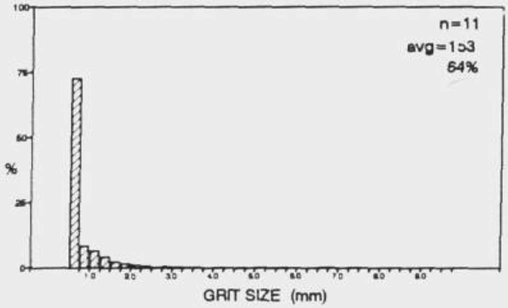


Appendix A4. Size histograms of grit: large non-granivores. n = number of individuals, avg = average, percentage is portion of individuals with grit in their gizzard.

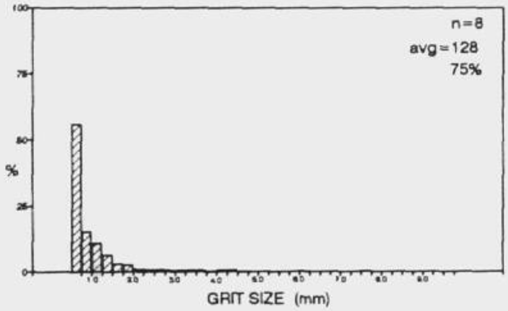
Carrion Crow



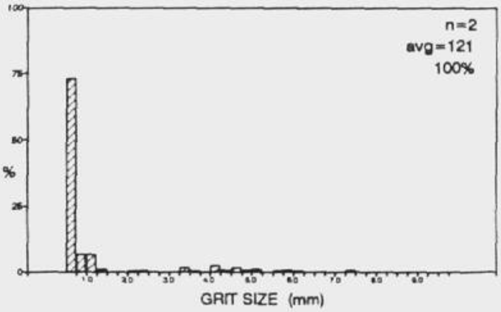
Magpie



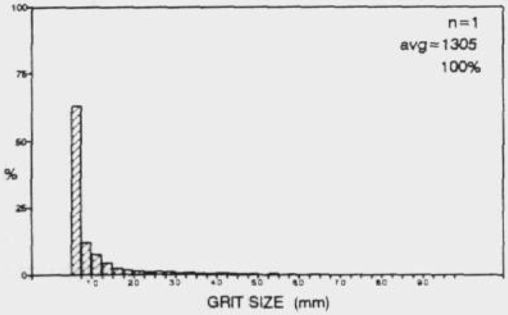
Black-headed Gull



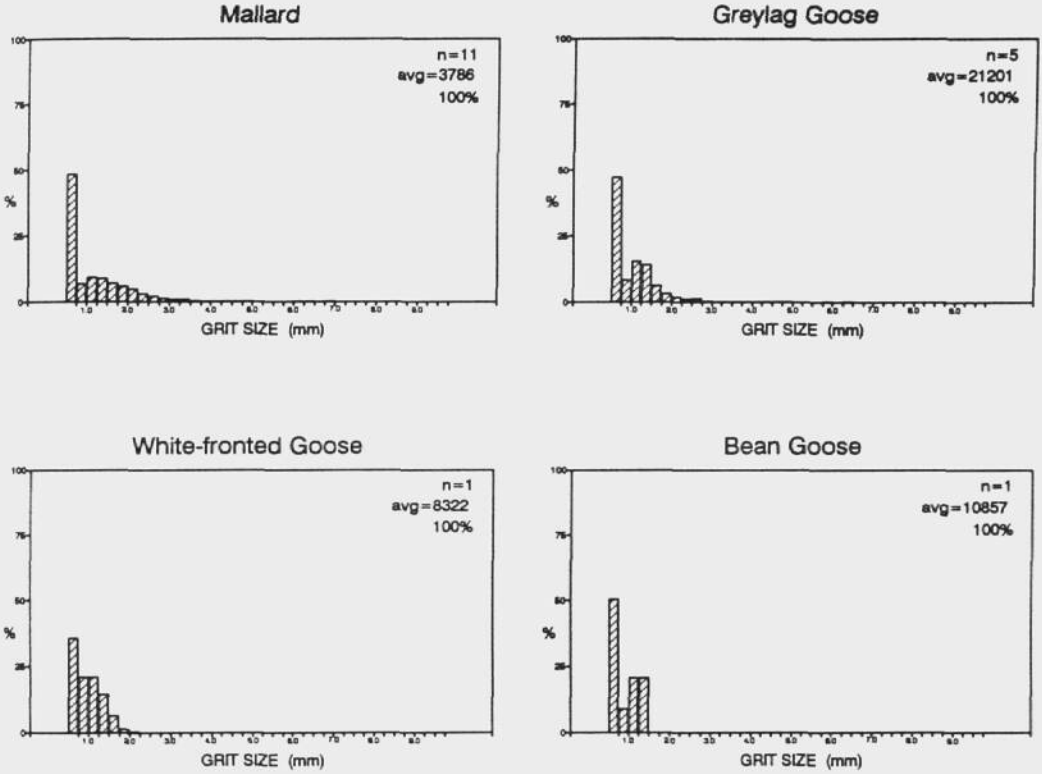
Lapwing



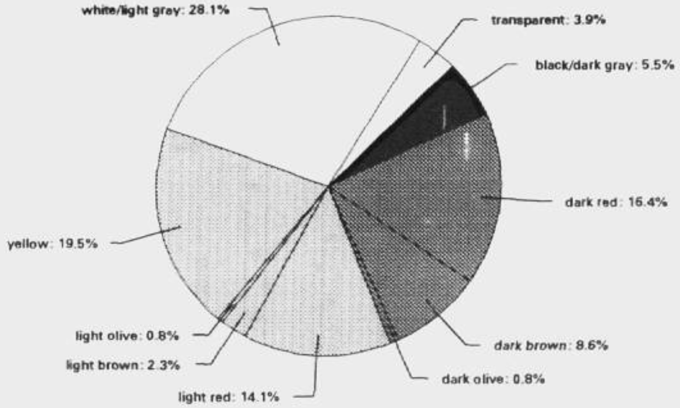
Jackdaw

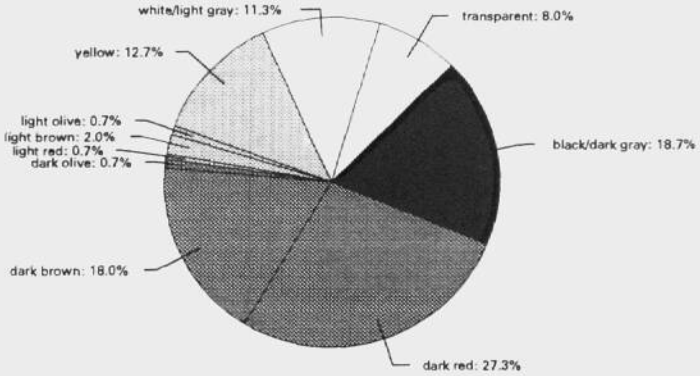


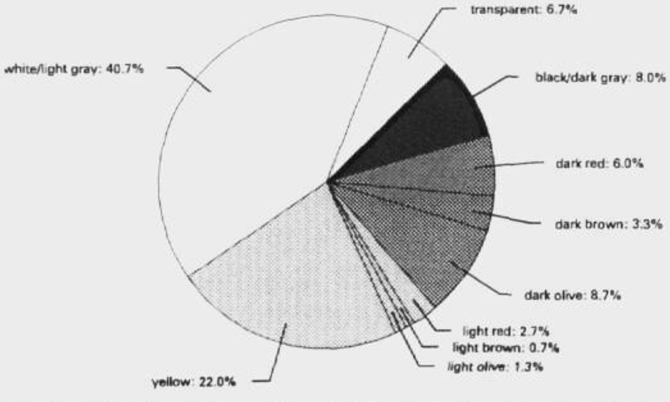
Appendix A4. Size histograms of grit: ducks & geese. n = number of individuals, avg = average, percentage is portion of individuals with grit in their gizzard.



Appendix A5. Grit colours: small granivores

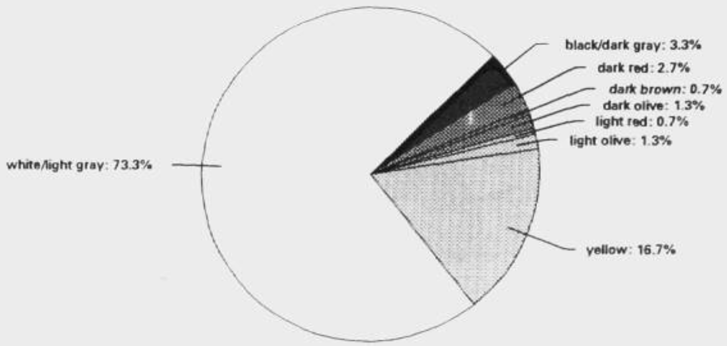

Chaffinch


Greenfinch

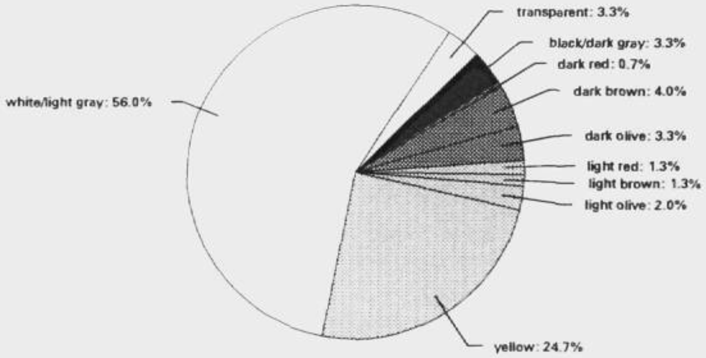

House Sparrow

Appendix A5. Grit colours: large granivores

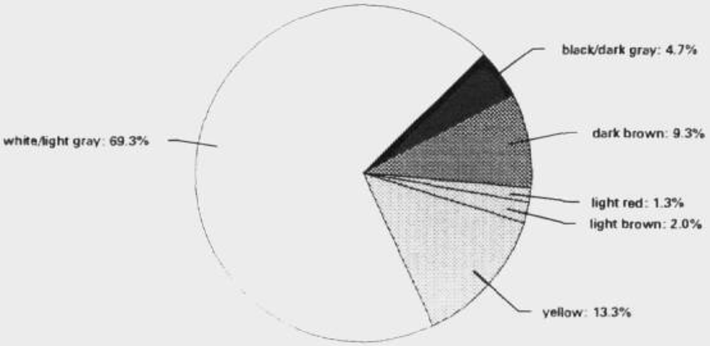
Pheasant



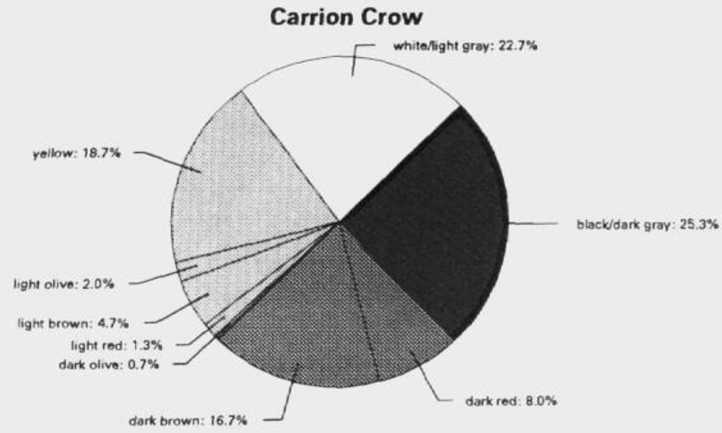
Gray Partridge

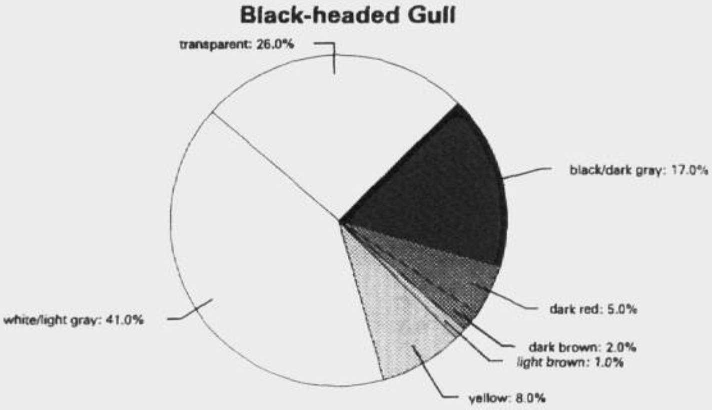


Wood Pigeon



Appendix A5. Grit colours: large non-granivores

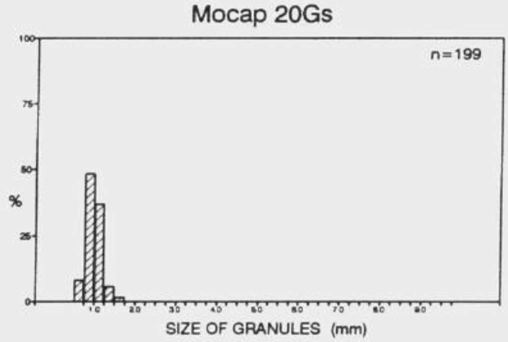

Carrion Crow

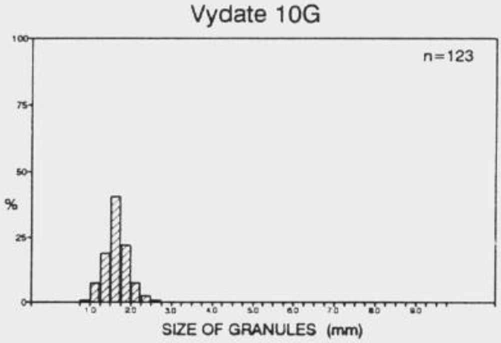

Black-headed Gull

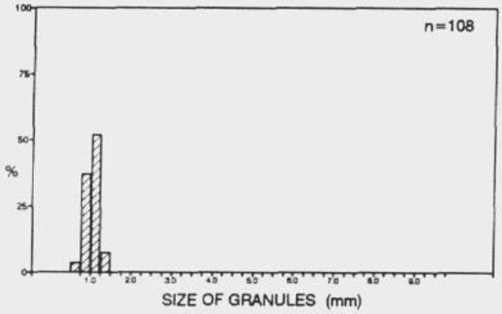
Appendix A6. Shape index of grit.

large granivores	
Partridge	1.34
Woodpigeon	1.43
Pheasant	1.40
small granivores	
Skylark	1.34
House Sparrow	1.35
Tree Sparrow	1.40
Chaffinch	1.38
Greenfinch	1.37
Linnet	1.36
Twite	1.33
Brambling	1.37
Goldfinch	1.39
large non-granivores	
Carrion Crow	1.42
Magpie	1.36
Jackdaw	1.36
Black-headed Gull	1.37
Lapwing	1.38
small non-granivores	
Blackbird	1.37
Song Thrush	1.39
Starling	1.30
Reed Bunting	-
Meadow pipit	1.36
White Wagtail	1.37
ducks & geese	
Greylag Goose	1.36
Bean Goose	1.34
White-fronted Goose	1.32
Mallard	1.35

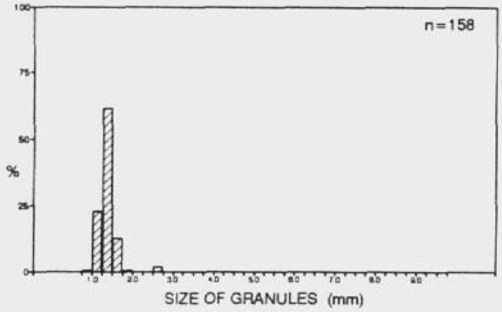
Appendix A7. Size distributions of granules and pelleted seeds.


Mocap 20Gs


Vydate 10G

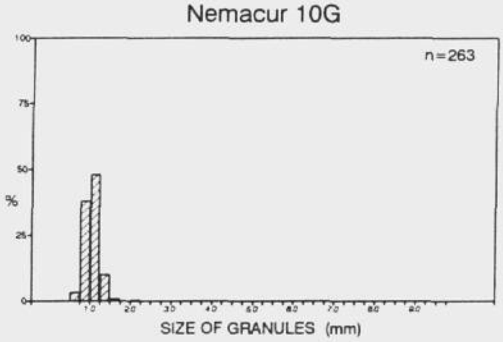


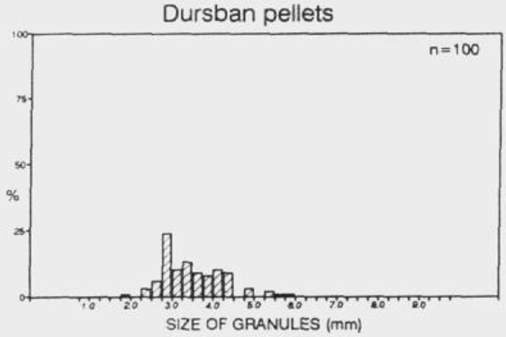
Curater granules

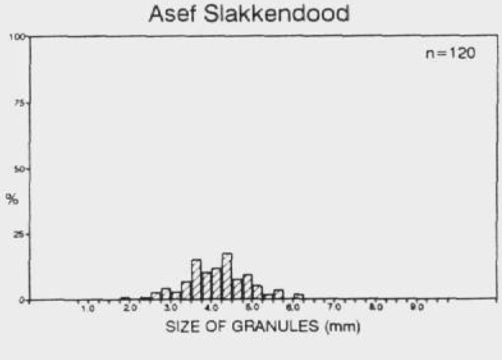


Temik 10G Gypsum

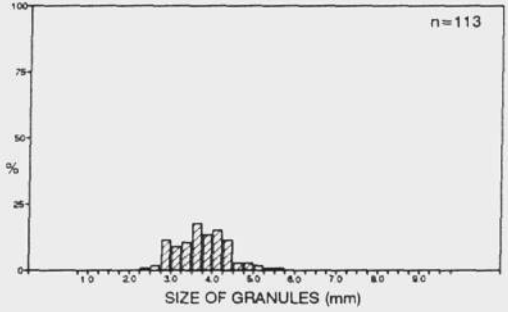
Appendix A7. (continued)

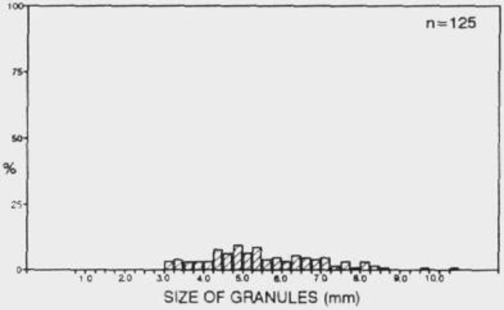



Dursban pellets


Asef Slakkendood

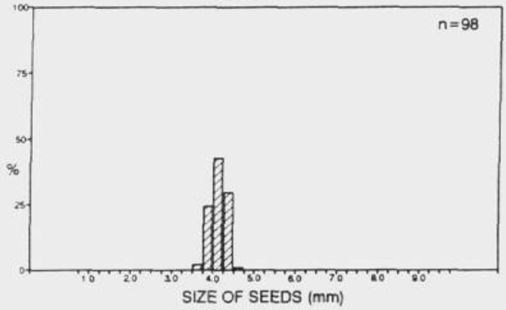
Appendix A7. (continued)


Mesurol pellets

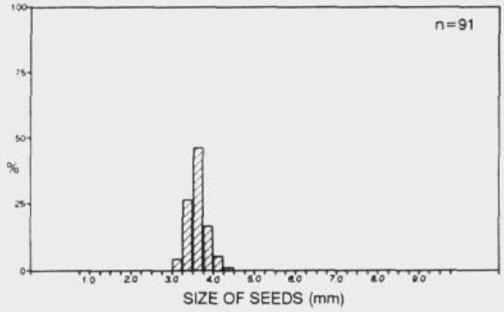

Luxan pellets

Appendix A7. (continued)

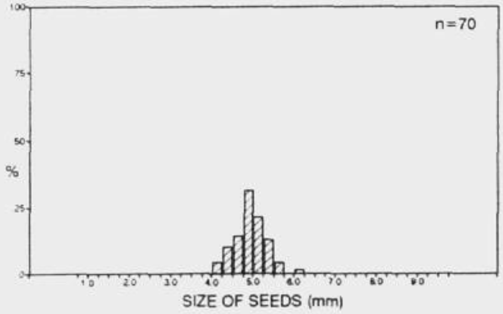
Carrot



Onion



Sugar beet



Appendix A8. Trade names and manufacturers of granules.

Trade name	Manufacturer
Mocap 20 GS	Rhône Poulence B.V.
Vydate 10G	Shell Nederland B.V.
Curater	Bayer B.V.
Temik 10G Gypsum	Rhône Poulence B.V.
Nemacur 10G	Bayer B.V.
Dursban	B.V. Chem.Pharm.Industrie "Luxan"
Mesurol	Bayer B.V.
Asef Slakkendood	Asef B.V.
Luxan Slakkenkorrels Super	B.V. Chem.Pharm.Industrie "Luxan"

Appendix A9. Toxicity of the examined granules and pelleted seeds to birds. LD50 doses are derived from Linders (1994). "LN50" = "lethal number", this is defined as the number of particles that add up to the LD50 dose.

Trade Name	Active ingredient	perc. of active ingr.	weight per particle (mg)	LD50 per kg bird	"LN50" per kg. bird
Granules					
Mocap 20GS,	ethoprofos	20%	0.119	5.6	235.5
Vydate 10G	oxamyl	10%	0.264	4.6	174.0
Curater granules	carbofuran	5%	0.426	4.6	216.1
Temik 10G Gypsum	aldicarb	10%	0.529	3.4	64.3
Nemacur 10G	fenamifos	10%	0.071	0.7	99.1
Dursban pellets	chloorpyrifos	2%	14.868	8.0	26.9
Mesurol pellets	methiocarb	4%	16.273	4.7	7.2
Asef Slakkendood	metaldehyde	6%	11.125	181.0	271.2
Luxan pellets	metaldehyde	6.4%	29.661	181.0	95.4
Pelleted seeds					
Sugar beet	furathiocarb	2.2%	27.797	12.0	20.0
Carrot	chlorfenvinphos	0.1%	38.625	3.0	100.0
Onion	furathiocarb	0.5%	30.269	12.0	75.0

Appendix A10. Hazard to birds. Expected (="E") numbers of ingested granules or pelleted seeds/day/species group. In parentheses: number of granules or pelleted seeds causing lethal effects in 50% of the average birds of the various species groups (="LN50").

	small granivores (23 g)	*large* granivores (665 g)	*small* non-gran. (53 g)	*large* non-gran. (288 g)	*ducks &* geese (2338 g)
granules					
Mocap 20GS	26.2 (5.42)	17.1 (156.64)	35.7y (12.48)	109.4y (67.84)	2456.8y(550.70)
Vydate 10G	19.9 (4.00)	46.4 (115.72)	2.1y (9.22)	19.8y (50.12)	1126.3y(406.85)
Curater granules	22.8 (4.97)	13.2 (143.72)	2.7y (11.45)	27.8y (62.24)	1189.8y(505.30)
Temik 10G Gypsum	18.8 (1.48)	23.2 (42.74)	1.8y (3.41)	16.5y (18.51)	1026.9y(150.26)
Nemacur 10G	22.8 (2.28)	13.2 (65.92)	2.7y (5.25)	27.8y (28.55)	1189.8y(231.78)
Dursban pellets	0.16 (0.62)	30.1 (17.89)	0.15y (1.43)	6.6y (7.75)	52.4y (62.90)
Mesurol pellets	0.06 (0.17)	23.6 (4.80)	0.11y (0.38)	5.6y (2.08)	27.6y (16.88)
Asef Slakkendood	0.06 (6.24)	23.5 (180.32)	0.11y(14.37)	6.1y (78.09)	27.6y(633.97)
Luxan	0.06 (2.19)	15.8 (63.41)	0.04y (5.05)	4.8y (27.46)	16.6y(222.92)
pelleted seeds					
Sugar beet	0.0 (0.46)	5.1 (13.30)	0.0y (1.06)	2.0y (5.76)	2.8y (46.76)
Carrot	*0.0 (2.30)*	*5.9 (66.50)*	*0.0y (5.30)*	*1.6y (28.80)*	*2.8y(233.80)*
Onion	0.03 (1.73)	9.9 (49.88)	0.04y (3.98)	2.4y (21.60)	13.8y(175.35)

Part B:

Availability of treated seeds resembling natural food

PART B: CONTENTS

CHAPTER 1: INTRODUCTION

1.1 Framework and aim of the study

Treated seeds may pose a risk to birds if they are seen as a source of food. Incidents involving gamebirds (pheasant, partridge), waterfowl (goose, duck), pigeons, starlings, house sparrows, greenfinches and crows feeding on treated seeds have been reported by Murton & Vizoso (1963), Fuchs (1967), Porter (1977), Greig-Smith (1987a), Cooke (1988), and Hart & Clook (1994). These incidents were attributed to dieldrin, aldrin, carbophenthion, lindane, chlorfenvinphos, fonofos and methiocarb. At the present time the latter four are approved in the Netherlands for seed treatment (Mandersloot, 1993; pers. comm. College voor Toelating van Bestrijdingsmiddelen).

In the risk-assessment scheme for treated seeds, the risk to birds (and small mammals) is assessed on the basis of the amount of pesticide on the soil surface per m^2 (see Fig. 2; Luttik & De Snoo, 1992). This amount can be calculated by multiplying the amount of pesticide on one seed by the number of treated seeds on the soil surface per m^2. This method ignores the fact that birds can dig up treated seeds that are buried. When the amount of pesticide per m^2 is below 0.1 LD50 of the species concerned, a low risk is assumed; when the amount is between 0.1 LD50 and 10 LD50, an intermediate risk is assumed; and when the amount is above 10 LD50 a high risk is assumed.

These risk levels are dependent on the number of treated seeds on the soil surface after seeding. When using the risk assessment scheme, it is therefore necessary to know this number. In the United Kingdom, the United States and Germany the number of unburied seeds has been investigated under different circumstances (Davis, 1974; Westlake *et al.*, 1980; Murphy Chemical Limited, 1975; Maze *et al.*, 1991; Hänisch & Gemmeke, 1992; Muton & Vizoso, 1963; Jefferies *et al.*, 1973; Riedel *et al.*, 1992). Most of these studies are situated in the United Kingdom. However, because there are probably large differences in the seeding conditions in various countries (e.g. soil condition, weather conditions and agricultural practice), it is uncertain whether the results of these studies are also valid for the Dutch situation. Moreover, studies to date have so far focused on only two crops: cereals and rapeseed. To estimate the risk to birds of treated seeds, it is necessary to have a good estimate of the number of unburied seeds for every treated crop sown in the Netherlands.

A field study was therefore carried out, with the aim of determining the number of seeds at the soil surface for a number of crops in the Netherlands. This number can be affected by such factors as soil condition and agricultural practice. Because these factors can vary with time and place, it is necessary to know how these factors affect the number of surface seeds. Therefore, a secondary goal of the field study was to assess the effect of some of the factors that might influence the number of surface seeds. It should be possible to extrapolate the results of this field study to all crops and situations in the Netherlands.

However, there is some uncertainty about the risk levels based on the amount of pesticides per m^2. In the first place, this risk measure was originally developed for granules, and it is unclear whether it is also valid for treated seeds. In the second place, a risk measure based on the amount of pesticide/m^2 implies that there is no difference in risk between different seed densities that result in the same amount of pesticide/m^2. From the point of view of the optimal foraging theory, this seems unlikely. Therefore, a literature study was carried out, in which the risk measure was evaluated based on the optimal foraging theory.

1.2 Research parameters for the field study

The field study focused on a number of parameters. Some of these relate to differences among crops, while others are concerned with field conditions, agricultural practice and weather conditions. The choice of these research parameters will be explained in this section.

The main crop-related parameters that may influence the number of surface seeds are: seed weight, seed rate, seeding depth and drilling technique. Because studies have so far focused on two crops only, little information is available on the influence of these parameters.

One of these parameters, drilling technique, has been investigated in a few studies. Some authors describe the effects of differences, for instance in harrow or hoe applications, between drills used with the same crop. There are no studies focusing on the difference resulting from the same crops being drilled using different techniques. Moreover, there is

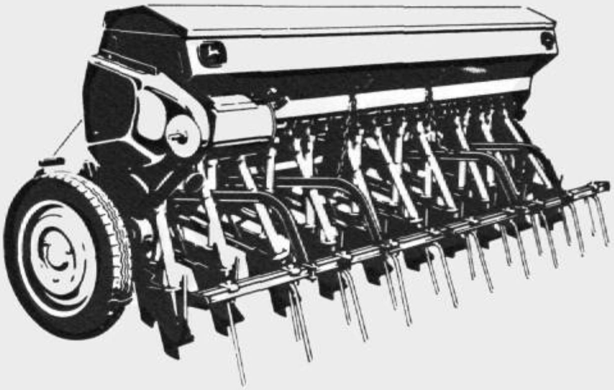


Figure 1.1. View of a standard drill.

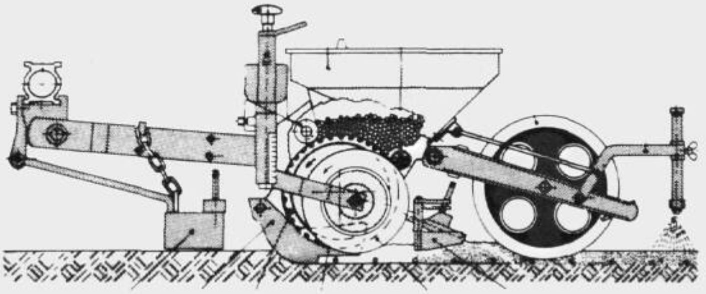


Figure 1.2. Schematic view of a precision drill.

a large difference in agricultural practice in the Netherlands and the United Kingdom, the country where most of the studies have been performed. The crop rotation system in the Netherlands includes sugar beet and potatoes. These crops require thorough seed bed preparation, including ploughing every year after harvesting. In the UK cereals are often sown on a field for several years in succession, or they are sown after another crop that does not cause any substantial soil disturbance. In these cases ploughing is not necessary (pers. comm. Darwinkel, Stichting Proefstation voor de Akkerbouw en Groenteteelt in de Vollegrond: PAGV). Because 'direct drilling' (without ploughing or cultivating first) gives a higher yield than drilling after ploughing or cultivating, direct drilling will be the technique most commonly used in the UK (MAFF, 1980a). Besides a difference in seed bed preparation this will probably also mean that different types of drills are used in the two countries.

In the Netherlands two main drilling techniques are used: standard drilling and precision drilling. A standard drill first makes a furrow, into which the seeds are dropped one by one. There is often a harrow attached behind the drill (Fig. 1.1). In the case of precision drilling, a very smooth seed bed is needed. Fields that are to be seeded with a precision drill are therefore prepared more carefully, leaving less clumps, than fields to be sown with a standard drill. Machinery for precision drilling first removes the clumps before the furrow is made. In addition, a precision drill makes a much smoother furrow than a standard drill, allowing the seeds to be sown at a more regular depth. After the furrow has been made, the seeds are dropped in one by one at very regular intervals. The furrow is closed using one or two press wheels, after which a harrow or hoe sometimes follows. Many different implements are used for both standard and precision drilling operations (see Appendix 1 for the implements used in the present field study), the main differences lying in the methods for closing the furrow and the various optional harrow or hoe applications. Standard drills will probably leave more seeds on the surface than precision drills, because the latter can deposit the seeds more precisely at the desired location and depth. The influence of standard and precision drilling on the number of surface seeds is not mentioned in the literature.

In this field study the influence of the parameters drilling technique, seed weight and seed rate was investigated. Bosch & De Jonge (1989) report that heavy (and large) seeds are generally drilled deeper than light (and small) seeds. Hence, seed weight is strongly correlated with seeding depth. The parameter seeding depth was therefore not studied separately.

The literature makes clear that there are a number of factors unrelated to the crop that may influence the percentage or number of seeds left on the soil surface. The most important factors mentioned are: soil condition, location in the field and spillage.

Soil condition is the condition of the field during drilling. This factor is determined by soil type, weather before and during sowing, seed bed preparation and the presence of debris from previous crops (stubble). The condition of the soil influences the number of surface seeds considerably. Hänisch & Gemmeke (1992) report a higher number of rape seeds on the soil surface in heavy cloddy soils than in light soils. According to Davis

(1974), soil condition has a greater influence than soil type. He found that the number of surface seeds was highest on clay after heavy rain. On a sandy loam with a better tilth the number was less, but the number of surface seeds was even less on clay with a good tilth. Davis found that the lowest number of surface seeds occurred on a peaty soil under good weather conditions. Murphy Chemical Ltd. (1975) reports that 4 to 5 times more seeds remain on the soil surface on the cloddy part of a field than on the well-tilled part of the same field. Davis (1974) describes a negative influence of the presence of sugar beet debris, which interfered with the drill, on the number of wheat seeds on the soil surface. In contrast, after wheat Maze *et al.* (1991) reports the opposite effect: in wheat stubble less seeds were counted on the soil surface than under ideal drilling conditions (summer-fallow). This was attributed to less seeds being covered by surface debris in summer-fallow.

Most authors report a higher number of surface seeds on the headland of the field than at the centre (Davis, 1974; Westlake *et al.*, 1980; Murphy Chemical Ltd., 1975; Hänisch & Gemmeke, 1992). In the Netherlands the headland is often the place where the drilling implement is turned when the centre of the field is being seeded. After the centre has been seeded, the headland itself is seeded crosswise (see Fig. 2.3). As a result of this procedure, during drilling the soil condition on the headland is often worse than at the centre of the field, and a small section of the headland, the strip where headland drilling overlaps centre drilling, is drilled twice.

Spillage of seeds can occur when the drilling implement is filled or cleaned. Davis (1974) and Maze *et al.* (1991) point out that seed spillage may constitute a major source of exposure to treated seeds. Davis (1974) found grain spillage along field edges.

In conclusion, the factors spillage and location in the filed (headland versus centre) were investigated because they may possibly have a major impact on the number of surface seeds and because these factors have never been investigated thoroughly. Some work has been done on the influence of the factor soil condition on the number of surface seeds. These studies show that the effect may be substantial, but no research has been done in the Dutch situation. Knowledge of these three factors is essential if the results of the field study are to be utilized in all the situations existing in the Netherlands.

The last research parameter was the decline of the number of seeds in the first two weeks after seeding. This parameter was measured because it may provide an indication of the length of the period in which treated seeds continue to pose a risk to birds and mammals.

Summarizing, the following parameters were studied: *a.* drilling technique, *b.* seed weight, *c.* seed rate, *d.* soil condition, *e.* location in the field, *f.* spillage and *g.* post-seeding decline.

1.3 Outline of Part B

Chapter 2 describes the study area, the methods used to count the surface seeds and the methods used to assess the effect of the research parameters. In Chapter 3 the results of the field work are presented, and in Chapter 4 they are discussed. In Chapter 5 the consequences for the risk assessment scheme are discussed and the risk level itself is evaluated.

CHAPTER 2:
STUDY AREA AND METHODS

2.1 General set-up

The field study was carried out during the spring of 1994 and during the autumns of 1993 and 1994. In the spring of 1994, 43 fields were studied. On these fields the number and percentage of seeds left on the soil surface after drilling were counted for different crops (parameters: drilling technique, seed weight and seed rate) and the influence of the parameters soil condition, location in the field and spillage were studied. The effect of soil condition was studied in wheat only, supplementing a more thorough study of this factor in the autumn. In the autumn of 1993, 17 fields were studied, and in the autumn of 1994, 14 fields. On these fields the number and percentage of surface seeds were studied for one crop: winter wheat. The autumn studies focused on the parameters soil condition, location in the field, spillage and post-drilling decline. A general overview of the field study is presented in Table 2.1.

In this chapter, first the areas in which the study took place and the weather conditions are described. Second, the method used to count the seeds is described. Finally, the methods used to study the influence of the various factors on the number and percentage of surface seeds are explained.

Table 2.1. Overview of the field work. X: seed counting at the centre of the field used in this study, 1: seed counting at the centre and on the headland, 2: estimation of the number of seeds at spillage spots, 3: only in the autumn of 1994.

	AUTUMN	SPRING					
	winter wheat	spring wheat	pea	flax & alfalfa	onion	sugar beet	maize
techniques		X	X	X	X	X	X
seed weight		X	X	X	X	X	X
seed rate				X			
soil condition	X	X					
location	X^{13}	X^{1}	X^{1}	X^{1}	X^{1}	X^{1}	X^{1}
spillage	X^{23}	X^{2}	X^{2}	X^{2}	X^{2}	X^{2}	X^{2}
decline	X						

2.2 Study areas

The research was performed in three different areas of the Netherlands: the Haarlemmermeerpolder, the eastern part of the Flevopolder and the south-eastern part of Gelderland. These areas lie roughly on a east-west transect of the Netherlands. The Haarlemmermeerpolder is a polder situated in the west of the Netherlands that consists of clayey soils. The Flevopolder is a polder in the middle of the Netherlands and also consists of clayey soils. The south-eastern part of Gelderland is an area on the Pleistocene sandy soils in the east of the Netherlands. The three areas are more or less representative of arable farming conditions on clay and on sandy soils in the Netherlands.

The three areas differ in soil type. To distinguish between heavy and light soils we used a measure that is widely used among farmers in the Netherlands: the fraction of the soil that consists of particles $< 16\ \mu m$. This fraction is referred to as the fine-particle fraction. In the Haarlemmermeerpolder the soil type ranges from sandy clay to heavy clay. The fine-particle fraction in this area ranged from 19-62% (mean: 32%) on the fields studied. The soil type in the eastern part of the Flevopolder ranges also from sandy clay to heavy clay. The fine-particle fraction ranged from 34-60% (mean: 43%) on the fields studied. The soil type in the south-eastern part of Gelderland is mainly sand. The fine-particle fraction on the fields studied was 0%.
Arable farming practice also differs among the three areas, More specifically, owing to the difference in respective soil types there are differences between Gelderland and the other two areas in terms of seed bed preparation, harrowing, drilling machinery and so on. The light soils in Gelderland require different machinery than the heavier soils in the

two polders. There is also a difference between most fields in the Flevopolder and those in the Haarlemmermeerpolder. The majority of the fields studied in the Flevopolder were not cropped by individual farmers but by Rijkswaterstaat (RWS), a government department. Because the RWS fields are cropped on a larger scale, there were differences in machinery, drilling technique, etc. between the RWS fields and the fields of individual farmers. These differences did not result in significant differences in the percentages of surface seeds (see Appendix B2).

2.3 Weather conditions

The weather conditions before and during drilling influence the condition of the soil during drilling. The most important factor influencing the soil condition is precipitation (pers. comm. farmers). Precipitation and frost after seeding can influence the rate of disappearance of the surface seeds in the first few weeks after drilling (Westlake *et al.*, 1980; Jefferies *et al.*, 1973). Appendix B3 reviews the total amount of precipitation and frost occurrence in the months just before drilling (September and March) and during drilling (KNMI, 1993a & b, 1994a & b). It can be concluded that the months September 1993 and March, April, September and October 1994 were very wet months compared to other years (see Appendix B3). As a result, drilling conditions were poor in the autumn of 1993 and 1994 and drilling in the spring of 1994 was very late compared with other years.

2.4 Seed counting

The seeds were counted by placing a one square metre frame on the field and counting all the seeds that were visible from different angles, without removing clumps. This was repeated ten times at the centre of the field and where possible also ten times on the headland. The centre quadrants were situated approx. 10 m apart, and at least 25 m from the edge and the headland of the fields to prevent edge effects. The quadrants in the headlands were also situated approx. 10 m apart. Fig. 2.1 shows the positions of the quadrants in the spring and autumn of 1994. In autumn 1993 the quadrants at the centre and on the headland were on a line parallel to the drilling direction instead of on a diagonal, as shown in Fig. 2.1. In almost every field the number of surface seeds per square metre was counted on the day the field was seeded or one day later (day 0 or 1). In the spring of 1994, on 7 fields the seeds were counted on day 2 or 3.

In some cases (see Chapter 3) it proved more convenient to present the percentage of seeds drilled remaining on the soil surface instead of the absolute number of surface seeds. In these cases this percentage was calculated by dividing the absolute number of seeds per m^2 by the seed rate. Information on the actual seed rate was provided by the farmers that exploited the fields.

2.5 Methods to study separate parameters

2.5.1 Crop-related parameters

<u>Drilling technique and seed weight</u>
The influence of these two factors on the number and percentage of surface seeds was studied in the spring of 1994 on 43 fields in the Haarlemmermeerpolder and in the Flevopolder. Three seed weight classes were distinguished: light = < 0.01 g/seed, medium = 0.01-0.1 g/seed, and heavy = 0.1-1 g/seed. These three weight classes were combined with two groups of drilling techniques (standard drilling and precision drilling), resulting in six relevant combinations (Table 2.2).

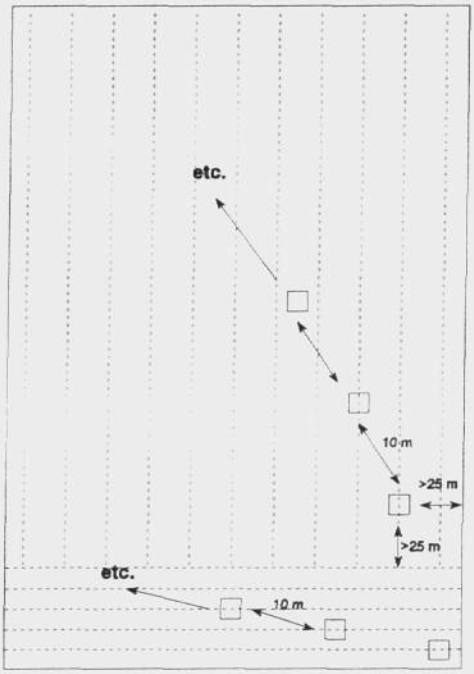


Figure 2.1. Location of quadrants in the field. □: quadrant, ··········: direction of the furrows.

Table 2.2. Crops investigated in the spring of 1994. Seed weight: light < 0.01 g, 0.01 g < medium < 0.1 g, heavy > 0.1 g.

seed weight	standard drilling	precision drilling
light	flax and alfalfa	onion (not pelleted)
medium	summer wheat	sugar beet (pelleted)
heavy	pea	maize

Within each seed weight and drilling technique class, a crop was selected that is cultivated on at least 1000 ha in the Netherlands. In one class (standard drilling, light seed) two crops were selected to investigate the effect of seed rate (see following paragraph). This resulted in 7 crops (Table 2.2). Each crop was represented with at least 6 replicas (fields), except onions, which were represented with 5 replicas.

Detailed information about the drilling and harrowing equipment (brand and type) and agricultural practice was provided by the farmers exploiting the fields. Some farmers had 'rolled' the field after drilling, using a machine with a large roller that compacted the soil and crumbled the clumps. This method was found in three crops: alfalfa, flax and pea. There was no significant difference between rolled and unrolled fields (Mann-Whitney U test: $P > 0.05$) and the fields were subsequently treated alike in this study.
The Mann-Whitney U test was used to test for any significant difference among the three weight classes in the number or percentage of surface seeds at the centre of the field. The Mann-Whitney U test was used to test the significance of the difference between the two drilling techniques, in terms of number and percentage of surface seeds at the centre of the field.

Seed rate
This factor was studied in the spring of 1994 in the Haarlemmermeerpolder and in the Flevopolder by comparing the percentage of seeds on the soil surface (field centre) for two crops that are sown at different rates: flax (mean seed rate: 2251 seeds/m^2) and alfalfa (mean seed rate: 1117 seeds/m^2). Each crop was represented by 6 fields. The difference between the two crops was tested with the Mann-Whitney U test and the correlation between the seed rate and percentage of surface seeds was tested with the Spearman rank correlation test.

2.5.2 Other parameters

Soil condition
The effect of soil condition was studied in wheat in the autumn of 1993 and 1994 and the spring of 1994 on 38 fields in the Haarlemmermeerpolder, the Flevopolder and Gelderland. Because soil type is one of the main factors influencing the soil condition during seeding, a wide range of soil types was included in the study (see Section 2.2).
We used three measures to describe the soil condition: two measures for factors governing the soil condition, soil type and moisture content, and one measure for the overall soil condition. The soil type was characterized by the fraction of fine particles. Information on this fraction was provided by the farmers exploiting the fields. For the fields cropped by RWS only an indication of the lutum content could be given. In this case the fine-particle fraction was calculated using the equation: fine-particle fraction = 1.6 x lutum content (pers. comm. A. Remmelzwaal, RWS). When only a range was given, the mean of this range was used in the calculations. The moisture content was determined by weighing soil samples and reweighing them after a period of two weeks in a kiln at 90°C. In the autumn of 1993 the moisture content was measured using two samples from the centre of the field, one near the first and one near the tenth quadrant in which seeds were counted. In the spring and autumn of 1994 three samples were taken: near the first, fifth and tenth quadrant. In the spring the moisture content was determined for wheat only. The overall soil condition was determined by weighing the 10 largest clumps in a square metre and

calculating the mean 'clump weight' of these clumps. This is an old method that was formerly used and advised by B. Kroesbergen of the Soil Treatment research group of Wageningen Agricultural University. The weight of the 10 largest clumps per m^2 was measured, as with the moisture content, near squares one and ten in 1993 and near squares one, five and ten in 1994. This resulted in 3 measures that could be related to the percentage of seeds on the soil surface at the centre and on the headland: *a.* fine-particle fraction, *b.* moisture content, and *c.* clump weight. The correlation between these measures and the percentage and number of surface seeds was tested with the Spearman rank correlation coefficient.

There may be a substantial difference in soil condition in spring and autumn. In a wheat crop, the soil condition and percentages of surface seeds in spring (7 fields) and autumn (31 fields) were compared to see if they differed significantly. The significance of these differences was tested using the Mann-Whitney U test. The soil condition and percentage of surface seeds on sand (4 fields) were compared with the soil condition and percentage of surface seeds on soils containing clay (27 fields). This difference was also tested with the Mann-Whitney U test.

Location in the field

The difference between the number of surface seeds on the headland and at the centre of the field was studied in the spring and autumn of 1994 in the Haarlemmermeerpolder, the Flevopolder and Gelderland (in autumn only). On 45 fields in 8 different crops (flax, alfalfa, spring wheat, winter wheat, pea, onion, sugar beet, and maize) the number of surface seeds on the headland and at the centre was compared. The Wilcoxon matched-pairs signed-ranks test was applied to reveal if there was a significant difference between headland and field centre.

Spillage

In the spring and autumn of 1994 in the Haarlemmermeerpolder, the Flevopolder and Gelderland (in autumn only) we assessed the number of spilled seeds per field. This survey was carried out on 53 fields. Spilled seeds are defined as seeds found in spill spots: spots where seeds are accidentally dropped instead of sown. This happens, for example, when the drilling implement is filled or parts of it lifted or lowered. Spill spots are therefore to be found on headlands and near field entrances. To gain an idea of the number of spilled seeds per field, we counted the number of spill spots and estimated the number of seeds in these spill spots on the route leading from the field entrance to the site that drilling was started, plus 100 m field margin. We extrapolated this number to the total field margin. We then calculated the number of spilled seeds per ha by dividing the number of spilled seeds on the field margin by the surface area of the field. This very rough measure is compared with the number of seeds on the soil surface on 1 ha at the centre of the field.

Post-seeding decline

In the autumn of 1993 and 1994 the disappearance of the surface seeds in the first two weeks post-seeding was investigated. In 1993, on four fields in the Flevopolder the surface-seed count was repeated 1, 2, 7 and 14 days after the first count. In 1994, on four fields in the Haarlemmermeerpolder the surface-seed count was repeated 3, 7 and 14 days after the first count. The repeat counts took place on permanent quadrants.

The weather conditions in the two weeks post-seeding differed in 1993 and 1994. In 1993 the precipitation in the two weeks post-seeding (20/10-2/11) was 9 mm (KNMI 1993a). In 1994 there was 105 mm precipitation in the two weeks post-seeding (22/10-4/11) (KNMI 1994a). In 1993 frost occurred in the first and second nights after sowing (Appendix 3). By comparing the post-seeding decline in 1993 and 1994, the possible effects of these differences in weather condition were examined. The Mann-Whitney U test was used to test for any significant difference in decline between the two years.

CHAPTER 3:
RESULTS OF THE FIELD STUDY

3.1 Introduction

In this chapter the results of the field study are presented. Most of the results are given in terms of number and percentage of surface seeds. The influences of seed rate and headland are given as percentages only, because the absolute numbers provide no extra information. Spillage is presented in absolute numbers, because it is unrelated to seed rate. The post-seeding decline in the number of surface seeds is also shown in absolute numbers because the decline in a percentage is less illustrative than the decline in a number. Besides, the initial seed rate is of no interest in this case.

3.2 Overview: seeds on the soil surface in the Netherlands

Table 3.1 shows the percentage of seeds remaining on the soil surface at the field centre for the eight different crops studied in three seasons. The number of surface seeds per square metre is also shown.
There was greater inter-crop difference in the absolute numbers of seeds on the soil surface than in the percentages (Table 3.1). Still, there was great variation among the various crops in the percentage of seeds remaining on the soil surface. Two main factors are responsible for this inter-crop difference: the drilling technique (see Section 3.3.1) and the soil condition (see Section 3.4.1). In the following sections the influence of each research parameter is described separately. The variance in the number of surface seeds between samples on one field is shown in appendix 4.

Table 3.1. Percentage and number of seeds per m^2 on the soil surface at the field centre. Mean ± SD. n: number of fields; weight: seed weight, l: light, m: medium, h: heavy; technique: drilling technique, p: precision, s: standard.

Crop	n	season	technique	weight	percentage	number
Onion	5	spring 1994	p	l	0.06 ± 0.05	0.06 ± 0.05
Sugar beet	6	spring 1994	p	m	0.17 ± 0.41	0.02 ± 0.04
Maize	6	spring 1994	p	h	0.18 ± 0.43	0.02 ± 0.04
Alfalfa	6	spring 1994	s	l	0.09 ± 0.09	1.03 ± 1.03
Flax	6	spring 1994	s	l	0.33 ± 0.22	6.98 ± 4.30
Pea	7	spring 1994	s	h	1.39 ± 2.59	1.24 ± 2.33
Spring wheat	7	spring 1994	s	m	0.52 ± 0.45	1.66 ± 1.26
Winter wheat	17	autumn 1993	s	m	4.29 ± 4.41	19.84 ± 21.47
Winter wheat	14	autumn 1994	s	m	7.49 ± 8.43	31.26 ± 34.69

3.3 Crop-related parameters

3.3.1 Drilling technique

Both the percentage and the number of surface seeds at the centre of the field were higher for standard-drilled crops (flax, alfalfa, spring wheat, pea) than for precision-drilled crops (onion, sugar beet, maize) in the spring of 1994. The difference between standard and precision drilling, with seed weight classes combined, is significant for both percentages and numbers (Mann-Whitney U test: $P < 0.01$). The percentages of surface seeds for standard-drilled crops are approximately 4 times higher than those for precision-drilled crops. The absolute numbers of surface seeds for standard-drilled crops are approximately 90 times higher than those for precision-drilled crops (Table 3.2). This large difference is caused by the overall higher seed rate for standard-drilled crops.

Table 3.2. Mean percentage and number (± SD) of surface seeds for standard- and precision-drilled crops, with seed weight classes combined. Number of fields in parentheses.

	percentage	number
Standard-drilled	0.61 ± 3.40 (26)	2.63 ± 3.40 (26)
Precision-drilled	0.14 ± 0.34 (17)	0.03 ± 0.04 (17)

3.3.2 Seed weight

The absolute number of light surface seeds was significantly higher than the number of heavy surface seeds (Mann-Whitney U test: $P < 0.05$). However, this effect disappeared completely when we compensated for seed rate by calculating the percentage of seeds remaining on the soil surface. The percentage of surface seeds appeared to be even higher for heavy seeds than for light seeds, but this difference proved to be insignificant (Table 3.3), even when data for standard and precision drilling were evaluated separately.

Table 3.3. Mean percentage and number of exposed seeds for light, medium, and heavy seeds, with drilling techniques combined. a and b denote significantly different groups, group ab is not significantly different from a or b.

	Number	Percentage
Light	2.03 a	0.13
Medium	0.84 ab	0.34
Heavy	0.63 b	0.78

3.3.3 Seed rate

As can be seen in Table 3.1, there is a difference in the percentage of surface seeds between alfalfa (mean seed rate: 1117 seeds/m^2; percentage on surface: 0.09) and flax (mean seed rate: 2251 seeds/m^2; percentage on surface: 0.33). This difference is significant (Mann-Whitney U test: $P < 0.05$). However, the seed rate per field was not significantly correlated with the percentage of surface seeds per field. This was tested for both crops combined and for each crop separately (Spearman rank correlation test: $P > 0.1$). This suggests that the significant difference in surface seeds between flax and alfalfa is not caused by the difference in seed rate. This will be discussed in Section 4.2.

3.4 Other parameters

3.4.1 Soil condition

The correlation between some measures of soil type and soil condition and the number and the percentage of seeds on the soil surface (field centre) is shown in Table 3.4 for winter wheat in 1993 and 1994 and spring wheat in 1994 combined. All three measures of soil condition showed a significant correlation with the number and percentage of surface seeds. The best correlation was found for the overall measure 'clump weight' (mean wet weight of the 10 largest clumps per m^2). This shows that the overall soil condition has more effect on the percentage of surface seeds than the condition factors soil type and moisture content. In Fig. 3.1 the number of seeds is plotted against clump weight.

The soil condition in the spring of 1994 was much better than in the autumns of 1993 and 1994. The mean clump weight in spring never exceeded 300 grams, while in the autumn it could reach over 1700 g. The clump weight was 4.4 times higher in the autumn than in the spring (Mann-Whitney U test: $P < 0.01$). As a result, the percentage and number of wheat seeds remaining on the soil surface were, respectively, 13.1 and 18.1 times higher in the autumn than in the spring (Mann-Whitney U test, both: $P < 0.01$).
In soils containing clay (fine-particle fraction > 0%) the mean clump weight was 638 g (range: 153-1640 g). This was 5.4 times higher then the clump weight in sandy soils (fine-particle fraction = 0%), which was: 116 g (range: 86-193 g). This difference was significant (Mann-Whitney U test: $P < 0.01$). However, this did not result in a significant difference in the percentages of seeds on the soil surface, which were, respectively, 7.4% (range: 0.13-43%) and 2.7% (range: 0.16-4.9%).

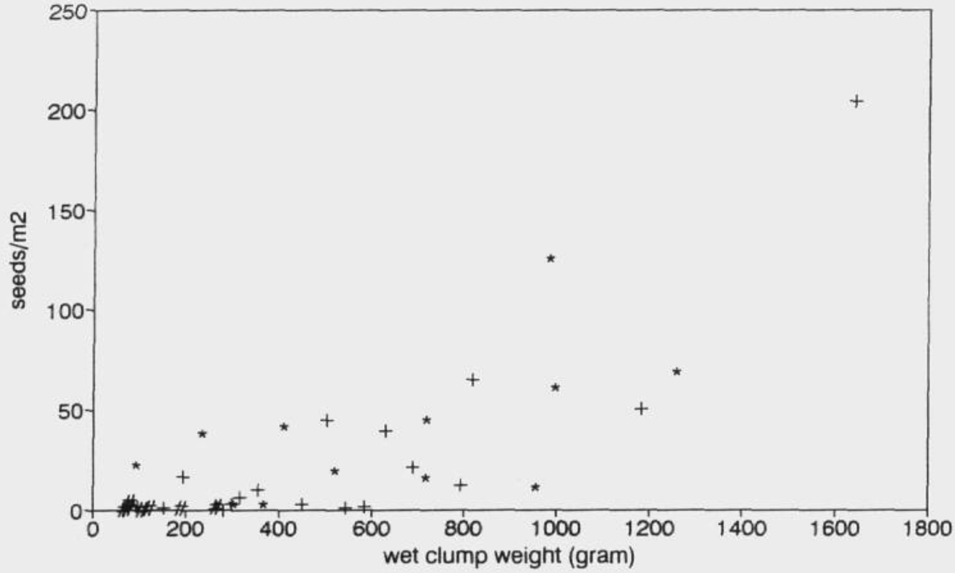


*Figure 3.1. Plot of number of wheat seeds on the soil surface against wet clump weight. +: autumn 1993, *: autumn 1994, #: spring 1994.*

*Table 3.4. Spearman rank correlation coefficients for correlation between the number and percentage of surface seeds and clump weight, fine-particle fraction and moisture content. Winter and spring wheat. n = 38. ns: not significant, *: P < 0.05, **: P < 0.01.*

	number of seeds	percentage
clump weight	0.72^{**}	0.70^{**}
fine-particle fraction	0.39^{*}	0.34^{*}
moisture content	0.54^{**}	0.52^{**}

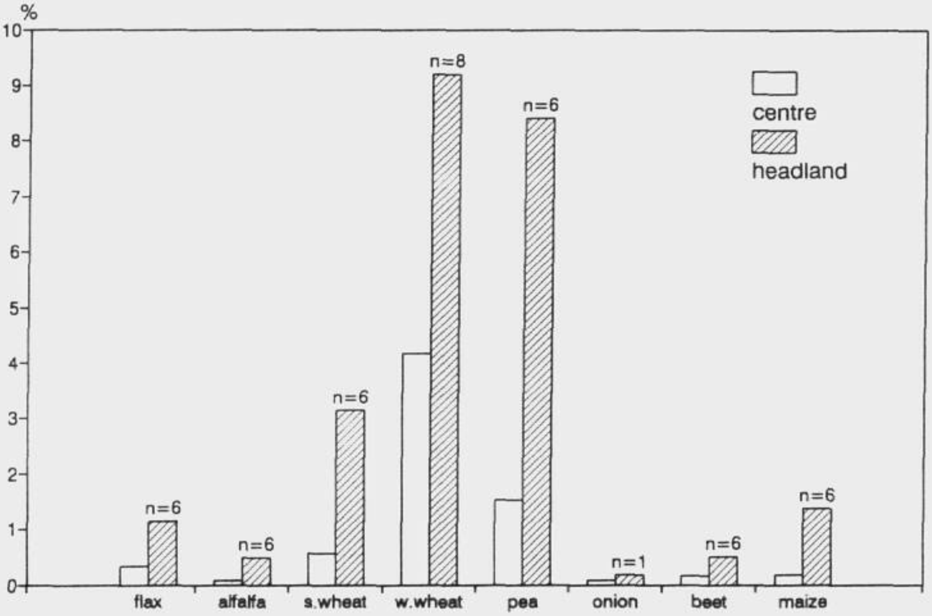


Figure 3.2. Percentage of seeds on the soil surface at the field centre and on the headland in 8 crops in 1994. n: number of fields.

3.4.2 Location in the field

Fig. 3.2 shows the percentages of surface seeds on the headland and at the field centre for 8 different crops (45 fields) in the spring and autumn of 1994. The 1993 data on winter wheat are not included in these results, because in 1993 the counts on the headland and at the field centre took place on different dates under very different conditions.

For all crops, the percentage of seeds remaining on the soil surface was higher on the headland than at the field centre. On average (geometric mean), the percentage was 3.5 times higher on the headland than at the field centre (all fields per crop combined). The difference between headland and field centre was significant (Wilcoxon matched-pairs signed-rank test: $P = < 0.01$).

3.4.3 Spillage

In wheat and maize, spillage occurred more frequently than in the other crops investigated (Table 3.5). The average number of spill spots on fields where spillage occurred was 2. Table 3.5 also shows the range of the estimated numbers of spilled seeds per ha seeded. The largest numbers of seeds spilled per ha seeded were found in flax and wheat. In some crops (sugar beet, flax, spring wheat) the number of seeds spilled per ha was of the same order of magnitude as the total number of surface seeds at the centre of the field.

Table 3.5. Percentage of fields where spillage occurred and estimated number of spilled seeds per ha field seeded (range). n: number of fields.; spill spots per field: mean number of spill spots per field.

Crop	n	surface seeds/ha (field centre)	percentage of fields	spill spots per field	spilled seeds/ha seeded
Alfalfa	6	10300	0 %	0	0
Onion	5	600	0 %	0	0
Sugar beet	6	200	35 %	1	5-200
Flax	6	69800	35 %	1.5	340-12500
Winter wheat (1994)	12	312600	40 %	1.7	40-725
Pea	7	12400	43 %	2.8	5-25
Spring wheat	7	16600	70 %	2.8	65-10000
Maize	6	200	80 %	2.4	5-130

3.4.4 Post-seeding decline

Fig. 3.3 plots the number of winter wheat seeds in the first two weeks post-seeding for four fields in 1993 and four fields in 1994. In 1993 only one field showed a decrease in the number of seeds post-seeding. In this field 54% of the seeds had disappeared after 14 days. In the other three fields the number of seeds even increased. In 1994 all four fields showed a decline of 99-100% after two weeks. The rate at which the number of seeds declined ranged from 27% to 73% per day, with a geometric mean of 40% for the four fields, assuming an exponential decrease. For all four fields the DT_{90}, which can be interpreted as the period during which the risk persist, ranged from 3.2 days to 8.5 days, with an average of 5.6 days. The DT_{50} ranged from 1.0 days to 2.6 days, with an average of 1.8 days. The difference between 1993 and 1994 in the overall decline after two weeks was significant (Mann-Whitney U test: $P < 0.05$). This difference between 1993 and 1994 may be due to the difference in weather conditions in the two weeks post-seeding in 1993 and 1994. The rain in 1994 seemed to enhance covering of the surface seeds. This is supported by the data for 1993. Most of the minor amount of rain that fell in 1993 fell on day 2. On that day the number of surface seeds decreased in every field. In Fig. 3.3a this decrease cannot be seen clearly for all fields because of the scaling of the y-axis. This decrease ranged from 19-36%, but for most fields it was compensated by an increase in the subsequent days, which cannot be explained. However, it cannot be excluded that the decline in the number of surface seeds was caused by predation by birds or mice. On the other hand, it is not very likely that in 1994, during heavy rains, there was more predation than in 1993, when it rained less. Beside the effect of the rain, the frost may have had an effect in 1993 in the fist two nights post-seeding. On day one we found more seeds than on day zero. This could have been a result of the frost, which crumbled the soil and thus exposed buried seeds.

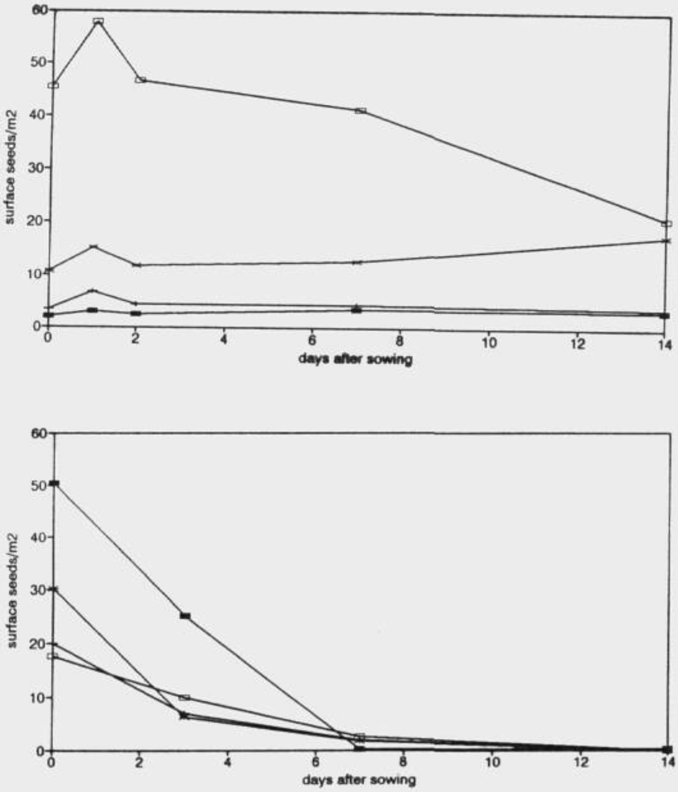


Figure 3.3. Number of wheat seeds in the first two weeks post-seeding for four fields. a: autumn 1993; b: autumn 1994.

3.5 Conclusions

In this research, the main factors affecting the percentage of surface seeds were: drilling technique, soil condition, and location in the field: headland or centre. First, standard drilling left 4 times more seeds on the soil surface than precision drilling. Second, the percentage of seeds was strongly correlated with the soil condition. The large difference in the percentage of surface seeds, by a factor 13, between spring and autumn can probably be largely explained by the unfavourable soil conditions in the autumn. Third, on the headland the percentage of surface seeds was 3.5 times higher than at the centre of the field.

The factor seed weight did not affect the percentage of surface seeds significantly. Although there was a difference in the percentage of surface seeds between alfalfa and flax, this difference was probably not due to the difference in seed rate between these crops.

Spillage occurred on 0-80% of the fields, depending on the crop. In some crops the number of seeds spilled per ha was of the same order of magnitude as the total number of surface seeds at the centre of the field.

The period during which treated seeds remained a risk (DT_{90}) was more than 14 days in 1993 and 5.6 days in 1994.

CHAPTER 4:
DISCUSSION

4.1 Introduction

In this chapter first the methods used in this field research are discussed. Second, our results are compared with those found by others with other crops in other countries. Finally, the results are discussed in a broader perspective, some consequences of the results for the risk to birds are mentioned and some recommendations for agricultural practice are given.

4.2 Methods used

Seed rate

The effect of seed rate on the percentage of seeds on the surface was examined by comparing two crops in the same seed-weight/drilling-technique class: alfalfa and flax. This method proved unsuitable for examining the influence of different seed rates. Besides differing in seed rate, these crops also differed in the drilling implement used and in the shape of the seeds. Alfalfa has small spherical seeds, while the seeds of flax are larger but very flat. It is therefore possible that the differences in the percentage of seeds on the surface between the two crops were due to factors other than seed rate. The fact that we did not find a significant correlation between seed rate and percentage of surface seeds suggests that the difference between alfalfa and flax is due at least partly to factors other than seed rate.

Spillage

The method used to calculate the number of spilled seeds (Section 2.5.2) gave only a rough estimate of the number of spilled seeds/ha. This method has one disadvantage. Spillage usually occurs on one headland only: the headland where the drilling implement is filled. Because we only counted one headland per field, it is possible that on some fields we did not see spill spots, spillage occurring on the other side of the field. This could have resulted in an underestimate of the occurrence of spillage.

4.3 Comparison with literature data

In the United Kingdom, the United States and Germany, similar studies have been carried out in which the number of seeds on the soil surface was counted. The results of these studies have been compared with our own results.

4.3.1 The Netherlands compared with other countries

We counted the number of exposed seeds in 8 different crops. Only the results for spring and winter wheat could be compared with the results of other studies, because these studies all focus on treated cereals - mostly wheat - (UK, US) and rapeseed (Germany). The number of wheat seeds on the soil surface in our study ranges from 1.7 seeds/m^2 for spring wheat to 31.3 seeds/m^2 for winter wheat. In Table 4.1 it can be seen that our results for spring wheat are lower by a factor of 2.5 than those found in the UK or the US, which ranged from 4.3 to 6.8 seeds/m^2. The results of our autumn counts, in contrast, are higher by more than a factor 5 than those found in the UK, which ranged form 0.6 to 5.8 seeds/m^2. Apparently, seeding conditions differ more between spring and autumn in the Netherlands than in the other countries. This is probably caused by the difference in agricultural practice between the Netherlands and the United Kingdom. The crop rotation scheme in the Netherlands includes sugar beet and potatoes. After these crops have been harvested, the field has to be ploughed quite deep before cereals can be sown. Ploughing in the autumn before the drilling of winter wheat often gives rise to a very cloddy soil with large clumps (MAFF, 1980a). In the UK a different rotation system is used, with cereals being sown without ploughing. This results in less cloddy soils. None of the authors mentioned in Table 4.1 mentions ploughing of the field. This could explain the difference between the number of surface seeds for winter wheat in the Netherlands and the UK. Another explanation could be that different types of drilling implement are used in the UK and the US, or that the weather conditions were different, or that the wheat was sown on different soil types.

Table 4.1. Mean number of exposed seeds/m² directly after drilling (day 0 or 1) under normal conditions, field centre or, if not available, whole field numbers (Tamis et al., 1994).

surface seeds/m²	no. of fields x samples	season and year	source	country
<u>wheat</u>				
0.6	2 x 20	autumn 1969	Jefferies *et al.*, 1973	UK
3.0	4 x 1-2	autumn 1966	Davis, 1974	UK
5.8	18 x 20	autumn 1972	,,	UK
6.8	1 x 40	spring 1975	Murphy Chem. Ltd., 1975	UK
4.0	1 x 60	autumn 1977	Westlake *et al.*, 1980	UK
2.3	12 x 10	experiment	Maze *et al.*, 1991	US
<u>cereals</u>				
4.3	14 x 20	spring 1961	Murton & Vizoso, 1963	UK
4.3	27 x 20	autumn 1961	,,	UK
4.0	- x 20	spring 1962	,,	UK
<u>rapeseed</u>				
13.9	4 x 10	? 1988	Riedel *et al.*, 1992	D
3.9	3 x 6-21	? 1987-1989	Hänisch & Gemmeke, 1992	D

4.3.2 Crop-related parameters

<u>Drilling technique</u>
We found that drilling technique is one of the major factors influencing the number of surface seeds. The percentage of surface seeds in standard-drilled crops was higher by a factor 4 than in precision-drilled crops (see Table 3.2). In the literature such a difference could not be found, because no precision-drilled crops have been studied. Maze *et al.* (1991) did find an effect of drilling technique on the number of surface seeds in wheat. He describes a higher number of surface seeds when a press drill was used than when a hoe drill or an air seeder (with or without subsequent harrowing) was used. The maximum difference was found between an "air seeder harrow packer operation" and a "press drill operation". The number of seeds left on the soil surface was 12 times higher when the press drill was used than when the air seeder with harrow packer operation was used. Davis (1974) describes a decline of 60% in the number of surface seeds when drilling is followed by harrowing.

<u>Seed weight and seed rate</u>
These parameters have not been investigated in other studies.

4.3.3 Other parameters

Soil condition

We found a correlation between all three parameters measuring different aspects of the soil condition and the number and percentage of seeds on the soil surface. The best correlation was found for the parameter 'clump weight', which is a measure of the overall soil condition. It can be concluded that the overall soil condition, which is a combination of soil type and other factors such as weather conditions and seed bed preparation, has more influence than soil type alone. This result is confirmed by the results found in the literature (see Section 1.2), especially those of Davis (1974), who found less seeds on clay with a good tilth than on a sandy loam.

Location in the field

We found a ratio between the number of surface seeds on the headland and at the field centre of 3.5. This is in agreement with the ratios found by other authors (Table 4.2).

Table 4.2. Mean number of exposed seeds/m² at the field centre and on the headland directly after drilling (Tamis et al., 1994).

field centre	headland	ratio H/FC	no. of fields	source
3.6*	11.6	3.2	1	Davis, 1974
6.8	20.8	3.1	1	Murphy Chem. Ltd., 1975
4.0	23.1	5.8	1	Westlake *et al.*, 1980

Spillage

Except for a remark by Davis (1974), who found grain spillage at the edge of the field, the occurrence of spillage is not mentioned in the literature.

Post-seeding decline

We found that in 1993, when there was only 9 mm of precipitation after seeding and frost occurred, in most fields there was no decline in the number of seeds; in 1994, when there was 105 mm of precipitation and no frost, almost 100% of the surface seeds had disappeared after two weeks. The geometric mean of the decrease per day was 40%, the mean DT_{50} was 1.8 days and the mean DT_{90} was 5.6 days in 1994. Comparing these values with the rates of decline found by others (Table 4.3), we see that in our experiment in 1994 the seeds disappeared faster than in other studies. This may be the result of the heavy rains occurring in our study. Westlake *et al.* (1980), on the other hand, found an increase after rainfall, but the amount of rain they report (10 mm) is less than that in our experiment (105 mm).

Table 4.3. Percentage decrease of exposed seeds per day and number of weeks needed to reach 90% loss of exposed seeds. Calculations carried out with a simple exponential equation. - = data not mentioned (Tamis et al., 1994).

Decrease % d^{-1}	no. of fields	no. of dates	DT_{50} (days)	DT_{90} (days)	remarks	source
14.3	24	16	4.8	16.1	spring 1961	Murton & Vizoso, 1963
16.4	27	14	4.2	14.0	autumn 1961	,,
38.3	-	6	1.8	6.3	spring 1962	,,
15.1	1	10	4.6	15.4	autumn 1969	Jefferies *et al.*, 1973
30.8	3	3	2.2	7.0	autumn 1966	Davis, 1974
32.2	1	5	2.2	7.0	spring 1975	Murphy Chemical Ltd., 1975
8.1	1	10	8.6	28.7	autumn 1977	Westlake *et al.*, 1980
15.8	1	5	4.4	14.7	1987-1989	Hänisch & Gemmeke, 1992

Jefferies *et al.* (1973) describe a pronounced effect of snow and thaw, which resulted in crumbled soil. He found that the number of exposed seeds increased from 0.9 exposed seeds/m^2 on the first day to 6.5 seeds/m^2 on the 15th day as a result of the crumbling of the soil. This is in accordance with our own observations in 1993.

4.4 General discussion of results and recommendations

In this section some of the consequences of the results of the field study for the risk of treated seeds to birds are discussed. Where possible, recommendations for risk reduction are given.

One conclusion that can be drawn from the result is that although there is no significant difference in the percentage of surface seeds for wheat sown on sand and wheat sown on soils containing clay, the percentage of exposed seeds on sand is never very high. The maximum percentage on sand is 4.9%. On soils containing clay the percentage is very variable and percentages of seeds on the surface as high as 43% can be found.

Another conclusion of the field study is that the number of seeds on the headland is higher than at the centre of the field. Some bird species, such as the Partridge, prefer to forage on the edges of the field (Benjamini, 1981; Green, 1984), while other birds like the Skylark prefer 'open land' and will most likely forage at the centre of the field (Hardman, 1974). Because of the high number of surface seeds on the headland, birds foraging on field edges will probably be exposed to a higher number of surface seeds than birds foraging at the field centre and therefore run a higher risk.

Moreover, on the headland spill spots may also occur. In the previous chapter we compared the number of seeds spilled with the number of surface seeds by 'spreading' both numbers of seeds over the whole field. This does not account for the fact that in spillage spots a lot of seeds are exposed over a very small area. According to the optimal foraging theory (see Section 5.4.2) these spillage spots might attract birds and spilled seeds might therefore be consumed more frequently than seeds scattered over a field. Spillage of seeds should therefore be prevented. This can readily be achieved, for instance by spreading canvas on the ground where the drilling implement is filled.

Based on the results of the field study, it can be concluded that the risk for birds is highest on the headlands of fields with a poor soil condition, in a standard-drilled crop. An example of such a situation in the Netherlands is the headland of winter wheat fields. Winter wheat is sown with a standard drilling implement in the autumn, when the soil is often very cloddy. In winter wheat fonofos and lindane are allowed for seed treatment, pesticides which have caused incidents with birds in the past (Section 1.1). From the point of view of bird protection, therefore, reducing the availability of winter wheat treated with these pesticides should be given high priority.
This could be accomplished by advising farmers to drill this treated winter wheat only when the soil condition, i.e. the clump weight, is such that not too many treated seeds remain on the soil surface. On the basis of Fig. 3.1 it is possible to derive a 'maximum tolerable clump weight' from the point of view of risk to birds. For example, if we assume that the maximum tolerable number of treated seeds on the soil surface is $50/m^2$, the maximum tolerable clump weight should be around 800 g. A maximum tolerable clump weight does not have to conflict with farmers' demands, as long as it is not too low. On light soils a low clump weight could result in soil compaction, which in turn would lead to lower yields.

It is not only the treated seeds on the soil surface that are available to birds and small mammals: buried seeds may also be eaten. Mice and birds can dig out sugar-beet seeds (MAFF, 1980b). Birds can ingest treated seeds by pulling out seedlings (Porter, 1977; Dunning, 1974; Green, 1980; Benjamini, 1981). There is therefore no certainty that a field with only a small number of seeds on the soil surface does pose a low risk to birds or small mammals.

From the field study it can be concluded that the period during which treated seeds remain uncovered and the attendant risk to birds persists can be very variable. Rain following drilling may cover the surface seeds, but from Westlake *et al.* (1980) the opposite can be concluded. The results of the field study cannot therefore be used to derive recommendations to shorten the period for which an avian risk persists.

CHAPTER 5:
CONSEQUENCES FOR THE RISK-ASSESSMENT SCHEME

5.1 Introduction

This chapter deals with the application of the risk-assessment scheme to granules and treated seeds (Fig. 2 on page xvi). Only the application of the part of the scheme dealing with the risk to birds if they see the treated seed as food will be discussed here. The risk of granules and treated seeds to birds if these are picked up as grit is discussed in part A of this report. In this chapter we discuss the integration in the risk-assessment scheme of the results found in Chapter 3. These results are used to calculate if the amount of pesticides exceeds the two risk levels: 0.1 LD50/m^2 and 10 LD50/m^2 (4a and 4b in Fig. 2). If the amount of pesticide used for seed treatment is lower than 0.1 LD50/m^2, a low risk is assumed; if this amount is between 0.1 and 10 LD50/m^2, an intermediate risk is assumed; and if this amount is greater than 10 LD50/m^2, a high risk is assumed. In Sections 5.3 and 5.4 these criteria are evaluated based on the data underlying the criteria and on the optimal foraging theory. Proceeding from this evaluation, some recommendations are made for an alternative criterion based on the optimal foraging theory. In Section 5.5 the consequences of the 'old' and the alternative approach are illustrated by carrying out a risk assessment using the respective methods for several different cases.

5.2 Incorporation of the results in the risk-assessment scheme

The results of chapter 3 must be incorporated in the risk-assessment scheme for treated seeds (Fig. 2). The results are necessary to estimate the factor K (amount of pesticide/m^2)

in the scheme. Such incorporation requires extrapolation of the results we found for 8 different crops to all possible crops.

This extrapolation should be based on the percentage of the seeds sown that remain on the soil surface rather than on the absolute numbers of surface seeds. By taking the percentage it is possible to compensate for the effects of seed rate. In Section 3.4 we found that the effect of seed weight on the absolute number of surface seeds was probably due to the difference in seed rate for the various weight classes. When we compensated for this effect by calculating the percentage of seeds remaining on the soil surface, this effect disappeared. So, by using percentage rather than absolute number, the same percentage can be used for crops differing in seed rate and seed weight.

The percentage of seeds remaining on the soil surface for standard-drilled crops proved to be 4 times higher than for precision-drilled crops (Section 3.3). Therefore, in the calculation of *K* a distinction should be made between standard-drilled and precision-drilled crops.

In Section 3.5 we found that soil condition has a significant effect on the percentage of surface seeds. As a result of poor soil conditions, the percentage of wheat seeds on the soil surface (field centre) in autumn was higher by a factor 13 than in spring. This difference between autumn sowing and spring sowing should be incorporated in *K*. There was no significant difference in the percentage of surface seeds between wheat sown on sand and wheat sown on soils containing clay. Therefore, on the basis of this research it is not necessary to incorporate this difference in soil type in the risk-assessment scheme. Moreover, except for the difference between spring and autumn, the effect of soil condition during drilling cannot be incorporated in the risk assessment, owing to the general character of the risk-assessment scheme. The soil condition is based on local circumstances such as soil type and seed bed preparation and on weather conditions. These parameters vary in space and time and cannot therefore be considered in the risk-assessment scheme.

The percentage of seeds on the soil surface on the headland of the field is higher by a factor 4 than at the field centre (Section 3.4.2). Because some birds forage on the edges of the field (Section 4.3) they may be exposed to more treated seeds than is estimated on the basis of data collected at field centres. We therefore recommend that risk assessment be based on data collected from the headland of the field.

Spill spots can be a source of treated seeds, but they cannot be incorporated in *K* because this is a surface-area-related measure and spill spots are not area-related.

These extrapolations lead to three different values for the percentage of seeds remaining on the soil surface, based on drilling technique and season (Table 5.1). There are no crops that are precision-drilled in autumn. The percentages for the three classes are mean values of the percentages on the headland for the crops in the respective classes. These values can be used for calculating *K*, by multiplying these percentages by the seed rates of the crops concerned.

Table 5.1. Percentage of seeds remaining on the soil surface on the headland after drilling, for three different types of crops. In parentheses: crops on which the percentage is based.

Crop	percentage
spring, precision-drilled	0.5% (onion, sugar beet, maize)
spring, standard-drilled	3.3% (flax, alfalfa, spring wheat, pea)
autumn, standard-drilled	9.2% (winter wheat)

5.3 Evaluation of the use of the EPA risk level for treated seeds

In the previous section we incorporated the information from the field study on the percentage of treated seeds on the soil surface in the risk-assessment scheme. The criteria used to decide whether the risk is high or low are based on the amount of pesticide per m^2. These criteria are derived from the risk level used by the EPA (US Environmental Protection Agency) for granules: high risk above 10 $LD50/m^2$.

The risk level of 10 $LD50/m^2$ is used by EPA as a screening step to identify those granular pesticide applications that may pose acute lethal risk to birds and thus need more in-depth risk assessment (EPA, 1992). In this section the data on which the level is based and the way it is used by the EPA is described. Based on this information, the applicability of this criterion in the risk-assessment scheme is discussed.
The risk level is based on field data. "EPA selected 10 $LD50/m^2$ as the cut-off level of concern, because field study data submitted to EPA thus far indicate that pesticide applications resulting in environmental concentrations of at least 10 $LD50/m^2$ have resulted in avian mortality" (EPA, 1992). EPA also states that occasionally there is mortality when the amount of pesticide/m^2 is less than 10 LD50, but no descriptions of these situations are given. The aforementioned field data have not been published and were therefore not available to us.
Field data were also used to confirm the potential risk indicated by estimates of $LD50/m^2$. It is not clear if these confirmatory data include the aforementioned data. The confirmatory data came from three types of sources: field studies conducted by registrants, reports of bird-kill incidents to the US Fish and Wildlife Service (and other state wildlife agencies) and several open literature studies. These field studies have some drawbacks. Only acute effects were addressed and quantity, magnitude, frequency or duration of the adverse effects were not measured. Mortality incidents involving small birds, which are often the most vulnerable, are almost never reported (Hart & Clook, 1994). EPA discerns some of these disadvantages and therefore uses the criteria only as a rough indicator of comparative risk (EPA, 1992).

The extrapolation from high risk at 10 $LD50/m^2$ to low risk at 0.1 $LD50/m^2$ is debatable. Thus far only some confirmatory data concerning pesticide applications where the amount

of pesticide per m^2 was higher than 10 LD50 (songbird) have been evaluated by EPA. These data all show avian mortality. Data concerning pesticide applications where the amount of pesticide was below 10 LD50 (songbird)/m^2 were not evaluated. It is not therefore possible to extrapolate from this data that if the amount of pesticide remains below 0.1 LD50/m^2, *the risk to birds is low, as is stated in the risk-assessment scheme.*
The use of the criterion of 10 LD50/m^2 is also debatable. This criterion is based on field data on avian mortality resulting from the use of granules. This criterion can only be used if bird forage on seeds in the same way as on grit and if granules are consumed at the same rate as treated seed. This is not very likely because they are eaten for very different reasons.

5.4 A risk measure based on the optimal foraging theory

5.4.1 Introduction

There have been several criticisms of the validity of the amount of pesticide/m^2 as a risk index (Stafford *et al.*, 1993; Fisher & Best, 1993; Fisher, 1993, Best & Fisher, 1992). Using this criterion, two different cases with the same amount of pesticide/m^2 - a high seed density with a low pesticide concentration per seed and a low seed density with a high pesticide concentration per seed - result in equal risk estimates. The amount of pesticide per surface area is potentially a good measure if birds ingest, or run a greater risk of ingesting, more pesticide as the pesticide density increases.

EPA (1992) assumed that granules are equally distributed on the field together with other equally good grit particles and that granules and other non-toxic grit particles are picked up randomly. In this case, if the pesticide used is not repellant, birds will ingest more pesticide with increasing pesticide density, because the average amount ingested would be given by:

$$\#granules/m^2 \cdot pesticide/granule \cdot \frac{\#grit\ needed}{\#grit/m^2}$$

For granules, therefore, a surface-area-related measure such as the amount of pesticide/m^2 can be used as a measure of risk.

Treated seeds, in contrast, are not found on an arable field together with other equally good food items such as untreated seeds. Therefore, if a seed-eating bird is foraging for food and it finds the treated seeds attractive, it will probably continue to feed on the seed until it is satisfied. In this case the amount of pesticide the bird ingests is related only to the amount of pesticide on one seed and not to the seed density:

$$pesticide/seed \cdot \#seeds\ needed$$

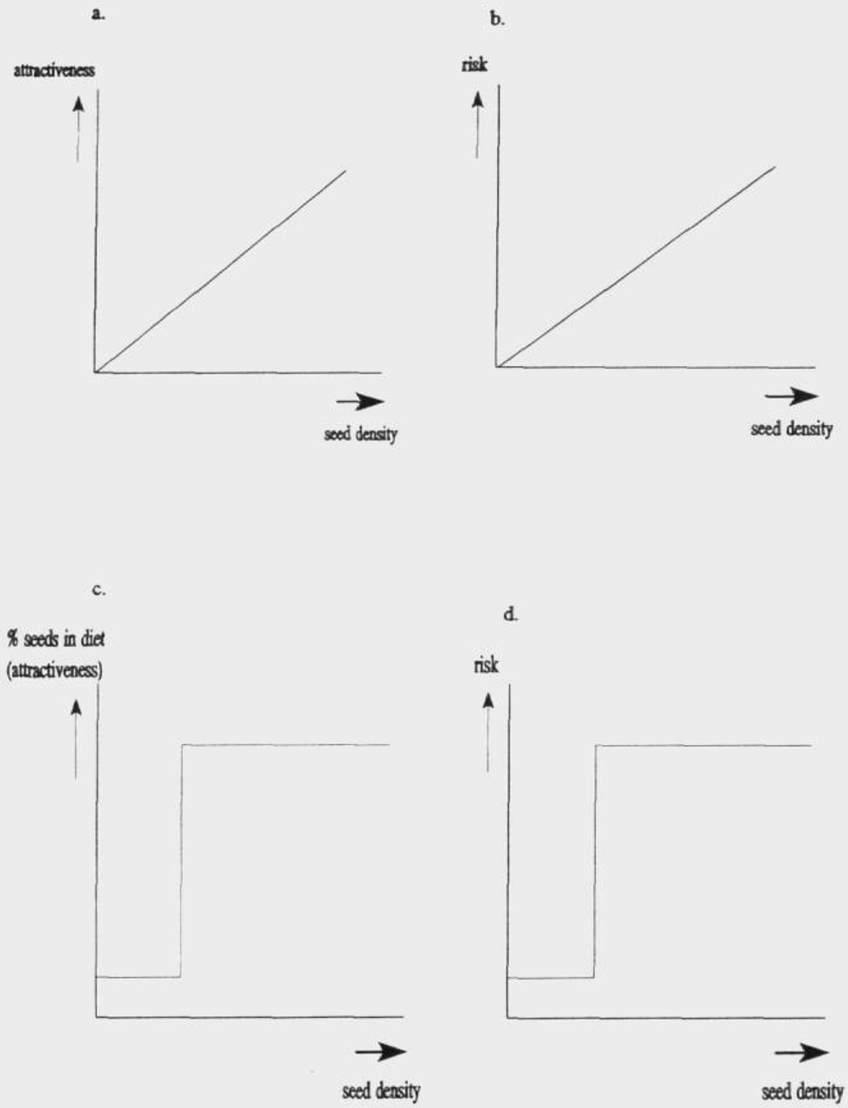


Figure 5.1. Two possible relationships between seed density and attractiveness (a and c) and between seed density and risk (b and d), supposing the relationship between attractiveness and risk is linear.

However, the attractiveness of a field with treated seeds to birds does depend on the seed density. If the field looks attractive, because of the high availability of seeds, the risk of a bird staying to eat the seeds will be higher than if the seed density and attractiveness are low. If the attractiveness is determined by the seed density and increases linearly with the avian risk (Figs. 5.1 a and b), the amount of pesticide per surface area might be a good risk measure. This measure combines the amount of pesticide an individual bird ingests with the seed density. However, this attractiveness of the treated seed depends not only on the seed density, but also on such things as profitability, taste and availability of other food. The attractiveness of food items and the effect on the foraging behaviour of birds is described by the optimal foraging theory. This theory may help to evaluate the attractiveness of treated seeds on arable fields for different seed densities.

Therefore, this section focuses on the optimal foraging theory in relation to treated seeds. First, some basic principles of the optimal foraging theory are described, as well as the factors influencing the decisions of birds to eat a specific food item. Next, the possible effects of these factors on the attractiveness of treated seeds to birds are discussed. Third, the consequences for the risk-assessment scheme are described.

5.4.2 The optimal foraging theory

The optimal foraging theory endeavours to explain on the basis of which criteria animals choose their food. The main rationale is that "animals will, as a result of evolutionary selection, tend to harvest their food efficiently" (Krebs & Davies, 1991). To harvest efficiently, animals must make foraging decisions at two levels: what to eat and where to eat. The first decision is dependent on the nutrient requirements of the animal and the energy per handling time a prey-type yields. The second decision is dependent on the energy the animal can obtain per unit of time.

The choice of a food item is influenced by a number of factors:

- relative rank of the food item depends, *inter alia*, on:
    - profitability (net food intake/handling time) of a food item (e.g. Krebs & Davies, 1991; Clark *et al.*, 1986))
    - type of food, e.g. seed, insect, leaf (e.g. Green, 1980)
    - energy/nutrient content of a food item (e.g. Reichman, 1977; Green, 1978)
    - palatability of a food item (e.g. Avery, 1989; Luttik, 1993)
    - appearance (e.g. colour, shape) of a food item (e.g. Pank, 1976; Greig-Smith, 1987b)

    These factors are not all independent of one another: for instance, the nutrient content of a food item is dependent on the food type. Most of these factors are influenced by the species concerned.
- availability and density of the food item (e.g. Green, 1978)
- availability of other food items (e.g. Murton & Vizoso, 1963)
- species

- food item recognition
- nutritional requirements of the species
- response to risk of predation.

Animals that are efficient harvesters will choose food items that will maximize their energy and nutrient uptake per unit time. This means that they will eat only the food item with the highest possible rank. However, if this food item is not abundant (density) or not easy to find (dependent on availability and species behaviour), the time spent searching for this item may be too high and other food items with a lower rank will be included in the diet.

An animal's choice of foraging patch is influenced by the following factors (Krebs & Davies, 1991):
- density of food items and availability
- rate of return of patch (= availability of food in patch x intake rate)
- average rate of return of all patches in area
- travel time among patches.

Both food item choice and patch choice can be influenced by the social behaviour of the species, e.g. knowledge of environment, or flocking. This may complicate the optimal foraging behaviour of an individual.

5.4.3 The attractiveness of treated seeds to birds

The amount of pesticide ingested by birds on arable fields picking up treated seeds is largely dependent on the share of treated seeds in their diet. It can be deduced from the previous section that if a food item is attractive, a bird will choose to eat only this food item (Fig. 5.1c). If it were to include less optimal food items, its energy and nutrient uptake per unit time would be lower. If treated seeds are attractive to birds, therefore, optimally foraging birds will prefer these seeds to other food items and a very large share of their diet will consist of treated seeds. If the risk to birds is related to the number of treated seeds ingested, this would mean that, based on attractiveness, two risk levels exist: a higher risk if the seed is attractive, and lower risk if the seed is unattractive (Fig. 5.1d). Some of the main factors determining the attractiveness of treated seeds to birds are discussed below.

Relative rank

Relative rank is largely governed by the profitability of a food item: energy intake/handling time. Seed has a relatively high calorific value compared to other food items and has a low handling time. Seed may therefore be a food item with a high rank, especially for granivores, which are adapted to eating seed and therefore probably have a very low handling time per seed. Greig-Smith (1987a) has suggested that it may be difficult to protect birds from highly profitable (treated) seeds, because many animals appear to choose food on the basis of its profitability. For omnivorous species, the relative rank may be somewhat lower, because these species also eat insects, which may have an even higher calorific value (Green, 1980). If insects are available, these species may find these at least as attractive as the seeds. However the relative rank is The relative rank of a food item does not only depend on the energy content and profitability od the food item but also on other factors such as the nutriënt content and the palatability.

Pesticide application may change the palatability and appearance of the seed and thus influence the rank of the food item (Luttik, 1993; Avery, 1989; Benjamini, 1981; Green, 1980; Rogers & Linehan, 1977; Murton & Visozo, 1963; Pank, 1976; Greig-Smith & Rowney, 1987). Most studies report a repellency effect of pesticides. Some pesticides are used deliberately as a bird repellant. However, not all pesticides used for seed treatment result in avoidance behaviour (Hart & Clook, 1994). Luttik has shown that avoidance is affected by the concentration of the pesticide on the food and that the 'No Repellent Concentration' (NoRC) is sometimes higher than the concentration used in seed treatment (Luttik, 1993). Greig-Smith (1987b) concludes on the basis of literature that birds associate visual cues such as colour and texture with unpleasant consequences rather than flavours. Pank (1976) found that artificially coloured seeds were eaten less frequently by birds than naturally coloured seeds. When the texture of the seeds was also changed, preference for such seeds was even lower.

Density, availability and availability of other food items

Density and availability may affect the attractiveness of treated seeds to birds. Green (1978) found that Skylarks ate winter grain when available, but when the grain seed density was low leaves formed the bulk of the diet. Greig-Smith (1987a) has suggested that reducing availability by increasing seed incorporation in the soil might reduce the preference of birds for these seeds.

The availability of treated seeds should always be seen in relation to the availability of other food items. It is possible that attractive alternative feeding sites cause birds to ignore sowings. Murton and Visozo (1963) saw that Pigeons ignored autumn sowings of grain when recently harvested fields were near. The reason for this is that the grain density on these fields can be very high, especially immediately after harvest (>100 grains/m^2). If, in autumn, attractive alternative food supplies exist, autumn sowings with treated seeds may pose less risk to birds than spring sowings (Hart & Clook, 1994). In accordance with Murton & Visozo, Green (1978) shows that Skylarks "spent more time foraging for seeds on ploughed land than grazing only where seed densities and sizes allowed a higher rate of energy intake from searching for seeds than from grazing. Where seed densities were low, leaves formed the greater part of the food". Gillespie (1982), on the other hand, mentions that Greenfinches prefer rape seed to available grass seeds at certain times of the year.

Patch selection is also influenced by seed density. The definition of a patch is an area in which only one type of food item is available. It is not necessary for the food items to be evenly distributed within a patch. A bird will choose to eat in a particular patch if the rate of return in that patch is higher than the average rate of return of all the patches in the area. It will stay to forage in that patch only as long as the patch's rate of return is higher than the average. For seed-eating birds, fields with high densities of exposed seeds are attractive, especially if the surrounding area does not offer high densities of profitable food. Until the density in the field decreases, the birds will remain foraging on this field and possibly attract others. Murton & Visozo (1963) deduced this on the basis of the flocking behaviour of Pigeons. Spill sites may also be considered as separate patches. Fisher & Best (1993) found that birds consumed more granules when exposed to spill sites than they did in the control situation.

Bird behaviour

As already mentioned, flocking behaviour may influence the amount of treated seeds eaten by birds. Another aspect of behaviour, also mentioned by Murton & Visozo (1963), is that Pigeons tend to remain conservative in their choice of feeding ground.

It can be concluded that treated seeds are potentially a very attractive food item, especially for seed-eating birds because seeds are a highly profitable food item. The relative rank of treated seeds might therefore be very high if they are not treated with a repellant pesticide. A high density, and especially spill spots, can enhance the attractiveness of the treated seeds. Flocking can amplify the influence of spill spots. When other high-ranking food items are available, the attractiveness of the seeds might be somewhat lower.

5.4.4 The attractiveness of treated seeds and risk assessment

In Section 5.4.1 we stated that the validity of the criterion 'amount of pesticide/m^2' is dependent on the linear relationship between the attractiveness due to seed density and the risk to birds. From the optimal foraging theory it follows that the attractiveness of the seed is determined by more factors than seed density alone. Moreover, the relationship between seed density and attractiveness is unlikely to be linear, especially at high densities. Murton *et al.* (1963) found that below 2 grains/m^2 the field was not attractive to Wood pigeons and above 150 grains/m^2 there was no additional advantage for these birds. If enough seeds are available to make a field an attractive foraging ground for birds, more seeds will not make the field more attractive. In this section an alternative risk-assessment scheme is therefore proposed which incorporates more factors determining the attractiveness of treated seeds to birds and which does not assume a linear relationship between attractiveness and avian risk.

From the point of view of the optimal foraging theory there are two possibilities: the treated seeds are either attractive or unattractive to birds of a certain species. If the treated seeds are attractive, it may plausibly be stated that a very large part of the diet of the bird in question will consist of the treated seed. In this case the risk level in the risk-assessment scheme should be based on the amount of pesticide a bird ingests if its entire diet consists of the treated seeds. High, intermediate and low risk could be based on this risk criterion, instead of only low risk, as in the present decision scheme (Fig. 2). If the attractiveness of treated seeds to individuals of a bird species is low, it may plausibly be stated that birds will only eat the seed by accident, or if no better food items are available. In this case the risk level should be the amount of pesticide a bird ingests if a minor portion of its diet consists of the treated seeds. It still appears to be impossible to base the size of this 'minor portion' on data from the literature. Therefore, an arbitrary fraction of 5% of the daily food intake is proposed here.

In Fig. 5.2 these two possibilities are incorporated in the risk-assessment scheme for treated seeds. The risk levels for attractive seeds are now:
DFIxPEC(food)/LD50 $\leq$ 0.001 -> low risk
DFIxPEC(food)/LD50 $\leq$ 1 -> intermediate risk
DFIxPEC(food)/LD50 $\geq$ 1 -> high risk,
and the risk levels for unattractive seeds:
0.05xDFIxPEC(food)/LD50 $\leq$ 0.001 -> low risk
0.05xDFIxPEC(food)/LD50 $\leq$ 1 -> intermediate risk
0.05xDFIxPEC(food)/LD50 $\geq$ 1 -> high risk.

Using this new risk-assessment scheme, two cases with the same amount of pesticide/m^2 may result in different risk estimates: a high seed density with a low pesticide concentration per seed, and a low seed density with a high pesticide concentration per seed. In the first case, the seed is probably very attractive to certain bird species and therefore the risk estimate should be based on the amount ingested if the whole diet consisted of treated seeds. In the second case, the seeds might be less attractive, so the risk should be based on a small part of the diet consisting of the seeds.
When using this new scheme, it is necessary to determine whether the seeds are attractive to individuals of the bird species considered. The main factors determining this attractiveness have been mentioned in the previous sections. A scheme can be developed to decide whether the attractiveness of a treated seed is high. Such a scheme will be discussed stepwise below.

Step 1: Is the pesticide treatment repellent to birds?
Yes . . . . > low attractiveness
No . . . . > proceed with step 2

This criterion is based on the knowledge that seeds treated with a pesticide which has repellent characteristics may be less attractive to birds (Section 5.4.3). For a seed treatment to be repellant, the concentration of the pesticide on the seeds must be higher than the NoRC (No Repellent Concentration). The NoRC for pesticides with repellent

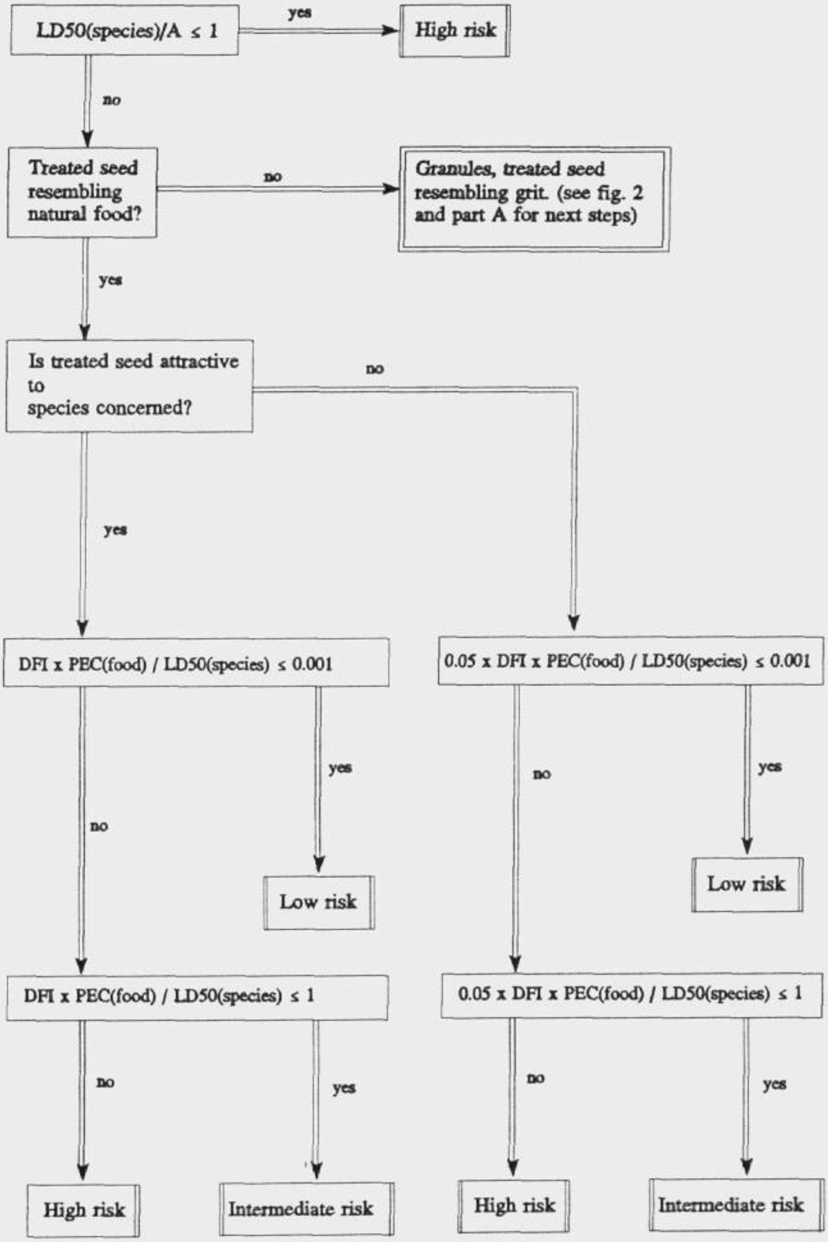


Figure 5.2. Risk-assessment scheme for treated seeds resembling food.

characteristics can be derived from Luttik (1993).

Step 2: Is the treated seed sown with a precision drill?
Yes . . . . > low attractiveness
No . . . . > proceed with step 3

This second criterion is based on the difference in availability of surface seeds between standard- and precision-drilled crops. The optimal foraging theory states that when other more attractive food sources are available, birds will not eat the treated seeds (Section 5.4.3). As seen in Chapter 4, the number of seeds on the soil surface is much lower for precision-drilled crops than for standard-drilled crops. Because standard-drilled seeds are far more readily available than precision-drilled seeds, the precision-drilled seeds will not attract birds when both standard- and precision-drilled crops are sown in the same area. Because of the rotation system used in Dutch agriculture, precision- and standard-drilled crops are often sown in the same area. In the risk-assessment scheme, therefore, it can be assumed that the seeds of precision-drilled crops are not attractive to birds. Moreover, Murton *et al.* (1963) found that grain densities below 2 grains/m_2 were too low for Wood pigeons to exploit successfully. The density of precision-drilled crops is far below this number (approx. 0.02 seeds/m^2), while the density of standard-drilled crops is greater than 2 seeds/m^2 on average.

Step 3. Does the untreated seed have a high relative rank?
No . . . . > low attractiveness
Yes . . . . > high attractiveness

The relative rank of a specific seed for the species concerned can be derived from the literature for a number of crops. Grain, for instance, probably has a high rank for birds like Pigeons, Pheasants, Skylarks and other seed-eating birds because it is frequently reported to be consumed, even when it is treated with a pesticide (Cooke, 1988; Green, 1978; Murton & Vizoso, 1963; Fuchs, 1976). For most crops, little information on avian attractiveness can be found in the literature. In this case the relative rank might be extrapolated from the energy and nutrient content of the seed, or from aviary experiments in which birds are given pairwise choices between different seeds and other food items. The size of the seed may also play an important role. Small birds probably cannot eat very large seeds. However, it may be very difficult to determine the rank of each relevant food item for birds, because this rank may depend on season, age or sex. For example, the diet of nestlings of many granivorous birds consists of insects. Macmillan (1981), for instance, found that young nestlings of the House sparrow were fed predominantly insects, but at 11 days their diet was mainly herbivorous and similar to that of the adults. This proves that the relative rank of food items may change with age.
A second, more serious problem is the step from relative rank to attractiveness. In fact this step is based on the relative rank of the seeds in relation to other food items. This is determined by the local environment. When better food items are scarce, a food item with

a low relative rank in aviary experiments might be the best food item available. Because it is not possible to incorporate local influences in a general risk-assessment scheme, this possibility must be discarded.
There has not yet been any research undertaken on the relative rank of different seeds for different bird species. Until these relative ranks of seeds for different species are quantified, it would be wise to base the risk assessment on the most vulnerable group of birds: the granivores. For granivores all seeds probably have a high rank and the answer to the question in step 3 would be *Yes*.

One factor not incorporated in the stepwise procedure described above is the presence of spill spots. Such spots may be very attractive to birds. One possible way to deal with the occurrence of these spots is to assume that, in fields where spill spots are present, the seeds cannot be unattractive on the basis of a low seed density. It is then possible to calculate the respective risks in fields with and without spillage. Based on the percentage of the fields in which spillage occurs (see Section 3.4.3), the percentage of fields in which high risk occurs can be calculated. The acceptability of the evaluated pesticide application can be based on the percentage of fields with high risk. However, before this method can be used it will be necessary to carry out a field experiment, to determine the percentage of fields in which spillage occurs. The research described in Section 2.5.2 was only a preliminary study, giving a very rough indication of spillage in the Netherlands.

Concluding, it is possible to incorporate the attractiveness of treated seeds to birds foraging on arable fields in the risk-assessment procedure. For detailed risk-assessment with this new method, for every species it is necessary to know the relative rank of the seeds compared to other food items available. This is unnecessary for deciding whether or not a pesticide application should be approved. Step 3 in the 'attractiveness scheme' should then be answered with *Yes*, because when the risk-assessment scheme is used for this goal the risk to the most vulnerable species should be normative. These are the seed-eaters.

5.5 Risk assessment, two approaches

The main differences between the 'old' and the 'new' approach are: the addition of repellency in the new method, the possibility of incorporating relative rank in the new method (this has not yet been elaborated) and the way in which seed density is incorporated. In the old method the risk is proportional to the seed density; in the new method seed density is one of the factors in deciding whether or not the seed is attractive, resulting in a *Yes* or *No* answer (Figs. 5.1 b and d).

In this section we carry out a risk assessment for two species: the Wood pigeon (*Columba palumbus*) and the Chaffinch (*Fringilla coelebs*). Ten different cases of seed treatment with two different pesticides are evaluated with both the 'old' method, using the results of

Chapter 4, and the alternative method described in Section 5.4.3. The data required to carry out the two assessments are presented in Table 5.2. The results are presented in Table 5.3 (old method) and Table 5.4 (alternative method).

Table 5.2. Data needed for the risk assessment of treated seeds for the Wood pigeon and the Chaffinch.

a. Pesticides

*Dose: Mandersloot (1993), LD50: Luttik & De Snoo (1992); *: maximum dose.*

Pesticide	dose (mg/kg seed)	$LD50_{\text{Wood pigeon}}$	$LD50_{\text{Chaffinch}}$
Lindane	wheat: 0.6	17.47	0.778
	beet: 2.0*		
Mancozeb	wheat: 1.6	3193.60	142.080
	beet: 6.3		
Isofenfos	onion: 16.0	3.91	0.193
Methiocarb	pea: 2.5	0.66	0.030
	maize: 5.0		
Fonofos	wheat: 1.0	4.99	0.222

b. Species

Body weight: Luttik & De Snoo (1992), Daily food intake based on Nagy (1987).

Species	Body weight	Daily Food Intake
Wood pigeon	499.0 g	29.6 g
Chaffinch	22.2 g	5.6 g

c. Crops

Seed rate: Luttik & De Snoo (1992), % on soil surface and number of seeds on soil surface/m^2: this research.

Crop	seed rate	% on soil surface	number on soil surface/m^2
s.wheat	15.0 g/m^2	3.3	0.50
w.wheat	15.0 g/m^2	9.2	1.38
pea	12.0 g/m^2	3.3	0.40
onion	0.7 g/m^2	0.5	0.0035
beet	0.5 g/m^2	0.5	0.0025
maize	3.3 g/m^2	0.5	0.017

Table 5.3. Results of risk assessment using the 'old' method.
pest: amount of pesticide/m^{2}; no. of $LD50_{Wood}$: Number of $LD50_{woodpigeon}/m^2$; no. of $LD50_{Chaf}$: Number of $LD50_{Chaffinch/m2}$; int.: intermediate.

Pesticide treatment		pest (μg/m2)	no. of $LD50_{Wood}$	no. of $LD50_{Chaf}$	risk Wood pigeon	risk Chaffinch
Lindane	s.wheat	0.30	$1.7 \cdot 10^{-5}$	$3.9 \cdot 10^{-4}$	low	low
	w.wheat	0.83	$4.8 \cdot 10^{-5}$	$1.1 \cdot 10^{-3}$	low	low
	beet	$5.0 \cdot 10^{-3}$	$2.9 \cdot 10^{-7}$	$6.4 \cdot 10^{-6}$	low	low
Mancozeb	s.wheat	0.79	$2.5 \cdot 10^{-7}$	$5.6 \cdot 10^{-6}$	low	low
	w.wheat	2.2	$6.9 \cdot 10^{-7}$	$1.6 \cdot 10^{-5}$	low	low
	beet	$1.6 \cdot 10^{-2}$	$5.0 \cdot 10^{-9}$	$1.1 \cdot 10^{-7}$	low	low
Isofenfos	onion	$5.6 \cdot 10^{-2}$	$1.4 \cdot 10^{-5}$	$2.9 \cdot 10^{-4}$	low	low
Methiocarb	pea	0.99	$1.5 \cdot 10^{-3}$	$3.0 \cdot 10^{-2}$	low	low
	maize	$8.3 \cdot 10^{-2}$	$1.3 \cdot 10^{-4}$	$2.8 \cdot 10^{-3}$	low	low
Fonofos	w.wheat	1.4	$2.8 \cdot 10^{-4}$	$6.3 \cdot 10^{-3}$	low	low

Table 5.4. Results of risk assessment using the alternative method.
dose: Daily dose (PECxDFI).

Pesticide treatment		dose (μg) Woodpigeon	dose (μg) Chaffinch	dose/ $LD50_{Wood}$	dose/ $LD50_{Chaf}$	risk Wood pigeon	risk Chaffinch
Lindane	wheat	18.0	3.4	$1.0 \cdot 10^{-3}$	$4.3 \cdot 10^{-3}$	low	int.
	beet	3.0	0.56	$1.7 \cdot 10^{-4}$	$7.2 \cdot 10^{-4}$	low	low
Mancozeb	wheat	47.0	9.0	$1.5 \cdot 10^{-5}$	$2.4 \cdot 10^{-5}$	low	low
	beet	9.3	1.8	$2.9 \cdot 10^{-6}$	$3.9 \cdot 10^{-6}$	low	low
Isofenfos	onion	24.0	4.5	$6.1 \cdot 10^{-3}$	$2.3 \cdot 10^{-2}$	int.	int.
Methiocarb	pea	3.7	0.7	0.11	0.47	int.	int.
	maize	7.4	1.4	$1.1 \cdot 10^{-2}$	$4.7 \cdot 10^{-2}$	int.	int.
Fonofos	wheat	30.0	5.6	$5.9 \cdot 10^{-3}$	$2.5 \cdot 10^{-2}$	int.	int.

Both methods show that the small granivore (Chaffinch) runs a higher risk than the large granivore (Wood pigeon). In both Tables 5.3 and 5.4 the two 'risk measures' number of LD50/m^2 and (PECxDFI)/LD50 are higher for the Chaffinch than for the Wood pigeon. The risks predicted with both methods are mostly 'low'. In the new method a few treatments show 'intermediate' risk. These low risks are unexpected because at least one of these pesticides, fonofos, has caused some incidents with birds (Greig-Smith, 1987a; Cook, 1988). Because the risk levels on which high and low risk are based are arbitrarily chosen in both methods, they may possibly be too low to give a realistic estimate of the risk of pesticide treatments.

Another consequence of the arbitrarily chosen risk levels is that it is impossible to compare the two methods on the basis of the predicted risk. The 'risk measures' of the two methods are expressed in different terms and are therefore also impossible to compare. However, it is possible to compare the 'relative risk' predicted with the two methods. The relative risk is the risk of a pesticide treatment relative to the risk of other treatments. These relative risks are shown in Table 5.5 for both methods.

From Table 5.5 it can be seen that there is not much difference between the results of the two methods. With both methods, the highest risk is predicted for the methiocarb and fonofos treatments. Methiocarb is often seen as a bird repellant. However, Luttik (1993) shows that the 'No Repellent concentration' is higher by a factor 30-160 than the concentration added to pea or maize. Therefore, methiocarb is not treated as a bird repellant in the new method. Both methods predict the lowest risk for all mancozeb treatments. In Table 5.2a it can be seen that methiocarb is the most poisonous and mancozeb the least poisonous pesticide tested. This indicates that in both methods the most important factor determining the risk estimate is the toxicity of the treatment.

Table 5.5. The relative risk of different pesticide treatments, calculated with the 'old' and the 'new' method. 1: highest risk, 10: lowest risk

Pesticide	crop	rel. risk Chaffinch 'old' method	rel. risk Chaffinch 'new' method
Lindane	s.wheat	5	5
	w.wheat	4	5
	beet	8	7
Mancozeb	s.wheat	9	8
	w.wheat	7	8
	beet	10	10
Isofenfos	onion	6	4
Methiocarb	pea	1	1
	maize	3	2
Fonofos	w.wheat	2	3

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APPENDIX B1: Drilling implements

This appendix lists the types and brand names of the drilling implements employed in this study. Most standard drills are used in combination with a preliminary harrow, cultivator or suchlike to prepare the seed bed, with a small harrow behind the drill to close the furrow. In this study, precision drills were never used in combinations, with a harrow being used separately before seeding and the furrows being closed by press wheels instead of harrows behind the drills.

Autumn 1993 (winter wheat)

Brand	Type	pre-drill	post-drill	no.
Amazone	standard	harrow	harrow	5
Amazone	standard	harrow	-	1
Accord	standard	harrow	harrow	7
Nordstein	standard	cultivator	harrow	2
Nodet Gougies	standard	harrow	harrow	1
Roger	standard	harrow	harrow	1

Autumn 1994 (winter wheat)

Brand	Type	pre-drill	post-drill	no.
Hassia	standard	harrow	harrow	1
Nodet Gougies	standard	harrow	harrow	1
Nodet Gougies	standard	cultivator	harrow	2
Amazone	standard	harrow	harrow	5
Nordstein	standard	cultivator	harrow	1
Stegsted	standard	har. or cult.	harrow	1
Roger	standard	cultivator	harrow	2
.....	standard	*	harrow	1

*: This drilling combination first turned the soil over before drilling and harrowing.

Spring 1994

Brand	Crop	Type	pre-drill	post-drill	no.
Roger	w	standard	harrow	harrow	1
Nodet Gougies	w	standard	harrow	harrow	2
Hassia	w	standard	harrow	-	2
Accord	w	standard	-	harrow	2
Accord	a	standard	harrow	harrow	1
Accord	a	standard	cultivator + germinator	harrow	3
Accord	a	standard	cultivator +harrow	harrow	2
Accord	a	standard	cultivator	-	
Hassia	f	standard	cultivator + germinator	harrow	5
Hassia	f	standard	cultivator + germinator	plough	1
Hassia	p	standard	-	harrow	
Accord	p	standard	harrow	plough	1
Acoord	p	standard	harrow	-	1
Accord	p	standard	harrow +germinator	harrow	1
Amazone	p	standard	harrow	harrow	1
Hassia	p	standard	germinator	harrow	1
Nodet Gougies	p	standard	harrow	harrow	1
Kongskilde	m	precision	-	-	1
Hassia	m	precision	-	-	1
Vicon Maxi Air	m	precision	-	-	2
Monozem	m	precision	-	-	2
Becker	o	precision	-	-	5
Monzentra	b	precision	-	-	2
Vicon Monopil	b	precision	-	-	1
Hassia	b	precision	-	-	3

APPENDIX B2: Flevopolder versus Haarlemmermeerpolder

This appendix considers whether, as a result of differences in agricultural practice, there is a significant difference in the number or percentage of surface seeds between the Flevopolder and the Haarlemmermeerpolder. To this end, the results for winter wheat in 1993 are compared. The results for 1994 could not be used for this comparison because in this year different crops were sampled in the two areas.
The table shows the mean number and percentage (± standard deviation) of surface grains in the Flevopolder and the Haarlemmermeerpolder. The difference between the two groups is tested with the Mann-Whitney U test.

	Flevopolder n=7	Haarlemmermeerpolder n=8	Mann-Whitney U test
Number:	24.5 ± 25.7	37.9 ± 69.5	P = 0.77
Percentage:	5.2 ± 5.3	8.0 ± 14.6	

APPENDIX B3: Weather conditions in 1993 and 1994

This appendix gives the precipitation (mm/month) in the study areas just before and during drilling. The precipitation in an area is calculated by taking the mean of the measured values at all weather stations in this area.
Weather stations in Haarlemmermeer area: Hoofddorp, Schiphol, Lijnden, Heemstede and Aalsmeer: weather stations in Flevopolder area: Lelystad, Zeewolde, Zeewolde Schillinkweg, Harderwijk and Oostvaardersdiep; weather stations in Achterhoek area: Lochem and Almen. The precipitation in each month is compared with the 'normal' values: the mean precipitation for this month in 1961-1990.

Total amount of precipitation per month (mm) in the three areas. The 'normal' values are shown in parentheses (KNMI, 1993a and b, 1994a and b). n.a.: data not yet available.

	Haarlemmermeer	Flevopolder	Achterhoek
Sept. 1993	150.3 (78.9)	148.1 (67.5)	151.0 (58.7)
Oct. 1993	84.4 (86.8)	66.7 (70.8)	89.2 (60.3)
Nov. 1993	63.4 (91.8)	42.7 (74.3)	49.8 (71.1)
Dec. 1993	145.6 (83.8)	150.8 (75.3)	180.3 (77.1)
Mar. 1994	93.0 (61.0)	120.4 (58.8)	113.7 (61.4)
Apr. 1994	83.0 (48.7)	79.4 (51.0)	72.4 (48.2)
May 1994	45.3 (51.9)	61.3 (61.1)	56.0 (62.8)
Sept. 1994	163.2 (78.9)	137.6 (67.5)	129.9 (58.7)
Oct. 1994	144.3 (86.8)	125.0 (70.8)	96.7 (60.3)
Nov. 1994	48.3 (91.8)	59.9 (74.3)	68.9 (71.1)
Dec. 1994	n.a	n.a	n.a

Night frost occurred only in the post-seeding decline experiment in 1993, with frost on 19 and 20 October.

Night frost in the drilling period occurred from 17 to 21 October and from 16 November to 2 December in 1993; and on 11, 21, 22 and 27 March, 6, 7, 9, 10, 18 and 19 April and 18 October in 1994.

Appendix B4: Variation in the number of seeds/m^2 per field

This appendix gives the mean number of seeds/m^2 per crop (= the mean of the mean number of seeds/m^2 per field for a crop) in combination with the mean of the coefficients of variation per field for 9 crops (Sokal & Rohlf, 1981).

Number of seeds/m^2 and mean coefficient of variation for crops. coef. var. = coefficient of variation, n = number of fields

Crop	season	number	coef. var.	n
Onion	spring 1994	0.06	180%	5
Sugar beet	spring 1994	0.02	50%	6
Maize	spring 1994	0.02	50%	6
Alfalfa	spring 1994	1.03	181%	6
Flax	spring 1994	6.98	97%	6
Pea	spring 1994	1.24	94%	7
Spring wheat	spring 1994	1.66	161%	7
Winter wheat	autumn 1993	19.84	89%	17
Winter wheat	autumn 1994	31.26	101%	14