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Availability of pesticide-treated seed on arable fields

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Abstract: A study of the availability of pesticide-treated seed on arable fields was performed. The research was carried out in three different areas of The Netherlands (soil types ranging between sand and heavy clay) and included the following topics: drilling techniques, soil conditions, location on the field and spillage. The results show that there is a large variation among the various crops in the percentage of seed remaining on the soil surface. This is mainly caused by differences in drilling techniques and soil conditions. The percentage of surface seeds after standard drilling is approximately four times higher than after precision drilling. The best correlation for the impact of soil conditions was found for the overall measure of clod weight. Large differences in seed densities (factor of 3.5) were found between the headland and the field centre. Spillage occured in most crops investigated, with an average of two spills per field. Based on the field data it is recommended to use in the current risk assessment for birds and mammals the following percentages of seed remaining on the soil surface: 0.5% for precision drilling, 3.3% for standard drilling in spring and 9.2% for standard drilling in autumn.
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1 INTRODUCTION

Seeds treated with pesticides may pose a risk to birds and mammals if they are seen as a source of food. Incidents involving different bird species such as gamebirds (pheasant, partridge), waterfowl (goose, duck), pigeons, starlings, house sparrows, greenfinches and crows feeding on treated seeds have been reported over the years.[1–6]

In the risk-assessment scheme for the allowance of pesticide applications in The Netherlands, the risk of treated seeds to birds and mammals is assessed on the basis of the amount of pesticide on the soil surface per square metre.[7,8] This amount can be calculated by multiplying the amount of pesticide on one seed by the number of treated seeds available per square metre of soil surface. In the first tier of the new EPPO scheme (2003, in press) for assessing the risk of seed treatments for birds and mammals and in the new technical guidance document for refining the risk assessment for birds and mammals it is assumed that the entire daily food consumption consists of treated seeds. In the case of high risk, one has to consider whether such an assumption is reasonable. For instance, Murton *et al*[9] found that grain densities below two seeds per square metre were too low for wood pigeons to exploit successfully. When using these risk-assessment schemes or guidance documents, it is therefore necessary to know the number of available seeds on the soil surface after seeding. In the United Kingdom, the USA and Germany the number of unburied seeds has been investigated under different circumstances.[1,10–19] However, these studies have focused on only two crops: cereals and rape seed. To estimate the risk to birds and mammals of treated seeds, it is necessary to have a good estimate of the number of unburied seeds for different treated crops. Therefore a field study was carried out with the aim of determining the number of seeds at the soil surface for a number of crops. This number can be affected by agricultural practice, for example by seeding depth, the quality of the seedbed preparation, etc,[17,18] so that a secondary goal of the field study was to assess the effect of drilling technique (standard and precision drilling), soil condition during drilling, location in the field (main field or headland, with a lower seeding depth[18]) and spillage. The risk assessment for birds and mammals on arable fields is discussed on the basis on the results obtained.

2 MATERIALS AND METHODS

2.1 Study area and general set-up

The research was performed in three different areas of The Netherlands: the Haarlemmermeerpolder, the Flevopolder and Gelderland. In the first area soil type ranges from sandy clay to heavy clay. The fine-particle

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fraction (particles <16 μm: silt, *cf* standard Dutch soil classification) in this area ranged from 19 to 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 to 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%.

The field studies were carried out in autumn (for 2 years) and in spring. In each field the number of seeds left on the soil surface after drilling was counted. The autumn studies (17 and 14 fields respectively) focused on winter wheat and the spring study (43 fields) on different crops (onion, sugar beet, maize, alfalfa, flax, pea and spring wheat) and drilling technique (standard and precision drilling). The effect of soil condition was studied in wheat only (spring wheat and winter wheat) and the effect of location in the field and spillage in each crop. Table 1 summarises the set-up of the study.

2.2 Seed counting and soil conditions

The seeds were counted by placing a frame (1 m^2) on the field and counting all the seeds that were visible from different angles, without removing clods. This was repeated ten times at the centre of the field and also ten times on the headland. Measurements were situated approximately 10 m apart. Seed counting in the centre of the field was situated at least 25 m from the edge of the headland to prevent edge effects. 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). Information on the seed rate used at drilling was provided by the farmers.

The number of spilled seeds per field was assessed. Spilled seeds were defined as seeds found in spill spots: spots where seeds were accidentally dropped instead of sown. This happened, for example, when the drilling implement was filled or parts of it were lifted or lowered. Spill spots were found on headlands and near field entrances. To gain an idea of the number of spilled seeds per field, the number of spill spots was counted and the number of seeds in each spill spot estimated on the route leading from the field entrance to the site where drilling started and for 100 m of field margin. This number was then extrapolated to the total field margin and expressed in terms of spilled seeds per hectare treated.

Three measures were used to describe the soil condition: the fraction of fine particles, provided by the farmers exploiting the fields; moisture content, determined by weighing two or three soil samples and re-weighing them after a period of two weeks in a kiln at 90 °C; and overall soil condition (cloddiness) determined by weighing the 10 largest clods (selected by eye) in a square metre and calculating the mean 'clod weight' of these clods (two or three replicates per field). To measure the 10 largest clods is a reliable simplification of an image analysis method suitable for field application and extension services.[20]

3 RESULTS

3.1 Number of unburied seeds in different crops

Table 2 shows the percentage and number of seeds remaining on the soil surface at the field centre after drilling in spring for the eight different crops studied (wheat in spring and autumn). There was greater inter-crop difference in the absolute numbers of seeds on the soil surface than in the percentages. Nevertheless, 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: drilling technique and soil condition.

3.2 Impact of drilling technique

In spring, 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). The difference between standard and precision drilling, with seed-weight classes combined, was significant for both percentages and numbers (Mann–Whitney U test: $P < 0.01$). The percentages of surface seeds for standard-drilled crops were approximately four times higher than those for precision-drilled crops. The absolute numbers of surface seeds for standard-drilled crops were approximately 90 times higher than those for precision-drilled crops (Table 3). This large difference was caused by the overall higher seed rate for standard-drilled crops.

3.3 Impact of soil condition

All three measures of soil condition showed a significant correlation with the number and percentage of surface wheat seeds (field centre). The best

Table 1. Number of fields investigated in the different crops and years

	Total number of fields	Autumn 1993 winter wheat	Autumn 1994 winter wheat	Spring 1994 spring wheat	Spring 1994 pea	Spring 1994 flax	Spring 1994 alfalfa	Spring 1994 onion	Spring 1994 sugar beet	Spring 1994 maize
Drilling techniques	74	17	14	7	7	6	6	5	6	6
Soil condition	38	17	14	7	—	—	—	—	—	—
Location field	45	—	8	6	6	6	6	1	6	6
Spillage	55	—	12	7	7	6	6	5	6	6

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Table 2. Percentage and number of seeds on the soil surface at the field centre

Crop	Number of fields	Season/year	Technique[a]	Seeds on soil surface (m^{-2}) (±SD) Percentage	Number
Onion	5	Spring 1994	P	0.06 (±0.05)	0.06 (±0.05)
Sugar beet	6	Spring 1994	P	0.17 (±0.41)	0.02 (±0.04)
Maize	6	Spring 1994	P	0.18 (±0.43)	0.02 (±0.04)
Alfalfa	6	Spring 1994	S	0.09 (±0.09)	1.03 (±1.03)
Flax	6	Spring 1994	S	0.33 (±0.22)	6.98 (±4.30)
Pea	7	Spring 1994	S	1.39 (±2.59)	1.24 (±2.33)
Spring wheat	7	Spring 1994	S	0.52 (±0.45)	1.66 (±1.26)
Winter wheat	17	Autumn 1993	S	4.29 (±4.41)	19.84 (±21.47)
Winter wheat	14	Autumn 1994	S	7.49 (±8.43)	31.26 (±34.69)

[a] P: precision-drilling technique; S: standard-drilling technique.

Table 3. The impact of drilling technique on the amount of surface seeds after sowing: mean percentage and number (±SD) of surface seeds at the centre of the field

Technique	Percentage m^{-2} (±SD)	Number of seeds m^{-2} (±SD)
Standard-drilled	0.61 (±3.40)	2.63 (±3.40)
Precision-drilled	0.14 (±0.34)	0.03 (±0.04)

correlation was found for the overall measure 'clod weight': mean wet weight of the 10 largest clods per square metre (Spearman rank correlation coefficients of 0.7 with $P < 0.01$). With an increasing wet clod weight, the numbers of seeds on the soil surface also increased. 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.

3.4 Impact of location in the field

Figure 1 shows the percentages of surface seeds on the headland and at the field centre for eight different crops (45 fields) in the spring and autumn. 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: $P < 0.01$).

3.5 Spillage

In alfalfa and onion crops no spill plots were found. In spring wheat and maize, spillage occurred on more fields than in the other crops investigated (Table 4). The average number of spill spots on fields where spillage occurred was two. Table 4 also shows the range of the estimated numbers of spilled seeds per hectare 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 hectare was of the same order of magnitude as the total number of surface seeds at the centre of the field (see Table 2: number of seeds per square metre).

4 DISCUSSION

4.1 Number of exposed wheat seeds

The results of our seed counts in wheat can be compared with the results of studies of the UK and

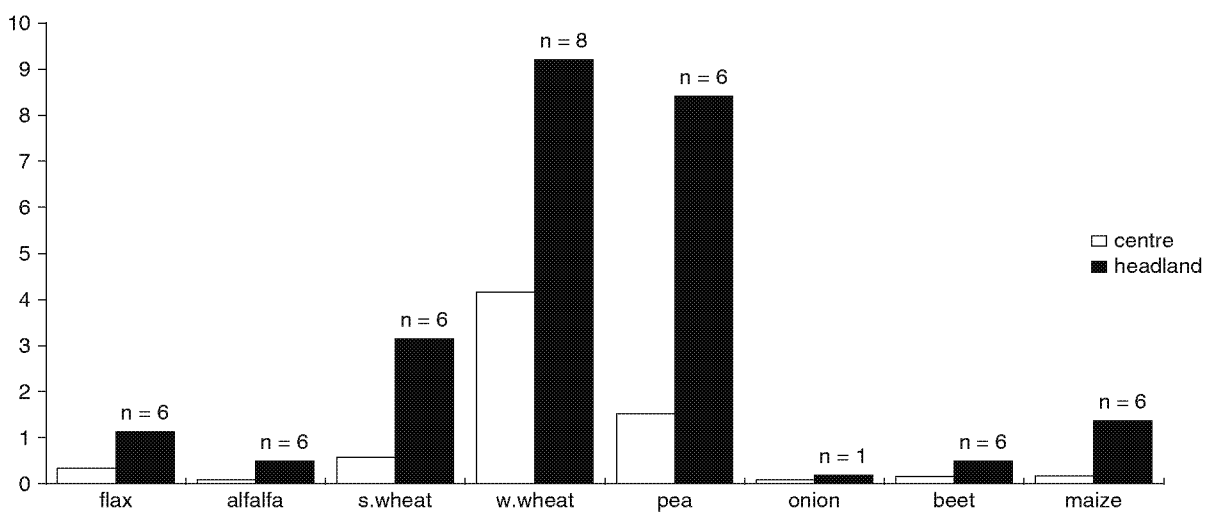

Figure 1. Percentage of seeds on the soil surface at the field centre and on the headland in eight crops in spring and autumn. n = number of fields.

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Table 4. Percentage of fields where spillage occurred, number (*n*) of fields included in research, mean number of spill spots per field and number of spilled seeds per hectare (range)

Crop	*n*	Percentage of fields	Spill spots per field	Spilled seeds ha^{-1}
Alfalfa	6	0	0	0
Onion	5	0	0	0
Sugar beet	6	35	1	5–200
Flax	6	35	1.5	340–12 500
Winter wheat (1994)	12	40	1.7	40–725
Pea	7	43	2.8	5–25
Spring wheat	7	70	2.8	65–10 000
Maize	6	80	2.4	5–130

the USA gathered by Tamis *et al.*[21] In our study the number of wheat seeds on the soil surface ranges from 1.7 seeds m^{-2} for spring wheat to 31.3 seeds m^{-2} for winter wheat. The results of our autumn counts are higher by a factor of more than five than those found in the UK, which ranged from 0.6 to 5.8 seeds m^{-2}. In contrast, our results for spring wheat are lower by a factor of 2.5 than those found in the UK or the USA, which ranged from 4.3 to 6.8 seeds m^{-2}.[21] Apparently, seeding conditions differ more between spring and autumn in The Netherlands than in the other countries. This could be caused by the difference in agricultural practice between The Netherlands and the UK. 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 deeply in autumn before cereals can be sown. This often gives rise to a very cloddy soil with large clods.[22] In the UK in general a different rotation system is used. Cereals are sown in autumn without ploughing, resulting in less cloddy soils. Other possible explanations could be that different types of drilling implements are used in the UK and the USA, that the weather conditions were different, or that the wheat was sown on different soil types.

4.2 Impact of soil condition

The percentage of seeds on the soil surface 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. The best correlation was found for the parameter 'clod weight', which can be used as a measure of the overall soil condition.[20] 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 results found in the literature. Davis[10] 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, and on clay with a good tilth even lower numbers were found. Davis found the lowest number of surface seeds on a peaty soil under good weather conditions. Murphy Chemical Ltd[12] reported that four to five times more seed remains on the soil surface on the cloddy part of a field than on the well-tilled part of the same field. Hänisch and Gemmeke[14] reported a higher number of rape seeds on the soil surface in heavy cloddy soils than in light soils. Finally Pascual *et al*[18] also found that seed incorporation into the soil was affected by seedbed conditions: percentage and density of exposed seeds were significantly higher in the rough seedbeds than in the fine seedbeds. Although in our study no significant difference was found in the percentage of surface seeds for wheat sown on sandy and clay soils, 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 as much as 43% of seeds can be found on the surface.

4.3 Impact of location in the field

In our study, on the headland the percentage of surface seeds was 3.5 times higher than at the centre of the field. The headland is defined as the place where the drilling implement is turned when seeding. After the centre has been seeded, the headland itself is seeded crosswise. As a result of this procedure, during drilling the soil condition on the headland is often worse than at the centre of the field, seeding depth of the seeds is lower[18] and a small section of the headland, the strip where headland drilling overlaps centre drilling, is drilled twice. Authors in UK and Germany also report a higher number of non-incorporated cereal seeds on the headland of the field than at the centre.[14,18,21]

Some bird species, such as the partridge, prefer to forage on the edges of the field,[23,24] while other birds like the skylark prefer 'open land' and are most likely to forage at the centre of the field. 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.

4.4 Spillage

Spillage occurred on six of the eight crops. In some crops the number of seeds spilled per hectare was of the same order of magnitude as the total number of surface seeds at the centre of the field. The method used to calculate the number of spilled seeds gave only an estimate of the number of spilled seeds per hectare. This method has one disadvantage. Spillage usually occurs on one headland only: the headland where the drilling implement is filled or cleaned. Because we only counted one headland per field, it is possible that on some fields we did not see spill spots although spillage occurred on the other side of the field. This could have resulted in an underestimate of the occurrence of spillage. Except for a remark by Davis,[10] who found grain spillage at the edge of the field, the occurrence of spillage is not mentioned in the literature.

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In spillage spots a lot of seeds are exposed over a very small area. According to the optimal foraging theory, these spillage spots might attract birds and mammals 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.

4.5 Incorporation of the results into the risk-assessment scheme

In this research, the main factors affecting the percentage of surface seeds were soil condition, drilling technique and location in the field: headland or centre. On the basis of the results of the field study, it can be concluded that the risk for birds and mammals in a standard-drilled crop is highest on the headlands of fields with a poor soil condition.

Soil conditions are the result of parameters varying in space and time, such as soil type, seed-bed preparation and weather conditions, and are normally not considered in a general risk-assessment scheme. In this study no significant difference was found in the percentage of surface seeds of wheat sown on sand and wheat sown on soils containing clay. Therefore, it may be not necessary to incorporate differences in soil type in the risk-assessment scheme.

Variation in soil condition resulted in large differences between autumn sowings and spring sowings of wheat, and it is therefore recommended that differences between autumn and spring sowings are accounted for in the risk-assessment scheme.

Large differences were found in the percentages of seeds remaining at the surface between standard-drilled and precision-drilled crops, and it is recommended that these differences in should be accounted for in risk assessment.

The percentage of seeds on the soil surface on the headland of the field proved to be higher than at the field centre. Because some birds forage on the edges of the field, they may be exposed to more treated seeds than is estimated on the basis of data collected at field centres. Therefore it is recommended that the 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 accounted for because both the number of spill spots and the number of spilled seeds are not related to the size of the field.

These recommendations lead to three different values for the percentage of seeds remaining on the soil surface (headland data), based on drilling technique and season: 0.5% for precision-drilled crops (onion, sugar beet, maize) in spring, 3.3% for standard-drilled crops in spring (flax, alfalfa, spring wheat, pea) and 9.2% for standard-drilled crops in autumn (winter wheat). There are no crops that are precision drilled in autumn. These percentages can be used to improve the risk assessment of pesticide-treated seeds for birds and mammals.

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