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Movement and conversion of aldicarb and its oxidation products in potato fields

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Abstract

In Spring, the insecticide and nematicide aldicarb in the granular formulation Temik 10G (supplied by Union Carbide) was broadcast on three potato fields and incorporated by rotary cultivation. Ridges were formed by repeated runs with ridging implements. The soil was sampled in layers of 0.1 m up to 0.8 m depth three to four times during the growing season. Aldicarb itself was almost completely converted on a humic sand soil and two loam soils within one month. During the growing season, its sulphoxide and sulphone, which are toxic and are formed by oxidation, were retained mainly in the top 0.3 m of all three soils. Relatively high concentrations were measured only in the top 0.2 m, indicating limited redistribution by leaching.

Low to very low contents were found up to 0.8 m depth especially on one of the loam soils where the highest total rainfall was measured from May to October (328 mm). In a humic sand soil, leaching in the furrow was deepter than below the ridge. At the end of the growing season, the sulphoxide plus sulphone corresponded to a mass fraction of 5.7 to 6.7% of the dosage in the two loam soils and to 17% in the humic sand soil. These residues were mainly concentrated in the centre of the ridges.

Additional keywords: concentration patterns, soil types, rainfall, effect soil surface, residues.

Introduction

In recent years, there has been an increasing interest in non-volatile pesticides to control harmful nematodes in potato growing in the Netherlands. One of these pesticides is the oxime-carbamate aldicarb, 2-methyl-2-(methylthio)propional-dehyde *0*-methylcarbamoyloxime, which is applied as granules (Temik 10G) at planting time at a dose of active ingredient of 3 kg/ha. In soil, aldicarb is rapidly oxidized to its sulphoxide, which in turn is oxidized more slowly to aldicarb sulphone (Smelt et al., 1978a, b, c; Bromilow et al., 1980).

Aldicarb is assumed to act on nematodes mainly in the soil solution by interfering with locomotion and feeding of the hatched larvae, causing death by starvation or poisoning of part of the pupulation (Hague and Pain, 1970, 1973). The development of larvae in the roots may be further retarded or prevented by the substance or its oxidation products (Steele and Hodges, 1975; Steele, 1976). The nematicidal compounds should be present around the roots to protect them against nematodes. A thorough distribution of the nematicide in the rooting zone is essential.

Deep (15 cm) and homogeneous incorporation of the nematicide granules generally gave more reliable increases in yield and better inhibition of increase in cyst-nematodes than shallower incorporation (Moss et al., 1976) or band applications in the seed furrow (Whitehead et al., 1975). The desired depth of incorporation and equal distribution of the granules may be best obtained by rotary cultivation with L-bladed rotavators rather than with other implements (Bromilow and Lord, 1979, Whitehead et al., 1975, Smelt et al., 1976). However, deep incorporation by rotavators is costly and the seedbed may become too loose. On sandy soils, the risk for wind erosion may increase.

The redistribution and rate of conversion of a pesticide in soils in the field may be simulated with computer models. Comparisons between simulated concentration patterns and patterns measured in columns of fallow soil have given encouraging results for oxamyl (Leistra et al., 1980) and for aldicarb sulphoxide and sulphone (Bromilow and Leistra, 1980). The behaviour of aldicarb and its oxidation products in grassed soil columns in the field has been studied. (J. H. Smelt, C. J. Schut and M. Leistra, submitted). Computer simulations for that situation gave roughly the same picture for movement and conversion as the columns did (M. Leistra and J. H. Smelt, submitted).

The soil system in a ridged potato field is much more complex than in fallow or grassed soil columns. Tillage with ridging implements will drastically change the distribution of the broadcast granules. In such fields, infiltration of water after rain or sprinkler-irrigation may be uneven (Saffigna et al., 1976). This would induce deep leaching of the pesticide in some places, whereas little movement would occur elsewhere. The conversion rates of aldicarb and its oxidation products in a potato field could be different from those measured in studies with grassed soil columns and in incubation experiments under controlled conditions. These rates are relevant for assessment of the period with adequate nematicidal activity. They also govern the levels of the residues at the end of the growing season; these residues may be leached to the subsoil in the subsequent winter. This study was designed to trace possible complications in the movement and conversion of aldicarb and its oxidation products in ridged potato fields.

Materials and methods

Site of field trials and manner of application. In spring 1979, aldicarb was applied as Temik 10G granules on plots of 500 m^2 in potato fields on three fields in the Netherlands, near Westmaas (South Holland), Wierum (Friesland) and Vortum-Mullem (North Brabant). Soil characteristics of the top soil to 0.3 m depth and of layers down to 1 m depth are given in Table 1. The fields were fertilized as normal for seed potatoes (Wierum) and ware potatoes (the ofther fields).

The two loam soils were prepared by one tillage with a power take-off harrow (Lely Roterra). The humic sand soil near Vortum-Mullem was plowed a few days before treatment. The granules were broadcast over the plots with drills (2 or 3 m; 12.5 cm apart) with a studded-roller feed system. A round bar (diameter 4 cm) mounted under the feed mechanisms, spread the free-falling granules. At the time of application, there was very little wind, which promoted uniform distribution of granules. The drills were adjusted to release about 50 kg of Temik granules per

Table 1. Characteristics of the soils at the trial sites.

Origin	Textural class	Soil classification	Layer (m)	Org. matter (%)	Clay (<2 μm) (%)	Silt (2-50 μm) (%)	$CaCO_3$ (%)	pH-KCl	Phosphate P-Al (mg/kg)	Potassium K-HCl (mg/kg)	Magnesium (mg/kg)	Nitrogen water extractable (mg/kg)	Nitrogen total (mg/kg)
West-maas	Loam	Typic fluvaquent	0-0.3	2.1	20	20	8.2	7.4	196	149	56	40	1300
			0.3-0.6	1.7	18	44	12.3	7.6					
			0.6-1.0	1.0	11	30	11.7	7.8					
Wierum	Loam	Typic fluvaquent	0-0.3	2.2	19	45	2.4	7.1	223	141	84	30	1300
			0.3-0.6	0.9	21	48	2.5	7.2					
			0.6-1.0	0.8	19	49	9.5	7.4					
Vortum-Mullem	Humic sand	Typic haplaquod	0-0.3	2.4	4	6	0.1	4.3	384	83	29	30	1300
			0.3-0.4	1.3	4	9		4.6					
			0.4-0.6	0.3	2	3		4.8					

Tabel 1. Grondkarakteristieken van de proefvelden.

hectare. The real dose was calculated from the remaining mass of granules after drilling. For the fields at Westmaas, Wierum and Vortum-Mullem, it was found to be 4.4,5.5 and 5.3 kg of active ingredient per hectare, respectively, which is higer than the recommended dose of 3 kg per ha for nematode control in potatoes. The treatments were on 15 May, 10 May and 24 April, respectively.

On the fields at Wierum and Vortum-Mullem, the granules were incorporated with a rotovator (1.5 m width) with L-shaped blades, mounted in the three-point hitch of a tractor. The machine was adjusted to till a layer of 0.12 m thickness, which depth was indeed reached. The loam soil at Wierum was still rather wet, so that the seedbed was cloddy with an uneven tilth of 0.17 to sometimes 0.20 m thickness. On the sand soil at Vortum-Mullem, the granules were uniformly incorporated in the tilth of 0.17 m. On the field at Westmaas, only a top layer of 0.06 to 0.08 m was suitable for rotary cultivating. On this field, granules were incorporated in that top layer with a rototiller (0.75 m width) with L-shaped blades mounted on a twowheeled unit.

Planting and management. Within two days after treatment, potatoes were planted on the three plots in rows 0.75 m apart. At Westmaas they were planted with a potato planter mounted in the three-point hitch of a tractor. The top of the tubers were placed level with the soil surface and subsequently covered with about 8 cm of soil by disc-ridgers, which drew the soil beside the seed furrow to a maximum depth of 5 cm. The ridges were further built up by two runs with a rotovator with tines and attached ridging shares: the last tillage was on 8 June. Mean height of the ridges was 20 cm, measured from top of the ridges to the middle of the furrow. For further weed control, metribuzin (as Sencor) was applied in mid-June at 0.7 kg a.i./ha.

At the field near Wierum, shallow trenches were drawn in which tubers were planted by hand. Subsequently small ridges were formed with a rotovator with one ridging share behind mounted on a two wheeled unit. On 11 June, ridges were built up with the same equipment. The loam soil was then rather wet, so the soil was not crumbled well by the rotovator and did not draw well along the ridging body. This resulted in shallow ridges 18-21 cm high with a flat top 25 cm wide on average. The top was concave with the centre of the ridge 2 to 5 cm lower than the edges.

At Vortum-Mullem, ridges were built up in one operation with a unit mounted with three ridging shares. Ridges were rather sharp at the top and were 22 cm high. Tubers were planted in the ridges with a dibber about 10 cm below the top of the ridge. No further cultivations were carried out. Weed was controlled by spraying dinoseb-acetate at 1.5 kg a.i./ha and monolinuron at 0.39 kg a.i./ha (as the mixture Ivorin).

At Westmaas and Wierum, *Phytophthora infestans* was controlled conventionally with fungicides without riding the tractor across the trial plots.

Rainfall was measured with rain-gauges. At Westmaas, rainfall was read daily. At the two other sites, rain-gauges were read periodically, in general after periods with distinct rainfall. The cumulative rainfall measured at the three sites is given in Fig. 1.

Sampling. The soil profile at each site was sampled at three points in the cross-section of the ridge: on top of the ridge, in the middle of the furrow and on the slope of the ridge half way between. On eacht sampling date, a field was sampled at 30

Fig. 1. Cumulative rainfall at the experimental sites.
Blocs indicate average monthly rainfall in the Netherlands in 1979 and monthly rainfall averaged over many years (KNMI, 1979).

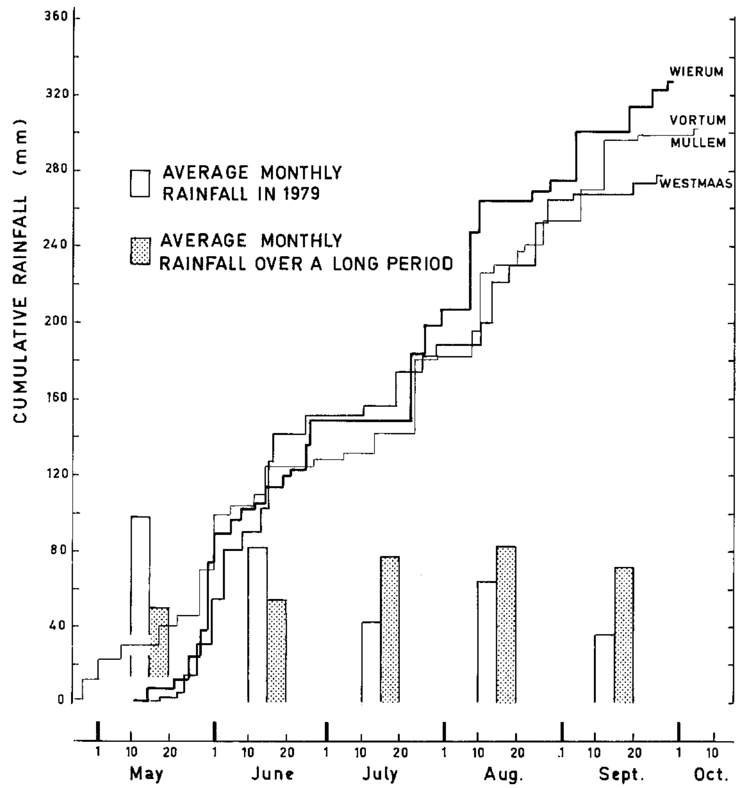

Fig. 1. Cumulatieve neerslag op de proefvelden.
Staven geven de gemiddelde maandelijkse neerslag in Nederland in 1979 weer en de maandelijkse neerslag over een veeljarige periode (KNMI, 1979).

sites, systematically distributed over two transects (15 per line) oblique to the direction of the ridges and marked with sticks.

At Vortum-Mullem and Westmaas, 20 sites were sampled on each line on the first sampling date. The duplicate samples collected in this way were analysed separately. On average, the data from the two analyses differed less than 10% from their mean. For the layers below 0.3 m, with low contents, the duplicates differed by up to 50%.

The first 0.40 m of the profile was sampled with a split-tube auger with a cutting ring of inner diameter 50 mm, which was hammered into the soil. The diameter of the auger tube was 1 mm larger to prevent compression of the core. After the auger had been dug out or pulled out, one half of the tube was removed and the soil core cut into 4 sections 0.1 m thick. For the layer between 0.4 and 0.8 m, an open-faced auger with an inner diameter of 25 mm was used and samples were taken from the enlarged and cleaned hole left by the split-tube auger. Each time, the open-faced auger was pushed 0.10 m into the soil and only the last 0.05 m in the auger was taken as sample for the corresponding layer. Care was taken to avoid contamination of deeper samples with soil from the top layers. By this means, we collected samples from deeper layers with contents below the detection limit, although contents in the top layers were 10000 times the detection limit.

Cores from each layer at the 30 sampling sites were combined, partially dried in tanks out of doors if necessary and thoroughly mixed in a mechanical mixer. Subsamples were taken for chemical analysis and moisture contents were determined by drying overnight at 105 °C.

Chemical analyses. Subsamples (100 g of moist soil) were extracted with 300 ml of acetone in 800-ml glass jars for 2 h on a reciprocating shaker. The three toxic compounds in the extracts, aldicarb, its sulphoxide and its sulphone were separated on silica gel columns. Aldicarb and its sulphoxide were oxidezed to sulphone with 3-chloroperbenzoic acid. Concentrations of sulphone in the extract were measured with a Tracor 550 gas-chromatograph provided with a Tracor 702 thermionic nitrogen and phosphorus detector. Technical details of the liquid and gas chromatography were given by Smelt et al. (1977) and by J. H. Smelt, C. J. Schut and M. Leistra (submitted).

Recoveries of analytical grade compounds added in aqueous solutions to 100 g of soil from the three fields were found to be 85%, 89% and 96% for aldicarb, sulphoxide and sulphone, respectively. All contents were corrected for recovery. Limit of detection of the procedure of the three compounds in dry soil for the whole period of analysis was 2 μg kg^{-1} (substance content 0.01 μmol kg^{-1}).

Results and conclusions

Distribution of the aldicarb residue in soil. The contents of aldicarb, its sulphoxide, and its sulphone in the soil profiles are given in Fig. 2, 3 and 4. In the deeper layers and in other layers with very low contents, the components of the residue were not measured separately, but as total toxic residue. The soil profile beneath the slope of the ridges was only sampled to 0.40 m depth. The level of the soil surface at the three sampling points in the ridge-furrow system of course differed, as imitated in the figures.

The soil was first sampled in each field after the last tillage. The distribution of aldicarb and its oxidation products on the first sampling dates was greatly affected by ridging. Much of the compound was displaced to the ridge areas, leaving a little in a thin layer in the furrow (Fig. 2, 3 and 4). Highest contents were probably where most of the potato roots were developing. During the whole growing season, the amounts of the nematicidal substances were highest in the ridge, whereas the amounts in the furrow were low.

During the growing season, there was a gradual decrease in aldicarb sulphoxide and sulphone in the soils. During the first few months, there was little leaching from the top 0.1 m of the ridge and slope despite the fairly high rainfall. Movement of substantial amounts downward below the incorporation zone seemed to be limited to about 0.1 m in the growing season.

On the first sampling dates, small amounts of aldicarb sulphoxide and sulphone were already detected down to 0.8 m in the two loam soils at Westmaas and Wierum

(Fig. 2 and 3). Leaching was most distinct at Wierum where rainfall was highest (120 mm, Fig. 1) during the 41 days between treatment and first sampling. The humic sand soil at Vortum-Mullem was only sampled down to 0.4 m on the first date. The very sharp decrease in contents below 0.3 m (Fig. 4) indicated that leaching of residues to layers below 0.4 m would be very small. During the 28 days between treatment and first sampling, rainfall on this field (40 mm) was close to average.

In mid-summer, the contents of aldicarb sulphoxide and sulphone in the deeper layers of the Westmaas field remained roughly the same (Fig. 2). Some further penetration may have been offset by conversion and by uptake by roots. Penetration below the ridge and furrow was roughly the same. Contents of sulphoxide plus sulphone in the deeper layers of the Wierum field, with the highest amount of rainfall in and around July, increased somewhat (Fig 3). Penetration was somewhat greater below the ridges, perhaps because of their imperfect shape. In the Vortum-Mullem field, the compounds penetrated somewhat further in the soil below the furrow, whereas contents below the ridge remained extremely low (Fig. 4).

In the last period of the growing season, the contents at almost any depth had further decreased. Rainfall was less than average and further movement of the compounds would have been small. Decrease in the residues seemed to be comparatively slow in the deeper layers of the furrow areas of the Vortum-Mullem field (Fig. 4).

Composition of the residue. Low to very low contents of aldicarb were found on the first sampling dates. A great deal of the aldicarb had been oxidized to aldicarb sulphoxide, which was in turn partly oxidized to aldicarb sulphone. On the first sampling dates, the substance ratio of sulphoxide to sulphone in the top 0.3 m was on average 2.8 at Westmaas, 2.2 at Wierum and 4.5 at Vortum-Mullem. The ratio for the two loam soils at Westmaas and Wierum gradually decreased with time to about 0.6 at the second sampling and to about 0.4 at the last sampling. The ratio in the humic sand soil at Vortum-Mullem field was on average 1.0, 0.32, and 0.2 at the second, third and last sampling, respectively. Lower conversion rates for sulphone in a peaty sand soil than for sulphoxide were also found by Smelt et al. (1978 a, b, c).

At Wierum, the ratio in the deeper layers was distinctly higher than in top soil. This was already found at the first sampling but was most pronounced at the second sampling. The large rainfall, 120 mm between first and second sampling date, had leached the residues, mainly sulphoxide, to the deeper layers. The conversion of sulphoxide in these layers may have been slower than in the top soil, as can be seen in higher ratios. Low conversion rates for sulphoxide in a silty layer (70-90 cm depth) of a clay loam soil were found by incubation at 15 °C (Smelt et al., 1978 b). In spring and summer soil temperatures at greater depths are generally lower than in the upper layers so that conversion rates are lower.

Amounts remaining in soil. The total amount of toxic residue per unit of the projected surface area was calculated for each of the regions: ridge, slope and furrow. The amount in the upper 0.4 m was calculated from measured contents, masses of dry soil in the combined samples per section, and the surface area sampled with the split-tube auger. The corresponding amounts in the 0.4 to 0.8 m sections were calculated from measured contents, bulk density and thickness of the sampled

Fig. 2. Contents of aldicarb and its conversion products sulphoxide and sulphone in the soil profile of the field near Westmaas.

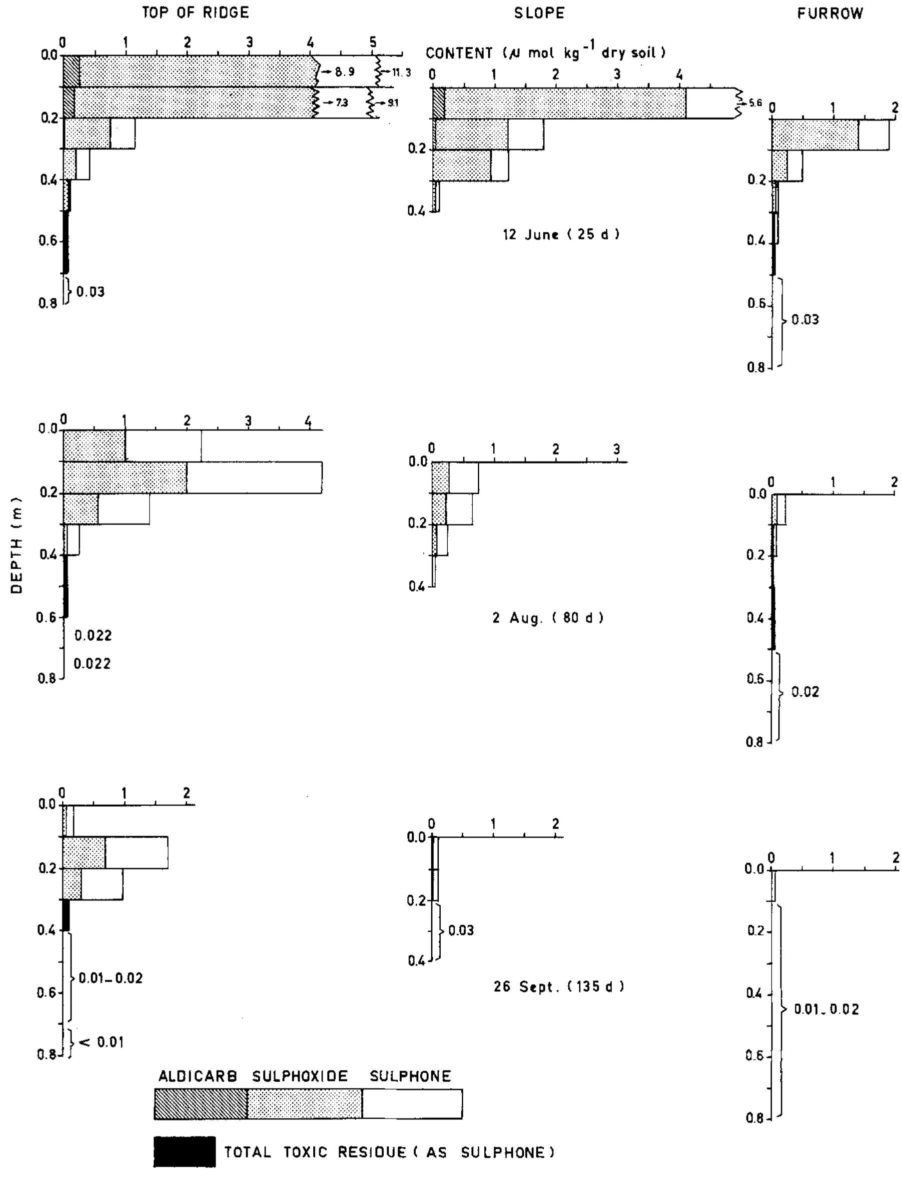

Fig. 2. Gehalten van aldicarb en zijn omzettingsprodukten sulfoxide en sulfon in het bodemprofiel van het proefveld te Westmaas.

Fig. 3. Contents of aldicarb and its conversion products sulphoxide and sulphone in the soil profile of the field near Wierum.

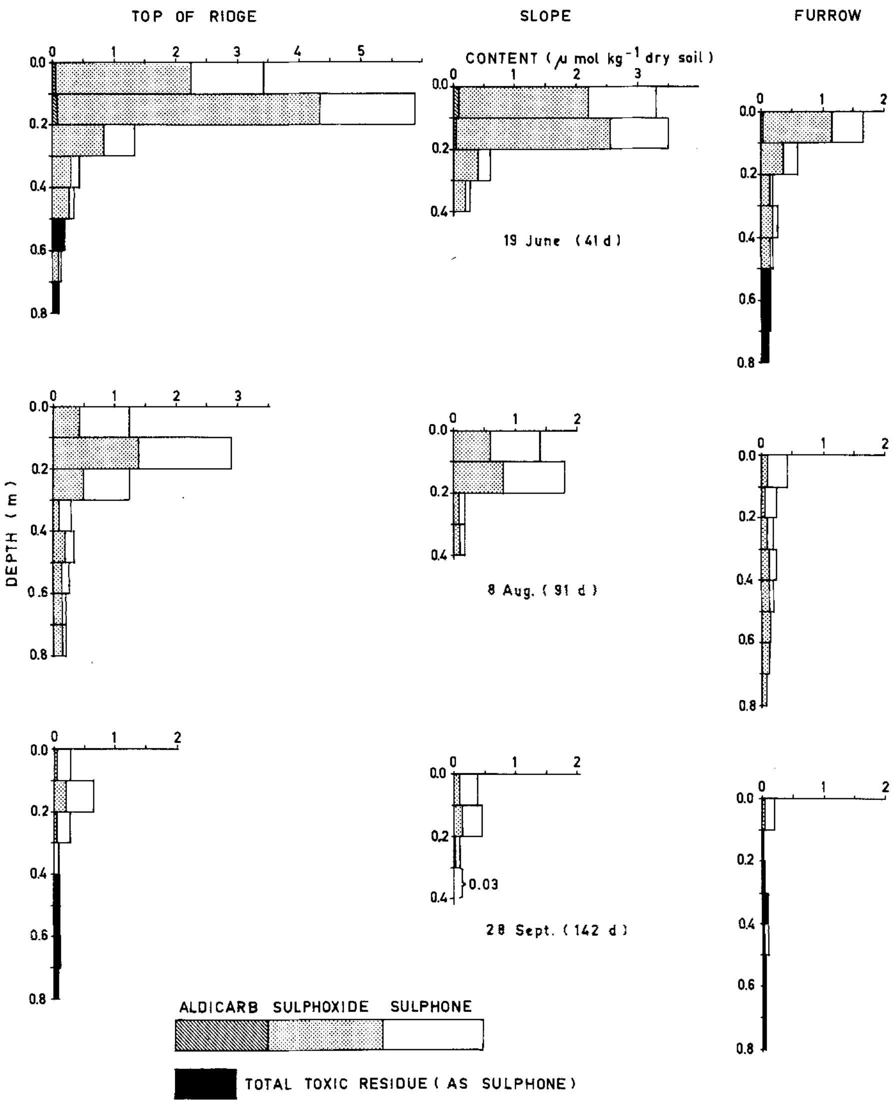

Fig. 3. Gehalten van aldicarb en zijn omzettingsprodukten sulfoxide en sulfon in het bodemprofiel van het proefveld te Wierum.

Fig. 4. Contents of aldicarb and its conversion products sulphoxide and sulphone in the soil profile of the field near Vortum-Mullem.

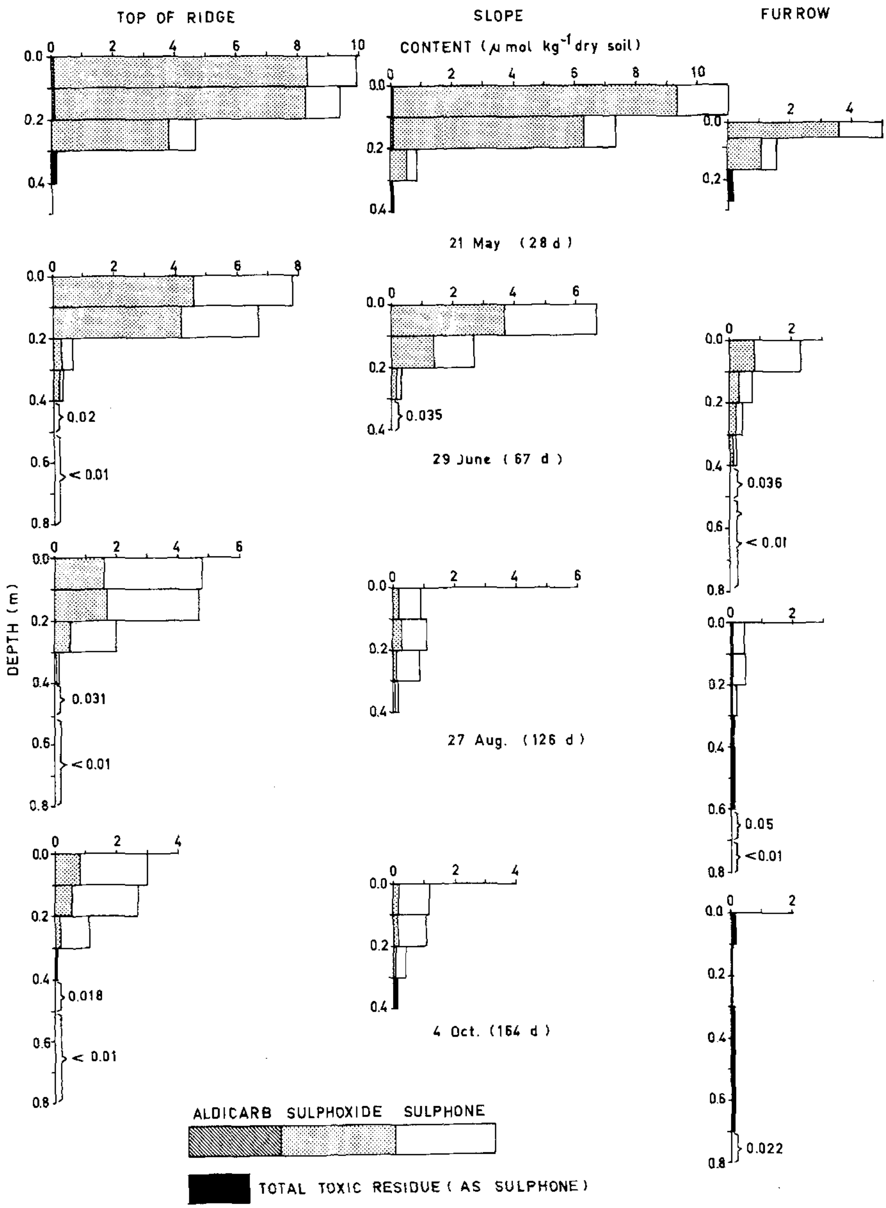

Fig. 4. Gehalten van aldicarb en zijn omzettingsprodukten sulfoxide en sulfon in het bodemprofiel van het proefveld te Vortum-Mullem.

section. The amount of toxic residue was then expressed as a fraction of the dosage (Table 2). In this way, the calculated fractions can be higher than 100% of the overall dosage as a result of the displacement of treated soil to the ridge areas.

During the growing season, the residue gradually decreased. At Vortum-Mullem with the humic sand soil (pH 4.3), the decline was distinctly slower than in the loam soils at Westmaas (pH 7.4) and Wierum (pH 7.1). The differences in rates of decline agree with expectations based on the results of incubation studies with related soil types (Smelt et al., 1978 a, b, c).

Average amounts remaining were calculated from the amounts present in the total profile at the three sampling points. The amounts in the 0.4-0.8 m layers on the slope of the ridge were not measured. They were estimated to be the mean of the amounts detected in the 0.4-0.8 m layers under the top of the ridges and the 0.3-0.8 m layer at the furrow. The amounts at the end of the growing season calculated in this way almost agreed with those found in grassed columns with the same soils (J.H. Smelt, C.J. Schut and M. Leistra, submitted). At the end of October, 5.9%, 6.6% and 18.7% of the dosage was left in the Westmaas, the Wierum and the Vortum-Mullem soil, respectively, in the column tests.

Discussion

Distribution of the compounds was mainly determined by soil tillage. Redistribution after tillage was limited. Although rainfall in May and June was higher than in other years (Fig. 1), distinct fractions of the dose were transported only about 0.1 m downwards. The toxic compounds were leached from the upper 0.1 m layers to a limited extent. In potato growing, with ridging cultivations, rain will seldomly reduce contents of toxic compounds in the upper layers below the effective level. In years with less rainfall in May and June, the redistribution may be expected to be even less. Contents in the layers below those in which the nematicide is incorporated may not then reach the levels needed to protect the roots in the first months after planting, when nematode attack is most damaging.

The distribution patterns measured in our field studies clearly support the results of Moss et al. (1976) and Whitehead et al. (1975), who found that deep and homogeneous incorporation of the nematicide granules in general gave more reliable increase in yield and better inhibition of the increase in cyst-nematodes than shallower applications. However, on a sandy loam soil, Seinhorst and Den Ouden (1980) found the same rate of nematode multiplication in the top 0.2 m of plots to which aldicarb was applied broadcast or mixed in by rotary cultivation (0.15 m). In their trial, aldicarb at practical dosages was much less effective against potato cyst nematodes in deeper layers, as indicated by multiplication rate, than in the top 20 cm of the soil. In the centre of the ridges of such plots, multiplication rate was reduced to a high degree but below the furrows reduction of multiplication rate was considerably less (Seinhorst and Den Ouden, 1980). These results seem to fit in with the general distribution patterns measured in our field trials. However, in the trial of Seinhorst and Den Ouden (1980), much less rain fell in May (54 mm) and June (37 mm) and more in July (78 mm) and August (75 mm) and this could have restricted penetration of the toxic compounds in the first months.

Soil columns were taken from the same fields and placed near a meteorological

Table 2. Amounts of aldicarb residues in the soil profiles during the growing season.

Field	Date	Relative amount per unit of surface area to dosage (%)					
		top of the ridge		slope of the ridge	furrow		average amount remaining
		0-0.4 m	0.4-0.8 m	0-0.4 m	0-0.3 m	0.3-0.8 m	
Westmaas	12 June	121	1.9	50	16	1.5	64
	2 Aug.	43	1.0	7.0	2.0	1.0	19
	26 Sept.	17	0.3	1.6	0.6	0.4	6.7
Wierum	19 June	45	4.3	33	6.5	4.6	33
	8 Aug.	24	5.4	15	4.2	3.9	19
	28 Sept.	5.4	2.3	4.1	1.1	2.0	5.7
Vortum-Mullem	21 May	112	—	95	20	—	76
	29 June	69	0.1	48	18	1.3	45
	29 Aug.	51	0.2	15	6.0	2.1	25
	4 Oct.	32	0.1	15	1.3	2.3	17

Tabel 2. Hoeveelheden aldicarb residuen in de bodemprofielen gedurende het groeiseizoen.

station. Movement of aldicarb sulphoxide and sulphone in those grassed columns was found to be restricted also (J.H. Smelt, C.J. Schut and M. Leistra, submitted). At the end of October, the residues were found for far the greater part between 0.1 and 0.2 m depth. Concentrations in the upper 0.1 m layer, in which aldicarb was incorporated, had decreased much more than measured in the field trial. This could indicate that water flow through the soil columns was more uniform than in the ridged potato fields. In the field trials and column tests, movement of the compounds was restriced because evaporation and transpiration reduced net water flow to deeper layers.

In the field trials on the two loam soils, low contents of aldicarb sulphoxide and sulphone had already penetrated to 0.8 m on the first sampling dates in June. In the Wierum field, the amount of total toxic residue below 0.4 m was sometimes about 5% of the dosage. Uneven infiltration and rapid downflow of water through macropores may have resulted in the observed rapid and deep displacement of the substances in the two loam soils. Models of infiltration of water into loamy soils are based on almost uniform displacement of already present water by incoming water. Such models as the one tested by M. Leistra and J.H. Smelt (submitted) with the soil columns are not very suitable for describing movement of substances in ridged potato fields.

On the humic sand soil at Vortum-Mullem residues were leached much deeper in the furrow area than under the top of the ridge. Perhaps infiltration after rainfall was uneven, because of interception by the potato canopies and run-off from the ridges. Water is repelled by soil after dry periods and this would also cause uneven infiltration on this humic sand soil. Uneven infiltration by flow along the stems, as found by Saffigna et al. (1976), might be restricted under natural rainfall of generally low intensity.

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Samenvatting

Herverdeling en omzetting van aldicarb en zijn oxidatieprodukten in aardappelvelden

In het voorjaar werd op drie aardappelvelden het insecticide en nematicide aldicarb als Temik 10G breedwerpig toegediend en met een frees ingewerkt. Ruggen werden opgebouwd door herhaalde bewerkingen met aanaardwerktuigen. Gedurende het groeiseizoen werd de grond drie tot viermaal bemonsterd in laagjes van 0,1 m tot op 0,8 m diepte. Aldicarb zelf was binnen een maand bijna geheel omgezet zowel in een humeuze zandgrond als in twee zavelgronden. Gedurende het groeiseizoen bleven

het sulfoxide en het sulfon, welke produkten eveneens toxisch zijn en door oxidatie van aldicarb worden gevormd, voornamelijk in de toplaag van 0,3 m bij alle drie gronden. Relatief hoge concentraties werden alleen gemeten in de bovenste 0,2 m, wat wijst op een beperkte herverdeling door uitspoeling.

Lage tot zeer lage gehalten werden tot 0,8 m diepte gevonden, met name in één van de zavelgronden waar ook de grootste hoeveelheid neerslag van mei tot oktober (328 mm) werd gemeten. In een humeuze zandgrond was de uitspoeling in de voor groter dan die beneden de rug. Aan het eind van het groeiseizoen kwam de hoeveelheid resterend sulfoxide plus sulfon in de twee zavelgronden overeen met een massafractie van 5,7 tot 6,7% van de dosering en in de humeuze zandgrond met 17%. Deze residuen waren voor het grootste deel geconcentreerd in het centrum van de ruggen.

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