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Potato growing in short rotations and the effect of *Streptomyces* spp., *Colletotrichum coccodes, Fusarium tabacinum* and *Verticillium dahliae* on plant growth and tuber yield

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Summary

The yield of potatoes decreased as the frequency of growing this crop in a rotation increased, even in the absence of well-known soil pathogens e.g. *Globodera* spp. Soil disinfection with methylbromide or pasteurization at 60 °C with steam for 30 min eliminated the rotation effect on yield, suggesting that it was caused by a complex of microbial pathogens. Organisms thought to belong to the complex were *C. coccodes, F. tabacinum, V. dahliae* and *Streptomyces* isolates causing russet (netted) scab. Their effects on growth and yield were studied in non-sterilized soil that had never carried a potato crop before. *V. dahliae* decreases the yield of susceptible potato cultivars, *C. coccodes* may cause damage only late in the growing season in weakened plants. In the highly susceptible cv. Amethyst yield loss by *V. dahliae* was almost doubled in the presence of *C. coccodes. F. tabacinum* did not influence growth and tuber yield neither singly nor in combination with other pathogens. The *Streptomyces* isolates cause extensive root damage and yield loss in susceptible potato cultivars.

Introduction

Growing potatoes at increasing frequencies in a rotation may lead to substantial yield losses even in the absence of pests or pathogens well known to reduce tuber yield, e.g. *Globodera* spp. Hoekstra (1981) reported tuber yield losses of 15 % in a 1:3 (every third year) and 6 % in a 1:4 rotation compared to yield in a 1:6 rotation on marine clay. Lamers (1981) noted 30 % loss by continuous cropping compared to a 1:3 frequency. Scholte (unpublished) found on both sandy soil and marine clay 30 % yield loss of tuber weight when potatoes were grown continuously and 15–20 % when grown in a 1:2 frequency compared to a rotation frequency of 1:5. Roth et al. (1981) analysed the effects of frequency of cropping potatoes in twelve rotations in fields none of which were infested with cyst nematodes. The average yield loss in a 1:4 fre-

quency was 3.2 %, compared to a 1:8 frequency. When 1:3, 1:2, 2:3, 3:4 and 1:1 frequencies were compared to 1:4, yield decreases were 2.4, 7.9, 14.4, 18.0 and 30.2 %, respectively. O'Sullivan (1978) found 27 % and McDole & Dallimore (1978) 14 % yield loss comparing continuous cropping and a 1:2 frequency. Emmond & Ledingham (1972) compared continuous cropping with a 1:3 frequency and found 19 % yield loss.

The percentage yield reductions cited above all refer to total tuber yield, but real losses of marketable product are higher because shortening the rotation also leads to small, poorly shaped tubers.

In preliminary pot experiments an increase in soil pathogens was identified as a possible cause of yield losses of potatoes associated with short rotations. We therefore investigated the pathogenicity of some soil fungi (*Colletotrichum coccodes, Fusarium tabacinum* and *Verticillium dahliae*) and actinomycetes (*Streptomyces* spp.) causing russet scab, and their interactions, in a series of pot experiments. *C. coccodes, V. dahliae* and the *Streptomyces* spp. are known pathogens of the potato plant; *F. tabacinum* was included because this fungus is strongly stimulated by potato growing (van Emden, 1972) and can be isolated in large numbers from potato roots (our observations, unpublished).

Materials and methods

Experiment 1, 1977

For all experiments, soil was taken from the crop rotation field experiment 'De Schreef' in the polder Oostelijk Flevoland (Hoekstra, 1981), where, since 1962, 14 rotations with different frequencies of a number of agricultural crops are compared in such a way that every crop in a rotation is grown in each year. Rotation and crops grown in 1962 (and then successively in the sequence given) were as follows:
Rotation 1: flax - grass seed - rape seed - spring barley - peas - winter wheat.
Rotation 3d: spring barley - grass seed - sugar beets.
Rotation 5b: potato - grass seed - sugar beets.
For experiment 1, soil from rotation 1 was collected after the rape seed crop and from rotation 3d and 5b after the sugar beet crop. Each soil was sieved and thoroughly mixed before applying three soil treatments:
C: no treatment;
M: disinfection with methylbromide;
S: sterilization with steam at 100 °C for one hour.
Black plastic pots (5.8 l) were filled with the treated soil and placed in a glasshouse held at 18/10 °C day/night temperature for 13 weeks and then at 24/18 °C for 7 weeks under natural light conditions.

Eight pots of soil × treatment were planted on 21 April with a 13-g single sprouted tuber, cv. Bintje, previously disinfected with ethyl mercury bromide (Aardisan, 4 % a.i.; tubers were immersed for 5 min in a 0.3 % solution of the trade product). The following total amounts of nutrients were applied per pot, apportioned over four applications from the planting date to 10 weeks after planting: 3780 mg N, 930 mg P, 4485 mg K, 360 mg Mg and 10 ml of a trace element solution containing 20 g $MNSO_4 \cdot 1$ aq., 30 g H_3BO_3, 5 g $ZnSO_4 \cdot 7$ aq., 1 g $CuSO_4 \cdot 5$ aq. and 1 g $Na_2MoO_4 \cdot 2$ aq. per l water. The amounts of the main elements were based on expected dry matter yield of haulm and tubers and their mineral content.

Experiment 2, 1978
Soil was again collected from rotations 3d and 5b after the sugar beet crop, prepared as before, and treatment P (soil pasteurization at 60 °C with steam for 30 min) applied as well as treatments C and M.

Black plastic pots (5.8 l) were filled and placed in white enamel pots, which were placed outdoor during the summer months. Cultivar and tuber treatment (10 replicates) were as in Experiment 1, the planting date was 18 April and the total amounts of nutrients applied per pot, added as in Experiment 1, were: 3780 mg N, 775 mg P, 5265 mg K, 360 mg Mg and 10 ml of the trace element solution.

Experiment 3, 1981, with Streptomyces spp., C. coccodes and F. tabacinum
In Experiment 2, roots of cv. Bintje growing in soil of rotation 5b showed brownish lesions from which 60 streptomycetes were isolated. From these, 30 were selected on visual characteristics as isolates possibly causing russet scab. Their pathogenicity to the potato plant was tested as described by Labruyère (1971). Ten of the isolates were pathogenic to cv. Bintje and two of the most pathogenic ones, both tyrosinase-positive, were selected and used in Experiments 3 and 4. No attempt has been made to identify these isolates any further and, although Labruyère (1971) states that tyrosinase-positive russet scab isolates may be assigned to *Streptomyces scabies*, the isolates might have belonged to two different species.

These two isolates and two isolates of each fungus were used to inoculate non-sterilized marine clay from 'De Schreef', rotation 3d, where since the reclamation of the polder in 1958 potatoes never had been grown. Inoculum of each organism was added to and mixed thoroughly in the soil in a 1:100 ratio (volume/volume) and check pots consisted of soil with killed innoculum of all three organisms. Each species was used singly or in all combinations and when a given organism was omitted from a treatment an equal volume of a sterilized culture of that organism was added instead. Single-sprouted 14-g tubers, cv. Bintje, disinfected as in Experiment 1, were planted singly on 20 August in 5.8-l black plastic pots (10 per treatment) placed in white enamel pots that remained in the open until 17 September. Then they were transferred to a glasshouse at a fluctuating day temperature (3 h, 18 °C; 6 h, 26 °C and 3 h, 18 °C) and a constant night temperature (12 h, 10 °C). During daytime, additional light was supplied by 400-W high-pressure mercury lamps. The total amounts of nutrients applied per pot, added as in Experiment 1, were: 2353 mg N, 683 mg P, 4173 mg K, 336 mg Mg and 9 ml of the trace element solution.

Experiment 4, 1982, with Streptomyces spp., C. coccodes and V. dahliae
Inoculum of each organism was added to and mixed thoroughly in non-sterilized soil from rotation 3d in a 1:200 ratio (volume/volume). The organisms were used singly and in combinations following the same procedure as in Experiment 3. Singly-sprouted 14-g tubers, cvs Bintje, Amethyst and Mirka, disinfected as in Experiment 1, were planted singly on 29 April in 5.8-l black plastic pots (6 per treatment) placed in white enamel pots in the open field. The total amounts of nutrients applied per pot, added as in Experiment 1, were: 3696 mg N, 930 mg P, 5382 mg K, 432 mg Mg and 12 ml of the trace element solution. The relative genotype susceptibility relationships are given in Table 1.

Table 1. The relative susceptibility of Bintje, Amethyst and Mirka to *Streptomyces* spp., *V. dahliae* and *C. coccodes*.

	Streptomyces spp. [a]	*V. dahliae*	*C. coccodes*
Bintje	very susceptible [b,1]	susceptible [b,3]	unknown [5]
Amethyst	resistant [b,2]	very susceptible [b]	unknown
Mirka	resistant [b]	tolerant [c,4]	unknown

[a] *Streptomyces* spp. standing for the russet (netted) scab causing isolates – *Streptomyces spp. bezeichnet die Netzschorf verursachenden Isolate – Isolats de Streptomyces spp. causant la gale commune (russet scab)*
[b] Derived from pot experiments at the Department of Field Crops and Grassland Science – *Herkunft aus Topfversuchen vom Abteilung für Landwirtschaftlichen Pflanzenbau und Grünlandkunde (LH) – Provenant des expériences en pots réalisées par Section pour l'étude des plantes de grande culture et de la culture herbagère (UA)*
[c] Krikun & Orion (1979)

[1] *Sehr anfällig – Très sensible;* [2] *Resistent – Rèsistant;* [3] *Anfällig – Sensible;* [4] *Tolerant – Tolérant;* [5] *Nicht bekannt – Inconnu*

Tabelle 1. Die relative Anfälligkeit von Bintje, Amethyst und Mirka für *Streptomyces* spp., *V. dahliae* und *C. coccodes*.
Tableau 1. Sensibilité relative de Bintje, Amethyst et Mirka au *Streptomyces* spp., *V. dahliae* et *C. coccodes*.

Analyses
In Experiments 1 and 2, total dry matter yield is a summation of dry haulm weight and dry tuber weight. In Experiment 3, during the growing season the height of the plants was recorded periodically and their degree of maturity estimated by counting the numbers of dead leaves. On 21 October, two pots per treatment were harvested for interim observation of the underground plant parts.

For determining the uptake of nutrients in Experiments 1 and 2, haulms and tubers were dried at 105 °C for 14 h, ground and thoroughly mixed. Subsamples were analysed after digestion in sulphuric acid and hydrogen peroxide. Potassium was determined with a flame photometer and phosphate and nitrogen were measured with a colorimeter.

Inoculum
The *Streptomyces* isolates were cultured in 50-ml lots of potato-glucose-peptone solution (200 g of peeled tubers boiled in 1 l water for 1 h, filtered, and 17 g of glucose and 7 g peptone added) dispensed in 100 ml flat medicine bottles, sterilized at 120 °C for 1/2 h, inoculated with spores and mycelium fragments, and shake-cultured at room temperature (ca 20 °C). Twenty-five ml of culture of each *Streptomyces* isolate was added to 100 g silver sand and the mycelium fragmented by grinding in a mortar. This quantity of mixture was added and thoroughly mixed with the pot soil.

Both *C. coccodes* and *F. tabacinum* were grown in Erlenmeyer flasks containing 50 g of a mixture of Trio pot soil (a pot soil containing 60 % organic material

manufactured by Trio BV) and 5 % oatmeal. After sterilizing at 120 °C for 1/2 h on two successive days to ensure death of sporeforming bacteria, the flasks were inoculated with spores and mycelium fragments from 10-day old tube cultures of the fungi and incubated at 22 °C for approximately three weeks.

V. dahliae was cultured in 300-ml Erlenmeyer flasks, each containing 100 ml perlite (granules) + 45 ml Czapec Dox solution sterilized at 120 °C for 1/2 h. Inoculum for each flask was obtained by adding 5 ml of sterile water to a sporulating 10-day old tube culture of *V. dahliae*, the surface of the culture was gently rubbed with a glass rod and then the tube was gently shaken to produce a suspension containing numerous spores. The flasks were incubated at 22 °C until the perlite became blackened by numerous microsclerotia and this inoculum was then added in a 1:200 ratio (v/v) to the soil.

When killed inoculum was needed, culture flasks were sterilized at 120 °C for 1/2 h.

Results

Experiments 1 and 2

Fig. 1 shows that the production capacity of the untreated soils in rotations 1 and 3d did not differ; neither soil had been cropped to potatoes. The soil from rotation 5b, which had carried a potato crop once every three years during a 15-year period, had a much lower capacity, but after it had been disinfected with methylbromide or partially sterilized with steam this negative effect disappeared. A similar result was obtained in Experiment 2: the poorer productivity of the soil from rotation 5b, 20 % less than that of the 3d-soil, was restored simply by pasteurization (Fig. 2).

The uptake of nutrients by the plants growing in untreated soil from rotation 5b was not only much less than from the other soils (Figs 3 and 4) but it was far less than the amount of nutrients given in the fertilizer. However, the uptake was the same as that of the control soil after disinfection, sterilization or pasteurization.

Experiment 3

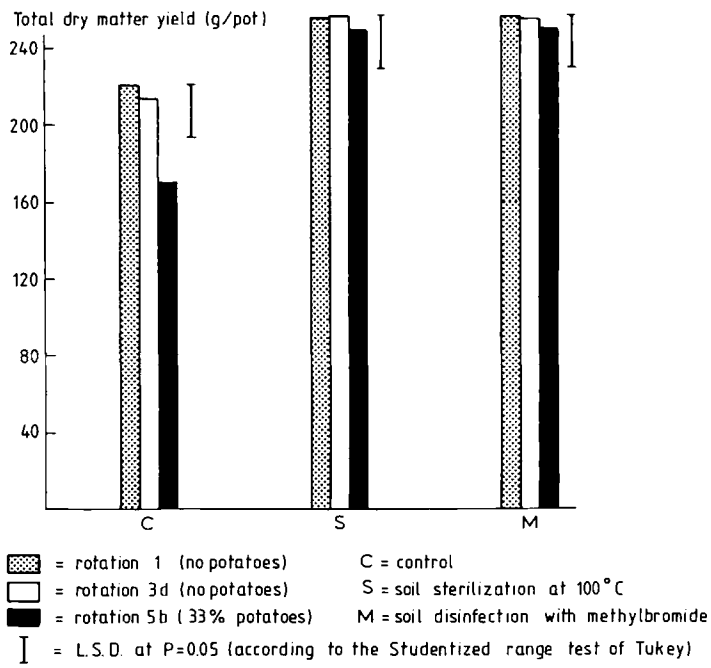
The *Streptomyces* isolates caused a 14 % loss in tuber yield and decreased tuber numbers (Table 2), whereas *C. coccodes* and *F. tabacinum* influenced neither yield nor tuber numbers. At the beginning of the growing season, plant height was reduced in the presence of the *Streptomyces* isolates (Table 3) and this was associated with a severe attack on the entire root system (Fig. 5). Infection occurred as soon as the roots started to grow and became manifest by the presence of numerous light brown lesions. Fine rootlets were completely destroyed and stem bases, stolons and young tubers were also affected. During the growing season plants tended to recover so that at the end of the growing season their heights were comparable to those of the controls (Table 3) but their senescence was retarded (Table 4).

F. tabacinum had no effect on plant growth; senescence was retarded but at the end of the experiment root health was not different from that of control plants. Initially, *C. coccodes* had no effect on plant growth and at the interim harvest (21 October) the root system was still unaffected. However, at the end of the growing season leaf senescence accelerated (Table 4). At final harvest, *C. coccodes* was present on all underground plant parts, including tubers, showing numerous microsclerotia and there was a greyish discoloration on many roots.

Experiment 4

The addition of *Streptomyces* isolates to the soil caused a yield reduction averaging 7 % in cv. Bintje (Table 5) but not in the resistant cvs Amethyst and Mirka. As in Experiment 3, yield reduction of Bintje was associated with an extensive attack of the underground plant parts, especially of the roots. Again, growth was retarded

Fig. 1. Total dry matter yield of potato plants as related to rotation and soil treatment. Experiment 1.



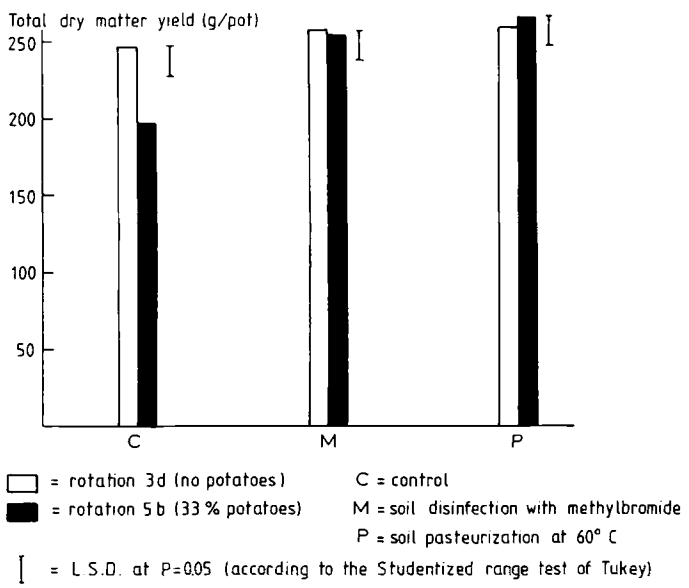
Total dry matter yield (g/pot) – *Gesamttrockensubstanz (g/Topf)* – *Rendement en matière sèche totale (g/pot);* Rotation (no or 33 % potatoes) – *Fruchtfolge (ohne oder 33 % Kartoffeln)* – *Rotation (sans ou 33 % pommes de terre);* Control – *Kontrolle* – *Témoin;* Soil sterilization at – *Bodensterilisation bei* – *Stérilisation du sol à;* Soil disinfection with methylbromide – *Bodendesinfektion mit Methylbromid* – *Désinfection du sol avec le bromure de méthyle;* LSD at $P=0.05$ (according to the Studentized range test of Tukey) – *LSD mit $P=0,05$ (bezogen auf den studentisierten Range-Test nach Tukey)* – *ppds à $P=0,05$ (test de Student selon la méthode de classement de Tukey)*

Abb. 1. Ertrag an Gesamttrockensubstanz bei Kartoffelpflanzen in Beziehung zu Fruchtfolge und Bodenbehandlung. Experiment 1.
Fig. 1. Rendement en matière sèche totale des pommes de terre en fonction de la rotation et du traitement de sol. Expérimentation 1.

mainly during the early stages and this was associated with fewer tubers per pot (Table 6). There was no evident interaction between *Streptomyces* and *V. dahliae* or *C. coccodes* in the three cultivars.

V. dahliae caused a yield decrease of ca 8 and 10 % in Bintje and Amethyst, respectively (Table 5). The yield of cv. Mirka was not reduced by *V. dahliae*. All three cultivars were unaffected by *C. coccodes* when inoculated singly, but when combined with *V. dahliae*, yield reduction by this fungus in cv. Amethyst was increased from 10 to 19 %.

Fig. 2. Total dry matter yield of potato plants as related to rotation and soil treatment. Experiment 2.



Total dry matter yield (g/pot); Rotation (no or 33 % potatoes); Control; Soil disinfection with methylbromide; LSD at $P=0.05$ (according to the Studentized range test of Tukey) – *Siehe Abb. 1 – Voir fig. 1;* Soil pasteurization at 60 °C – *Bodenpasteurisierung bei 60 °C – Pasteurisation du sol à 60 °C*

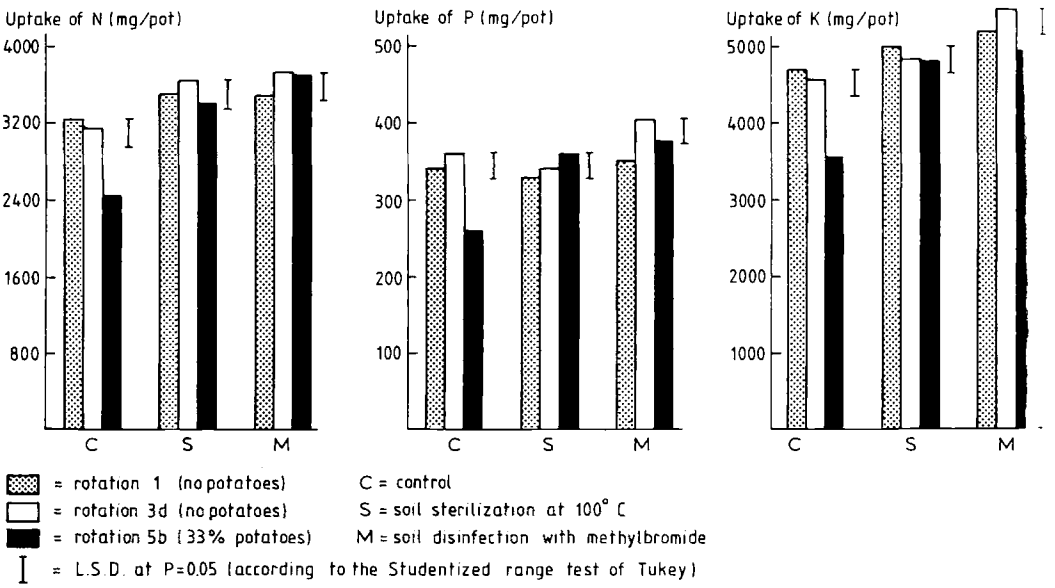
Abb. 2. Ertrag an Gesamttrockensubstanz bei Kartoffelpflanzen in Beziehung zur Fruchtfolge und Bodenbehandlung. Experiment 2.
Fig. 2. Rendement en matière sèche totale des pommes de terre en fonction de la rotation et du traitement de sol. Expérimentation 2.

Discussion

Soil pathogens in relation to short potato rotations

There may be yield losses when potatoes are grown in short rotations even in the absence of potato cyst nematodes (*Globodera* spp.). Pot experiments 1 and 2 showed that soil disinfection with methylbromide or pasteurization at 60 °C for 30 min sufficed to eliminate the adverse effects of short rotations on yield. Preparing the soil by sieving and thorough mixing minimized possible effects of texture between otherwise similar soils from the different rotations. Nevertheless there was a substantial yield loss and decreased uptake of nutrients associated with root systems weakened by soil pathogens in soil that frequently carried potatoes compared to a

Fig. 3. Uptake of nutrients as related to rotation and soil treatment. Experiment 1.



Uptake of (mg/pot) – *Aufnahme von (mg/Topf) – Absorption de (mg/pot);* Rotation (no or 33 % potatoes); Control; Soil sterilization at; Soil disinfection with methylbromide; LSD at $P=0.05$ (according to the Studentized range test of Tukey) – *Siehe Abb. 1 – Voir fig. 1*

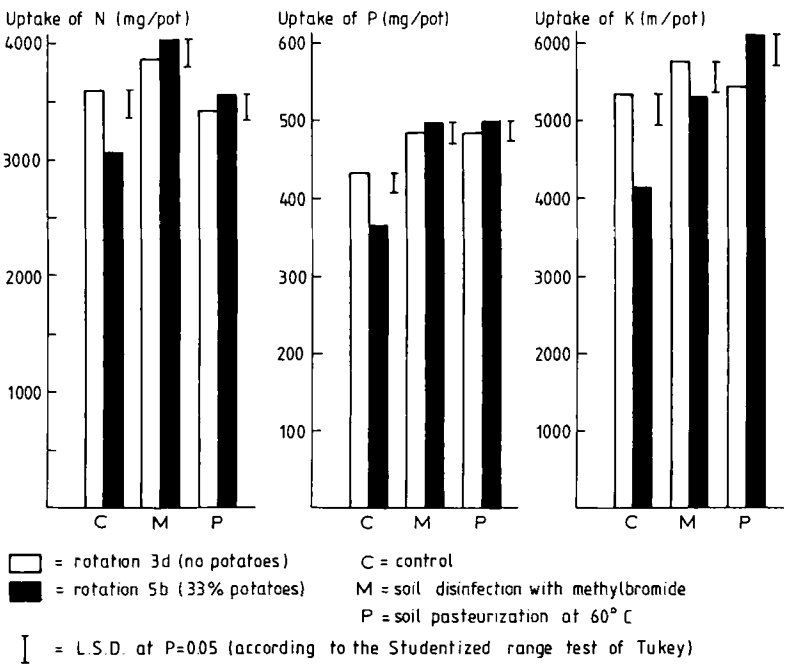
Abb. 3. Nährstoffaufnahme in Beziehung zur Fruchtfolge und Bodenbehandlung. Experiment 1.

Fig. 3. Absorption des éléments nutritifs en fonction de la rotation et du traitement de sol. Expérimentation 1.

non-potato soil, indicating the potentially important role of these pathogens.

Which soil organisms are responsible for yield reductions when potatoes are grown in short rotations cannot easily be determined. More organisms than we have investigated may be involved and the complex may differ with other crops and their succession in a rotation, the frequency and cultivar of potato grown, soil texture and moisture, climate and the time of year, and from one soil type to another. Pathogenic organisms may be synergistic, e.g. *Pratylenchus thorneī* and *V. dahliae* (Siti et al., 1979) or there may be inhibition by non-pathogens, e.g. *Rhizoctonia solani* by strains of *Verticillium biguttatum* (Jager & Velvis, 1983).

Fig. 4. Uptake of nutrients as related to rotation and soil treatment. Experiment 2.



Uptake of – *Siehe Abb. 3* – *Voir fig. 3;* Rotation (no or 33 % potatoes); Control; Soil disinfection with methylbromide; LSD at $P=0.05$ (according to the Studentized range test of Tukey) – *Siehe Abb. 1* – *Voir fig. 1;* Soil pasteurization at 60 °C – *Siehe Abb. 2* – *Voir fig. 2*

Abb. 4. Nährstoffaufnahme in Beziehung zur Fruchtfolge und Bodenbehandlung. Experiment 2.

Fig. 4. Absorption des éléments nutritifs en fonction de la rotation et du traitement de sol. Expérimentation 2.

The complicated interactions between organisms and between organisms and their environment makes it difficult to unravel the whole complex, the more so where the interactions take place in the soil. Direct observation is virtually impossible and understanding such a complicated system can be achieved only step by step.

Fusarium tabacinum

Our research and that of van Emden (1972) shows that when potatoes are grown in short rotations all their roots may be contaminated with *F. tabacinum*. This soil fungus is probably stimulated by potato growing, but in Experiment 3 there were neither lesions on the roots nor yield reductions. It is therefore unlikely that *F. tabacinum* is a pathogen of potato roots.

Fig. 5. Plants from Experiment 3. Left: control. Right: russet (netted) scab caused by *Streptomyces* spp.

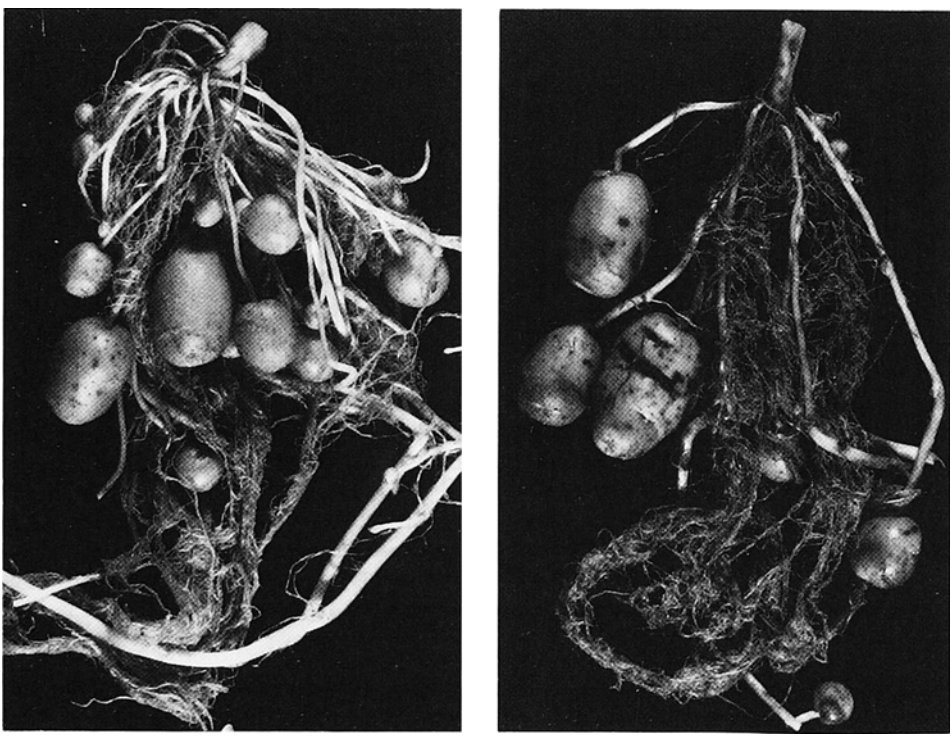


Abb. 5. Pflanzen aus Experiment 3. Links: Kontrolle. Rechts: Streptomyces spp. (Netzschorf).
Fig. 5. Plantes provenant de l'expérimentation 3. A gauche: témoin. A droite: Streptomyces spp. (russet scab).

Table 2. Dry matter yield of tubers in g/pot and number of tubers per pot. Experiment 3.

	Tuber yield [1]				Numbers of tubers [2]			
	So		Sl		So		Sl	
	Co	Cl	Co	Cl	Co	Cl	Co	Cl
Fo	117	112	89	103	13.0	17.0	8.7	10.3
Fl	114	114	100	102	13.7	14.0	9.3	10.0
Mean [3]	115		99***		14.4		9.6***	

S = *Streptomyces* spp.; F = *F. tabacinum*. C = *C. coccodes*.
o = inoculum sterilized – *Inokulum sterilisiert – Inoculum stérilisé;* l = inoculum alive – *Inokulum lebend – Inoculum vivant.*
*** Significantly different from So at $P<0.001$ – *Signifikant different von So mit $P<0,001$ – Significativement différent pour So à $P<0,001$.*

[1] *Knollenertrag – Rendement en tubercules;* [2] *Anzahl der Knollen – Nombre de tubercules;* [3] *Mittelwert – Moyenne*

Tabelle 2. Trockensubstanzertrag aus Knollen in g/Topf und Anzahl der Knollen pro Topf. Experiment 3.
Tableau 2. Rendement en matière sèche des tubercules en g/pot et nombre de tubercules par pot. Expérimentation 3.

Table 3. Plant height (cm) at successive dates. Experiment 3.

Date [1]	So	Sl	Fo	Fl	Co	Cl
18/ 9	9.6	8.1**	9.0	8.8	8.5	9.3
25/ 9	14.7	13.2**	14.2	13.7	13.4	14.5
2/10	22.0	19.5**	21.4	20.2	20.3	21.3
9/10	31.3	27.8**	30.3	28.9	29.1	30.1
16/10	35.5	32.2**	34.3	33.4	33.5	34.2
23/10	41.4	38.1**	40.1	39.4	39.5	40.0
30/10	48.1	46.0	47.1	47.0	47.1	47.0
6/11	50.8	50.8	51.0	50.6	51.1	50.6
13/11	51.1	51.8	51.8	51.1	51.8	51.0

Symbols are explained in Table 2 – *Erklärung der Symbole in Tabelle 2 – Les symboles sont expliqués dans le tableau 2.*
**l significantly different from o at $P < 0.01$ – *l signifikant different von o mit $P < 0,01$ – l significativement différent pour o à $P < 0,01$.*

[1] *Termin – Date*

Tabelle 3. Höhe der Pflanzen (cm) in aufeinanderfolgenden Terminen. Experiment 3.
Tableau 3. Hauteur des plantes (cm) à des dates successives. Expérimentation 3.

Table 4. Number of senescent leaves per plant at successive dates. Experiment 3.

Date[1]	So	Sl	Fo	Fl	Co	Cl
12/11	3.0	1.5***	2.9	1.6***	1.8	2.6*
20/11	4.3	1.9***	3.9	2.3***	2.8	3.4
27/11	10.7	4.2***	8.8	6.0***	6.9	7.9
1/12	16.2	7.4***	14.0	9.6***	10.7	13.0**

Symbols, see Table 2 – *Symbole, siehe Tabelle 2 – Symboles, voir tableau 2.*
*,**,*** l significantly different from o at $P<0.05$, $P<0.01$ and $P<0.001$, respectively – *l signifikant different von o mit $P<0,05$, $P<0,01$ bzw. $P<0,001$ – l significativement différent de o à $P<0,05$, $P<0,01$ et $P<0,001$.*

[1] *Termin – Date*

Tabelle 4. Anzahl alternder Blätter pro Pflanze in aufeinanderfolgenden Terminen. Experiment 3.
Tableau 4. Nombre de feuilles senescentes par plante à des dates successives. Expérimentation 3.

Table 5. Dry matter yield of tubers in g/pot. Experiment 4.

Cultivar[1]	0	S	0	V	0	C	0	VC
Bintje	224	209***	225	207***	217	215		
Amethyst	202	200	216	195***	216	219	216	176***
Mirka	242	245	244	243	244	243		

0 = control – *Kontrolle – Témoin;* S = *Streptomyces* spp.; V = *V. dahliae;* C = *C. coccodes.*
*** significantly different from control at $P<0.001$ – *Signifikant different von der Kontrolle mit $P<0,001$ – Significativement différent au témoin à $P<0,001$.*

[1] *Sorte – Variété*

Tabelle 5. Trockensubstanzertrag aus Knollen in g/Topf. Experiment 4.
Tableau 5. Rendement en matière sèche des tubercules en g/pot. Expérimentation 4.

Table 6. Number of tubers per pot. Experiment 4.

Cultivar[1]	0	S	0	V	0	C
Bintje	13.3	9.8***	11.3	11.8	11.6	11.4
Amethyst	19.5	18.9	20.0	18.4	20.3	18.2
Mirka	15.0	16.4	15.9	15.5	15.3	16.1

0, S, V, C, ***, [1] see Table 5 – *siehe Tabelle 5 – voir tableau 5*

Tabelle 6. Anzahl Knollen pro Topf. Experiment 4.
Tableau 6. Nombre de tubercules par pot. Expérimentation 4.

Streptomyces isolates

In Experiments 3 and 4, the *Streptomyces* isolates reduced tuber yield by 14 and 7 %, respectively. There was no interaction between them and *C. coccodes, F. tabacinum* or *V. dahliae.*

Mygind & Begtrup (1970) found a reduction in tuber yield after inoculating plants of cv. Bintje with the russet scab organism, and Bång (1979) noted 15 % loss in field experiments when seed tubers of cv. Bintje were infected with russet scab; Labruyère (1971) also recorded yield loss in that cultivar.

Root infection by the russet (netted) scab organism starts during plant emergence. Later, stem bases, stolons and tubers become infected and develop light brown lesions; root infection is most extensive and fine rootlets are more or less systemically invaded, do not function normally and die off. The superficial tuber lesions develop shallow cracks and ridges in square or pentagonal patterns and large areas of the tuber surface may be affected. Early plant growth is retarded, resulting in an inferior leaf development and plant height. Root development is restricted and fewer tubers are initiated. Plants may later recover when growing conditions are good and this may explain why Bång (1979) noticed less yield reduction in the south of Sweden compared to the middle and northern parts where the growing season is shorter and chances for recovery are less.

Bång also found low numbers of stems per plant, probably because the seed tubers used were heavily infected resulting in a reduced number of buds developing into sprouts. When infection originates from the soil, sprouting is not always affected.

Yield loss in Experiment 3 was twice that of Experiment 4, perhaps because of differences in the soil moisture content. Labruyère (1971) observed more russet scab under moist conditions during tuberization and the pots of Experiment 3, standing outdoors in a rainy period, initially became wet, whereas those of Experiment 4 had a dry period.

Russet scab can be regarded as a disease associated with short rotations. Scholte (unpublished) observed a substantial increase in russet scab in several field experiments with susceptible cultivars when the rotations were short and the results of one of those field experiments are given (Table 7). Hoekstra (1981) also found more russet scab in cv. Bintje in a 1:3 than in a 1:6 rotation.

The russet scab described in this paper seems to be identical with that described by Mygind (1965, 1970) in Denmark, by Bång (1979) in Sweden and by Labruyère (1971) in the Netherlands on cv. Bintje. The russet scab described by Harrison (1962) in the US, however, differs in several characteristics from the one described here. Scholte & Labruyère (1985) therefore propose to change the name of russet scab as it occurs in Western Europe to 'netted scab'.

Verticillium dahliae and Colletotrichum coccodes

Our results show that both fungi belong to a complex of organisms which adversely affect the yield of potatoes grown in short rotation. The potato plant is a good host for both fungi and at the end of the growing season they produce large numbers of microsclerotia on all plant parts. Microsclerotia of *V. dahliae* (Coley-Smith & Cooke, 1971) and of *C. coccodes* (Farley, 1976; Blakeman & Hornby, 1966) survive in soil for a long time.

Huisman & Asworth (1976) concluded that once *V. dahliae* has reached a high inoculum density in the soil its reduction under non-host crops is slow. However, Evans

Table 7. Relation between russet (netted) scab index (0–100) and frequency of potatoes in the rotation. Field experiment on clay soil, 1981.

Crop sequence [1]						Netted scab index [2]	
1976	1977	1978	1979	1980	1981	Bintje	Allerfrüheste Gelbe
potato [a,3]	wheat [4]	sugar beet [5]	wheat	barley [6]	potato [b]	23	20
potato [a]	wheat	sugar beet	wheat	potato [a]	potato [b]	64 ***	76 ***

[a] Cv. Bintje – *Sorte Bintje* – *Variété Bintje.*
[b] Cv. Bintje and Allerfrüheste Gelbe.
*** significantly different from the crop sequence barley-potato at $P < 0.001$ – *Signifikant different von der Anbauhäufigkeit Gerste-Kartoffeln mit $P < 0{,}001$ – Significativement différent par rapport à la rotation orge-pomme de terre à $P < 0{,}001$*

[1] *Anbaufähigkeit – Rotation;* [2] *Netzschorf-Index – Indice de gale réticulaire;* [3] *Kartoffel – Pomme de terre;* [4] *Weizen – Blé;* [5] *Zuckerrübe – Betterave sucrière;* [6] *Gerste – Orge*

Tabelle 7. Beziehung zwischen dem Netzschorf-Index (0–100) und der Häufigkeit des Kartoffelanbaus innerhalb der Fruchtfolge. Feldversuche auf Lehmboden, 1981.
Tableau 7. Relation entre l'indice (0–100) de gale commune (russet scab) et la fréquence des pommes de terre dans la rotation. Expérimentation de plein champ en sol argileux, 1981.

& McKeen (1975) recorded a considerable reduction in the number of viable microsclerotia by growing a non-host like oats or by a fallow period.

Besides the potato and other Solanaceae, *V. dahliae* has many hosts belonging to widely different plant genera (Woolliams, 1966) and growing them may increase or maintain inoculum levels in soil. *Chenopodium album* (Busch et al., 1978; Woolliams, 1966) is an excellent weed host that often occurs extensively in crop rotations with potatoes.

Yield reduction caused by *V. dahliae* depends on cultivar susceptibility (Susnoschi et al., 1975, 1976) and on the population density of certain nematodes, e.g. *Pratylenchus penetrans* (Martin et al., 1982), *P. thornei* (Siti et al., 1979) and *Meloidogyne hapla* (Jacobson et al., 1979).

C. coccodes is generally considered to be a weak pathogen and according to Schmiedeknecht (1956) lives predominantly on Solanaceae. Komm & Stevenson (1978) concluded that infection occurs early in the season and that the seed tuber is usually the source of inoculum; they therefore, doubt the preventive effect of crop rotation. Infection from the seed tuber can be prevented only by early disinfection with organo-mercury compounds (Mooi, 1956), because later the fungus has penetrated too deeply into the tuber tissue to be completely killed.

In our research, *C. coccodes*, when alone, did not adversely affect tuber yield, although at final harvest symptoms of the black dot disease (*C. coccodes*) were present in abundance on roots and the other underground parts and leaf senescence was accelerated. When plants were harvested half-way the growing season no symptoms were observed on the roots. According to Schmiedeknecht (1956) *C. coccodes* has a

long incubation period, and Hornby (1968) observed an initial slow colonization of tomato roots that accelerated when flowering started.

No synergism between *C. coccodes* and *Streptomyces* was noticed. *V. dahliae* decreased tuber yield of both Bintje and Amethyst, but not of Mirka in our Experiment 4. Krikun & Orion (1979) found the last named cultivar to be highly tolerant to *V. dahliae*. On cv. Bintje, no synergism was found between *V. dahliae* and *Streptomyces* or between *V. dahliae* and *C. coccodes*. On Amethyst, however, synergism between the last two fungi did occur and yield loss was nearly doubled compared to the loss caused by *V. dahliae* alone. Amethyst is highly susceptible to *V. dahliae*, showing severe leaf symptoms. Davis & Howard (1976) also noticed synergism of these two fungi on cv. Russet Burbank. Synergism between *C. coccodes* and other pathogens possibly occurs when the other organism tends to express its main effect in the second half of the growing season, as *V. dahliae* does. Any other stress at that time in combination with *C. coccodes* may also cause loss of yield, as shown by Otazu et al. (1978) in the case of heavy rainfall.

Conclusions

1. Yield of potatoes decreases with an increasing frequency of potato crop in the crop rotation even in the absence of *Globodera* spp.
2. The main cause of the yield loss is due to action of other soil organisms.
3. The russet (netted) scab organism (*Streptomyces* spp.) causes a yield reduction in susceptible cultivars by a severe attack on the root system early in the growing season.
4. *C. coccodes* is a weak pathogen that damages potato plants during the growing season only when they are already weakened by other causes, e.g. by an attack of *V. dahliae*.
5. Damage caused by *V. dahliae* is strongly influenced by cultivar susceptibility.
6. *F. tabacinum* is strongly stimulated by potato cropping but causes no damage to the potato plant.

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Zusammenfassung

Knollenanbau in engen Fruchtfolgen und der Einfluss von Streptomyces spp., Colletotrichum coccodes, Fusarium tabacinum und Verticillium dahliae auf das Pflanzenwachstum und den Knollenertrag

Kartoffelpflanzen aus einem Boden mit Kartoffeln in der Fruchtfolge (Frequenz 1:3) zeigten, verglichen mit der Ertragsleistung von Kartoffeln aus einem Boden ohne bisherigen Kartoffelanbau, einen auffälligen Ertragsverlust an Gesamttrockensubstanz (Abb. 1 und 2). Auch die Nährstoffaufnahme war hier signifikant verringert (Abb. 3 und 4). Ertragsleistung und Nährstoffaufnahme liessen sich jedoch durch Desinfektion des Bodens mit Methylbromid und durch Dampfsterilisation oder durch Pasteurisierung verbessern (Abb. 1, 2, 3 und 4).

Inokulationen des Bodens ohne bisherigen

Kartoffelanbau mit *Fusarium tabacinum* oder *Colletotrichum coccodes* beeinflussten den Knollenertrag nicht (Tab. 2), während Inokulationen mit Schorferregern (*Streptomyces* spp.) 14 % weniger Knollenertrag verursachten, die Anzahl der Knollen verminderten (Tab. 2) und das Pflanzenwachstum sowie die Abreife der Pflanzen (sorte Bintje) beeinflussten (Tab. 4 und 5). Obgleich sich *F. tabacinum* bei enger Fruchtfolge an den Wurzeln der Kartoffelpflanzen manifestiert, kann es hier nicht als Pathogen betrachtet werden.

Inokulationen mit *C. coccodes, Verticilium dahliae* und *Streptomyces* (Netzschorfisolate) in die für diese Pathogene unterschiedlich anfälligen Sorten Bintje, Amethyst und Mirka ergaben einen Ertragsverlust bei den für *Streptomyces* oder *V. dahliae* empfindlichen Sorten; ausserdem wurde ein durch *C. coccodes* verursachter synergistischer Effekt an den von *V. dahliae* hervorgerufenen Schäden in der Sorte Amethyst beobachtet (Tab. 5). In der Sorte Bintje wurde die Knollenzahl nur dann verringert, wenn *Streptomyces* dabei beteiligt war (Tab. 6). Netzschorf kann als Fruchtfolgekrankheit betrachtet werden (Tab. 7).

Résumé

La culture de la pomme de terre en rotations courtes et influence de Streptomyces spp., Colletotrichum coccodes, Fusarium tabacinum et Verticillium dahliae sur la croissance et le rendement en tubercules

Le rendement en matière sèche totale est considérablement réduit lorsque l'on compare la productivité d'une culture de pomme de terre dans une rotation de 3 ans à celle d'un sol non cultivé en pommes de terre au préalable (fig. 1 et 2). De même l'absorption des éléments nutritifs est réduite de façon significative dans les sols à pommes de terre (fig. 3 et 4). La productivité et l'absorption peuvent être retrouvées par la désinfection du sol au bromure de méthyle, la stérilisation à la vapeur ou la pasteurisation (fig. 1, 2, 3 et 4).

L'inoculation avec *Fusarium tabacinum* ou *Colletotrichum coccodes* dans un sol n'ayant pas reçu de pommes de terre, n'a aucune influence sur le rendement en tubercules (tabl. 1) alors que l'inoculation avec la gale commune russet scab provoqué par *Streptomyces* spp. provoque une perte de rendement en tubercules de 14 %, une diminution du nombre de tubercules et modifie le développement et la maturité des plantes (tabl. 3 et 4) avec la variété Bintje. *F. tabacinum*, quoique présent sur les racines de pommes de terre dans les rotations courtes, ne peut être considéré comme un pathogène de cette culture.

L'inoculation avec *C. coccodes, Verticillium dahliae* et *Streptomyces* (isolats de gale commune provoquant le russet scab) des variétés Bintje, Amethyst et Mirka, de sensibilité différente pour ces pathogènes, se traduit par une diminution de rendement pour les variétés sensibles à *Streptomyces* ou *V. dahliae* et par un effet de synergie de *C. coccodes* pour les dommages causés par *V. dahliae* sur la variété Amethyst (tabl. 5). Le nombre de tubercules de la variété Bintje n'est diminué qu'en présence de *Streptomyces* (tabl. 6). La gale commune (russet scab) peut être considérée comme une maladie de rotation (tabl. 7).

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