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The causes of the lack of self-tolerance of winter rye, grown on light sandy soils. 1. Influences of foot rots and nematodes

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Summary

In a 18-year rotational experiment on a slight sandy soil rye, grown after rye, showed a depression in seed yield of 30 % and in straw yield of 10 %, compared to rye following other crops.

Investigation into the causes of this reduction in yield made it highly probable that neither nematodes nor foot rot fungi are the main culprits. Rye grown after rye seems to take up less nitrogen from the soil than in any other sequence.

Introduction

In contrast to other species of small cereals, rye has always been considered to be self-tolerant apart from its susceptibility to stem eelworm attacks in certain soil types. In rotational schemes one can even find a recommendation of the sequence rye – rye (Zoschke, 1966). Research done in our department has produced evidence that the self-tolerance of rye can be rather low. This evidence was obtained by analysing the results of a long-duration field experiment (1952-1970). This experiment was carried out on a light sandy soil. Soil texture was a rather coarse sand with a low (2 %) organic matter content. Three rotations were compared:

Year	*A*	*B*	*C*
1	potatoes	potatoes	potatoes
2	oats	oats	oats
3	rye[1]	rye[1]	ley
4	mangolds	potatoes	ley
5	maize	rye	rape
6	rye[1]	rye[1]	rye[1]

[1] Followed by fallow turnips.

The experiment was laid out in such a way that each crop appeared in replication each year.

The crops: potatoes and oats were placed at the head of the rotation to find out any effect of the three rotations on soil fertility. A report on the effect of rotations on soil fertility is in preparation.

The yields of rye expressed as kg dry matter ha^{-1}, are worthy of note (Table 1). It is clear that the sequence rye – rye leads to a strong depression in yield compared to the other preceding crops.

In literature one can find many statements contrary to the results. Aufhammer (1963), Börner (1968), Klapp (1967), Könnecke (1956), Roemer & Scheffer (1959) and Zoschke (1966) have called rye a self-tolerant crop though without presenting evidence.

However, other research workers have found evidence that even rye can suffer from the preceding crop: rye. Franke (1962) found a depression in the yield of rye in continous cropping on a sandy soil (experiment Zoitsch). There was no yield depression in another field experiment on loamy soil (experiment Mösslitz). Jegorow (1964) cites Prjanischnikows. The latter, in an experiment on Russian podsol, and averaged over the period 1912-1960, found a difference in yield between two cropping systems of rye. Continous rye yielded 730 kg seed ha^{-1}; rye grown after one year of clover: 1410 kg ha^{-1}. Prjanischnikows believed that the difference in yield could be attributed solely to the nitrogen effect of clover. Potatoes and other crops however did not react sharply on the preceding clover, so the proposed explanation does not seem to be the sole reason. Grootenhuis & Mulder (1962) also found that rye as a continous crop can lead to a yield depression.

The famous 'eternal' rye experiment at Halle as reported by Schmalfuss (1957), does not show a strong depression in yield but it does not prove that rye is self-tolerant. The yield depression may have occurred in the very first years of the experiment. In the later years the averaged yields more or less stabilize. In the Halle experiment the comparison fails with rye grown in a 'healthy' rotation.

In this publication, which is the first of two on this subject, we are presenting the results of an investigation into the cause or causes of this phenomenon based on field experiments. In a subsequent paper the results of the pot experiments will be shown.

The field experiments

Experiment 1 (1952-1970). In this experiment the three rotations described in the introduction were used. In 1960, 1965 and 1966 soil samples from each plot were investigated with respect to nematodes. In 1970 the systemic fungicide Tecto-90 (thiabendazol) was applied to a number of rye plots which were in the last year of a complete rotation. Our purpose was to find out if some forms of foot rots possibly damaged the crop.

Experiment 2 (1970). A field experiment where the systemic fungicide Benlate (benomyl) was used in order to control foot rots in rye grown either after rye or potatoes.

Experiment 3 (1971). Purpose and set-up were the same as in Experiment 2.

The fungicides were applied with 600 litres water ha^{-1} directed as carefully as possible near the soil surface, and at different growth stages of the crop.

The schemes of the three experiments can be compared as follows (the number indicates the kg weight of the fungicide ha^{-1}):

Stage of development	*Experiment 1* Tecto-90	*Experiment 2* Benlate	*Experiment 3* Benlate
F1[1]	—	—	1.5
F4	2.2	1.6	1.8
F7	2.2	1.3	2.0
F10.5	3.0	1.9	2.6

[1]F: according to the original scale of Feekes.

In all experiments the rye cultivar Dominant was used. At the start of experiment 1 this cultivar of rye was not yet available and Petkuser was used. The seed was always treated with TMTD (thiram).

Results

The yields of rye in dependence of the preceding crop

The results of Experiment 1 averaged over the period 1953-1970 are shown in Table 1. From 1965 onwards a more detailed analysis was carried out. The results of this analysis are given in Table 2.

Comparing the yields as mentioned in Tables 1 and 2, it is evident that the introduction of modern cropping techniques in the latter period has raised the yield considerably. Split application of the nitrogen fertilization and the use of herbicides should be mentioned. However it is also clear that despite good cultural practice the depression in yield of the rye – rye variant still exists.

It follows from Table 2 that this yield depression was already apparent in the F7 stage. The number of tillers per plant in the rye – rye plots was consistently lower. This phenomenon was even more spectecular in the number of ears at harvest. These plots showed a yellowing of the lower leaves at the beginning of the booting stage.

The crop of the rye – rye variant ripened about a week earlier than the other rye plots.

Table 1 Yields of rye (kg dry matter ha^{-1}) averaged over the period 1963–1970 (3 cycles of 6 years).

Rotation Preceding crop	A oats	A maize	B oats	B potatoes	B rye	C rape
Grains	2735	2856	2671	2660	1864	2824
Straw	5456	5162	5408	5365	4935	5574
Total	8191	8018	8079	8025	6799	8398

Table 2. Yield analysis of rye following a number of crops averaged over the period 1965–1970. Weights in kg dry matter ha^{-1}.

Rotation	A	A	B	B	B	C
Preceding crop	oats	maize	oats	potatoes	rye	rape
Seed	3084	3327	3018	3044	2192	3205
Straw	5704	5529	5686	5759	5225	6137
Number of plants per m^2 4 weeks after harvest	297	286	301	304	303	303
Number of tillers per m^2 in the middle of the booting stage	347	344	348	358	320	367
Number of ears per m^2 at harvest	314	313	315	310	269	304
Number of grains per ear	33.9	34.7	34.2	33.9	32.7	36.4
1000-grain weight (kg)	35.1	35.2	33.8	33.4	29.5	34.8

The number of grains per ear was not affected very much but the depression in 1000-grain weight clearly indicates some kind of deficiency in the second half of the growing period. Nitrogen deficiency could be considered in this case.

Nematodes

Table 3 gives the results of the analysis for nematodes. There is no evidence that rye after rye had a higher number of nematodes than the other preceding crops. The B rotation as a whole shows a higher number of *Heterodera* larvae.

The foot rots

Foot rots were determined one week after the flowering stage. The disease index is used in Table 4. This index is: the percentage of the severely attacked culms plus half the percentage of slightly attacked culms.

Table 4 shows that on this soil type rye is very susceptible to foot rots. But it

Table 3. Number of nematodes in 100 ml soil averaged over the years 1960, 1965 and 1966.

Rotation	A	A	B	B	B	C
Preceding crop	oats	maize	oats	potatoes	rye	rape
Pratylenchus sp.	260	452	200	182	229	164
Paratylenchus sp.	6	9	0	3	7	2
Tylenchorhynchus sp.	453	449	350	290	404	792
Rotylenchus sp.	20	33	31	0	4	62
Heterodera larvae	19	0	4	111	44	3
Meloidogyne larvae	2	3	7	32	13	1
Other Tylenchida	55	121	76	64	86	85
Saprophytic nematodes	1140	1104	1057	1215	1275	1284

Table 4. Disease index, total yield (straw + seed) in kg dry matter ha⁻ and the lodging index related to preceding crops and the influence of fungicides.

Experiment		1 (1970)			2 (1970)		3 (1971)	
Preceding crop		maize	rye	rape	potatoes	rye	potatoes	rye
Disease index[1]	—F	66	81	72	86	74	52	78
	+F	16	16	16	28	32	34	47
Total yield[1]	—F	6782	6168	8333	7753	7112	10858	9018
	+F	8040	6471	9135	8498	7286	11265	10243
Increase in %		18.5	4.9	9.6	9.6	2.3	3.7	13.6
Lodging index[1,2]	—F	0	0	0	0	0	2.7	3.2
	+F	0	0	0	0	0	2.6	2.4

[1] —F = no fungicides; +F = fungicides.
[2] 0 = no lodging; 5 = completely lodged.

also shows that the sequence rye – rye is not obviously worse in this respect than the other preceding crops.

In Experiments 1 and 2 the effect of the application of fungicides was spectacular. In Experiment 3 the difference in disease index is less but this effect can be attributed to another form of foot rot.

In Experiments 1 and 2 *Pseudocercosporella herpotrichoides* was the main culprit and to a lesser extent *Fusarium* brown rot. These fungi react strongly on the applied fungicide. In Experiment 3 foot rot is mainly caused by *Rhizoctonia solani.* Van der Hoeven & Bollen (1971) proved that *Rhizoctonia solani* is usually less reactive to an application of benomyl. They also found that soil treated with benomyl, behaves less antagonistically to *R. solani* than untreated soil.

In all the experiments fungicides increased the seed yield but in Experiments 1 and 2 the lowest increase was in the rye – rye sequence. In rye after rape and maize there was a bad attack of mildew in Experiment 1. Tecto-90 controlled mildew excellently. The increase in yield after application of this fungicide is due more to its excellent control of mildew and less to its effect on the foot rots.

In the rye – rye plots there was only a slight attack by mildew. So the depression in yield increased for this variant after the application of fungicides.

In Experiment 3 this was not the case. In Table 4 the lodging indices indicate that especially in the untreated rye – rye plots there is early lodging due to foot rot. Treatment with a fungicide reduced the foot rot attack and lodging occurred only on a small scale. The yields of rye preceded by potatoes were severely depressed by lodging but this lodging was mainly caused by too rich an uptake of nitrogen.

The uptake of nitrogen

On the basis of the chemical analysis of seed and straw, Table 5 gives an estimation of the uptake of nitrogen by rye preceding by a number of crops. From Table 5 it follows that rye grown after rye always takes up less nitrogen than rye grown after

Table 5. Nitrogen uptake in kg ha^{-1} by rye, treated and non treated with a fungicide and following after a number of crops.

Experiment	Preceding crop	kg nitrogen ha^{-1}		
		—fungicide	+fungicide	mean
1	maize	68.5	72.5	70.5
	rye	62.6	67.8	65.2
	rape	81.5	100.1	90.8
2	potatoes	71.3	85.3	78.3
	rye	56.5	75.0	65.8
3	potatoes	101.6	104.5	103.1
	rye	79.1	89.5	78.3

any other crop. Treatment with a fungicide enhances the nitrogen uptake but the effect of the preceding crop is not reduced.

Discussion

In our opinion Experiment 1 has demonstrated that rye is not as self-tolerant as is sometimes claimed, at least when grown on light sandy soils. Compared to the average yield of rye grown after five other crops, the reduction in seed yield of rye after rye was more than 30 %. The reduction in straw yield was only 10 %. This difference in behaviour points towards the idea that the main reduction in yield occurs during the grain filling stage. The onset of the yield depression however starts much earlier in the growing period.

It has already been mentioned that rye in the sequence rye – rye showed a yellowing of the lower leaves at the beginning of the booting stage. At that stage internal shadowing within the crop cannot be an important factor, so it looks as though a clear case of an insufficient nitrogen supply. From Table 5 it can be seen that rye grown after rye takes up less nitrogen. The reduction of uptake can be caused by a reduction in the supply of nitrogen from the soil or by a reduction in the extension of the root system or its function.

When we compare the supply of nitrogen by the soil after oats as the preceding crop in rotation B, it seems rather improbable that the supply function of the soil is an important cause of the reduction in yield. The stagnation in growth at the beginning of the booting stage of the rye – rye plots indicates that the lower ear number per m^2 at harvest is caused by lack of vigour of the tillers which also leads to a lower fertility in the developed ears and to an appreciable reduction in 1000-grain weight. As far as the nematodes population is concerned this otherwise well known cause of rotational effects does not give a clue in this case.

It is true that the *Heterodera* larvae in rotation B are more numerous than in A and C but rye grown after potatoes or oats in rotation B does not show any reduction in yield.

Lodging occurred occasionally, as is to be expected in rye. When in Experiment 1 lodging occurred in certain years, it was always caused by a heavy attack of foot rot. Foot rot occurs more readily in the sequence rye – rye than with other preceding crops. Though the treatment with fungicides reduced the infection considerably and increased seed yield, in Experiments 1 and 2 the relative depression in yield of the rye – rye plots also increased. Treatment with fungicides against foot rots usually also have an effect on leaf parasitic fungi.

In Experiment 3 the application of Benlate prevented to a great extent early lodging of the rye after rye. We think that foot rots are more damaging in plants which are already suffering in some way. In the plots with rye following potatoes the culms were stronger and of a larger diameter than in the rye – rye plots.

It is not surprising that the control of foot rots with fungicides does not show a clear reduction of the yield depression. Hoppe & Maykuhs (1975) could not obtain a significant increase in yield of rye grown on typical rye soil and treated with fungicides against foot rots. Only on more fertile soils did they reach an increase in yield of 5 to 10 %.

Ehrenpfordt et al. (1975) conclude that the control of *Pseudocercosporella herpotrichoides* by means of fungicides can lead to an increase in yield of only 15 %, even in the case of a very strong attack. Range (1966) concludes that foot rots can only lead to damage of any importance when they attack the plants at an early stage directly or indirectly by causing early lodging.

In the experiments described, the difference in infection with foot rots as caused by the different preceding crops, is too small to explain the considerable difference in yield between the rye – rye sequence and rye following other crops. Vez (1975) came to the same conclusion after an analysis of rational problems of winter wheat.

Conclusions

1. Rye grown in a 18-year rotational experiment on light sandy soil is not self-tolerant.
2. The reduction in yield of the rye – rye sequence is preceded by a reduction in growth, visual at the end of the booting stage. The yields of seed were 30 % lower.
3. In this case well known parasitic nematodes were not responsible for the reduction in growth.
4. Rye seems to be susceptible to foot rots independent of the preceding crops. The foot rots were caused by *Pseudocercosporella herpotrichoides, Rhizoctonia solani* and to a lesser extent *Fusarium* sp.
5. Yield depressions as caused by foot rots were relatively small. The effects of the rotations on the gravity of the attacks were also slight.
6. From items conclusions 3 and 5 it follows that the yield depression of the rye – rye sequence is caused by other unknown factors.
7. Rye grown after rye seems to take up less nitrogen from the soil than rye grown after any other crop.

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References

Aufhammer, G., 1963. Neuzeitlicher Getreidebau, 2. Auflage. DLG-Verlag, Frankfurt/Main.

Börner, H., 1968. Das Problem der Bodenmüdigkeit und Selbstunverträglichkeit der höheren Pflanzen. Handbuch der Pflanzenkrankheiten 1, 3. Lieferung, 7. Auflage, S. 119-126. Paul Parey, Berlin/Hamburg.

Ehrenpfordt, V., E. Kuntzsch & E. Roth, 1975. Die Halmbruchkrankheit (*Cercosporella herpotrichoides* Fron) im konzentrierten Getreideanbau in abhängigkeit von eigenen acker- und pflanzenbaulichen Faktoren. *Arch. Acker- u. PflBau u. Bodenk.* 19 (6) 445-458.

Franke, G., 1962. Zur Frage der Verträglichkeitsbeziehungen bei Getreide. *Kühn-Arch.* 76: 22-130.

Grootenhuis, J. A. & J. K. Mulder, 1962. Verslag 1959, 1960, 1961 PR Lov 1. Graanvruchtwisselingsproef met winterrogge, wintertarwe, zomergerst en haver op de Dr. H. J. Lovink-Hoeve. *Rapp. Inst. Bodemvruchtbaarh. Groningen* 14.

Hoeven, E. P. van der & G. J. Bollen, 1971. The effect of benomyl on antagonism towards fungi causing foot rot in rye. *Acta bot. neerl.* 21 (1) 107-108.

Hoppe & Maykuhs, 1975. Halmbruchkrankheit in Wintergerste und Winterroggen. *Kurtz und bündig* (BASF) 28 (4).

Jegorow, W. J., 1964. Die Ergebnisse fünfzigjähriger Untersuchungen über den Einfluss von Fruchtfolgen, Monokulturen und Düngung auf die Dynamik der Fruchtbarkeit podsolierter Böden. *Kühn-Arch.* 78 (1) 157-161.

Klapp, E., 1967. Lehrbuch des Acker- und Pflanzenbaues, p. 382-389. Paul Parey, Berlin/Hamburg.

Könnecke, G., 1956. Die Bedeutung der Vorfruchtwerte bei der Aufstellung von Fruchtfolgen. *Z. Acker- u. PflBau* 101: 171-182.

Range, W., 1966. Ertragsbildung, Fusskrankheitsbefall und C/N-Umsatz im Boden in Abhängigkeit von Strohdüngung und Gründüngung in getreidereichen Fruchtfolgen. Diss., Giessen.

Roemer, Th. & S. Scheffer, 1959. Lehrbuch des Ackerbaues, p. 202-206. Paul Parey, Berlin/Hamburg.

Schmalfuss, K., 1957. Der Feldversuch 'Ewiger Roggenbau' in Halle. *Die Phosphorsäure* 17: 133-143.

Vez, A., 1975. Observations dans les essais de rotation de cultures à Changins au cours des 10 dernières années. *Rev. suisse Agric.* 7: 113-118.

Zoschke, M., 1966. Zur Problematiek der künftigen Fruchtfolgestaltung. *Kali-Briefe* (July).