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Bioassay to assess root rot in pea and effect of root rot on yield

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Abstract

Infection of pea roots by soil-borne pathogens causes foot and root rot. In 1985 research was started to develop a method to predict the root rot likely to occur in prospective pea fields. In a bioassay the pea cultivar Finale was sown in a composite soil sample from each field in pots under standardized conditions in the greenhouse. The plants were removed at the green bud stage and the severity of root rot recorded. Between 1985 and 1988 approximately 200 field pea crops were monitored for root rot development. Forty-eight fields were bioassayed in 1986, 51 in 1987 and 30 in 1988. Each year, root rot readings in the bioassay and disease severity readings at field sampled plants at flowering and green pod were linearly correlated ($P < 0.001$). As the degree of root rot in the field crop increased, there was a proportional lower yield. In heavily infested fields, up to a 50% yield reduction occurred.

The bioassay in pots proved to be a reliable method for predicting root rot severity in sampled pea fields.

Additional keywords: *Pisum sativum*, disease prediction, soil-borne pathogens.

Introduction

Many soil-borne fungal species cause 'foot and root rot', hereafter called root rot, of agricultural crops. Peas are extremely susceptible to some of these pathogens. Root rot causes early stagnation of root growth and symbiotic nitrogen fixation; it limits the uptake of water and nutrients. The infested crop is stunted and matures prematurely. If the growing season is unfavourable, root rot can cause crop failure (Reiling et al., 1960; Riepma, 1967; Tu, 1987). Genetical resistance nor chemical control are effective in root rot management. Only avoidance of fields with high disease potential can prevent the problem.

Many techniques are available to quantify fungal populations in the soil (Menzies, 1963). The use of selective growth media permits the isolation of specific fungal genera from soil, but then their pathogenicity still has to be established. In addition, use of selective media does not take into account the relative soil tilth, suppressiveness, or fertility which directly influence root rot disease severity.

Baits, mostly pieces of vegetable material, permit the isolation of specific soil pathogens, their quantification and the assessment of their inoculum potential. Examples include apples to isolate *Phytophthora* spp. (Duncan et al., 1987), carrot disks for *Thielaviopsis basicola* (Yarwood, 1946), pieces of potato for *Pythium aphanidermatum* (Stanghellini and Kronland, 1985), *Fusarium solani* var. *coeruleum*, *F. roseum* var. *sambucinum* and *Phoma exigua* var. *foveata* (Tivoli et al., 1987).

These methods are unsatisfactory in the case of root rot, where several fungal species are involved. To deal with this problem, growing plants may serve as a selective substrate

to sample the pathogen flora of a soil, in a bioassay to determine the inoculum potential of the soil (IPS). By standardizing the infection conditions, reproducible results can be obtained. The final disease intensity results from:
– density and virulence of the pathogens;
– competitiveness of the pathogens in relation to the other soil microflora;
– susceptibility of the test plant;
– physical and chemical characteristics of the soil;
– environmental conditions.

The first two factors make up the 'inoculum potential' of the pathogen, which was defined by Garrett (1956) as 'the energy available for infection of a host at the surface of the infection-court'. This potential is modulated by biotic and abiotic soil factors, and the result is called 'inoculum potential of the soil', IPS (Mitchell, 1979; Alabouvette, 1989). Data on the magnitude of the IPS permit the estimation of root rot risk of a particular field. IPS can be expressed by a value for disease incidence, e.g. with wilt diseases, or by severity of the infection as in the case of root rots.

Bioassays have been in use for vining peas for many years. In 1957 Johnson published a bioassay with pots in a greenhouse which gave a good estimate of the contamination of the soil examined. Sherwood and Hagedorn (1958) described a method to estimate the potential for common root rot caused by *Aphanomyces euteiches*. This method is still in use in the USA. Good results have been obtained with this method in Sweden (Olofson, 1967) and the UK (Biddle, 1979, 1984). The British Processors' and Growers' Research Organization (PGRO) offers a commercial test to pea growers. In Canada, a version of the bioassay is the 'window method', applied and financed by the industry itself (J.C. Tu, personal communication).

The lack of means of control, the increasing limitations imposed upon chemical pest control, lack of a short-term perspective for producing root rot resistant cultivars (Gerlagh, 1985), changes in harvesting methods, which lead to higher quantities of trash remaining on the field, and the uncertainty about the length of a rotation period for adequate reduction of soil inoculum potential, led to a fear of increasing root rot problems with increasing pea acreage in the Netherlands. Consequently the development of a greenhouse bioassay in pots to assess the inoculum potential of soil (IPS) of prospective dry pea fields was an objective in pea disease research in the Netherlands between 1985 and 1988. The research strategy has been elaborated elsewhere (Oyarzun, 1991).

Materials and methods

Development of the bioassay. In developing the bioassay, the criteria recommended by Bouhot (1979) and Bouhot and Bonnel (1979) have been taken into account. Peas are in general very susceptible to root rot, and have already been used successfully as test plants (Sherwood and Hagedorn, 1958). Since seed exudates activate soil pathogens (Cook and Snyder, 1965; Harman et al., 1978; Norton and Harman, 1985), seeds were sown directly instead of using young pregerminated plants. Pre-soaking of the seeds may lead to a decrease in infection (Short and Lacy, 1976).

The environment must allow disease to manifest itself maximally for any level of soil contamination. To achieve this, the conditions which contribute to maximum speed, selectivity and sensitivity of the test were determined. Subsequently the method was standardized. Finally the criteria for assessment of the disease were formulated.

Field selection in root rot research. In 1985, 46 pea fields (26 located in the North and 20 in the South of the Netherlands) with varying severity of root rot were examined at flo-

wering time. Particular attention was given to the types of symptoms and the disease patterns in the fields. A significant number of sampled fields had never been or had long ago been cropped with peas.

In 1986 and 1987 the bioassay results were compared with results from evaluating root rot in the field. In 1988 and later, field research was done to validate the bioassay in practice.

The fields, 48 in 1986 and 51 in 1987, were situated in the traditional legume growing regions of the North and the South of the Netherlands. Selections of test fields were made according to the following criteria: a pea crop in the respective year; at least one legume crop during the last 10 years; a large diversity of soil types and soil properties among fields; data available on cropping history and on physical and chemical soil properties.

Sampling procedure and soil preparation. In each field, only 1 ha was taken for sampling. The sampled area corresponded to the most homogeneous part of the field, excluding 10-m-wide field borders. Fields were sampled after ploughing in the autumn preceding the pea crop, or in early spring. In the sampled area, 50 subsamples of 20–25 cm depth were taken with an auger (5 cm diameter), passing through the field in a W-pattern. The 50 subsamples were combined, mixed and stored in a plastic bag at 5 °C until use. If samples were too wet, they were first dried by exposure to ambient air. Before testing, samples were crumbled and passed through a 0.8-cm mesh sieve which assured good homogenization of the sample. Of each sample the actual water content and that at field capacity (pF = 2) were determined. Soil water potential was determined by filling 100-ml cylinders with soil and placing them on a pF table (Anonymous, 1976). The soil density used in determining water potential was the same as for filling the pots in the bioassay.

The test plants. The cultivar Finale was used for all bioassays. Seed of the highest quality standard was further selected for size (7–7.5 mm) and absence of lesions and fissures. Subsequently, the seed health was verified in an agar test following ISTA procedures. Before sowing, the seed was either treated with thiram (TMTD, 1.5 g a.i./kg) or soaked for 10 min in a 1% solution of NaOCl, followed by two rinses with tap water.

Test procedure. Each soil sample was distributed over four 2.6-l pots. Each pot first received a 1-cm layer of moist riversand and then the soil was added. To prevent crust formation and internal leaching when water was added, and to limit evaporation, the surface of the test soil in each pot was covered with a 0.5-cm layer of perlite. Pots were filled, care being taken to pack the soil homogeneously according to a standard method (Slangen, 1979). Twelve seeds were sown per pot at 4 cm depth. The soils were gradually brought to field capacity and then placed in the greenhouse. The greenhouse climate during each test was maintained at the following limits: temperature 17–20 °C; air humidity 80–90%; light, shading when the radiation outside was more than 400 W/m^2; from October to March additional light (60 W/m^2) for 12 h per day when the light intensity outside was less than 100 W/m^2.

During germination loss of water by evaporation was prevented by covering the pots. After emergence, the number of plants per pot was reduced to ten. Soil moisture was adjusted daily to field capacity. The quantity of water needed was added at the top by a specially designed automatic water dispenser as shown in Fig. 1. A few times a week water was added from the bottom. The position of the pots was rerandomized at least three times a week.

Assessment of root rot severity in the bioassay. When test plants were in thirteenth leaf

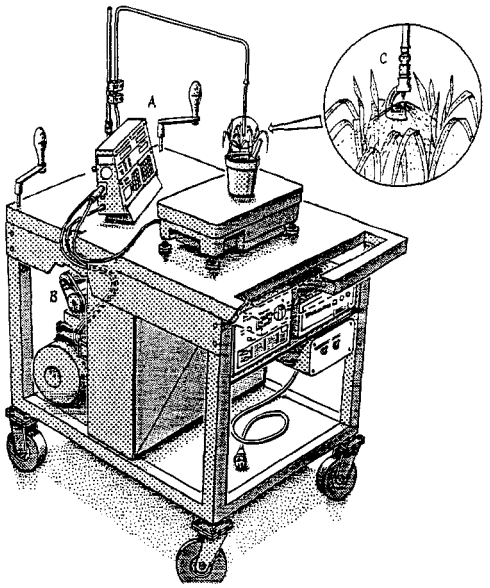

Fig. 1. Design of the automatic water dosage unit. Target weight is introduced manually or automatically (A). Difference between target weight (e.g. pot weight when soil water potential is -0.01 MPa) and current weight caused by evapotranspiration generates an electric signal which activates a valve linked with a water tank under pressure (B). When the difference disappears the valve closes instantaneously. A micro dosage unit (C) provides a fine water spray over the foots of the plants.

stage (green flower bud present), they were removed and their roots were carefully washed free of soil. Root rot severity per plant was scored on a 0–5 scale; 0 = healthy and 5 = roots 100% rotten. The Root Disease Index per plant (DIp) consisted of a weighted sum of the ratings of epicotyl, cotyledons, xylem and roots. Cotyledons represent the cotyledons themselves plus 1 cm of both epicotyl and roots. DIp was calculated using the formula:

$$DIp = 0.35 \times DI\ epicotyl + 0.20 \times DI\ cotyledons + 0.10 \times DI\ xylem + 0.35 \times DI\ roots$$

The Root Disease Index (DI) per sample is the weighted average

$$DI(sample) = [\overset{a}{\Sigma}[\overset{b}{\Sigma}DIp]/b]/a$$

where a = pots per sample and b = plants per pot.
DI characterizes IPS of the sample.

Field assessment of root rot. In 1986 and 1987, root rot in the field was assessed at three growth stages, when the plants had 7–8 leaves, at flowering (more than 50% of the plants with open flowers) and at early ripening (no more flowering; the lower pods filled but still green). Each sample consisted of sets of five plants taken at ten sites on a W path through the field, 50 plants in total. Plants were uprooted to a depth of 20–25 cm and for 10 cm at

each side of the row. The roots were washed free of soil and assessed for root rot. Visual estimation of the percentage of root affected by rot was scored on a scale (0–5) with 0 for white roots and 5 for 100% discoloration of underground parts or dead plants.

Fields were grouped according to root rot severity and the percentage of fields in each of four disease classes, negligible, slight, moderate and heavy disease, was determined. For comparison, results of the bioassay were grouped in the same way.

Crop stand and yield parameters. After emergence, crop stand was assessed by counting all plants at ten sites of 2 m length in two rows, 40 m in total. At the last sampling period yield-determining parameters (such as number of culms per plant, pods per culm, and the number of seeds produced per m^2) were scored. The thousand-kernel weight was supplied by the farmer. The yield was estimated by multiplying the number of seeds per m^2 by the thousand-kernel weight. This calculated yield was preferred over the yield as indicated by the grower. Since only part of the field was sampled, and since the farmer always looses some yield during harvest, the calculated yield is supposed to give a better estimate of the real dry grain production of the sampled area.

Time of execution of the bioassay. The possible deviation in IPS values of samples from autumn or spring was examined on 18 fields in 1986/1987. Test plants in spring were assessed for root rot when the first flowers had opened.

Bioassay for practice. In 1988, after the validation phase, bioassays were performed with soil samples taken without area restriction on 30 fields by workers of the Bedrijfslaboratorium voor Grond- en Gewasonderzoek (BLGGO) at Oosterbeek and compared to crop samples.

Data analysis. Analysis of data from bioassay and field assessments were performed by DAVE (data processing package at PAGV) or using facilities of GENSTAT.

Results

Field and crop data. Crop husbandry considerations did not lead to expecting limitations to pea growing on the selected fields (Oyarzun, 1991). In both years soil types varied from sandy loam to heavy clay; except a few peat and sandy fields, soils were alkaline with pH 7–7.5. Fields were well drained, but in 1987 water logging occurred in heavy clay due to abundant precipitation and a low infiltration rate.

In 1986, 75% of the seed lots were treated with fungicides, of which more than half with a mixture of thiram and carbendazim. In 1987 all seed was treated, of which 40% with metalaxyl or fosetyl-aluminium. In 1986, the most popular cultivar was Finale, in 1987 the semi-leafless cultivar Solara came up. In both years the average pea-free interval preceding the pea crop was longer than the 5 years (corresponding to a 6-year rotation) considered adequate for a healthy crop (Timmer et al., 1989). The legume share in the total crop rotation was modest (Table 1). Typically the soil was ploughed in October preceding the next pea crop and ploughing depth averaged 22–25 cm. The seedbed was prepared in March after harrowing, and seeds were sown at a depth of 4–5 cm (Table 2). The difference between intended (aim) and realised (real) seed depth is an indication of seedbed condition. The same applied to the difference between theoretical and real emergence, which was remarkably large in 1987, especially in the North (Table 2) where heavy clay soils prevailed.

Table 1. Share of different cultivars in the pea fields sampled in 1986 and 1987, the average number of years without peas (interval) preceding the crop, and the average frequency of peas and legumes in general over last 18 years. Data split up for the North and the South of the Netherlands.

Year	Region (n)	Share of cvs (%)			Pea interval	Pea in 18 years	Legume in 18 years
		Finale	Solara	Others			
1986	North (33)	73	7	20	7.6	1.5	1.9
	South (15)	33	21	46	7.9	1.4	2.3
1987	North (32)	68	21	11	6.6	1.2	1.4
	South (19)	25	47	28	7.8	1.2	1.9

n = number of fields in the region.

Root disease symptoms of test plants and of field crops. Three disease symptom categories could be distinguished: dark brown dry rot, black root rot and soft rot. Dark brown dry rot was the most frequent symptom. In 1986, test plants grown in some soil samples showed pronounced black root rot. This disease, caused by *Thielaviopsis basicola*, led to almost complete failure of the crop (Oyarzun, 1987). In both years, 1986 and 1987, soft rot occurred in the field and in the test plants. Later *A. euteiches* was isolated from such plants. The most representative root rot symptoms in test plants are illustrated in Fig. 2a–c.

Validation of bioassay results. In 1986, the linear correlation between DI of plants grown in the bioassay and in the field at the young plant stage was low (r = 0.50) but statistically significant. No correlation was found in 1987. With field plants in flower or immature pod stage, the relation between bioassay and field results is clear, and is best represented by a straight line (Figs 3a–d).

In 1986, the DIs from the bioassay were generally higher than of the fields. In 1987 the obverse was true. In 1986, the assessment in the field at the beginning of ripening was hampered in some fields by senescence of the crop. In 1987 the crop was still rather green at the last assessment date (mid July).

Classification of fields according to field rating of root rot severity and greenhouse bioassays. In 1985, root rot was generally slight (Table 3). Only 6% of the crops had moderate or heavy root rot. The relation between root rot in the field and in the bioassay is not

Table 2. Data on sowing and emergence. Figures represent the average values of the parameters for pea crops in the North and the South-West of The Netherlands. Theoretical field emergence is obtained by correcting the seed density by the germination capacity of the seed.

Year	Region	Seed rate (kg/ha)	Seeds per m^2	Depth		Field emergence (plants/m^2)		
				Aim	Real	Theor.	Real	% Real
1986	North	201	62	4.3	3.8	56	49	88
	South	191	57	4.2	4.7	54	50	93
1987	North	210	59	4.6	3.8	54	44	81
	South	190	57	4.6	4.7	54	50	93

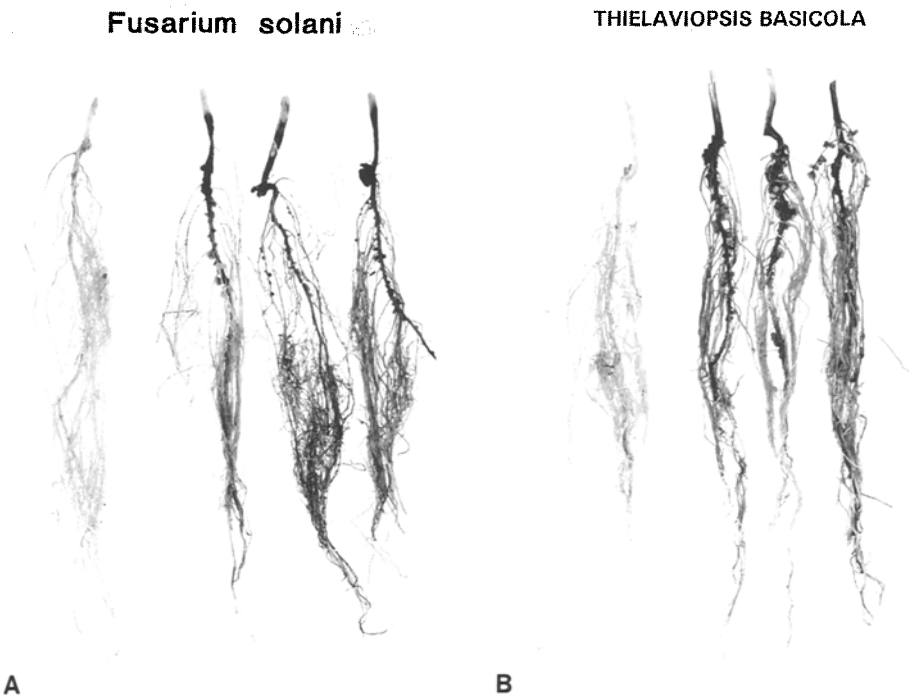

Fig. 2. Illustrations of the most representative pea root rot symptoms. Left, healthy pea roots; right = three diseased roots. (A) Root rot caused by *Fusarium solani* f.sp. *pisi*. Initial infection occurs near the area of seed attachment. Lesions enlarge and run together until epicotyl and tap root become completely shrunken and dark brown in color. Note blackened, degenerated nodules and the shrinking of epicotyls by the collapsing of dead cortical cells. (B) Black root rot caused by *Thielaviopsis basicola*. Infection primarily affecting taproot and lateral roots but no nodules. (C) Common root rot caused by *Aphanomyces euteiches*. Complete collapse of epicotyls and disappearance of the cortex. Strong reduction of the root system because the pathogen kills branch roots.

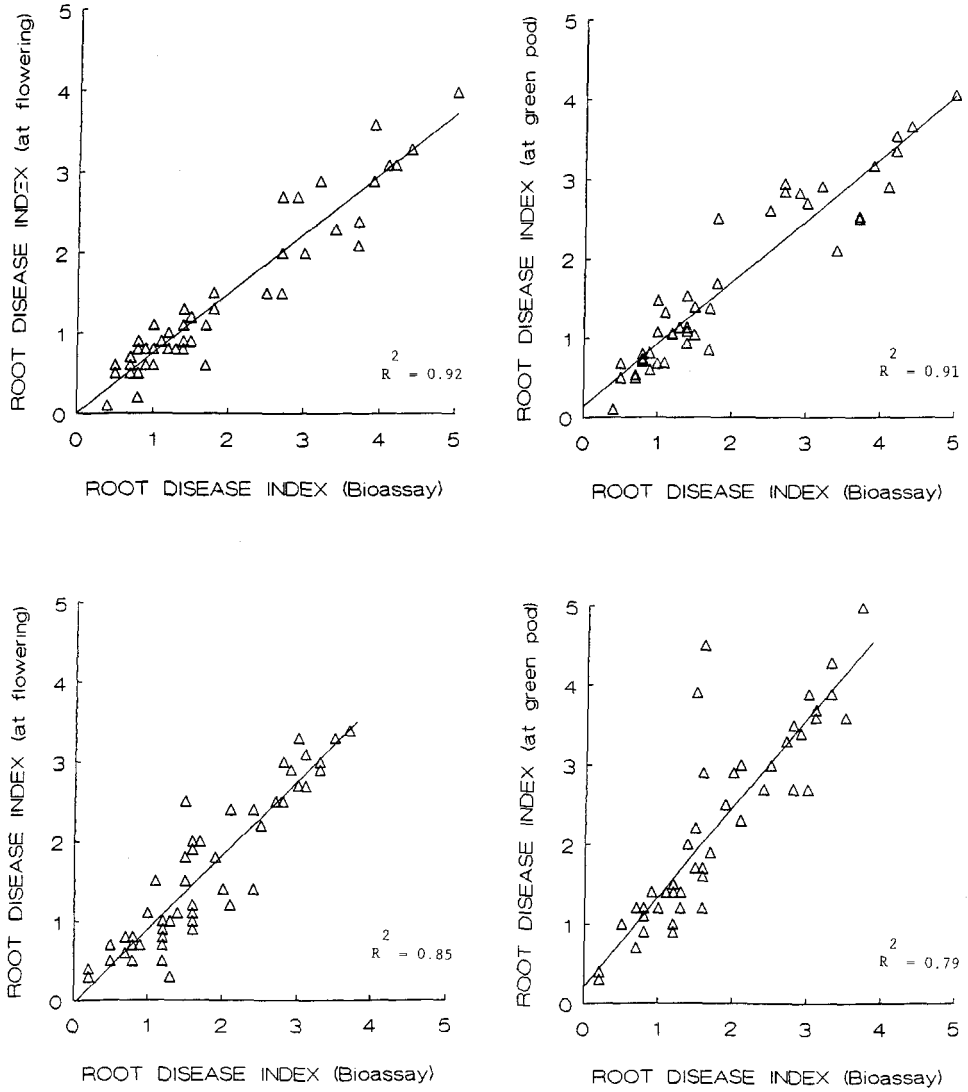

Fig. 3. Relationship between root disease index in a greenhouse bioassay and in field crops in 1986 and 1987 at flowering and green pod stages. (a) 1986, flowering; (b) 1986, green pod; (c) 1987, flowering; (d) 1987, green pod.

the same for 1986 and 1987. In 1986, DI in the field, at early ripening, ran parallel to the bioassay (χ^2-test, n.s.), but fields with very heavy infestation had lower ratings in the field than in the bioassay. In 1987, the fields with heavy attack were twice the number expected from the results of the test. Prolonged moist weather conditions caused heavy root rot even on slightly infested fields.

Relation between root rot severity and yield. Notwithstanding the high variability of fields, growth conditions and other factors, the correlation between yield and root rot (DI

Table 3. Percentage of fields in root disease classes according to the bioassay (BA) and to field assessment at flowering (FL) and ripening (RI) stage. In 1985 root rot was only assessed in the field.

Disease class	DI	1985	1986			1987		
		FL (46)[a]	BA (48)	FL (48)	RI (48)	BA (51)	FL (51)	RI (49)
Negligible	0–1	66	33	50	36	24	39	20
Slight	1–2	28	31	23	29	42	28	34
Moderate	2–3	2	13	15	24	22	25	22
Heavy	>3	4	23	12	11	12	8	24

[a] Number of fields.

at flowering) was significant ($P < 0.001$) with $r = 0.60$ and 0.64 for 1986 and 1987, respectively. Fig. 4a,b shows that an increase of 1 point in DI represents approximately a yield loss of 1 tonne per ha.

In 1986, the pea yield on fields with negligible disease was about 7 tonnes per ha. In the field with the most severe disease the yield did not reach 3 tonnes, even with an application of more than 200 kg N per ha. Disregarding the fields which were not harvested in 1987, yield losses due to root rot accounted for about 50% of the yield depression in fields in the class 'heavy disease'. In 1987, *Mycosphaerella pinodes* was the dominant foliar disease. It reduced thousand-kernel weight to 190–310 g, with an average of 260 g, more than 40 g lower than normal. This resulted in an average yield 1 tonne lower than in 1986 and a maximum calculated yield at the same level as the average in 1986.

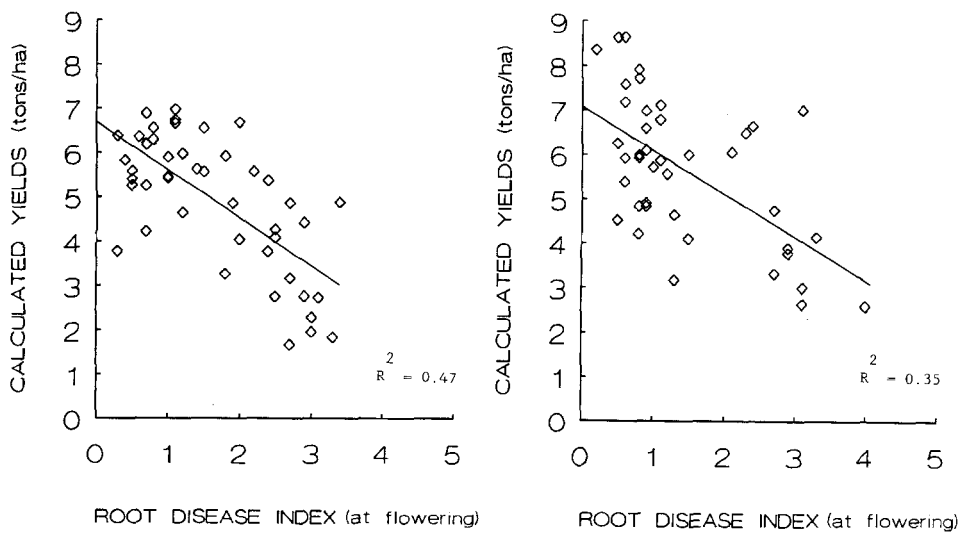

Fig. 4. Relation between the root disease index of pea at the flowering in the field and the calculated yield. (a) 1986; (b) 1987.

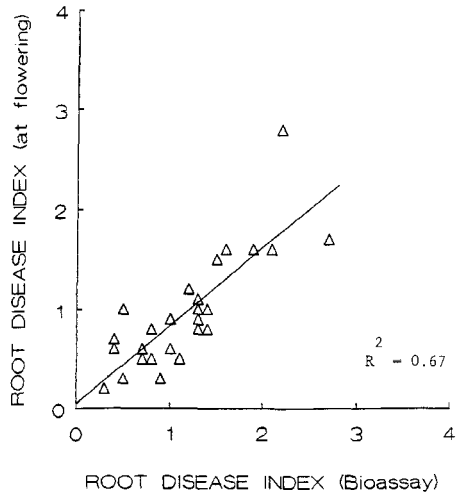

Fig. 5. Relation between root disease index of pea in bioassay and in the field in 1988. Field assessment was at the end of the flowering stage.

Time of bioassay execution. Paired differences between bioassay results of 18 soils in autumn 1986 and spring 1987 were not significant ($P < 0.05$, $n = 17$). The correlation between the two sets of data was good ($r = 0.92$, $n = 16$).

Bioassay for practical purposes. Though the percentage of the variation explained in 1988 was lower ($R^2 = 0.67$, $n = 30$) than for the 1986/1987 experiments, the correlation was significant ($P < 0.001$) (Fig. 5).

Discussion and conclusions

The years 1986 and 1987 were extreme for pea production. The year 1986 was very dry and sunny, with little disease. In 1987, continuing wet weather caused a catastrophe with regard to pea diseases and yields. Notwithstanding very different weather conditions in 1986 and 1987, the relation between test results and field assessment at flowering and ripening stages was good. Under the favourable 1986 circumstances, root rot depended on the quantity and vigour of the inoculum in the soil, since the environment did not predispose the crop to root infection. However, even in 1986 root rot occurred on some fields with good agricultural characteristics. Riepma (1967) described the same phenomenon. Bad years such as 1987 show that some management decisions, such as sowing on frozen soil or sowing on soils which easily get waterlogged, can greatly increase the occurrence of root rot and consequently infestation of the soil with root rot pathogens. As an example, the DI of test plants grown on soil samples of a field lightly contaminated before the 1987 pea crop increased from 1.5 before to 4.4 after the pea crop.

Characteristics of the bioassay. The bioassay gives an indication of the combined effect of all pathogenic fungi in the soil, and thus is aspecific. However, it is possible to modify the test conditions in such a way that a specific pathogen will dominate. At the start it was known, that *Fusarium solani, Phoma medicaginis* and *Pythium* spp. were the most com-

mon components of the root rot complex in the Netherlands (Schreuder, 1949; IPO, 1960–1970). The purpose of the bioassay therefore was to predict damage by this complex.

In bioassaying soil, high temperature was used by Kobriger and Hagedorn (1983) and saturation followed by drying to wilting point by Sherwood and Hagedorn (1958) to stimulate specific rot symptoms. We did not intervene to stimulate susceptibility of the test plants to specific pathogens. Conditions were created for optimal rooting in the available soil mass. Nevertheless, test plants showed conspicuous symptoms of infection caused by *T. basicola* and *A. euteiches*. It was also noted that the pea cyst nematode, *Heterodera göttingiana*, produced cysts in the pea roots within the test period. A great number of fungus species were identified in infected roots of test plants which corresponded with isolations from field plants (Schreuder, 1949; Riepma, 1952). A great advantage of bioassaying soil is that no seed-borne pathogenic species, such as *Phoma medicaginis* var. *pinodella*, *M. pinodes*, *Ascochyta pisi*, or seed contaminants such as *Fusarium* spp. will be scored if not present in the soil.

In root infections several fungus species are normally present. This explains why the IPS is assessed indirectly as a severity (DI), representing estimated percentages of attack, and not as a quantity of propagules per gram of soil corresponding to a certain percentage infection, as e.g. IPS(50): the number of propagules necessary to reach 50% infection. The latter is advised for individual pathogens (Bouhot, 1979; Rouxel, 1988).

IPS depends on biotic and abiotic properties of the soil (Alabouvette, 1989), which implies that IPS(50) must be substrate/field specific. Relating IPS to a number of propagules and using this number for various soils seems unwarranted.

Practical execution: Sampling. Sampling procedures depend on the distribution of the pathogen populations to be surveyed. In field observations (data not presented) disease patterns were often homogeneous. Observed within-field heterogeneities mostly reflected reparcellation, an old cultural practice among farmers in the Netherlands. Nevertheless we systematically sampled according to a W-pattern, as if the pathogens were clustered (Mihail and Alcorn, 1987). This sampling pattern is not always the most efficient (time, work), but it surely is the safest one. We took a sample every 200 m^2. Headlands were excluded. In comparable research situations one sample per 4000 m^2 has also given good results (Reiling et al., 1960; Olofson, 1967). The more homogeneous the distribution of the pathogen, the less intensive sampling may be. Then large samples instead of a big number of smaller ones give a more representative measure (Johnson and Curl, 1972).

The disease indices of test and field plants proved to be highly correlated. It should be kept in mind that soil sampling for the bioassay and disease rating of the field plants were always carried out in only 1 ha of the most homogeneous part of the field, and both according to the W-pattern. Omitting these precautions in 1988 led to a considerable decrease of R^2, the coefficient of determination; however, the linear correlation was still highly significant.

Test period. A bioassay must combine rapid production of reproducible results with simple procedures. A test period of 5–6 weeks is long and demands much space and labour. Experiments in 1988 have shown that the test period can be reduced by 10 days using early flowering cultivars (Oyarzun, 1991). The idea of using pots with a self-regulating moisture regime, as developed by Wisbey et al. (1977) or Snow and Tingey (1985), combined with tubes which use considerably less soil (Maduewesi and Lockwood, 1976), has been further elaborated into an automatized bioassay system (Oyarzun and Dijst, 1991).

Translation of bioassay results into a message to the grower. In formulating an advice regarding field-dependent root rot risks, cultural practices and other factors which could probably influence disease development should also be taken into account. The relative weight of each factor varies from year to year. This applies to the position of peas in the crop rotation with regard to root diseases and to the equivalence of the most frequently grown legumes as hosts of the root rot pathogens. In the dry year of 1986, the effects of legume frequency in the rotation on root rot were more pronounced than in the wet year of 1987 (Oyarzun and Hoogland, not published). In rainy years, physical constraints of the soil influence plant health to a larger degree. On heavy soils, root rot problems can easily occur due to waterlogging; 48 h of water saturation suffice to induce heavy root rot (Biddle, 1984). These factors are especially important when IPS is light or moderate. According to Rush and Kraft (1986) the effect of stress factors is to reduce the latent period. It is also possible that stress reduces plant resistance to such a degree that a lower level of inoculum potential suffices for the development of disease (predisposition).

Predictive value. The regression line of DIs of bioassay on field can be used to predict the probability of root rot in the crop. A perfect relation has an angle of 45° (1:1 line) and little dispersion. The variability of data and the deviation of the fitted line from 45° depend on the time of disease assessment in the field, the growing conditions of the crop, soil and climate, and on the conditions under which the bioassay is carried out. Pooling the bioassay and crop disease indices for 1986 and 1987, at flowering (Fig. 6), allows calculation

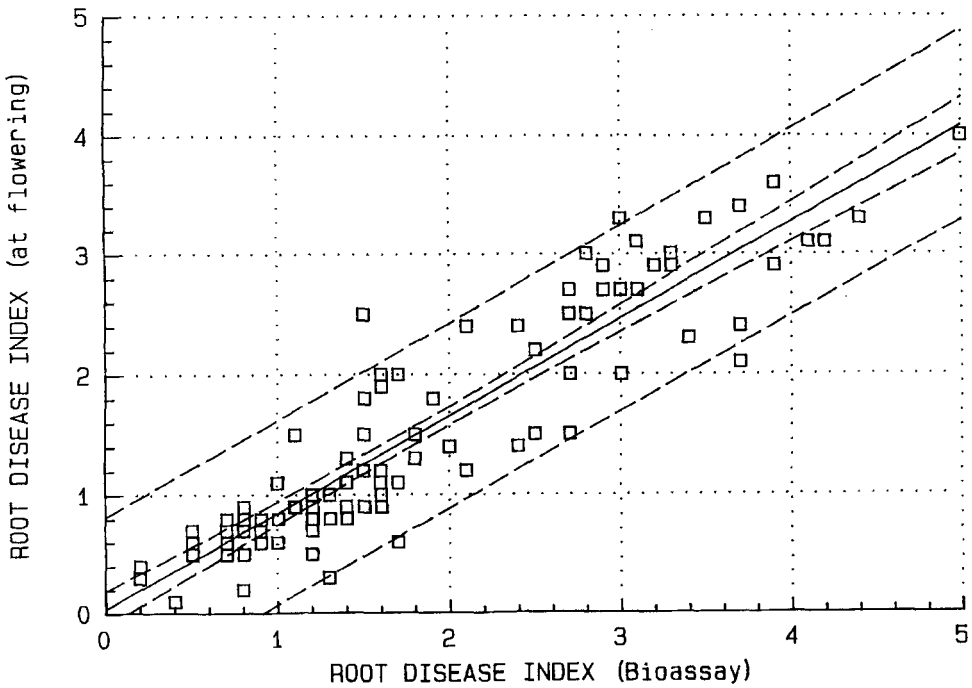

Fig. 6. Confidence interval of the population of regression lines (inner lines) and prediction interval (outer lines) for root disease index of individual field crops at flowering for a given bioassay result.

of a confidence interval for the fitted line and a prediction interval for individual points. In the climatologically extreme years of 1986 and 1987, individual differences with the fitted line on the average were not more than 20% at each point on the 0–5 DI scale (Fig. 6). Erroneous estimates thus seem improbable, but they may occur under extreme conditions. Thus a DI of 1.5 in the bioassay can correspond to heavy root rot in a rainy season. With a DI of >2.5 (root rot severity >50%) it is better to choose another field in all circumstances.

Economical considerations in the formulation of advice. In the Netherlands, pea should enlarge the flexibility of very narrow rotations, in which there are hardly any crops other than wheat, potato and sugar beet. Therefore the net financial result of pea has to be at least equal to wheat, the least attractive main crop. In this comparison, the price ratio pea/wheat and the yield stability of pea are decisive factors. Under favourable conditions, modern cultivars on commercial fields can yield 7 or even 8 tonnes dry seed (14% humidity) per ha (CEBECO, personal communication). On fields with a DI >3 yields of about 3 tonnes per ha were not uncommon.

Conclusions

Three years of field-oriented research have led to the following conclusions:
1. Values of the IPS as determined by a bioassay in pots in the greenhouse fit well with disease intensity in pea crops.
2. Soil sampling and the bioassay itself can be carried out in the autumn preceding the pea growing.
3. With test plants in pots the most common root rot pathogens of pea present in soil are successfully baited.
4. The bioassay produces a measure of the IPS and thus provides an indication of the suitability of a field for growing peas. This information may serve as an instrument in an integrated programme to control root rot.
5. In general the price/cost ratio of peas compared to cereals decides the short-term risk to be taken. In the field, light root rot infections also cause measurable yield depressions. Growing peas on slightly contaminated fields can endanger the long-term continuity of pea production, a risk which may be more important than a slight yield depression.

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