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Relation between cropping frequency of peas and other legumes and foot and root rot in peas

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Abstract

The relation between the frequency of legume crops in a rotation and the root rot severity in pea was examined in a field survey. Additionally, greenhouse experiments were performed with soil samples from legume rotation trials or from farmers' fields. The frequency of pea crops in current rotations proved to be much less than the recommended value of one in six years. The correlation between pea root rot and the number of years that pea or other legumes were not grown on the field under consideration (called crop interval) was weak. Root rot severity correlated better with the frequency of peas or legumes in general over a period of 18 years, but the frequency still explained only a minor fraction of the variation in disease index. Some experimental data pointed to the occurrence of a highly specific pathogen microflora with continuous cropping of only one legume species, but this phenomenon probably does not occur in farmers' fields. In field samples, root disease index for pea correlated well with that for field bean. The survival of resting structures of pathogens such as *Aphanomyces euteiches* probably explains why the frequency of legume cropping has a higher impact than crop interval on root disease incidence. Pea-free periods and legume frequencies have a poor predictive value for crop management purposes.

Additional keywords: soil pathogens, dwarf bean, *Phaseolus vulgaris* L., field bean, *Vicia faba* L., *Pisum sativum* L., *Aphanomyces euteiches*

Introduction

Due to their susceptibility to the attack by soil-borne pathogenic fungi, peas are known as a self-intolerant crop (Schreuder, 1949). In a recent paper (Oyarzun et al., 1993) we described the pathogenic fungi involved in pea foot and root rot (in this paper simply indicated as root rot). We also discussed aspects of physiological specialization of some of these fungi.

The changed situation in the 1980s, with growing acreage of pea, new cultivars and new cultural practices, asked for attention to the place of pea and related crops in the rotation with regard to the development of root rot diseases in pea. In the Netherlands, one pea crop in a 6-year (1:6) rotation is considered desirable agronomically (Achterstraat and Bouman, 1972; Timmer et al., 1989), but this view certainly needs further clarification. Studies relating root rot diseases in pea to crop rotation are scarce. Salt and Delaney (1985) cite Jones and Linford (1925), who stated that severe root rot develops after four consecutive cycles of pea growing. A comparable phenomenon was observed by Huiskamp (1987). These statements imply that rotations of more than 1:6 would not immediately lead to severe root rot development. However, the rate of increase of disease pressure in soil is not exclusively a function of cropping frequency. Normally, seed quality (Van Loon and Oyarzun, 1988), crop variety, soil type (Temp and Hagedorn, 1964) and soil structure (Smucker and Erickson, 1987) interfere with the level and activity of pathogenic fungus populations in soils. Further, pathogens greatly differ in production of types and number of survival structures and thus in the number of host-free years they can bridge (Wallen et al., 1967; Kraft et al., 1974). Probability of disease outbreaks by *Phoma medicaginis* var. *pinodella* or *Mycosphaerella pinodes* on pea after an interval of 5 years are considered nil by among others Sherf and Macnab (1986) and Sheridan (1973). Wallen et al. (1967) demonstrated the presence of pathogenic strains of *M. pinodes* in soils even 20 years after the last pea crop. Kraft et al. (1974) reported outbreaks of *Fusarium oxysporum* f. sp. *pisi* race 1 in a field when a susceptible variety was grown again after a period of 40 years.

In the current paper we examine the contribution of crop frequency and number of years without either pea or other legume crop (hereafter called 'crop interval') to the severity of root rot disease in pea crops. The results of a field survey conducted between 1985 and 1987 will be discussed. Field observations are complemented with results of crop rotation experiments.

Materials and methods

Field survey (1985–1987).
Normally, crop interval (number of years between consecutive pea crops) and crop frequency are unequivocally related. In practice, where technical or economical constraints dominate agricultural activity, these criteria may diverge. In order to test the possible relation between root rot in peas and the crop interval or the frequency of legume cropping, 46 fields were sampled in 1985, 48 in 1986 and 51 in 1987. In 1987, 24 extra fields, with a known frequency of legumes, were assessed at flowering. The fields were in the traditional pea-growing areas of the Netherlands, i.e. in the North and the South. Various soil types were represented in the survey, with heavy clay predominant in the North, whereas clay and loam to sandy loam were typical in the South. Of each field only one hectare was investigated. Legumes were represented by peas (*Pisum sativum* L.), dwarf beans (*Phaseolus vulgaris* L.) and lucerne (*Medicago sativa* L.); field beans (*Vicia faba* L.) were not found in the rotation of the fields.

The degree of root rot in crops was assessed at different times during the growth period. Root rot assessments discussed in this paper were made on 1 ha per field, at flowering. Groups of 5 plants were sampled at 10 sites along a W-path through the field, 50 plants per field. Roots were dug up to a depth of 20–25 cm, carefully cleaned from soil, and washed before disease assessment. Root disease index, used as a measure of root rot severity, was scored on a scale of 0–5, with 0 for healthy roots and 5 corresponding to 100% rotten roots of dead plants. For details see Oyarzun (1989).

The data of this survey were analyzed using GENSTAT 5 facilities. (Multiple) regression analysis and linear or higher degree models were tested. Disease index (0–5) was sorted out in disease classes and fields were arranged in histograms according to their index value.

Greenhouse and laboratory experiments.
Between 1985 and 1986, complementary studies on the relation of crop frequency and root rot severity were performed with bioassays in pots. Results of bioassays proved to be well correlated with the intensity of root disease in pea under field conditions (among others, Sherwood and Hagedorn, 1958; Olofson, 1967; Biddle, 1984).

Soil samples were obtained from field experiments at the Research Station for Arable

Farming and Field Production of Vegetables (PAGV) at Lelystad. PAGV fields consist of a deep, calcareous clay soil (pH KCl = 7.7; $CaCO_3$ = 7.2%) with a moderate content of organic matter (2.8%).

In other cases samples were obtained from commercial fields.

Per field a soil sample was composed by mixing 50 cores, taken to 25 cm depth, and passed through an 8-mm mesh sieve to standardize aggregates. Relations between water content and matric water potential of soil samples were determined on a pF-device.

In 1979, a single field experiment was started at PAGV to monitor yield and diseases of peas, field beans, and dwarf beans in continuous culture (CC–). Samples from these treatments are coded as CCP, CCF and CCB respectively. In 1982, a field experiment was started with the vegetable type of the three legume species in a rotation of: potato – legume – sugar beet – legume – spring wheat – legume. The same legume was grown on the same plot in consecutive years. Soil from these plots is coded as AR.

Fields where only two vining pea crops (CA8) or one crop of field bean or dwarf bean (ECC) had been grown since land reclamation were also included. Except on CA8 (last peas in 1982/83), soil samples were taken after the harvest of the legume crop.

Experiment 1. Frequency of legumes. In 1985, after seven (CCF and CCB), two (AR) and one (ECC) crop of field bean and dwarf bean the plots were sampled and bioassayed. In the winter 1986/87, a bioassay was performed with samples from AR plots after two crops of pea, field or dwarf bean. Five additional bioassays were performed with CA8 samples and nine with CCP.

Ten seeds of the cultivar Finale treated with Thiram (1.5 g a.i./kg) were sown at a depth of 4 cm in 2.5-l pots; five pots per soil sample. The pots were incubated at 20/15 °C day/night temperature and soil moisture was kept at field capacity, approx. 26% (g/g) at a density of 1.2 (g cm^{-3}), by daily replenishment. At the green flowerbud stage plants were harvested, roots washed and assessed for root rot severity. For details, see Oyarzun (1989).

Experiment 2. 1987. The ability of the specialized microflora of 'continuous culture soil' to induce root disease on other legumes was studied. For a number of different legumes – dwarf bean, pea, field bean, lupin (*Lupinus luteus* L.), lucerne (*Medicago sativa*) and white clover (*Trifolium repens* L.) – development of root rot was determined after 6 weeks growth in soil from fields which had been cropped for 8 consecutive years with pea, dwarf bean or field bean (CCP, CCB and CCF respectively). Test crops, in four replications, were randomly allocated to each soil sample. The methods and growth conditions in this experiment were the same as described above.

Experiment 3. 1987. Since field beans were not grown in the commercial fields sampled, soil samples from 13 pea fields, with a known variation in inoculum potential of pea root rot (Oyarzun, 1989), were assayed with field bean, cv. Alfred, and pea, cv. Finale. Five pots were used per soil sample and sown with five seeds per pot. Method and experimental set-up were as in Experiment 1. Root disease indices were assessed at flowering and compared.

Experiment 4. A series of ten soil samples, from different parts of the Netherlands and with a varying crop interval of pea, was especially examined for the presence of *Aphanomyces euteiches*, a pathogen known for its long survival as oospores, especially in the organic soil fraction (Mitchell et al., 1969). The soil samples were separated in an organic and an inorganic fraction by wet-sieving. Unsieved soil and small quantities of the organic and inorganic fractions were used to cover the root of pre-germinated pea of approx. 4 cm long, in Petri dishes. The soil was brought to saturation and the plants incubated for 8 days at 26 °C in darkness. Yellow brown softrot and the presence of distinct oospores in root tissue indicated the presence of *A. euteiches*.

Results

Field survey (1985-1987)
Notwithstanding the fact that the fields were in the traditional pea growing areas of the Netherlands, more than 60% had a pea-free interval longer than 5 years. Frequencies of just one or two legume crops in 18 years were most common (Fig. 1). The crop immediately preceding the pea was a cereal in over 50% of the cases; sugar beet preceded peas in nearly 30% of the fields, and potatoes or other crops in less than 20% (Fig. 2). The disease intensity showed no relation to the crop species immediately preceding the pea crop (χ^2, n.s.), as illustrated in Fig. 2.

Fig. 3 shows that severe root rot still occurred after a very long interval (longer than 9 years), whereas healthy crops on fields with a relatively short pea interval (0–4 years) were no exception. The correlation of the interval and the disease index was rather poor. Only for 1986 did the correlation reach any significance, but even then the length of interval only explains 4% of the variance in root rot (R^2; $P < 0.05$, Table 1). In the very wet years of 1985 and 1987 no significant correlation was established.

Regression analysis produced a poor but significant correlation between the frequency of legume (including peas) cropping over a period of 18 years and the development of root rot in dry peas (adjusted $R = 0.30$, $n = 169$, Table 1). The linear correlation of the root rot severity with the frequency of all legumes was slightly lower than for the pea frequency alone ($R = 0.30$ and 0.35 respectively; $n = 169$). Multiple regression analysis yielded a small increase in the quality of root rot severity prediction (variance accounted for increasing from 11.7% to 13.5%) when the pea frequency and interval were added to a linear model. Higher degree models did not improve the relationship.

When grouping the fields according to both legume cropping frequency and severity of

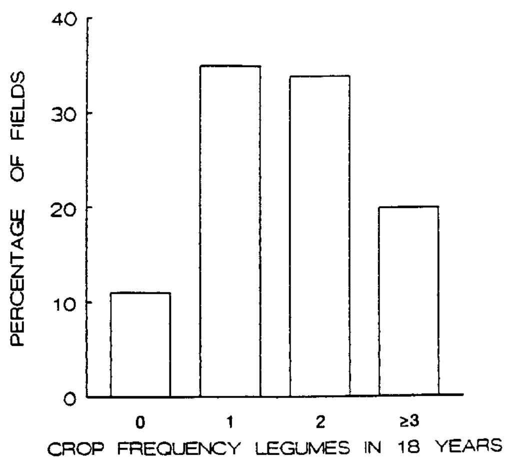

Fig. 1. Percentages of fields with different frequencies of legume crops over the last 18 years. Field surveys 1985–1987.

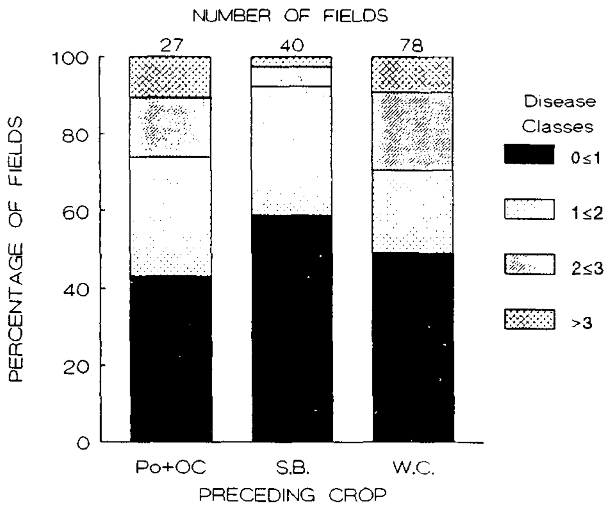

Fig. 2. Percentages of pea fields per disease class according to the root disease index (0–5) at flowering and to the crops immediately preceding pea. Field survey 1985–1987. Po + OC= potatoes and other crops; S.B.= sugar beet; W.C.= winter cereals.

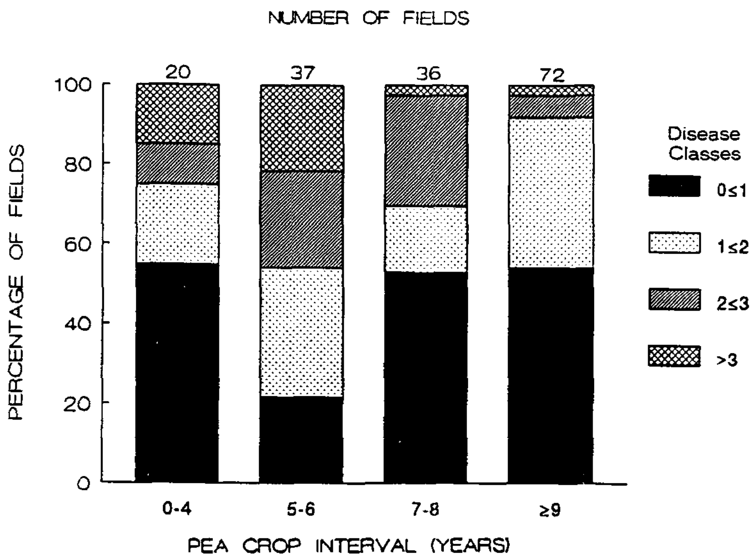

Fig. 3. Percentages of pea fields per disease class according to root disease index (0–5) at flowering and the lengths of the pea crop interval. Field surveys 1985–1987.

root rot in the crop at flowering, a shift to higher root disease indices with increasing cropping frequency was observed ($\chi^2 = 23.4$, df = 9, $P < 0.001$, Fig. 4). But even with a frequency of legume cropping of $\geqslant$ 3 in 18 years, field crops were evenly distributed over the root disease classes. The chances of obtaining either a healthy or a severely damaged crop seem to be equal.

Table 1. Field surveys 1985–1987. Correlation coefficients of root disease index of peas and pea interval (I), frequency of pea crops over 18 years (pea/18y) and legume frequency over 18 years (leg/18y). Figures per year, and for three years combined. (The percentage of variance of root rot indices explained by the length of pea interval combined with the cropping frequency is based on R2–adjusted.)

Factor	Year and number of fields							
	1985 (46)		1986 (48)		1987 (51)		1985–1987 (169)[a]	
	%Var	R	%Var	R	%Var	R	%Var	R
Interval	ns	ns	4	–0.25*	ns	ns	8	–0.29***
pea/18y	12	0.37**	10	0.35**	4	0.23*	12	0.35***
leg/18y	9	0.35**	9	0.32*	ns	ns	9	0.30***
I + pea/18	9	0.36**	9	0.35**	2	0.24*	14	0.38***
I + leg/18	7	0.33*	15	0.46***	ns	ns	13	0.38***

ns = not significant; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.005$.
[a] Including 24 supplementary fields.

Greenhouse and laboratory experiments
Experiment 1. Table 2 shows a low and similar degree of root rot in soil samples after continuous field and dwarf bean. Frequency of the crop did not affect the level of root rot significantly ($P > 0.05$, $n = 24$). In 1987, the root disease indices obtained in samples from AR fields were low and independent of crop effects ($P > 0.05$, $n = 18$).

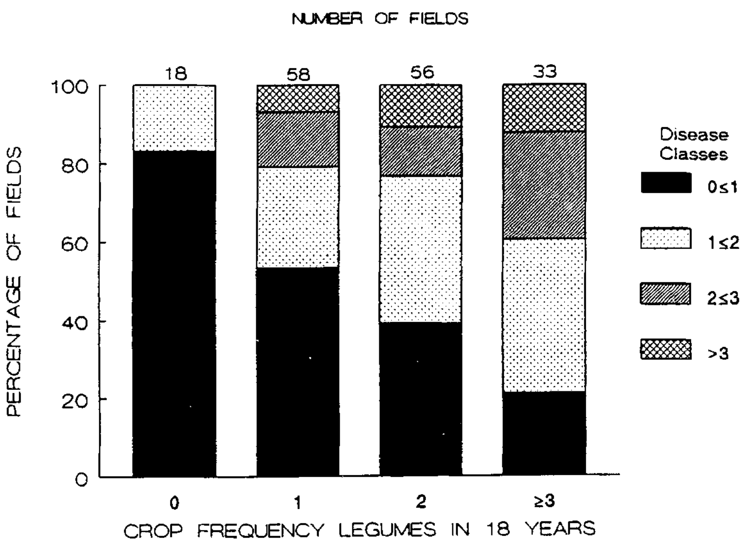

Fig. 4. Percentages of pea fields per disease class according to the root disease index (0–5) at flowering, and the frequencies of legumes in the rotation during a period of 18 years. Field surveys 1985–1987.

On soil sample CA8, with only two preceding vining pea crops, the mean root disease index was higher than on CCP ($P < 0.05$) with 7 years of continuous pea growing. This contrasts with the low DI after two pea crops on AR.

Experiment 2. Table 3 shows a similar infection pattern for peas on CC-samples as in Experiment 1. Root rot was most severe for plants on soil with a cropping history of the same species. Field beans on a soil sample with continuous cultivation of this crop showed a much lower root disease index than peas and dwarf beans on their respective continuous cropping soils. Lupins were never severely attacked. Lucerne and white clover, which were still in the vegetative phase at the moment of assessment, remained free of disease and were not included in the analysis.

Experiment 3. When the development of root rot was assessed for both peas and field beans, a significant positive correlation ($r = 0.67$; $n = 13$, $P < 0.05$) was observed (Fig. 5). If the aberrant point (1.2, 3.2) was excluded from the analysis because of its high deviation, correlation clearly increased ($r = 0.81$; $n = 12$, $P < 0.001$).

Experiment 4. Table 4 shows that *A. euteiches* survived for a considerable period. Even after 9 years without pea the pathogen was still viable, and its presence could be demonstrated in the organic and inorganic fraction of the soil. The only one sample with an interval of over 10 years had a lower root disease index than all but one of the other samples.

Table 2. Mean root disease index (DI: 0 = healthy; 5 = dead) of peas on soil samples from fields (CC–, CA8, AR, and ECC) with varying cropping frequencies of pea, faba bean and phaseolus bean, over a period of ten preceding years.

Frequency (10 years)	Pea	DI	Faba bean	DI	Phaseolus bean	DI
7	CCP[a]	3.0	CCF	1.0	CCB	0.6
2	CA8[a]	4.0	AR	0.7	AR	1.4
1	ECC	–	ECC	0.1	ECC	1.3
2b	AR	1.4	AR	1.0	AR	1.1

[a] Mean root disease calculated from several bioassays. *T*-test indicates means differing significantly ($P < 0.05$).
[b]1986/87 experiment; the other assessments were made in 1985/86.
– not performed.

Table 3. Mean root disease index (DI: 0 = healthy; 5 = dead) of different legumes grown for 6 weeks in pots with soil taken from fields with a cropping history of eight consecutive years of peas (CCP), dwarf beans (CCB) and field beans (CCF).

Soil code	Pea	Dwarf bean	Field bean	Lupin	Lucerne	White clover
CCP	3.8	0.8	1.3	0.5	0.0	0.0
CCB	1.0	3.4	1.0	0.4	0.0	0.0
CCF	0.8	1.5	1.9	0.4	0.0	0.0

For all comparaisons LSD: 0.47 ($P = 0.05$). Data on lucerne and white clover not included.

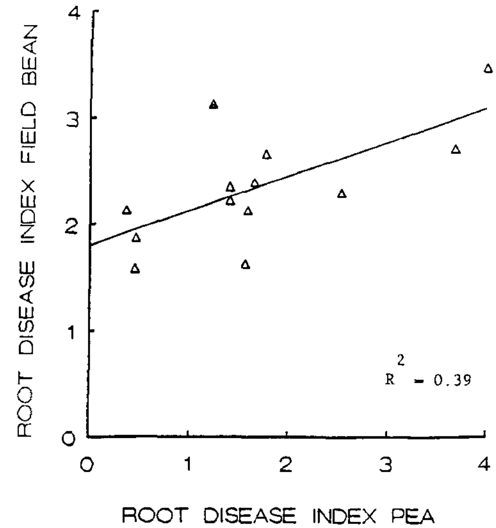

Fig. 5. Correlation between root disease indices of pea and of field bean. Experiment 3.

Table 4. Root disease index of peas (DI: 0 = healthy; 5 = dead) grown on soil samples from fields with pea intervals (years) of increasing length and the presence of *Aphanomyces euteiches* in different soil fractions.

Pea interval	Soft rot DI	Soil fraction		
		Unsieved	Organic	Inorganic
0	3.5	+	+	+
4	3.7	+	+	–
6	5.0	+	+	+
6	3.0	+	+	+
6	3.1	+	+	+
8	3.1	+	–	–
9	1.5	+	–	–
9	3.0	+	+	–
9	3.3	+	+	+
14	1.6	+	–	–

+ = Oospores of *A. euteiches* present in roots; – = *A. euteiches* not found.

Discussion

The data illustrate the low predictive value of the pea crop interval in relation to root rot inoculum potential in fields. In practice, the mere length of the interval gives little information about the suitability of a field for pea growing. In pots, root rot was significantly ($P < 0.05$) more severe on CA8 samples, 2 years after the last pea crop, than in soil samples from continuous pea for 7 years (Table 2).

The value of a 6-year pea rotation can be ascribed to a combination of delayed build-up and exhaustion, in non-host years, of root rot pathogens which keeps damage within economically acceptable limits. The limitations of the interval criterion are illustrated by the slow breakdown of survival structures of many pathogenic fungi, of which *A. euteiches* is a striking example. Under field conditions oospores can survive a period of 20 years without a pea crop and still retain their virulence (Sherf and Macnab, 1986). The frequency of pea growing over a certain period was slightly better correlated (Table 1) with the level of root rot in pea in the field (% variance accounted for = 11.7, n = 169) than crop interval (% variance accounted for = 8.2). But clearly these low values make interval and frequency of limited use as predictor of root rot for practical purposes.

Results of the experiment with soil from the continuous cultivation fields of specific legumes are in accordance with the well established fact that peas and beans do not support continuous culture. The results also pointed to some specificity of each crop's pathogenic microflora, implying specialization of pathogenic species (Oyarzun et al., 1993). This suggests that growing another legume crop in rotations in which one legume dominates, has a phytosanitary value somewhat comparable to unrelated crops in the rotation. However, in practice, when different legumes are regularly grown in a rotation, populations of pathogens might accumulate potential against more than one crop. The fair degree of correlation of the root rot severity with the frequency of peas or legumes in general (Table 1), and the good correlation between root rot disease indices of field bean and pea root rot on soils which had a history of pea growing only (Fig. 5), are warnings that in practice one should not rely too much on the 'favourable' effect of specialization of pathogens. It is but of limited use to distinguish between the different legume crops from the point of view of planning crop rotation.

It became apparent during the survey that current infestation levels of the soil (measured as disease severity on field and test plants) were as much a characteristic of a specific field as of a crop rotation (see e.g. the high DI after only two pea crops on CA8, but not on AR, Table 2). This field effect corresponds with results published by other workers such as Curl (1963), Burke and Hagedorn (1968) and Zerlik (1979). Interactions between field characteristics and the rate of increase of soil infestation have been known for a long time (MacMillan, 1919; Walker and Snyder, 1934). Suppressive and conducive soils to plant disease have been well recognized (Baker and Cook, 1974), but many different names have been used to describe this phenomenon (Huber and Snyder, 1982). The concept of soil receptivity has been proposed (Alabouvette et al., 1982; Bouhot and Joannes, 1983) to account for modulating effects of the soil biotic and abiotic environment on inoculum potential. Build-up and breakdown of soil-borne pathogen populations do not only depend on growing a susceptible host or not, but also on the biological, chemical and physical properties of the soil in which the crops are growing.

More research is needed to deepen the knowledge about the role of the soil in limiting root diseases in peas (Oyarzun and Dijst, 1991).

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