N.Z. Agronomy Society
Special Publication No. 6

Paper 9

ROOT ROT AND SOIL COMPACTION PROBLEMS OF PEA CROPS

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INTRODUCTION

This paper deals with two elements of the root environment of peas which directly affect their health and function. The first is root rot and its causal pathogens; the second involves the physical properties of the soil, and how these may change, through compaction, to disadvantage root growth and development.

The root rot problems of peas are divided into two main types, the first caused by the fusarium root rot complex, and the other due to infection by *Aphanomyces euteiches*. These will be described individually, along with the conditions under which infection is likely to occur, and methods for control.

The changes which occur in the soil as a result of compaction are outlined, and their effects on growth and development of pea roots and pea yield are described.

The main aim of this paper is to provide a simple basis for understanding what can occur in the root zone as a result of compaction. Methods for alleviating mechanical impedance and compaction in the soil will be discussed briefly.

FUSARIUM ROOT ROT

Fusarium root rot is caused by a complex of soil borne pathogens, predominantly *Fusarium solani* f. sp. *pisi. Phoma medicaginus* var. *pinodella (Ascochyta pinodella), Thanatephorus cucumeris (Rhizoctonia solani)* and *Thielaviopsis basicola,* other *Fusarium* spp., and *Pythium* spp. have been associated with *F. solani* as members of the complex. (S.A. Menzies, pers. comm.; D.J. Hagedorn, pers. comm.).

In 1955, fusarium root rot was reported to be present in pea crops in Canterbury, Marlborough, Hawkes Bay and Auckland, but was considered of minor importance (Brien *et al.,* 1955). However, it has since been identified as a serious problem in parts of Hawkes Bay. (Ivey and Parker, 1975, 1976) and in areas of Canterbury, Marlborough and Nelson with long histories of pea cropping (unpublished data).

Serious problems with fusarium root rot are more frequently encountered during hot dry seasons, when high soil temperatures favour infection and the development of the pathogen (Hagedorn, 1984). Close rotations, compacted soil and low soil fertility also increase the likelihood of infection.

Early symptoms of fusarium root rot include reddish-brown streaking of the roots about the cotyledon attachment point. This develops into a dark lesion encircling the roots and epicotyl as the streaks coalesce. The roots become shrunken and constricted by the lesions, and the vascular tissue in this region acquires a red discolouration. When root rot is advanced, the roots become blackened and weak, and frequently disintegrate when the infected plants are lifted from the soil. Infected areas in crops may appear to be quite healthy, then collapse suddenly, especially if hot dry weather occurs during pod fill when pea plants are particularly susceptible to moisture stress.

Partial control can be achieved by chemical seed treatment, plant resistance, wide rotation, and management to alleviate root and moisture stress, as will be discussed later. In areas of Hawkes Bay known to be infected with fusarium root-rot, profitable yields have been achieved by treating seed with Carbendazim fungicide before sowing (R.E. Parker and I.D. Ivey, pers. comm.). Avoiding growing highly susceptible cultivars like Canterbury 39 in infected locations or during high risk periods also reduces chance of crop loss.

Plant tolerance to *Fusarium solani* f. sp. *pisi* is known but resistant cultivars are not yet available in New Zealand. There is a breeding programme for fusarium root rot resistance being conducted at Crop Research Division of the Department of Scientific and Industrial Research (DSIR) in conjunction with Plant Diseases Division of DSIR but progress has been hampered by the lack of a simple and effective system by which resistant lines can be identified.

APHANOMYCES ROOT ROT

Aphanomyces root rot of peas is due to infection of pea roots by *Aphanomyces euteiches.* In New Zealand, aphanomyces root root was first detected in the 1977-78 season in the Nelson region and subsequently in Canterbury (Manning and Menzies, 1980), Hawkes Bay, Horowhenua (Manning and Menzies, 1984) and Marlborough (D.J. Hagedorn, pers. comm.).

Infection can occur at all temperatures conducive to pea growth, but the optimum is 16°C, with symptom expression occurring more rapidly at warmer temperatures (Hagedorn, 1984). High soil moisture also increases infection, as the organism has a motile zoospore stage, whose dispersal is assisted by free water in the soil. High levels of infection therefore frequently coincide with wet seasons, and flooding, as occurred in Nelson and Marlborough in the 1983/84 season, probably contributes greatly to dispersal of the pathogen. Seasons with a cool wet spring and a warm dry summer favour severe infections of aphanomyces root rot (Hagedorn, 1984).

The symptoms of aphanomyces root rot include a watersoaked, "honey coloured" lesion on the root and stem base, stunting and yellowing of the plant, and eventual wilting and death in severe cases (Hagedorn, 1976). Often when infected plants are pulled from the ground, the cortex sloughs off in the soil, revealing a naked stele.

No resistance is presently available, although lines with some field tolerance are being developed in the U.S.A. (J. Kraft, pers. comm.) and were grown in N.Z. over the 1985/86 season.

Work by the DSIR and Lincoln College has shown that the incorporation of brassica leaf material into *Aphanomyces euteiches* infected soil can reduce the level of inoculum, and lower the disease severity index (Chan, 1985). Some research has also indicated that incorporation of dinitro herbicides (e.g. Treflan) may reduce spread and infection by *Aphanomyces euteiches* by inhibiting the development of the motile zoospore phase, but this is not considered an effective control (Hagedorn, 1984).

Currently, the only effective control is to have prospective pea fields indexed for disease potential, and avoid those with moderate or high infection potentials. *Aphanomyces* populations increase very rapidly when peas are planted in infected soil, but inoculum decrease is very slow, even in the absence of peas (Hagedorn, 1984). A number of other legume crops are also hosts, including *Phaseolus* beans, lentils, lucerne (Hagedorn, 1984) and white clover (J.W. Ashby, pers. comm.). Soil testing for *Aphanomyces* inoculum severity is currently conducted by the Ministry of Agriculture and Fisheries.

EFFECT OF SOIL COMPACTION ON PEAS

Soil compaction is the process by which soil particles are re-arranged under compression, causing a reduction in pore space and an increase in soil bulk density (S.B.D.). The larger pore spaces, which have less mechanical strength, are most susceptible to destruction during compaction (Russell, 1977). The causes of soil compaction, as listed by Bowen (1981) are:

- Natural consolidation during soil formation.
- Trampling by animals, including humans.
- Natural shrinkage of soils upon drying.
- Pressures and deformations imposed by wheels, tracks and soil engaging tools.
- Overburden and water droplets on water weakened aggregates during rainfall and irrigation.

Compaction leads to increased soil strength and hence mechanical impedence to roots. The gaseous and moisture exchange properties of the soil may also be changed significantly.

Pea plants gain support, nutrients, oxygen and moisture from the soil through their roots. It is mainly from the larger pore spaces that roots obtain these, hence the changes in the physical properties of the soil which occur with compaction can significantly alter root growth and development. Pore spaces also provide a sink for material displaced by expanding roots during elongation. Mechanical impedance to root growth by compacted soil will occur if the pore size is less than the diameter of the extending root cap, and if soil strength prevents displacement of soil particles by the growing root (Russell, 1977; Bowen, 1981).

When elongating axial roots encounter pore spaces too small for penetration, thinner lateral roots develop, and a branching network of secondary and lower order roots results. A root system like this is shallow in nature, with a small proportion of the total root mass occupying deeper regions of the soil profile (T. Webb, pers. comm.).

The effect of compacted soil and a restricted root system on plant growth and crop yield depends on other factors. Root mass, in fact may not be greatly reduced, although the accessible soil volume will be much smaller. If adequate moisture, nutrients and aeration are maintained in the root zone, normal growth and yield may be expected. The plants are more susceptible to drought and moisture stress, however, and the increase in soil strength under dry conditions may intensify compaction (Bowen, 1981) and further limit root growth to new areas, higher in nutrients and soil moisture.

Several studies have been conducted to determine the direct effect of soil compaction on pea growth and development. Pea seedlings were grown in pressure cells in a growth chamber for 7 days, and root elongation and nutrient uptake were reduced in seedlings grown in soil subjected to mechanical stress (Castillo *et al.*, 1982).

When bulk density was increased from 1.16 g/cm3 to 1.28 and 1.38 g/cm3, root length decreased 42% and 87% respectively. Root weight, however, was only decreased at the higher S.B.D. The application of confining stress to the soil also reduced uptake of potassium, magnesium and calcium.

In England, soil compaction was found to reduce emergence of vining peas, and hence final plant density. Vining pea yield was reduced up to 50% by compaction, mainly because the plants which emerged were unable to compensate for the reduced population. The dry weight of pea plants was also approximately halved, with the peas growing in compacted soil having smaller leaves and stems, and fewer flowers (Hebblethwaite and McGowan, 1980).

Further work revealed similar responses, but with vining pea yield decreased by up to 70%. (Dawkins *et al.*, 1984). Results from different sites and over different seasons were not consistent, however, and some compacted treatments in one trial yielded at least as well as the controls. Again, it was concluded that the reduction in plant population and inability to compensate for such were the major factors contributing to reduced pea yield (Dawkins *et al.,* 1984).

This work indicated that soil moisture relations can modify the effect of compaction on pea yield. Under moist conditions, emergence and plant growth was virtually unaffected by soil compaction, hence no yield decrease occurred. Soil compaction also influences the moisture and gaseous exchange properties of the soil, however, and soil water relations. Because compacted soil has fewer and smaller pore spaces, water movement is restricted, the soil is prone to waterlogging, and anaerobic conditions develop with carbon dioxide, which is highly soluble in water, rapidly accumulating (Russell, 1977).

EFFECT OF WATERLOGGING AND ANOXIA ON PEA YIELD

Studies at the Letcombe Laboratories, England, have shown that the soil oxygen level near the roots of waterlogged peas drops rapidly after the onset of waterlogging. Soil oxygen content by volume dropped from 20.8% to under 1% after 24 hours, and to 0.5% after 3 days. The carbon dioxide level was also measured, and found to increase from normal atmospheric levels of about 0.03% to over 10% in 3 days (Jackson, 1979. Fig. 1).

Soil oxygen concentration is critical to the rate of radicle elongation of germinating pea seedlings (Eavis, Taylor and Huck, 1971). The growth and yield of peas are most severely reduced when oxygen deficiency and waterlogging occur just before or at flowering, although waterlogging at vegetative and post flowering stages also decreases yield (Eriuckson and van Doren, 1960; Belford *et al.,* 1980; Cannell *et al.,* 1979).

The flowering and pod filling stages have often been cited as the most appropriate growth stages for application of irrigation (Salter and Goode, 1967). However, if moderate to heavy rain follows irrigation, the likelihood of waterlogging, especially in a compacted or poorly drained soil is quite high (Greenwood and McNamara, 1987).

The duration of waterlogging also has a critical effect on the amount of damage caused by a waterlogging event (Table 1) (Jackson, 1979; Cannell *et al.,* 1979. Greenwood and McNamara, 1985).

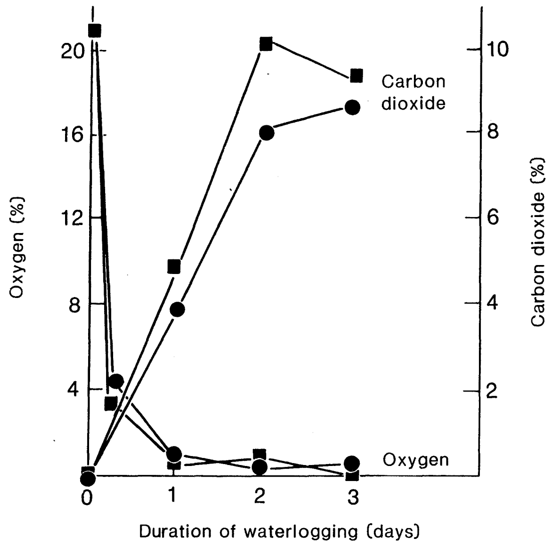

Figure 1. Concentration of oxygen and carbon dioxide during 3 days waterlogging of pea plants at the two- to three-leaf stage (●), or the nine- to ten-leaf stage (■). (From Jackson, 1979).

Table 1: Effects of waterlogging the soil on pea plants at the nine- to ten-leaf stage (from Jackson, 1979).

	Duration of waterlogging (days)				
	0	1	2	3	4
Final fresh weight (g)					
Stems and leaves	5.88	5.35	2.88a	2.37a	1.87a
Fruits	8.96	8.34	1.61a	0.53	0.16a
Final dry weight					
Stems and leaves	1.19	0.89a	0.76a	0.96a	0.78a
Fruits	1.53	1.48	0.29a	0.16a	0.06a
Number of leaves per plant					
Total	11.2	10.8	10.1a	9.6a	9.5a
Desiccated	1.7	4.7a	7.7a	8.2a	8.2a
Number of flowers and fruits per plant	3.8	3.4	2.7a	2.8a	2.3a

a Significantly different from non-waterlogged controls (P = 0.05).
Each value is the mean of 12 replicates.
Plants were waterlogged for 1-4 days at the beginning of the experiment and then grown on in well drained conditions until the 18th day when the measurements were made.

EFFECTS OF SOIL CONDITIONS ON ROOT DISEASE

Only one published study carried out in New Zealand has attempted to find any relationship between root disease and soil compaction, but no relationship was found (Shekell, 1984). Several studies have been conducted in North America, however, which are of relevance here.

In Wisconsin, the root rot pathogens *Aphanomyces euteiches* and *Fusarium solani* f. sp. *pisi* were prevalent in the ploughed layer of the soils in which they occurred (Burke *et al.,* 1970). The incidence of aphanomyces root rot was usually related to the amount of *Aphanomyces euteiches* inoculum in the soil, but this was not so with fusarium root rot. *Fusarium solani* f. sp. *pisi* was prevalent in all fields surveyed, averaging from 275 to over 6000 propagules per gram of soil, but there was no definite relationship between population and root disease history. The fields without root rot problems were found to have softer, less dense soil throughout the profile, and roots were able to penetrate below the ploughed layer into uninfected soil beneath.

In eastern Washington, root rot is primarily caused by a complex of *F. solani* f. sp. *pisi* and *Pythium ultimum,* the former being most important (Kraft and Giles, 1979). Subsoiling in root-rot infected fields was found to increase fresh pea yield, and total plant weight, although disease indices and pathogen populations were largely unaffected.

More recent studies in eastern Washington and in northeast Oregon revealed cultivation pans in all of 22 wheat and pea fields surveyed. Tillage practices were found to cause an accumulation of a layer of undecomposed wheat-straw residue immediately above the pan, which favoured the survival of high populations of *F. solani* f. sp. *pisi.* Pea roots, finding difficulty penetrating the pan were therefore restricted to a zone highly infected with this root rot pathogen. An accompanying root rot organism, *P. ultimum* was also abundant in the cultivated soil layer, which further increased the root disease pressure (Kraft and Allmaras, 1985).

Studies in Canada showed that fusarium root rot disease index was linked with S.B.D. (Figure 2), with variations in S.B.D. attributed to differences in tractor contact pressures. Pea yields, however, were not closely correlated with soil compaction (Vigier and Raghaven, 1980). Further work confirmed the relationship between S.B.D. and root rot indices, but found that increases in S.B.D. had a greater effect on green pea yield than did high root rot indices (Raghaven *et al.,* 1982). It was concluded that peas were sensitive to increases in S.B.D. and root rot, but if a soil management programme was effected to reduce S.B.D., the effect of root rot could be greatly decreased.

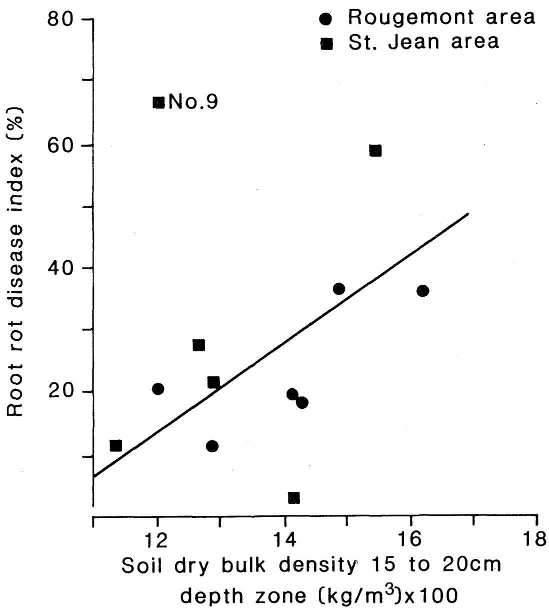

Figure 2. Root rot disease index plotted against soil dry bulk density in pea fields in the Rougemont and St.-Jean areas. Field no. 9 became waterlogged soon after seeding, resulting in high levels of root rot in the surviving plants (from Vigier and Raghaven, 1980).

METHODS FOR ALLEVIATING SOIL COMPACTION.

Bowen (1981), reviewed methods which have been used to reduce the effects of mechanical impedance on crop production, and described four main approaches by which root impedence could be prevented:

- Traffic control.
- Water content control.
- Soil pan shattering by plants.
- Altering soil to reduce mechanical strength.

Four methods to reduce the mechanical strength of soil were described.

- Addition of organic matter.
- Addition of polyelectrolytes.
- Earthworm managment.
- Addition of lime.

Bowen also discussed the use of mechanical equipment to modify impedence zones and improve root and water movement through the soil profile. This included an appraisal of the more common types of tillage equipment used for field cultivation (e.g. mouldboard and disc ploughs) which reduce impedance in the surface horizons of the soil, but create a compacted "plough-sole" immediately below the ploughed layer. The practice of rolling crops can also lead to an increase in S.B.D., especially in the top 0.2m of the soil (Bowen, 1981). Subsoilers and chizel ploughs, rippers and field cultivators are discussed in some detail, particularly with reference to their ability to shatter comparatively large soil masses. Their effectiveness, however, was shown to be affected by how they are adjusted, and the physical properties of the soil in which they are to be used.

An implement which has created interest in New Zealand as a means of reducing soil compaction is the "Howard Paraplow". A study of process pea crops in Canterbury has shown that peas grown in "paraplowed" soil exhibited more rapid root penetration, and a higher root density in the lower horizons than did peas direct drilled into non-paraplowed soil (Shekell, 1984). There was no comparison between paraplowed soil and conventional seedbed preparation as a growth medium for peas.

CONCLUSION

Although pea crops may be attacked by two different types of root rot (the *Fusarium* complex and *Aphanomyces*), and they may be adversely affected by soil compaction and waterlogging, these problems are not insurmountable, and healthy pea crops can still flourish. The effects of the *Fusarium* complex can be lessened by the use of appropriate seed treatments; by avoiding the use of very susceptible cultivars; by alleviating root and moisture stress; and by cropping on wide rotations (i.e. at least 5 years). Crop losses to aphanomyces root rot can also be reduced, mainly by avoiding paddocks with soil tests showing a moderate to high disease potential.

The problems of soil compaction can be reduced either by preventing the compaction process, or by using mechanical implements to shatter compacted zones in the soil and improve soil aeration. The former may be achieved by traffic and moisture control, and by altering the physical properties of the soil to reduce its mechanical strength (e.g. by earthworm management, or the addition of lime or organic matter to the soil). The latter involves the use of subsoilers, rippers, and other pan breaking implements, in addition to the cultivation equipment traditionally used for seedbed preparation.

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