Pine Mortality after Planting on Post-Agricultural Lands in South Africa

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Zwolinski, J.B., South, D.B. & Droomer, E.A.P. 1998. Pine mortality after planting on post-agricultural lands in South Africa. Silva Fennica 32(3): 271–280.

Successful afforestation has been practiced in South Africa for more than a century. Recently, however, problems with afforestation of pines have occurred in the northeastern part of the Eastern Cape Province. Rapid mortality of *Pinus patula* and *P. elliottii* have occurred when small container seedlings were planted on old-agricultural soils. Death would often occur within 5 months of planting. Growth of surviving trees was retarded and new needles were chlorotic and stunted. Acceptable survival was obtained when seedlings were planted on virgin grasslands. Apparently, some unseen factor in the post-agricultural soil reduces root growth, increases mortality, and decreases uptake of nutrients. Removal of the infested soil by scalping greatly improves survival and growth as does soil fumigation with methyl bromide.

Keywords *Pinus patula, Pythium* spp., afforestation, mortality, scalping
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Accepted 1 July 1998

1 Introduction

Commercial afforestation began in South Africa when a plantation was established in 1876 to help provide firewood for the early railroads. Today, plantations cover 1.5 million ha (about 1.2 % of the country's landbase). Both pines and eucalypts are widely planted. Planted pines include *Pinus elliottii, P. patula, P. radiata,* and *P. taeda.* Seedlings are raised in containers and are planted out after approximately four months for eucalypts and six months for pines. In 1992, pines covered about 668 000 ha while *Eucalyptus grandis* covered about 382 000 ha. In 1992, about 28 241 ha of first-rotation sites were established. Most occurred in the Natal region (59 %) and about 22 % occurred in the Cape region.

P. patula has been used as the major commercial pine species in Malawi, South Africa, Swaziland, and Zimbabwe (Poynton 1977). Establishment with this species is typically not a problem on virgin grassland sites or ex-pine sites (Evans 1986, Mwendera 1994). However, an afforestation problem has occurred in the northeastern part of the Eastern Cape Province. The general symptoms observed were lack of vigor and sudden seedling mortality. The problem was limited to the post-agricultural land since failures did not occur on adjacent virgin grasslands.

The problem appeared to be a new situation of which little was known. Experts from various fields were consulted to help solve the problem. Their input helped immensely during the information gathering process. Information was gathered on soil physical and chemical properties, insect, nematode, and fungal populations, and past cultural practices. As information was gathered, ideas about the problem began to emerge. Hypotheses were formulated and tested and a solution was finally implemented. This paper provides an overview of the former problem and summarizes some of the afforestation research conducted in the northeastern Cape.

2 Afforestation Programme

North East Cape Forests (NECF) purchased about 80 000 ha of lands from farmers in the northeastern part of Eastern Cape Province of South Africa. Most of the land (50 000 ha) has been designated for planting pine plantations and to lesser extend for planting eucalypts. Planting permits have been obtained to comply with South African standards for afforestation. The remaining 30 000 ha are retained for conservation purposes, including National Heritage Reserves, protection of wetlands, water courses, and rare and endemic fauna and flora. Of the 50 000 ha designated for tree planting, about 20 000 ha represent agricultural lands where corn (*Zea mays* L.), wheat (*Triticum aestivum* L.) and oats (*Avena sativa* L.) were intensively cultivated. These areas have been termed *old-fields* and the pathological complex associated with these sites has been termed *old-field syndrome*. The 30 000 ha of grassveld, so called *virgin lands*, were used as grazing lands or left unused by farmers.

2.1 Location, Site Conditions and Silviculture

The NECF lands are located near the towns of Maclear, Ugie and Elliot (31° S, 28° E). The plantations are established on the escarpment of the southwestern Drakensberg Mountains, at altitudes between 1160 and 2045 masl. The topography is variable ranging from flat areas on mountain plateaus to steep slopes with rock outcrops. The southern part of the region is drier with only 800 mm average precipitation compared to the northern part which has about 1200 mm. Most rain falls in summer. Temperatures range between –17 to 38° C. Heavy winds with maximum speed of 189 km/h are frequent. Hailstorms occur in summer and snow is common in winter. The soils are derived from sandstone and dolerite. Predominant soil types are Hutton (FAO: Ferralsols and Arenosols), Clovelly (FAO: Cambisols and Ferralsols) and Mispah (FAO: Lithosols). The potential rooting depth is in excess of 1 m on some sites. Rooting depth, however, is restricted on old-fields by plough pans common at depths between 15 to 30 cm.

Ripping was applied with a bulldozer to a depth of 1.2 m on slopes up to 40 % and to a depth of 0.5 m on 40–60 % slopes. A locally manufactured swivel ripper attached to this machine enables perpendicular (i.e. vertical) ripping on steep slopes. Initially, the typical soil cultivation method involved formation of ridges to reduce surface water flow, erosion and to increase water retention on slopes up to 40 %. The ridges were made by placement of 50 cm wide and 20 cm deep topsoil from both sides of the ripping line onto the rip line centre. A 40 cm strip of soil was left between the areas where soil was removed. Seedlings were planted by hand on the ridge tops. Hand pitting was used on steeper areas (40–60 % slopes). Later, hand pitting replaced ridging to improve tree performance after planting. Some seedlings were fertilized with N (9 g), P (14 g), and K (9 g) in a 15 cm radius around the seedling.

The major plantation species are *Pinus patula*, *P. gregii*, *P. elliottii*, *P. taeda*. Eucalypts (*Eucalyptus nitens*, *E. elata*, *E. fastigata*, *E. smithii*, and *E. macarthurii*) have also been established on about 2000 ha but due to desired pulping properties, it was decided to plant pines exclusively. Initially, container-grown seedlings were produced in other parts of the country and brought to the region for planting. Typically seedlings were grown in polystyrene trays at 550/m^2 (cavity volume of 36 cm^3). Frequently, prolonged storage in trays resulted in penetration of roots into container walls and etiolation. Recently, a container nursery was erected to produce about six million seedlings per year. In the field, pines are planted at 1111 trees/ha at a 3m × 3m spacing. Almost all sites were fertilized at time of planting but the type of fertilizer varied depending on site-specific recommendations.

2.2 Symptoms

Symptoms typical of old-field syndrome are widespread mortality and growth suppression of pines during the first few months after planting. The first visible symptom is necrosis of needle terminals after which seedlings rapidly wilt and die. Common symptoms also include poor root development, stunting, lack of apical dominance and necrosis of the growing tip. The symptoms appear to be related to species. *P. patula* was heavily affected while other pine species suffered only occasionally. Thus far, eucalypts do not appear to be affected.

Remarkable differences in tree performance were observed between old-field and virgin lands located on the same site. Boundaries would often be in straight lines and along fence-rows. Well performing trees on virgin sites occurred within a few meters of suppressed and dying trees on old-fields. In many instances, seedling size, origin, planting methods and planting dates were the same for both virgin land and old-fields. Mortality on the old-fields ranged from low (25 % or less) to high (100 %). Many of the sites were repetitively replanted, some up to six times, without obtaining satisfactory stocking. Where stocking was acceptable, tree growth was poor resulting in production losses and suppression of small seedlings by weeds.

3 Research on the Old-Field Syndrome

3.1 Soil Physical Properties

Louw et al. (1994) surveyed the sites and compared physical soil properties between the old-fields and virgin sites. Overall, soils ranging from 10 % to 28 % clay in the topsoil and 13 % to 57 % clay in the subsoil. On sites with good survival and growth, the clay content of the topsoils was slightly lower (18 %) than where bad performance was observed (21 %). Average bulk densities of these soils were 1.39 g/cm^3 and 1.45 g/cm^3, respectively. There was no clear difference in the soils strength defined with a penetrometer. However, the difference in soil strength on the ridge (planting line) and between the ridges was higher on sites with poor growth. On various sites penetrometer soil strength exceeded a value of 2000 kPa at a depth of 20–30 cm. In addition to higher soil strength in the topsoil of old-fields, bigger more numerous clods occurred on the plowed land than on virgin land. Clods were formed mainly during ripping operation and therefore were concentrated in the planting zone (Smith and Van Huyssteen 1992).

Soil instability was tested by taking topsoil samples from old-fields and virgin sites. The samples were dried and then wet-sieved on a 250 µm sieve to brake down unstable aggregates. After weighing, the aggregates were dispersed in an ultrasonic water-bath and the amount of sand left behind on the sieve was determined. After wet-sieving, the virgin topsoil contained eight times more water stable aggregates (by weight) than old-field topsoil.

3.2 Scalping

The original method of soil cultivation involved ripping and then formation of ridges by incorporation of topsoil into a planting bed. Seedlings were planted on the top of the ridge (or bed). Since the method produced very poor results, scalping (removal of a 1 m wide strip of topsoil, 10–15 cm deep) was introduced. Scalping is beneficial in solving a similar problem in post-agricultural fields in Florida (Barnard et al. 1995). The scalping produces an opposite result to ridging. With ridging, topsoil is moved toward the planting spot and over the ripped line. Seedling roots have to travel through the disturbed soil before entering undisturbed topsoil and finally reaching the B-horizon (which often has higher moisture levels than ridges). With scalping, the topsoil is moved away from the planting spot and seedlings are often planted directly into the B-horizon, closer to wetter soil. Scalping moves pathogens associated with the topsoil away from the planting spot as well as providing some measure of weed control. Under drought conditions in North America, scalping increased soil moisture and improved survival of pines (Stransky 1961, Stransky and Wilson 1966). The negative side of such site preparation is that nutrients in the topsoil are also moved away from the seedling. However, applying nontoxic fertilizers has helped mitigate this disadvantage (Little et al. 1994).

3.3 Soil Nutrient Status and Fertilization

Analyses of soil nutrient elements on a range of sites representative to virgin and old-fields were performed by De Ronde (1992). Overall, there were no significant differences ($p<0.05$) between virgin and old-field soil organic matter (1.8 %), CEC (3.6 me/100 g) and soil acidity (pH 5.2). However, differences were detected for macro nutrients. Nitrogen, potassium, and magnesium were greater on the virgin soils but phosphorous and calcium were greater for the agricultural fields. On some productive virgin grasslands, soil acidity was as low as pH 4.3 (Nobel and Schumann 1993).

N fertilization of old-field sites has repeatedly improved pine growth (Schumann et al. 1994). For example, in one study, fertilizers (primarily nitrogen and phosphorus) increased first-year heights by 22 cm (Little et al. 1994). Fertilization at time of planting often eliminates the symptoms of yellow and stunted fascicles which develop without fertilization. However, fertilization does not seem to eliminate the sudden mortality often observed on old-fields.

Applying fertilizer after ridging occasionally increased mortality of *P. patula*. In one old-field study, a per seedling application of N (13 g) and P (24 g) reduced survival by 22 % but, as expected, growth of surviving trees was increased (Little et al. 1994).

Schumann and Noble (1993) reported nitrogen content (1.07 %) in foliage and N-deficiency symptoms in pines grown on old-fields. Based on results from a pot experiment, they concluded that adequate nitrogen nutrition on previously cropped lands is crucial for adequate growth of pines. They hypothesized nitrogen deficiencies in pine seedlings growing on agricultural soils are produced by: (1) impact of continuous cultivation on supply of mineralizable nitrogen, (2) intense competition from soil microflora for inorganic nitrogen, (3) inhibition of effective nitrogen uptake due to damage to roots by allelochemicals.

3.4 Toxic Chemicals

When establishment of pines failed after repetitive planting, toxic levels of agricultural chemicals are often suspected of causing problems (Steinbeck 1990, Schumann et al. 1994). This, however, appeared to be unfounded when soil analysis from one failure showed a small residue of atrazine (72 ppb). When evenly distributed in the top 15 cm of soil, this is approximately 166 g active ingredient (a.i.) /ha. Atrazine is a commonly used herbicide in maize and *P. patula* seedlings are tolerant of rates of 3 kg a.i./ha (Ball 1974).

A greenhouse study was established to determine the impact of soluble maize stove extract on lettuce (*Lactuca sativa*) and to evaluate the influence of nitrogen and phosphorus fertilization on performance of *P. patula* seedlings grown on the old-field soil (Noble and Schumann 1993). Root growth of lettuce was reduced by maize extract and growth was increased by fertilization. Steam sterilization and addition of various nitrogen fertilizers produced increases in initially low nitrogen content in the needles (1.05 % N). Plant mass was also increased with the application of nitrogen.

Although fungicides are often not phytotoxic, their use occasionally causes injury to seedlings. Benomyl is a fungicide that is used to increase survival of pines in the southern United States (Barnett et al. 1988, Barnard et al. 1995, Hallgren and Ferris 1995). However, under some soil conditions, treating roots of pines with a slurry containing benomyl will result in mortality (Boyer and South 1986, Stumpff and South 1991, South and Loewenstein 1994). On old-fields in South Africa, treating seedlings with benomyl also increased mortality of *P. patula*

(Little et al. 1994). In one study, adding a 2.5 % slurry of benomyl to roots reduced survival by 31 %. The increase in mortality might have resulted from a reduction in new root growth (South and Loewenstein 1994). However, benomyl has not been used operationally on pines by NECF.

3.5 Rodent Damage

In 1992 (two years after first large scale commercial planting of trees in this region), foresters reported an incidence of rodent damage during winter. In 1993, the problem escalated and, on average, 43 % of the trees died due to rodent damage on more than 900 ha. Trees in many other compartments were alive but damaged and malformed due to rodent feeding. Trees that were most damaged were growing on wet sites or next to water courses (especially in the northern part of the region which receives higher rainfall). The vlei rat (*Otomys irroratus*) or the stripped mouse (*Rhabdomys pumilio*) gnaw bark around the base on the main stem of young trees. When trees are older, the rodents climb up the stems onto the branches, which are also debarked. Both types of damage result in tree malformations and dieback. The other type of damage is caused by the Cape porcupine (*Hystrix africaeaustralis*). The base of the tree is gnawed in various places producing stem malformation and occasional ring-barking effect. The highveld gerbils (*Tatera brandsii*) indirectly kill very young trees by burrowing activity: seedlings become covered with soil or their roots are dislodged (Weir 1994).

Good control of rodents was achieved by erecting hundreds of raptor perches. An attempt to protect and increase the black-backed jackal (*Canis mesomelas*) population has been strongly opposed by local farmers who claim that the jackal is responsible for losses in sheep stock. Some good preventive measures included control burns on areas dominated by vlei rats and removal of vegetation around young trees (George Theart, NECF, pers. comm. 1995). Other proposed methods include live trapping and mechanical protection of stems. The use of poison has been rejected as an option.

3.6 Pathogenic Fungi

Isolations were made from roots of diseased trees as well as from soil in the rhizosphere on various sites (Linde et al. 1994). Several *Pythium* spp. were associated with tree death, but of these, only *P. irregulare* was consistently isolated from both soil and dying pines. A high population occurred on previously cultivated lands because maize, wheat and oats are known hosts to *Pythium* spp. (Scott 1987). Site preparation that involved ridging apparently enhanced the concentration of *Pythium* because *P. irregulare* is most common in the top 20 cm of topsoil. Scalping reduced population of the pathogen up to 75 % (Wingfield M.J., University of Pretoria, pers. comm. 1994).

Pathogenicity tests were performed in a greenhouse on *P. patula* and *Eucalyptus grandis* seedlings with *Pythium* spp. that were isolated from field samples. *P. irregulare* killed 100 % (24) *Eucalyptus grandis* seedlings (2-months-old) and 83 % (20) *P. patula* seedlings (4-months-old). *P. irregulare*, *P. tardicrescens*, *P. spinosum*, *P. acanthophoron* were also virulent to *P. patula*. Unexpectedly, *E. grandis* was susceptible to several *Pythium* spp., possibly because of the very young seedling age (Linde et al. 1994).

3.7 Soil Insects

In North America, the failure of pines to become established on post-agricultural lands is occasionally related to soil insects. In particular, white grubs (Coleoptera: Scarabaeidae) have caused mortality in maize (Luginbill 1938) and in pine plantations (Watts and Hatcher 1954, Sutton and Stone 1974, Mitchell et al. 1991). In South Carolina, more than 3200 hectares of newly planted pine seedlings were heavily attacked (Speers and Schmiege 1961). In some plantations, application of an insecticide at planting reduced both pine mortality and the frequency of damage by whitefringed beetle larvae (*Graphognathus* spp.) or white grubs (Bennett 1967, Mitchell et al. 1991, Barnard et al. 1995). At five sites in Florida (Barnard et al. 1995), use of the insecticide carbofuran increased survival by 32 %, 21 %, 13 %, 6 % and 3 % (the last value not significantly different from control).

In South Africa, white grubs are pests of eucalypts and have sometimes been recorded on pines. In one study, white grubs reduced survival of *Eucalyptus grandis* by 13 % (Govender 1993). In South Africa, black maize beetles (*Heteronychus arator*) have caused problems in maize and in some cases were associated with ring-barked pine stems (Schumann and Noble 1991). However, although soil fumigation with methyl bromide increased survival on one old-field site, an application of oxamyl did not increase survival (Atkinson 1992).

3.8 Soil Nematodes

Several genera of nematodes are known to damage pine seedlings (Ruehle 1969, 1973, Bassus and Banimivatee 1985). One genus even killed young pine seedlings within three months of inoculation (Dwinell 1985). Typical injury symptoms include sparse, stunted roots, needle chlorosis and stunting of the shoot (Sutherland and Webster 1993). For example, endoparasitic nematodes (*Pratylenchus*) can produce symptoms of chlorosis, stunting, and root necrosis under both field and greenhouse conditions (Marks et al. 1985). Other genera feeding on pine roots may increase mortality by reducing the seedling´s ability to survive other stresses such as drought (Mitchell et al. 1991). For some species, root mass can be reduced by 50 % (Ruehle 1969). Nematode damage may also provide infection loci for pathogenic fungi (Ruehle 1973, Sutherland and Webster 1993). It should be noted that according to Sutherland and Webster (1993), nematode damage often occurs in conifer nurseries located on old agricultural fields with indigenous nematode populations.

In 1991, plant parasitic nematodes were sampled at five old-field sites in the northeastern Cape region (Atkinson 1992). Samples were also taken from five virgin grassland sites. More plant-parasitic nematodes were found on post-agricultural sites than grassland sites. *Paratylenchus* were relatively abundant at several problem sites. At three of the five sites, population levels exceeded 200 nematodes per 100 ml of soil. Under greenhouse conditions, *Paratylenchus* and *Pratylenchus* can cause great damage to the feeder roots of *P. patula* (Bassus and Banimivatee 1985). In the western Transvaal, *Pratylenchus zeae* is the most common endoparasite in maize roots (Jordaan et al. 1989).

3.9 Weed Control

Weeds are controlled both manually and with herbicides. Manual weeding involves hoeing of vegetation to mineral soil around the planted seedling. This prevents weed competition in proximity to the tree and also reduces rodent damage. The chemical method involves application of glyphosate (1.9 kg a.i./ha) or gramoxone (0.9 kg a.i./ha). This application is repeated three to four times per annum. During each application, pines are protected with plastic tubes. Occasionally, injury results when herbicides penetrate the inside tube (contacting the foliage) or when no care is taken to protect exposed foliage. This type of damage, however, occurs most frequently on well performing trees (i.e. on trees with abundant foliage and well developing branches) and therefore is easily distinguished from the old-field syndrome.

3.10 Methyl Bromide Fumigation

Soil fumigation with methyl bromide (392 kg a.i./ha) can improve both survival and growth of seedlings planted on post-agricultural soils in northern Florida (Barnard et al. 1995). Although not operationally cost effective, this fumigant is useful in testing hypotheses regarding *old-field* syndrome. Generally, effective fumigation controls weeds, nematodes, disease and grubs without affecting soil physical properties. In Florida, fumigation improved survival of *P. elliottii* 21 % on one site and 17 % on another. Due to these positive responses, methyl bromide was tested on two *old-field* sites in the northeastern Cape. In one study, fumigation with 972 kg a.i./ha increased seedling survival by 12 % (Atkinson 1992). In another study *P. patula* seedlings growing in fumigated soil averaged 90 cm in height (420 days after planting) compared to 51 cm for control seedlings (Little et al. 1994). In the second study survival was high for both treatments (95–96 %).

4 Discussion

It is believed this is the first time afforestation has failed on such a large scale in South Africa. Identification of the reason for rapid mortality has been difficult since there are no obvious *footprints* that lead to the primary vector(s). Although rodents did kill many seedlings, we doubt they cause unexplained mortality since rodent injury is relatively easy to identify. Likewise, white grubs are relatively easy to find in the soil and injury symptoms can be recognized by feeding scars on roots (Sutton and Stone 1974, Barnard et al. 1995). Although many contributing factors must be considered, it is most likely that the prime cause (1) resides in the topsoil; (2) reduces initial root growth; (3) is too small to be detected with the unaided eye; and (4) is species specific.

Likely candidates that could cause sudden mortality include fungi and nematodes. Historically, complexes of both fungi and nematodes have caused injury in both agricultural crops and pine nurseries (Evans et al. 1993). Combinations can cause more injury than either pathogen alone. For example, in the maize growing areas in South Africa, the fungus *Fusarium moniliforme* is a major cause of root disease. However, stunting of maize is greater when both fungi and nematodes such as *Pratylenchus* are present (Jordaan et al. 1987). In other cases, injury from nematodes is a prerequisite for significant disease development.

Pythium irregulare was consistently found in old-field soil and in diseased roots of *P. patula* (Linde et al. 1994). This fungus appears to be an important factor associated with the old-field syndrome. If this fungus is the primary cause of mortality, it is likely that wide-scale failures on post-agricultural soils have been caused by *Pythium*. However, it is a well-known fact that root diseases are of a complex nature and often involve more than one pathogen. It may be that a combination of nematodes and *Pythium* do more damage to *P. patula* roots than either could alone. This might explain why soil fumigation can increase seedling survival by 20 % while no other treatment was able to do so. Fungicides such as aluminum tris, benomyl and metylaxyl are not nearly as effective on *Pythium* spp. as methyl bromide.

It is not clear why eucalypts survive and grow better on agricultural fields than *P. patula*. However, large differences in tolerance to fungi or nematodes exist at both the variety and species level. This suggests a biotic cause of mortality rather than an abiotic factor. It seems unlikely that such dramatic species difference would occur if nutrient imbalances, or waterlogging, or soil compaction, or small herbicide residues were the primary cause of mortality.

Scalping of the soil before planting has multiple benefits. It moves pathogen- laden soil away from the planting spot, it increases the availability of soil moisture (especially for small root systems of 6 month-old pines), and it provides some measure of weed control. The combination of these factors results in greater survival of pine seedlings. Any reduction in height growth or chlorosis due to lower fertility in the B-horizons is easily overcome by the addition of nitrogen and phosphorus.

Under some conditions, fertilization can increase mortality of *P. patula* seedlings (Little et al. 1994). This was partly attributed to *fertilizer burn*. However, fertilization with N and P increased growth of the pines and this may have increased root exudates. Germination of sporangia of *P. irregulare* may be greater when root exudates are increased (Agnihotri and Vaartaja 1970) and this might have increased pathological mortality. For example, fertilization with nitrogen can increase root-rot of pine seedlings caused by *Macrophomina phaseolina* (Rowan 1971). This theory is supported by the observation that fertilization did not cause fertilizer burn or mortality when applied after removal of the topsoil by scalping (Little et al. 1994). Although fertilizer may have exacerbated the problem, it was not the primary agent since; (1) mortality on old-fields was common in unfertilized areas; (2) mortality was not a problem on fertilized areas in virgin grasslands; (3) mortality was not a problem when applied on scalped areas; and (4) mortality was species dependent.

The above findings support the theory that seedling mortality is a result of biotic factors (fungi and/or nematodes) which increased during consecutive rotations of agricultural crops. Scalping increases seedling survival apparently because the inoculum resides mainly in the top

20 cm (Linde et al. 1994). Scalping moves most of the inoculum away from the planting spot. Soil fumigation with methyl bromide also increased survival which may have resulted due to effective control of damaging soil pathogens.

There remain differences in opinions regarding the primary causes of *old-field* syndrome. Occasionally, the *old-field* syndrome occurred on sites with low *Pythium* populations. Also well performing trees were found where *Pythium irregulare* was common. Therefore, Wingfield (pers. comm. 1994) distinguished pathological sites from sites where the cause is not known. This suggests a complex nature of the problem and a possibility that *Pythium* attacks are secondary to a predisposing factor(s).

It is well established that intensive soil cultivation exerts a profound influence on soil genesis through the modification of physic-chemical soil properties (Ghildyal et al. 1961). Repetitive tillage and continuous cropping of farm lands results in decrease of soil fertility especially on sensitive soils such as those found in NECF (Mullins et al. 1989). Typical symptoms of soil degradation in the Eastern Cape include plow pans, surface crusts, grey colours and cloddy and dusty "tilth" after tillage (Smith and Van Huyssteen 1992). The lower organic matter associated with higher bulk densities on the old lands indicate intensive harvesting and tillage of the soils with possible compaction resulting from frequent machinery traffic. The 1.4 g/cm^3 or larger soil bulk density found may restrict pine root development (Sands and Bowen 1978, Tuttle et al. 1988). Lower organic matter content results in lower water holding capacities and decreased infiltration rates. The highly bleached A-horizon of such sites is symptomatic to unstable topsoils. Water infiltration on unstable soils may be only 25 % of that on stable topsoils (Louw 1991). Due to surface runoff, the soil may remain dry even after rain events. In proximity to tree roots, soil drying effect is enhanced by increased evaporation surface of elevated ridges and rapid vertical water outflow between clods and through ripping lines to deeper soil horizons. Severe weed competition on old lands aggravate water deficiency. Intensive soil tillage for tree planting destroyed aggregate stability and depleted macro pores that act as main channels for infiltration, oxygen diffusion and root penetration. Root expansion in the soil is also reduced by their inability to overcome the soil strength rapidly increasing outside the rip furrow, especially in the absence of soil pores. Van Huyssteen (1981) showed that even slight variations in soil strength from one zone within the soil to the next can seriously hinder root development. The escape of roots from the furrow is a function of natural tree and soil variation and therefore may lead to very uneven stands. Deficiency of available soil water, combined with poor root functioning resulting from insufficient soil aeration, poor root/shoot ratios and deformation of roots of the container stock, induce enough stress in the trees to expose them to soil pathogens.

Additional research is needed before there is a general consensus on the problem. Proposed research includes the formation of ridges using fumigated topsoil and reinoculation with specific pathogens. The following pathogens are logical choices: *Pythium irregulare*, *Pratylenchus zeae*, *Pratylenchus penetrans*, *Paratylenchus* spp. and combinations of these pathogens. A split-plot involving a nitrogen fertilizer treatment would help determine if mortality increases as root growth and root exudates increase. In addition, ridges formed using fumigated virgin grassland soil could be compared with ridges formed using fumigated old-field soil. Results from a susceptible species (*P. patula*) and a tolerant species (*P. taeda*) would be compared. This type of field study would be useful in identifying the primary agents that cause mortality of *P. patula* on post-agricultural soils.

Acknowledgments

We are indebted to Dr. P.R. Atkinson and to Dr. Bill Carey for providing comments on this review.

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