Availability of Phosphorus to Nursery Plants©

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INTRODUCTION

Lopez-Bucio et al. (2000) emphasises the importance of phosphorus (P) in world agricultural production. They state that it is one of the most important nutrients limiting agriculture. In acid and alkaline soils, which make up over 70% of the world's arable land, P forms insoluble compounds that are not available for plant use. To reduce P deficiencies and ensure plant productivity, nearly 30 million tons of P fertiliser are applied every year. Up to 80% of the applied fertiliser is lost because it becomes immobile and unavailable for plant uptake.

The production of plants in nurseries in Australia, South Africa, and New Zealand has a history of difficulties related to P nutrition. This is because these countries often have soils that are inherently low in available P and native flora is adapted to this. Often when these types of plants are grown with fertilisers containing P, they have a relatively high proportion of plants that are prone to P toxicity, particularly the Australian and South African floras. In New Zealand this may have been compounded by an agricultural nation which has grown up with the need to regularly apply superphosphate to the land, and in fact aerial topdressing was developed in this part of the world. This paper seeks to review the availability of P in soils and container mixes so that an improved understanding will aid the P fertilisation of nursery plants.

P AVAILABILITY IN RELATION TO DIFFERENT SOILS

New Zealand with its pastoral-based economy has a long history of phosphate application to the land and it is easy to adopt a mind set where all plants must receive large and regular doses of superphosphate. Most people have seen planes spreading superphosphate from the air onto pastures. The first reason for the need for frequent application of P fertilisers is to enhance nitrogen fixation by clovers and hence improve pasture production. Secondly, P application often needs to be high, as well as frequent, because many of our soils are naturally quite low in phosphorus and have a high P retention capacity. McLaren and Cameron (1990) divide P retention by the different soil types of New Zealand into three classes: low (0% to 30%), medium (31% to 85%), and high (86% to 100%). Retention is measured by using a standardised test to measure how much of a specific amount of added P is taken up by 5 g of soil after 24 h. It mimics the behaviour of P fertiliser when added to soils.

The need for P application varies greatly with the type of soil, as well as other factors like the P demands of the crop. The brown soils (formerly yellow brown earths) are one of the most widespread soils in this country and are in the medium P retention category. Also in this medium category are the pumice soils (formerly yellow brown pumice soils) of the Central Plateau. The amounts of iron and aluminium compounds are the key contributing factors. For example, allophane (a very reactive alumino-silicate clay) is common in volcanic soils and combines readily to form insoluble phosphates that are unavailable to plants with only minimal release over many years. Added P can be rendered largely unavailable, except for small quantities over time, on the allophanic and pumice soils (formerly yellow brown loams and yellow brown pumice soils) of the Central North Island. Soil tests coupled with an understanding of the P-retention capacity of the soil are key tools for assessing P fertiliser requirements by the nursery person with open ground crops.

THE VARYING CAPACITY OF PLANTS TO ASSIMILATE P

Uptake of P by plants depends predominantly on diffusion, i.e., movement of nutrient ions in the soil solution from a high concentration to a low concentration. The rate of diffusion of orthophosphates is typically 100 times less than that of potassium ions (Archer, 1985). Very little of the phosphorus in soil comes from mass flow due to the extremely low soil solution concentrations, which are generally below 0.3 µ $litre^{-1}$ (McLaren and Cameron, 1990). Therefore, P uptake is more dependant on aspects of plant root activity than is the case for other major nutrients. Soil P does not move to the root but its uptake depends on roots growing toward the P, especially in the enriched topsoil layer.

Plants in their native habitats are often faced with growing environments where P is scarce. This explains why mycorrhizal root associations are so common in plants. Phosphorus availability is particularly low in acid soils and yet some species like pines will grow in, and indeed tend to acidify, the soils in which they grow in dense monotypic vegetation. It is under these acidic conditions the beneficial fungi are most likely to inoculate the roots and begin a symbiotic mycorrhizal relationship. Assistance with P uptake is seen as the key function of mycorrhizas, which can colonise about 80% of all plant species. The mycelium of the fungus in the soils can help provide an enormously improved surface area for “netting” P from the soil. This is of particular benefit to plants like *Pinus* and totara (*Podocarpus totara*), which have root systems with very short stubby roots and few root hairs. It is based on the fact that mycorrhizal roots can take up several times more P per unit length than nonmycorrhizal roots (Marschner, 1995).

Proteoid roots are another tool for plants to survive on P-impoverished soils. Their key function is again P uptake. Proteoid roots are widely found on members of the Proteaceae and can account for 56% of the root system (Lamont, 1986). Their extensive surface area, like the mycorrhizal mycelium, greatly aids in the uptake of soil P. Proteaceous plants that come from impoverished soils also cope with poor fertility soils and dryness by having low growth rates.

PHOSPHORUS AVAILABILITY IN SOILLESS MEDIA

Soilless mixes based on bark or peat do not have a significant anion-exchange capacity (Bunt, 1988). This means that there is no gradual release of P from exchange sites or insoluble complexes with iron or aluminium, which can occur in soils. Levels of iron and aluminium are relatively low or very low (respectively) in soilless media. In contrast to the soil situation, P is readily available to plants. The influence of a soil medium, compared to a soilless one, on P retention was shown by a study comparing the leachates from a John Innes soil mix with that of a peat-sand mix (Bunt, 1988). The leachate collected when distilled water was poured through the soil based medium contained only 9% of the previously added P while with the peat-sand mix it was 56%. Forms of nitrogen (N) or potassium (K) were, however, 18% (or more) higher in their availability than P. This highlights the need for growers to be aware of the significantly higher availability of P in soilless rather than soil-based growing media. The implications of this relate to leaching loss in regard to plants needing P for growth, and the inherent danger of toxicity to those plants which are readily damaged by moderate or high P concentrations around their roots. Handreck and Black (1994) point out that this problem is more severe in peat-based mixes than in those based on pine bark. The risk of toxicity is strongly influenced by the capacity of the plants to assimilate P from their root zone, as discussed in the previous section.

Another factor influencing P availability in media is the pH and the lime rate. The pH of soilless media is important, but its effect on nutrient availability is different to mineral soils (McLaren and Cameron, 1990). In the absence of soil, P is available at a pH of 5 or less and tends to decline as the pH increases from 5 to 7. Liming will decrease the availability of P due to the formation of insoluble calcium phosphates.

SPECIES PRONE TO P TOXICITY

There appears to be a range of susceptibilities to P toxicity which relates to the inherent ability of plants to assimilate P. Handreck and Black (1994) list two groups of plants giving genera in which there are species which will show toxicity at relatively low levels of P and then a second group which respond negatively with moderately low levels. The habitat is the key aspect as illustrated by the fact that *Grevillea rosmarinifolia* is from low fertility soils and is quite susceptible while *G. robusta* is from fertile soils and shows no sensitivity (Thomas, 1980). Plants that are slow growing and from harsh and impoverished habitats would be the most susceptible such as *Protea* species from high altitudes. These species are commonly Australian and South African members of the Proteaceae as well as the Leguminosae, Myrtaceae, and Rutaceae.

Handreck and Black (1994) list the second group as those plants that may have inferior quality and/or reduced growth with even moderately low levels of phosphorus. They include *Rhododendron* (azaleas), *Camellia, Magnolia, Elaeagnus, Skimmia, Erica, Calluna, Cytisus, Hydrangea, Senecio, Viburnum*, and *Chamaecyparis*. Cresswell and Weir (1997) list 41 genera (two thirds of them Australian native plants) where species have been shown to be sensitive to P levels.

PHOSPHORUS FERTILISATION FOR OPEN-GROUND NURSERIES

Application rates of P for field grown stock will depend on such factors as the type of soil and its inherent P retention capacity, as well as the crop species. An indication can be gained from soil test values, such as the Olsen P test, and from foliar analysis. *Pinus radiata* should normally have at least 0.12% to 0.14% foliar P, the critical level (Knight, 1978a). Production of trees in the open ground has a major depleting effect on soil nutrients. *Pinus radiata* was found on average (New Zealand nurseries) to remove 1.45 g of elemental P per kilogram of crop dry matter, which is close to one tenth of the amount for N (Knight, 1978b). The same author makes the critical observation that while the rate of N application may need to be 2 to 3 times greater than the actual crop removal, the amount of P may need to be tenfold or more. A large forestry nursery grower in Canterbury applies 40 kg of P ha^{-1} annually. The range of application rates for this type of nursery throughout New Zealand can be expected to vary from 23 to 90 kg of P ha^{-1} annually (Knight, 1978a). Diammonium phosphate and superphosphate are the most commonly used sources of P for the open ground. A feature of many open-ground nurseries is the use of rotations that include time when the ground is put into pasture. New Zealand studies have shown that in well fertilised newly developed pastures, organic-P can accumulate at rates of 5 to15 kg P ha^{-1} per year (Mc Laren and Cameron, 1990). One Canterbury nursery uses the ground for 3 or 4 years of tree crops and then an equal time in pasture on an alternating basis. Pasture rotation is clearly a very valuable tool for maintaining fertility and also soil structure.

PHOSPHORUS FERTILISATION FOR CONTAINER-GROWN STOCK

The application of P to container-grown plants in soilless media has to be done with care since P retention is low and availability high. Deen (1980) reported on work at the Efford Research Station in the United Kingdom where a range of crops were given liquid feed and Osmocote® (The Scotts Company, USA) feeding regimes. Several species became chlorotic where supplementary P was used in conjunction with liquid feed. High P rates can readily induce iron deficiency in sensitive species. Trials at the New Zealand Nursery Research Centre on a range of woody plants grown in soilless media supplied with medium rates of Osmocote® (The Scotts Company, USA) found that only one species of the five tested was responsive to added P (Anon, 1985). Bunt (1988) made the observation in trials with two woody plants that Osmocote® (The Scotts Company, USA) alone may often supply sufficient P and that the application of additional superphosphate obtained no response because adequate P was supplied from the slow release fertiliser.

Handreck and Black (1994) noted that Nutricote® (Nichimen Corporation, Japan) has a very slow release rate for P. Some fertiliser companies have products specifically for P sensitive species, for example Osmocote® Plus (17N-1.6P-8.7K) (The Scotts Company, USA) and Green Jacket™ Formula 5 (16.3N-1.3P-19.1K) (Debco Pty. Ltd., Australia). These materials allow a balanced supply of nutrients but with P at low levels. A further safeguard can be to supply high iron levels, preferably in a slow release form. Iron, as does high calcium from liming, reduces the levels of available P.

CONCLUSIONS

The key purpose of this paper was to highlight the difference in P availability in soil compared to soilless media. New Zealand is a country with extensive areas of soil types with medium to high P retention characteristics. The P in the soil solution is at low concentrations and plants often need to utilise special root structures or fungi to avail themselves of this supply. Open-ground nurseries may utilise high P rates while in soilless media there is a need to provide relatively low but constant P supplies. Quite a large group of plants are sensitive to the levels of available P and they range broadly according to species and in accordance with the fertility of native habitats. It is therefore valuable to understand the principles of P availability in order to feed adequately or avoid P toxicity in relation to species and growing environments. A sound procedure is to monitor plant tissue P levels, as this is a reliable way to access the success of P fertilisation programmes.

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