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TECHNICAL PAPER

No. 19

The Detection of Mineral Deficiencies in *Pinus elliottii*, *Pinus radiata* and *Pinus taeda* by Visual Means

By

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CORRIGENDA

p.17 References.

Lyle, E.S. Jr. (1969) Mineral deficiency symptoms in loblolly pine seedlings. Agron. J. 61 (3):395-398.

The Detection of Mineral Deficiencies in *Pinus elliottii*, *Pinus radiata* and *Pinus taeda* by Visual Means.

I. The Major Essential Elements and Iron.

by

R. Truman.

SUMMARY

This report describes experiments in which seedlings of *Pinus radiata*, *P. elliottii* and *P. taeda* were grown in sand and solution cultures lacking the major essential elements and iron. The deficiency symptoms produced in each case are described and illustrated.

INTRODUCTION

The diagnosis of mineral deficiencies can be carried out in a number of ways. These include diagnosis by means of foliage analysis, soil analysis, visual symptoms, pot and field fertiliser trials and the direct application of chemicals to trees. These methods are largely complementary and diagnoses are generally not based on one method alone.

In the case of visual diagnosis, the symptoms produced by the lack of some elements are essentially different from all others, so that a decision can be reached with a fair degree of certainty.

However, with other elements symptoms are similar and do not provide conclusive evidence. This may occur when two elements are connected with the same growth process or processes within the plant. For example, manganese and iron which are both associated with chlorophyll formation, produce chlorotic symptoms in pines which are hard to separate.

Apart from this similarity of symptoms other factors which may complicate diagnosis, include toxicity, unfavourable climatic conditions, root pathogens and overdoses of biocides. The following are some examples.

In acid soils, excess manganese produces iron deficiency symptoms in pines.

Drought may either produce deficiency symptoms because of reduced water availability and nutrient uptake or may so check growth that in soils where deficiencies exist, no symptoms develop.

Little-leaf disease of pines caused by *Phytophthora cinnamomi* is evidenced by short and discoloured needles. Finally, an overdose of the herbicide amitrole which inhibits chlorophyll synthesis, produces symptoms similar to iron deficiency.

Despite its limitations the visual method is still useful in making at least preliminary diagnoses in the field. Such diagnoses should of course be confirmed by foliage and perhaps soil analysis before remedial measures are undertaken.

The work described in this report was carried out therefore to provide an aid to diagnosing symptoms exhibited by Pinus radiata, P. elliottii and P. taeda seedlings due to deficiencies of the major essential elements and iron.

The trace elements copper, zinc, manganese, molybdenum and boron were not included and will be the subject of a future investigation.

Materials and Methods

a) Sand cultures Seedlings were grown in purified dune sand in six-inch diameter plastic pots equipped with fritted glass syphons. The sand was purified by repeated soaking and leaching with 3% hydrochloric acid (Hewitt 1952) until the leachate gave a negative test for iron with ammonium thiocyanate, then by leaching with demineralised water until the leachate gave a negative test for chloride with silver nitrate, and finally by repeated soaking and leaching with the appropriate nutrient solution adjusted to pH 5.5 until the pH of the leachate remained approximately the same.

After purification, six-inch diameter circles of one-quarter inch thick black polyurethane foam plastic were placed on the sand. Seeds were placed on the plastic and covered with a moist filter paper. Plastic bags were then placed over the pots and secured with rubber bands.

When the seeds commenced to germinate the plastic bags and filter papers were removed. It was found that the roots of the seedlings easily penetrated the foam plastic which in turn completely prevented the growth of algae.

The appropriate nutrient solutions adjusted to pH 5.5 were added to the pots once each week, sufficient quantity being added to cause syphoning through the fritted glass tube.

The nutrient solutions used were those of Hoagland and Arnon (1950) and are shown in the Appendix. Trace elements were added as 1 ml. of the following solution to each litre of nutrient solution.

H_3BO_3		2.86 gm.
$MnCl_2 4H_2O$		1.81 gm.
$ZnCl_2$		0.104 gm.
$CuCl_2 2H_2O$		0.056 gm.
$(NH_4)_6Mo_7O_{24} 4H_2O$		0.018 gm.
Water	to	1 litre

Except for the iron deficient solution, iron was added in the form of Na Fe - EDTA to give a concentration of 5 ppm. Fe.

b) Solution cultures Seeds were germinated in washed sand contained in flats. After germination they were allowed to remain in the flats for approximately two weeks, after which time they were supported by means of cotton wool in holes drilled in the tops of 500 ml. wide-mouth plastic jars which had previously been coated with black paint, wrapped in aluminium foil and provided with a fritted glass aeration tube.

The solutions which were the same as those used for the sand cultures, were changed once each week and were aerated for approximately one minute each day.

Both sand and water cultures were situated in the glasshouse. Seedlings were allowed to grow until deficiency symptoms became evident, whereupon they were photographed and then returned to the glasshouse for further observation.

Results and Discussion

a) Nitrogen

Soon after emergence the growth of seedlings in the nitrogen deficient solutions fell behind that of the controls and they continued to remain stunted throughout the experiment.

In the early stages the stems tended to take on a reddish colour but this symptom was only transient. Almost from the outset the needles were pale green to yellow-green and shorter than normal. As deficiency became more severe, first the cotyledons and then the lower needles turned yellow and died. (Plates 1 - 3)

The above symptoms agree in general with those reported in the literature. Some examples are given in the following table.

Species	Symptoms	Reference
P. banksiana	Seedlings very small, pale green.	Swan (1960)
P. echinata	Stunted growth. Foliage pale yellow-green, never yellow.	Hobbs (1944)
P. radiata	Marked chlorosis with almost complete stagnation of growth.	Purnell (1958)
	Foliage a uniform yellowish green becoming yellow under severe conditions.	Will (1961 a)

Species	Symptoms	Reference
P. resinosa	Seedlings stunted. Foliage pale green, with tips of needles becoming deep red.	Hobbs (1944)
P. rigida	Seedlings stunted. Foliage pale green but never yellow.	Hobbs (1944)
P. strobus	Foliage a pale yellow-green	Mitchell (1934)
	Plants stunted with pale yellow-green foliage. Necrosis of the lower needles extending inwards from the tips.	Hobbs (1944)
	Plants stunted with pale yellow-green foliage. Needle tips reddish-brown.	Hacskaylo (1960)
P. sylvestris	Plants stunted. Needles pale yellow-green with reddish-brown tips.	Hacskaylo (1960)
	Seedlings stunted with short primary leaves and no secondary leaves or laterals. Needles pale green with tips red or sometimes brown.	Hacskaylo et al. (1969)
P. taeda	Needles yellowish-green. Needle tips become reddish brown and stem brownish red.	Lyle (1969)

Stone and Will (1965) described nitrogen deficiency symptoms in the field in New Zealand. They found that in second generation P. radiata the foliage colour of older regeneration was associated with foliar nitrogen.

The needles of lower branches in deficient stands and on smaller trees or coppice shoots were notably more yellow-green than foliage from the upper crowns of dominants. Also, analysis of comparable samples showed that they were lower in nitrogen.

When deficiency was severe, the second year and older first year needles of the lower crown levels showed apical chlorosis, sometimes followed by necrosis. On individual branches this was often progressive, affecting much of the length of the proximal needles and diminishing outwards with some regularity.

The lower branches of deficient trees retained their needles for only two or three years rather than up to five.

b) Phosphorus

1. *P. radiata*

For some time the seedlings in this series grew as well as the controls but as symptoms became more obvious, growth diminished considerably.

The first symptoms apparent were a blackening of the base of the stem and the production a dark to blue-green colour in the needles, especially those near the top. The lower needles then became pale greyish-green to yellow-green with necrotic, or chlorotic and then necrotic tips. These symptoms gradually extended upwards until they reached the growing point where due to lack of growth the needles were short and closely packed, giving a flat-topped or tufted appearance.

While the above symptoms were developing the lower needles died and collapsed (Plate 4). Death of needles continued upwards until all plants were dead.

2. *P. elliottii* and *P. taeda*

Seedlings in solutions lacking phosphorus remained stunted throughout the experiments.

In the early stages of deficiency the needles took on a dark to blue-green colour and blackened areas appeared at the stem base. At a later stage the lower needles became necrotic and showed a tendency to collapse (Plates 5 and 6). As deficiency became more severe the needles became progressively shorter. Necrosis extended upwards until just before the seedlings died, there remained only a tuft of needles at the top (Plates 7 and 8). At times needles took on a purple colour before becoming necrotic.

The following table contains some examples of the phosphorus deficiency symptoms reported for seedlings of *Pinus* spp.

Species	Symptoms	Reference
P. banksiana	a) No phosphorus. Seedlings very small. Ends of needles brown. abrupt change from green to brown.	
	b) Very low phosphorus. Seedlings small. Some lower primary needles show the following colours starting from the tips of the needles inwards: gold, yellow, purple, green.	Swan (1960)

Species	Symptoms	Reference
P. echinata	Plants stunted. Necrosis beginning with lower needles. Prior to death these needles frequently become reddish-coloured.	Hobbs (1944)
P. radiata	Growth slower than controls. Foliage a darker green.	Purnell (1958)
	Seedlings shorter than normal. Foliage dark to blue-green.	Will (1961a)
P. resinosa	Plants stunted. Pronounced tendency toward the development of a reddish colour in the lower needles.	Hobbs (1944)
P. rigida	As for P. echinata	Hobbs (1944)
P. strobus	Seedlings exhibit a purplish colour of the lower needles.	Mitchell (1934)
	Plants stunted. Needles develop a mild chlorosis followed by slight necrosis. Pronounced variability of colour in needles.	Hobbs (1944)
	Primary needles became yellow tipped and as necrosis becomes evident the needles turn a light reddish-purple.	Hacskaylo (1960)
P. sylvestris	As for P. strobus	Hacskaylo (1960)
	Seedlings stunted with primary leaves dark blue-green. Starting with the lower needles, the tips become purple, then olive green and finally brown. This brown necrosis then extends towards the base of the leaves.	Hacskaylo et al. (1969)
P. taeda	Needle tips brownish-yellow, cotyledons and lower needles reddish-purple.	Lyle (1969)

It has been reported that with low phosphate supply, rice (Sibuya and Salki, 1939) and tobacco plants (Takahashi and Yoshida, 1955) show much more marked deficiency symptoms when fed with nitrate nitrogen than with ammonium nitrogen.

The solutions used by Will (1961a) contained ammonium ions and this possibly explains why the symptoms he obtained for P. radiata did not progress beyond the early stage recorded in the experiments described herein. In the solutions used by Purnell (1958) nitrogen was supplied as nitrate ions, but the plants after showing early symptoms, eventually recovered. She attributed this to the ability of the mycorrhyzal fungi present to mobilise phosphorus from apatite in the sand and transport it to the seedling roots.

Lyle (1969) in his work with P. taeda also included ammonium ions in his solutions and this again could explain why the symptoms he described differ from those obtained in this work.

Wilson (1956) described phosphorus deficient P. radiata in the field in New Zealand as having needles which were short and were slate-green to yellow-green in colour. In Eastern Australia the severest onset of symptoms occurs in trees 6 to 15 years of age, the crowns being sparse with needles grey-green in colour and sometimes fused (Gentle and Humphreys 1967). Deficiency often occurs in trees growing on sandstone, sand, shales, slates or eroded soils.

c) Sulphur

Seedlings in this treatment grew as well as those in complete solution and at no stage did they show any symptoms of deficiency. Purnell (1958) obtained a similar result and attributed this to the presence of available sulphur in the sand she used. In the experiments reported here however no symptoms of sulphur deficiency were obtained in solution culture so that it is assumed that sufficient sulphur dioxide was present in the atmosphere to supply the needs of the seedlings.

No report can be found in the literature of sulphur deficiency affecting Pinus spp. nursery stock. Deficiency symptoms in some species have been produced in solution culture however and some examples are given in the following table.

Species	Symptoms	Reference
P. strobus	Terminal needles become yellow then necrotic.	Hacskaylo (1960)

Species	Symptoms	Reference
P. sylvestris	As for *P. strobus*	Hacskaylo (1960)
	Seedlings short with slender stems. Primary needles blue-green becoming pale yellowish-green. Secondary leaves abundant and short. Needle tips often slightly red with faint yellowish spotting or banding.	Hacskaylo et al. (1969)
P. taeda	Seedlings develop a greenish-yellow colour beginning with the terminal needles. No part of the needle becomes pure yellow. Some colour changes appear to begin at or near the needle base rather than at the tip.	Lyle (1969)

Sulphur deficiency has been recorded in some *P. radiata* plantations in New South Wales (Gentle 1970). Moderate deficiency is characterized by overall winter yellowing especially on the exposed aspects. When deficiency is severe, several feet of the leading shoot and sometimes terminal buds die back, at times associated with brownish-red or red-orange colourations. Yellowing is generally more pronounced at the base of the needles.

Unfortunately, the plantations affected by sulphur deficiency are in most cases also boron deficient so that symptoms become intermingled and difficult to identify exactly. Boron deficiency symptoms include bud death, localized areas of yellow-tipped needles and brown necrotic areas in the young pith (Gentle 1970).

d) Calcium

Seedlings growing in sand cultures grew almost as tall as the controls before the onset of deficiency symptoms. In solution culture, seedlings also grew as tall as the controls but symptoms appeared much more quickly, indicating that the pines in the sand cultures had been able to obtain a small quantity of calcium from the sand.

The first symptom evident was the appearance of resin droplets on the needles near the top. This was followed by collapse and death of the needles from the droplets to the tips (Plates 9 and 10).

As deficiency became more severe newly formed needles were pale to yellow-green, thinner and shorter than normal, and in most cases were reflexed. Internodes became shorter and stems took on a thickened appearance (Plate 11).

In the final stages the last formed primary needles often remained fused around the terminal bud (Plates 12 and 13) and secondary needles remained fused (Plates 14 and 15). In some cases death of the apical bud was followed by the appearance of a new leader which eventually succumbed in the same manner (Plate 16).

The symptoms described above agree in general with those reported elsewhere. Some examples are given in the following table.

Species	Symptoms	Reference
P. radiata	Beads of resin appear at tips of bracts surrounding terminal bud. Bracts become necrotic and plants die back from the top.	Purnell (1958)
P. strobus	Seedlings become stunted with upper needles chlorotic.	Mitchell (1934)
	Needles become pale green in the terminal regions with necrosis apparent in the terminal bud. Some recurving of the secondary needles.	Hacskaylo (1960)
P. sylvestris	As for P. strobus	Hacskaylo (1960)
	Terminal buds die. Secondary leaves show chlorotic bands near stem and develop necrosis, becoming red-brown. New secondary leaves near top are short, pale at the base and sometimes hooked at the tips. Ooze areas sometimes occur in the mid-section of secondary leaves.	Hacskaylo et al. (1969)
P. taeda	Terminal buds exude resin. Needles show greenish-yellow background colour with brownish-yellow patches located along the needle. In severe deficiency resin exudes from the needles.	Lyle (1969)

In trees, calcium deficiency of P. radiata is often associated with pale coloured volcanics, shales and areas of solodic soil types. The tip dies back, side branches sprout and also die back, giving a hedged flattened appearance to the top of the tree (Gentle and Humphreys 1967).

e) Magnesium

Seedlings growing in solutions lacking magnesium quickly became stunted. Symptoms first appeared in the younger needles, the tips of which became golden yellow with the remainder appearing dark to blue-green especially near the base.

As growth continued and deficiency became more severe, chlorosis extended further along the needles which became progressively shorter. In the case of P. radiata the uppermost needles were often reflexed, giving the seedlings a flat-topped appearance (Plate 17). Needles which first showed chlorosis became necrotic, first at the tip and then along their whole length (Plates 18 to 21).

In the final stages, death of the terminal buds was followed by death of the seedlings from the top downwards.

Wallace (1951), discussed the functions of magnesium and concluded that this element appears to be very mobile within the plant, this agreeing with the observation that signs of magnesium deficiency invariably make their appearance first in the older leaves and progress systematically from them towards the youngest ones. However, from a consideration of the symptoms given above and those included in the table that follows it would appear that Pinus spp. are exceptions to this rule.

Species	Symptoms	Reference
P. banksiana	Needle tips become golden yellow. Late in season needles show brown (at tips), yellow, green colouration. Some needles show brown (at tips), purple (narrow band), green colouration. Brown, yellow, green colour sequence also found on secondary needles.	Swan (1960)
P. echinata	Needle tip chlorosis, at first more accentuated on the upper part of the plant but in later stages needles all over the plant become affected. As deficiency becomes more severe chlorosis extends further down the needles and the tips become necrotic.	Hobbs (1944)
P. radiata	Golden needle tip chlorosis followed by necrosis. Chlorotic primary leaves at top of stem of young seedlings curl backwards soon after formation.	Will (1961a)

Species	Symptoms	Reference
P. resinosa	The entire length of the needles of the newest growth become yellowish green while the old needles remain normal green.	Hobbs (1944)
P. rigida	As for *P. echinata*	Hobbs (1944)
P. strobus	Primary needles blue-green with yellow tips. Some secondary needles become yellow-green in colour with golden to brown tips.	Hacskaylo (1960)
	As for *P. echinata*	Hobbs (1944)
P. sylvestris	As for *P. strobus*	Hacskaylo (1960)
	Tips of primary leaves become pale yellow-orange while tips of secondary leaves become a bright yellow-orange starting at the tip and progressing along the entire length of the leaves. Cotyledons and lower primary leaves remain blue-green.	Hacskaylo et al. (1969)

Will (1961) described deficiency symptoms in *P. radiata* nursery stock as being first evident in the younger needles. In more severe cases, more needles and greater lengths of needles were chlorotic. Necrotic needle tips were a feature of the most severely affected plants.

Stone (1953) described magnesium deficiency in *P. resinosa*, *P. strobus* and *P. banksiana* in Northeastern United States and reported the most conspicuous symptom to be a bright yellow discoloration of the tips of the current seasons needles, appearing in autumn and affecting the upper part of the tree most strongly.

In New South Wales magnesium deficiency in *P. radiata* is often associated with deep sands and overlimed soils. Needle tips are yellow "as if dipped in paint", the severest onset of symptoms appearing in trees 3 to 6 years of age (Gentle and Humphreys, 1967).

f) Potassium

For a time seedlings in this series grew as well as those in the complete solution, but as symptoms became more pronounced, growth decreased and they became stunted.

Primary needles turned blue-to grey-green (Plate 22) and later became necrotic at the tips (Plate 23).

Secondary needles were pale to yellow-green with first chlorotic and then necrotic tips. They formed a marked contrast to the grey-green of the primary needles (Plates 24, 25 and 26).

As deficiency became more severe the last formed primary needles often remained curled around the terminal bud which became enlarged. This symptom was most common in the case of P. taeda (Plate 27). Finally, necrosis extended downwards along the whole length of the needles. In some instances and especially in the case of P. radiata this death of needles commenced about half way up the stem, but in others there did not appear to be any regular pattern.

The following table is presented in order to compare the symptoms obtained elsewhere with those described above.

Species	Symptoms	Reference
P. banksiana	Primary needles, from the tip inwards, show the following colourations: brown, yellow, green. Dead needles purplish brown. Green needles a dull blue-green colour in contrast to the fresh bright green of the controls.	Swan (1960)
P. echinata	Seedlings are stunted and non-chlorotic. Needles blue-green in colour, many showing copper-coloured terminal necrosis. While the terminal shoots die back new side shoots arise at the base of the plants.	Hobbs (1944)
P. radiata	Needle tips become chlorotic and then necrotic. Necrosis extends down along the needles and plants die back from the top.	Purnell (1958)
	In young seedlings severe deficiency produces red patches on primary needles especially near the tips. In older plants needles show chlorosis which is more pronounced at the tips.	Will (1961a)

Species	Symptoms	Reference
P. resinosa	Needles become bluish green. Needles near the base of the plants show tan to copper-coloured necrosis at the tips.	Hobbs (1944)
P. rigida	As for P. echinata	Hobbs (1944)
P. strobus	Needles, which are normally bluish-green, show tip necrosis. This necrosis occurs on needles all over the plant.	Hobbs (1944)
	Needles become yellow-tipped and eventually a light brown colour.	Hacskaylo (1960)
P. sylvestris	As for P. strobus	Hacskaylo (1960)
	Primary leaves remain a dark blue-green colour. There is an abundance of lateral buds, prominent terminal buds and long lateral stems. There are few or no secondary leaves.	Hacskaylo et al. (1969)
P. taeda	Tips of a few of the older primary needles become purple or brown. The remainder turn greyish-green. Needle tip necrosis extends over the whole plant while uppermost needles remain spiralled around the terminal bud. Fascicular needles which are few in number are twisted.	Sucoff (1961)
	The live tissue colour of the foliage remains a normal green. In extreme deficiency the terminal needles spiral around the terminal bud and die, developing a brownish-red colour first at the tips and then along the whole length. In cases of less severe deficiency the symptoms appear on older needles as well as the terminals and the needle tips progress through reddish-brown to brownish-red. The basal portion of the needles remains green.	Lyle (1969)

It can be seen from the above table that the symptoms given by Purnell (1958) and Will (1961a) for P. radiata and by Lyle (1969) for P. taeda do not include the blue-green to grey-green colour obtained in the experiments described herein.

A possible explanation for this stems from the work of Jones and Hewitt (1950) who found that in the case of potato plants, increased iron supply increased the ultimate severity of potassium deficiency symptoms. The concentration of iron used in the present experiments was 5 ppm, while the concentrations used by other workers who reported the abnormal green colour were 1.9 ppm (Hobbs 1944), 5 ppm (Swan 1960) and 3 ppm (Sucoff 1961). On the other hand Will used 0.5 ppm iron and the solutions used by Lyle contained less than 0.1 ppm. It would appear then that the production of a blue-green to grey-green colour on the primary needles could be dependant on iron supply and that this colour does not become evident at concentrations below about 0.5 ppm.

The solutions used by Purnell contained 5.6 ppm iron but the seedlings she used were 9 months old and seven inches high. It is probable then that the symptoms she described were those shown by the secondary needles and are therefore in agreement with the symptoms found in these experiments.

This is borne out by the symptoms attributed to potassium deficiency in P. radiata in the field. Hall and Purnell (1961) described symptoms in four year old P. radiata in Victoria as follows:

(1) Chlorosis occurred mainly in the lower lateral branches of the trees, the younger upper branches frequently remaining unaffected, while the leading shoot remained apparently healthy.

(2) Vigorously growing shoots on the upper external branches however, did lack rigidity and many developed severe bends. Later in the growing season this tendency diminished, but a proportion of the bends became permanent.

(3) On the lower lateral branches the last formed needles of the previous season's growth, immediately below the expanding shoot, turned yellow very rapidly, and commonly died.

(4) The older needles on the lateral branches were the next to turn yellow and some of these gradually died from the tip. The oldest needles however, yellowed and died very quickly.

(5) The onset of chlorosis was rapid in the spring but by the end of autumn the yellowing was not particularly marked in the needles which were still alive and the foliage generally seemed to have a more even colour.

Gentle and Humphreys (1967) described potassium deficiency of P. radiata as being generally associated with deep sands and affecting trees 5 to 8 years of age most severely. The needles last only 18 months to 2 years instead of the normal 3 to 4 years, then yellow and fall.

g) Iron

Seedlings of P. radiata in iron deficient solutions continued to grow as tall as the control plants for some time after the first appearance of deficiency symptoms. The growth of seedlings of P. taeda and P. elliottii however quickly fell behind that of the controls.

In the early stages, needles were pale green but as growth continued the new needles which were formed were yellow, pale yellow, and finally almost white. In all cases the needles were affected over their whole length (Plates 28, 29 and 30).

Needles which were formed before the onset of deficiency remained normal in colour showing the immobility of iron within the plant. In the final stages, the terminal bud and last formed needles died and the plants died from the tops downwards.

No reference to the occurrence of iron deficiency in pines in the field has been found in the literature but the above symptoms agree with those described for seedlings grown in nutrient solutions (Hacskaylo 1960; Hacskaylo et al. 1969).

Conclusion

In the experiments described herein salts of the elements under investigation were omitted from the solutions, the only possible source of these elements for the plants being present as impurities in the other salts used. Because of this all stages of deficiency were observed. In the nursery or plantation however, where the deficient element is available in limited quantities, only the mild to moderate stages may be apparent.

The following key has been compiled in order to provide a means of quickly identifying deficiencies in young seedlings. Not all of the symptoms have been included so that the key should only be used in conjunction with the more detailed descriptions given earlier.

I. Needles Chlorotic

A. Obvious colour variation along the length of the needles.

1. Needle tips golden yellow, the remainder normal to blue-green. Younger foliage first affected.

....Magnesium

2. Tips of secondary needles yellow, the remainder yellow-green.

....Potassium

3. Needles grey-green to yellow-green, chlorotic at tips. Dead needles at base of crown collapsed.

....Phosphorus (*P. radiata*)

B. Little or no colour variation along the length of the needles.

1. Needles yellow-green, shorter than normal.

....Nitrogen

2. Younger needles yellow to pale yellow, older needles normal.

....Iron

3. Needles, pale to yellow-green, resin droplets present. Needles may be reflexed.

....Calcium

II Needles not chlorotic

A. Needle colour normal.

1. Lower needles purple coloured.

....Phosphorus (*P. elliottii* and *P. taeda*)

2. Necrotic needle tips scattered throughout crown.

....Potassium

B. Needle colour abnormal.

1. Needles dark to blue-green, lower needles may be necrotic.

....Phosphorus

2. Needles blue-green to grey-green, necrotic at tips. Secondary needles yellow-green and chlorotic at tips.

....Potassium

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APPENDIX

Quantities in mls. per litre of Nutrient Solution

REAGENT	SOLUTION						
	Complete	-N	-K	-P	-Ca	-Mg	-S
M KH_2PO_4	1				1	1	1
M KNO_3	5			6	5	6	6
M $Ca(NO_3)_2$	5		5	4		4	4
M $MgSO_4$	2	2	2	2	2		
0.5M K_2SO_4		5				3	
0.05M $Ca(H_2PO_4)_2$		10	10				
0.01 M $CaSO_4$		200					
M $Mg(NO_3)_2$							2

PLATE 1.

P. radiata - Nitrogen deficiency.

PLATE 2.

P. elliottii - Nitrogen deficiency.

PLATE 3.

P. taeda - Nitrogen deficiency.

PLATE 4.

P. radiata - Phosphorus deficiency

PLATE 5.

P. elliottii - Early stage of phosphorus deficiency.

PLATE 6.

P. taeda - Early stage of phosphorus deficiency.

PLATE 7.

P. elliottii - Advanced stage of phosphorus deficiency.

PLATE 8.

P. taeda - Advanced stage of phosphorus deficiency.

PLATE 9.

P. elliottii - Early stage of calcium deficiency showing resin droplets on needles.

PLATE 10.

P. elliottii - Early stage of calcium deficiency showing resin droplets and necrotic needle tips.

PLATE 11.

P. radiata - calcium deficiency.

PLATE 12.

P. radiata - Advanced stage of calcium deficiency.

PLATE 13.

P. radiata - Calcium deficiency.

PLATE 14.

P. taeda - Advanced stage of calcium deficiency.

PLATE 15.

P. taeda - Advanced stage of calcium
deficiency.

PLATE 16.

P. elliottii - Showing early and advanced stages of calcium deficiency.

PLATE 17.

P. radiata - Showing flat-topped appearance of magnesium deficient seedlings.

PLATE 18.

P. radiata - Magnesium deficiency.

PLATE 19.

P. elliottii - Magnesium deficiency.

PLATE 20.

P. elliottii - Magnesium deficiency.

PLATE 21.

P. taeda - Magnesium deficiency.

PLATE 22.

P. taeda - Early stage of potassium deficiency.

PLATE 23.

P. radiata - Showing necrosis of needle tips of potassium deficient seedlings.

PLATE 24.

P. radiata - Advanced stage of potassium deficiency.

PLATE 25.

P. elliottii - Advanced stage of potassium deficiency.

PLATE 26.

P. taeda - Early and advanced stages of potassium deficiency.

PLATE 27.

P. taeda - Showing needles curled around the apical buds of potassium deficient seedlings.

PLATE 28.

P. radiata - Iron deficiency.

PLATE 29.

P. elliottii - Iron deficiency.

PLATE 30.

P. *taeda* - Iron deficiency.

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