


Upper Mid-Crown Yellowing (UMCY) in Pinus radiata forests

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Abstract

Upper Mid-Crown Yellowing is a condition of radiata pine in which needles in the sub-apical zone of the upper crown become yellow tipped with age, needle retention is low, and crown dieback occurs.

Many factors have been suggested as possible causes of UMCY; however, ecological, physiological, and chemical evidence suggests that a nutritional imbalance involving magnesium and potassium is the most likely cause. Magnesium deficiency in young stands and UMCY in older stands occur because the effective supply of magnesium is too low to meet the needs of radiata pine. Expected changes in the relative supplies of soil Mg and K suggest that the incidence and severity of UMCY is likely to increase in the future; however monitoring of the severity of UMCY on a national scale has been inadequate to confirm this.

The available evidence suggests that deficiency symptoms appear more severely in genotypes with a predisposition to accumulate low amounts of magnesium and high amounts of potassium in their foliage. Radiata pine has an inherently low capacity to accumulate magnesium in its foliage in comparison with other species, and variation within radiata pine is also large. Foliage chemistry data from seedling trees, clones, and radiata families show that within-stand variation in foliar Mg arises from genetic differences in tree nutritional characteristics. Based on the evidence linking UMCY to nutritional traits, the heritability of UMCY is likely to be high but family differences in UMCY (narrow sense heritability) need to be determined.

Research is under way to survey the incidence and severity of UMCY, and its association with site and management factors. The effects of UMCY on individual tree and stand growth and yield are being determined, to assess the cost of UMCY. Trials are being established to determine if UMCY can be economically treated by fertilisation with magnesium. The heritability of UMCY, and the extent breeding for tolerance to UMCY impacts on growth and form are being investigated. Soil tests to predict Mg deficiency, and plant tests to screen for tolerance to UMCY are being examined.

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Introduction

Typified by yellow needles in the upper crown followed by needle loss and various degrees of crown dieback (Beets et al. 1991), UMCY is only easily visible from above the canopy of New Zealand’s older Pinus radiata D. Don stands. UMCY is difficult to observe from the ground because the affected zone is easily masked by healthy branches lower in the crown, but UMCY has been increasingly recorded by Forest Health Observers following adoption of aerial surveillance methods in 1982 (P. Gadgil, pers. comm.). Concern about UMCY subsequently increased, and a major effort is being initiated to identify the causes of UMCY and to find solutions.

Reports by forest health officers indicate that UMCY is widespread throughout New Zealand, with the possible exception of Northland. Many reasons have been suggested, singly or in combination, to explain UMCY, among these being physical damage...
from possums, wind, snow, and land subsidence, needle pathogens such as *Cyclaneusma* species, root diseases such as *Armillaria* species, site limitations such as poor drainage, and nutrient deficiency.

In this article we present our views regarding the following questions:

Is UMCY a new phenomenon?
Is magnesium deficiency the underlying cause?
Is it exacerbated by one or more of the other reasons postulated?
Is the condition really on the increase and if so why?
Is there a loss in yield associated with UMCY?

We also examine steps that are being taken to develop cost-effective solutions.

**Historical perspective**

UMCY has been of concern to foresters and researchers for several decades. Records indicate that UMCY was evident at least 15 years ago. UMCY may have been evident in radiata pine stands at Kaingaroa Forest in the 1930s (Birch 1933). Graham Will used the term “upper mid-crown yellowing” almost three decades ago to describe magnesium deficiency in radiata pine (Will 1966).

Magnesium deficiency is the most likely cause of UMCY because both conditions have many features in common (Beets et al. 1991):

1) The yellowing of needles found in the UMCY zone is symptomatic of magnesium deficiency. Both UMCY and magnesium deficiency lead to the development of a tree crown with a symmetrical sub-apical zone with low needle retention and yellow-tipped or completely yellow needles, resulting from retranslocation of magnesium out of older needles during the spring growth phase.

2) Foliar magnesium concentrations decrease with height up the tree and would explain why the UMCY zone is sub-apical.

3) Magnesium deficiency symptoms in young stands and UMCY in old stands both show marked tree to tree variation, and records of the same trees over many years show a progression between the two conditions.

4) Magnesium deficiency and UMCY are both common in radiata pine but magnesium deficiency and UMCY are rarely found in other species at Kaingaroa.

5) Young stands with marginal magnesium deficiency symptoms are found adjacent to old stands with UMCY.

6) Stands with magnesium deficiency usually respond slowly to Mg fertiliser and early indications are that the same is true for UMCY, though few attempts have been made to treat UMCY affected stands.

**The nutritional imbalance hypothesis**

Tree nutrition research has established that radiata pine has a low capacity to accumulate magnesium in its foliage in comparison with other species (Will 1961). Radiata pine is a coastal species and a pest in its natural range, where it is typically exposed to salt spray under low rainfall conditions (Forde 1966) – conditions under which magnesium can be expected to accumulate in the soil. The ecological literature has highlighted the importance of Mg exclusion as an important plant adaptation for survival on high magnesium (serpentine) soils (Lyon et al. 1971). It is also well known that magnesium uptake is inhibited following application of potassium fertiliser (Grunes et al. 1992). Interestingly, radiata pine growing on coastal dunes at Woodhill are free of UMCY and foliar magnesium concentration at that site are two to three fold greater than radiata growing in central North Island stands.

In addition to species differences, large within-species differences in UMCY are evident among adjacent radiata pine trees.
growing on sites where UMCY occurs (see photograph). UMCY is known to be highly variable among clones, suggesting that some genotypes are predisposed to UMCY (Beets and Jokela in preparation). Within-stand variation in foliar Mg and other nutrients in radiata pine is known to be large (Mead and Will 1976), but the cause of this variation was not known until clonal tests with rooted cuttings grown on a range of sites showed that clonal effects exceed environmental (microsite) effects on a range of soils (Burdon 1976, Knight 1978). In other words, both UMCY and foliar nutrient concentrations vary among clones. UMCY is also associated with clones earlier shown to have low foliar Mg. This link is based on only six clones, but is supported by a series of photographs taken over a ten-year period from the top of the meteorological tower at Puruki which showed that young seedling trees showing marginal magnesium deficiency symptoms subsequently developed UMCY.

Acceptance of evidence from clones was confounded by the fact that clones propagated as grafts in seed-orchard stands can show graft incompatibility symptoms, not unlike UMCY. Mortality from delayed graft incompatibility was of sufficient concern in seed orchards that clones were subsequently propagated as rooted cuttings. The appearance of symptoms similar to graft incompatibility in some of the rooted cuttings was unexpected. These symptoms were at that time ascribed to poor rooting, because cuttings taken from old trees were known to have various ageing characteristics and a reduced capacity to produce roots compared to cuttings from juvenile pines. However, in 18-year-old stands at Puruki, where rooted cuttings (with a physiological age believed to be around five years at time of planting) are growing in mixture with seedling trees, foliar nutrient concentrations of seedlings were similar to aged cuttings. Furthermore, seedling trees were no less prone to UMCY than trees propagated as cuttings, and UMCY in seedling trees was also associated with low foliar Mg (Beets et al. 1991).

Heritability of nutritional traits
A study involving three-year-old control-pollinated radiata pine families established on contrasting soils (coastal dune at Aupouri, inland clay at Maramarua, and inland volcanic ash at Kaingaroa), has shown that significant family differences in foliar nutrient concentrations (including Mg, K, Zn and other nutrients) are evident at an early age. The narrow sense heritability was estimated to be around 0.3 for Mg (Beets and Jokela, in preparation). Family mean Mg levels differed by up to 40% at the coastal site, indicating that genetic factors override environmental factors (resulting from atmospheric deposition of Mg on the needles), in accounting for total variation in foliar Mg levels.

Based on the evidence linking UMCY to nutritional traits, it seems reasonable to assume that the heritability of UMCY is high. However, the key question regarding the heritability and genetic correlations of UMCY, foliar nutrient levels, and growth remains unanswered.

Testing the nutritional imbalance hypothesis
A study of 17 physiologically aged seed orchard clones, each represented by four rooted cuttings, was made to test if the known clonal differences in UMCY were correlated with clonal differences in foliar Mg. With the lack of conclusive proof from fertiliser studies, it was also important to establish if Mg was the cause of UMCY. In this respect, we acknowledge that low foliar magnesium levels in the UMCY zone could conceivably be a symptom of UMCY rather than a cause. Furthermore, we also accept that poor rooting and other agencies related to non-genetic factors could affect foliar nutrient levels in some clones. The sampling design therefore aimed to test:

1. If UMCY was correlated with foliar Mg and other nutrients.
2. If the expected gradient in foliar magnesium with height was larger in clones exhibiting UMCY compared to tolerant clones.
3. If foliar, nutrient levels, resulting from poor rooting was a contributing factor to UMCY.

Foliar nutrient levels and UMCY both showed differences among clones and were inter-correlated. Figure 1 (from Beets and Jokela, in preparation) illustrates the highly significant relationship between the clone mean UMCY score and clone mean foliar Mg concentration in the upper crown. Data from the lower crown position showed a similar trend but at higher foliar Mg concentrations, because Mg in these clones decreased by a factor of two with height. The Mg concentration gradient with height was found to be similar in all clones irrespective of their susceptibility to UMCY.

At low foliar Mg levels, high UMCY scores occur in clones that accumulated potassium (in Figure 1 foliar K is given next to the plotted symbol) and nitrogen in foliage. UMCY was previously found to be associated with low foliar Mg and high K in a study using seedling trees at Puruki, but the implications of high foliar Mg were not appreciated at that time (Beets et al. 1991). Observations indicate that poor rooting resulting from waterlogged soil conditions or fungal attack, and disruption of phloem transport resulting from stem girdling were associated with low foliar concentrations of N, P, K, Ca and Mg (G. Will, pers. comm.). Active uptake and translocation of nutrients requires an energy source, and the transport of carbohydrates to the roots via the phloem is therefore essential. Poor rooting is unlikely to be the underlying cause of UMCY because only foliar Mg and Ca concentrations were low.

Given that seedling trees showed marked variation in foliar nutrient concentrations, and that clonal tests indicated that the effect of microsite variation on foliar nutrients is small, we conclude that within-stand variation in UMCY was largely determined by genetic differences in tree nutritional characteristics.

![Figure 1: Relationship between clonal mean Upper Mid-Crown Yellow (UMCY) score, foliar magnesium (Mg) concentration (% needle dry weight basis), and foliar potassium (K) concentration in 17 radiata pine clones. One-year-old needles were collected in November 1992 from the standard sampling position in the upper crown, UMCY was scored, and the four individual trees/clone analysed for nutrient content. Potassium concentration is shown next to the plotted symbol.](image-url)
An imbalance in K and Mg nutrition has been demonstrated in the seed orchard clones and seedling trees at Puruki. An assessment of nutrient balances at more sites should reveal if this finding is generally applicable.

**Role of other factors in UMCY**

Possum damage is frequently associated with UMCY, but we rejected this as an underlying cause. Magnesium enters the branch via the xylem and exits via the phloem (bark), so ring-barking by possums would effectively limit Mg transport back out of the branch. Magnesium deficiency symptoms must then precede possum damage. The fact that UMCY can be predicted using foliar chemistry data from the healthy lower crown position also positively excludes upper crown damage (possum chewing, snow damage, wind) as a contributing factor. However, small branches can be bent by possums, possibly interrupting xylem transport, but leaving phloem transport unaffected. The yellowing sometimes associated with this damage should not be confused with UMCY, which affects major branches.

The supposition that infection by *Armillaria* species results in UMCY seems plausible. However, *Armillaria* results in root rot, so the uptake of nutrients in addition to Mg would be expected to be reduced. As already stated, trees with UMCY, while having low Mg and Ca concentrations, have significantly higher foliar K and N concentrations than unaffected trees. Like magnesium, K uptake is highly clonal. *Armillaria* while found at only low levels in the seed orchard study reported here (Mark Self, pers. comm.), was neither clonal nor associated with UMCY at this site. We conclude that sub-lethal infection of radiata pine by *Armillaria* species is not the primary explanation for UMCY, though it may be implicated in more general health problems (perhaps including Mg) at some sites.

Yellowing associated with infection by *Cyclaneusma* fungus can be confused with UMCY, because both conditions are particularly evident in spring, but the *Cyclaneusma* fungus is not the cause of UMCY. *Cyclaneusma* normally affects the older needles at the base of tree crowns, but under some environmental conditions it can affect all needle age-classes over the entire length of the crown. In such extreme cases UMCY is difficult to distinguish from *Cyclaneusma* and the presence of UMCY at a site is then best confirmed by examining surrounding trees that are not heavily affected with this fungus or by using foliar analysis.

Abiotic factors complicate the picture, because low plant availability of magnesium can be the result of rapid loss of Mg from the rooting zone through leaching. For example, coastal inputs of Mg will not always prevent UMCY. In spite of soil organic matter content and cation exchange capacity being low, coastal inputs of magnesium of around 8-10 kg/ha/year (>240 kg Mg over a 30-year rotation) are sufficient to meet the needs of radiata pine at Woodhill Forest because evapotranspiration rates closely match precipitation, and leaching losses are therefore low (Jackson et al. 1983). In contrast, similar rates of magnesium input would be insufficient in Westland because rainfall far exceeds evapotranspiration and leaching losses would be high. It is well known that variations in water supply are associated with variations in foliar nutrient concentrations, but the effect of moisture supply on nutrient balances does not appear to have been explored.

In summary, magnesium deficiency in young stands and UMCY in older stands occur because the effective supply of magnesium is too low to meet the needs of radiata pine. The available evidence suggests that deficiency symptoms appear more severely in genotypes with a predisposition to accumulate low amounts of magnesium and high amounts of potassium. Upper crown vigour is low in trees with UMCY. Recovery from physical damage and disease may be poor in trees with UMCY, though this is untested.

Between-tree variation in Upper Mid-Crown Yellowing severity at an UMCY prone site. The yellow-tipped needles in the UMCY zone are typical of magnesium deficiency. UMCY symptoms are evident in genotypes with a predisposition to accumulate low amounts of magnesium and high amounts of potassium in their foliage.

**Magnesium deficiency symptoms have generally been ignored**

Mg deficiency has largely been ignored in the past for various reasons. Widespread deficiency symptoms in young radiata pine in Kaingaroa Forest were particularly evident during the drought of 1963, but it was thought that the symptoms disappeared once tree roots penetrated into Mg supplies contained in buried topsoil (Will 1966). Because magnesium deficiency symptoms become less evident from the ground with increasing tree size, the progression to UMCY may have gone largely unnoticed. Forest managers have generally been aware of magnesium deficiency in their forests but have only recently become aware of the true extent of UMCY.

Current foliage sampling practices for Mg may not be adequate. It is easier to sample foliage lower in the crown where critical Mg concentrations are unlikely, even though concentrations can be critically low in the upper crown. Alternative sampling times and needle age classes may be more appropriate (Mead and Will 1976). In addition, year-to-year variation in foliar Mg is large in radiata (and other species), average Mg concentration in radiata pine (expressed on needle dry weight basis) at Puruki ranging between 0.076 (in 1985) and 0.107% (in 1990). Variation among trees in a stand is also high for Mg compared to other nutrients. Sampling of a limited number of trees in a limited number of years is unlikely to provide an adequate picture of the nutritional health of stands. With these difficulties it is not surprising that Mg deficiency was considered to be a transient condition, spring yellowing, and was largely ignored.

**Relationship between UMCY and growth rate**

UMCY occurs in some of the most productive stands of radiata pine in New Zealand, where rapid tree growth may lead to the dilution of magnesium in some of the dominant and co-dominant trees in the stand. Magnesium is an essential nutrient in many important processes, for example, photosynthesis (as part of the chlorophyll molecule), protein synthesis (where its role is vital), and activation of enzymes (essential for the transport of carbohydrates), and these processes are disrupted when Mg supply is
low (Marschner 1986). Dieback is one result of magnesium deficiency (Hunten et al. 1986), and UMCY is apparently an expression of magnesium deficiency in older-aged trees. Poor shoot growth in the upper crown results in the localised accumulation of nitrogen in the UMCY zone, which indicates a failure to achieve full growth potential. High nitrogen is believed to be a symptom of UMCY. Nitrogen accumulation in shoots has been reported in agricultural crops that are deficient in Mg (Marschner 1986).

Predictions of growth loss resulting from UMCY were estimated using a leaf-area-based model (Beets 1982), which suggest that a growth reduction of around 10% could be ascribed to UMCY when half the crop trees in the stand are affected. A 10% loss in growth potential will be difficult to measure directly. No well-designed trials are available for assessing the effect of UMCY on productivity on a unit area basis. Realistic productivity targets are essential to determine if productivity is being forfeited. UMCY clearly does matter, but predictions of growth loss need to be validated. Even if growth losses associated with UMCY are of no economic consequence, at this stage UMCY should not be ignored.

UMCY is likely to be on the increase

The severity of UMCY is likely to be on the increase in the future because: 1) Future growth rates (per unit area) are known or are suspected to be increasing (through for example tree breeding, elevated CO₂, and altered cultural practices) and consequently tree demands for Mg relative to supply will likely increase; 2) Magnesium fertiliser is rarely applied on forest sites; 3) Radiata plantations are increasingly being planted on ex-pasture sites which have been somewhat depleted of their native supplies of Mg, have often been fertilised with potassic superphosphate, and have high nitrogen fertility owing to use of legumes — factors which jointly accelerate growth rates and raise the site K/Mg supply ratio; 4) The number of rotations is increasing and intensive harvesting is known to affect magnesium supply more so than potassium supply on volcanic soils (Will and Knight 1968) and perhaps others.

Forest health records show that UMCY has been increasingly reported in recent years. In part this has come about because of an increased awareness of UMCY. Forest Health Officers usually report the distribution of UMCY nationally, but not national trends in UMCY severity. (D. Kershaw, pers. comm.) Magnesium deficiency and UMCY may have increased for reasons stated earlier, but quantification of the condition on a national scale has been inadequate to confirm this.

Toward a solution to UMCY

Information is required on the distribution, incidence and severity of UMCY, and the environmental factors contributing to variation. The current and potential costs to forest management of UMCY also need to be determined. The inheritance of UMCY and associated foliar nutrient levels needs to be researched, to provide a basis for facilitating early evaluation of progeny tests for breeding for tolerance to UMCY. As a basis for initiating any breeding work the following studies would be desirable: 1) Determining the capacity of major soil types to continue to provide particular nutrients under intensive management; 2) Assessing nutritional management alternatives (e.g. oversowing with legumes in the case of N, and fertilisation for other nutrients) for maintaining and enhancing productivity. Radiata pine tolerance to a range of nutrient conditions could be improved, but it would be more effective if focused on those nutrients which are difficult to manage through manipulating site conditions. Better matching of nutrient supply with demand will be crucial in the case of magnesium.

These needs are encapsulated in the following research objectives recently formulated by the Upper Mid-Crown Yellowing Research Group comprising NZFRI researchers and forest managers from a number of companies. This group is open to involvement by interested parties. (Contact Tim Payne.)

Research Aims:

- To determine the distribution, incidence and severity of UMCY, and its association with site (soil type, climate) and management factors (rotation number, site preparation, fertilisation history).
- To predict the effects of UMCY on individual tree and stand growth and yield, and determine the “cost” of UMCY.
- To determine if UMCY can be economically treated by fertilisation with magnesium.
- To determine the heritability of UMCY score and whether it is genetically correlated with other traits (like foliar nutrient level), and then predict gains in volume growth which will result from selection for UMCY.
- To develop soil tests to predict Mg deficiency, and plant tests to screen for tolerance to UMCY tolerance.
- To develop methods for better matching nutrient supply with demand by the tree crop.

Literature


