DIFFERENTIAL DISTRIBUTIONS OF CATIONS IN THE REGOLITH AND VEGETATION

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INTRODUCTION

Differential distribution of cations in plants is a relatively new field of study, with interest being shown for many reasons. These include: plant exclusion of metals in cropping situations (Kochian *et al.* 2002); the use of plants to remove or concentrate toxic chemicals from the soil and/or water environment (Mishra *et al.* 2003); and, particularly for *Eucalypt sp.*, the need to augment soil nutrients for maximum biomass production in plantation situations (Laclau *et al.* 2000). Plants behave as accumulators, indicators, or excluders, depending upon the relationship between availability in the soil and their nutrient requirement for the cation (Baker 1981). Much of the research in this area has been done in laboratory situations. The present study examines the distribution of cations in old, established plants in a relatively undisturbed environment, adding to our knowledge.

METHODS AND MATERIALS

In 2003 a site was chosen at "Mulloon Creek", northeast of Canberra on the eastern edge of the Great Dividing Range. A 10 m transect was excavated between a *Eucalyptus mannifera ssp. maculosa* (Brittle Gum) and *Acacia faliciformis* (Mountain Hickory) by skid-steer loader, as deep as possible. Both plants were estimated to be well over 100 years old (Banks *pers. comm.* 2003). Fresh vegetation samples were taken in autumn from both the Eucalypt and the Acacia: leaf (new and old); twig; small and large branch; bark; large, small and fine roots wood; and, 38 mm bark cores from the trunk. These samples were oven dried, wet digested with perchloric and nitric acid and analysed using an Inductively Coupled Plasma Atomic Electron Spectrometer (ICP-AES), in the Department of Earth and Marine Sciences Laboratory at the ANU.

RESULTS

The cation distribution in plant parts was compared with a database study of Eucalypts by Judd *et al*. (1996). Judd *et al.* found that nutrient concentrations were highest in the foliage of the plant, with the exception of Ca, which was highest in the bark, and lowest concentrations were found in stem wood. At "Mulloon Creek" foliage concentrations of cations fell within the range described by Judd *et al*. but nutrient distribution in the plants varied with the cation and plant species. Patterns of cation distribution in these plants have some similarities to the patterns expected from their role in plant growth and their distribution in soil, with some notable exceptions. Cation distribution in the plants can be divided into five groups (Table 1).

Table 1: Distribution of cations in plant parts across the *Acacia* and *Eucalypt* sampled at "Mulloon Creek"

Group	Distribution in plant	Acacia	Eucalypt
1	Highest value in growing points – leaves and twigs, lower elsewhere in the plant	K, (Na) Mg, Mn	K
2	Highest value in phloem, followed by leaves and twigs	Ca, Sr	Ca, Sr, Mg, Mn
3	Highest value in wood	Fe, Cu	Fe, Zn
4	Highest value in roots	Al, Ba	Al, Ba, (Na), Cu
5	No real pattern	Zn	

The distribution across the plant was compared to the cation distribution in the soil horizons to determine if there was any similarity in distribution patterns between the cations in different groups (Table 2).

In an earlier paper, Leonard & Field (2003) showed that cations in soils corresponding to Group 1, 2 and 3 have lower surface values, increasing with depth and distance from the plant, which is counter-intuitive when considering nutrient cycling. Cations in Group 1 also show a lowering in soil values immediately beneath the tree, indicating the tree may be trying to accumulate this cation faster than it can become available from soil breakdown. Iron, in Group 2, by contrast has a higher concentration in the root zone, so could be actively excluded from nutrient uptake. This could also apply to Group 4 soil cations, which show very high values in the root zone of the *Acacia* only. Ca and Sr are both divalent cations that may be used by a nitrogen fixing

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plant to counter pH changes. Group 5 cations, Cu and Mn, have a relatively even distribution along and down the transect, with some pockets occurring in the same areas of the transect. Interestingly, while these pockets show higher concentrations of Cu, they show lower concentrations of Mn (Leonard & Field 2003).

Table 2: Distribution of cations in soil beneath the *Acacia* and *Eucalypt* at "Mulloon Creek"

Group	Distribution in soil	Soil
1	Low surface values increasing with depth, and falling in the tree rootzone	K, Na, Zn
2	Low surface values increasing with depth, and rising in the rootzone	Fe
3	Low surface values increasing with depth, no difference near trees	Al, Ba, Mg
4	High surface values, with very high values near the Acacia	Ca, Sr
5	Even distribution	Cu, Mn

Of the eleven cations studied only six, representative of different abundance patterns in Table 1, will be discussed.

Potassium (K), (Figure 1) is the most common element in Group 1 and is a macronutrient primarily available to the plant from the breakdown of feldspar, micas and clays, and from recycling of plant material. It functions in the plant to stabilize pH and osmoregulation. It is required to synthesise protein and carbohydrates, assists in the control of stomatal aperture and activates many enzymes. A deficiency of K causes necrosis of old and young leaves, with stunted growth from reduced photosynthesis and protein synthesis (Dell 1996). At "Mulloon Creek", the pattern of distribution of K is similar in both the *Acacia* and the *Eucalypt*, with the highest readings in the leaves and twigs, as expected, and slightly higher concentrations in the phloem. Abundances in the wood of the *Acacia* are up to 100% higher than in the *Eucalypt*. Abundances in the old leaves and twigs of the *Acacia* are double that of the *Eucalypt*, while fine root values in the *Eucalypt* are more than double that of the *Acacia*. The pattern of K distribution in the soil beneath these trees showed a slight lowering in the root zones of both trees (Leonard & Field 2003).

Also in Group 1, Mg (Figure 2) is a meso-nutrient needed for protein synthesis, activation of enzymes, regulation of cellular pH, and assisting in the cation-anion balance. It is also a coordinated metal in chlorophyll (Dell 1996). Distribution of this cation is slightly different between the *Acacia* and the *Eucalypt*. The highest above-ground values in the *Acacia* are present in the leaves and green twigs, followed by the phloem. In contrast, below-ground highest concentrations are in the root bark (peak in the largest roots) and in the decomposing root (not shown on this graph). In the *Eucalypt* the highest concentrations are in the phloem, closely followed by the growing points of leaves, twigs and fine roots, and finally the bark. While the values in leaves and twigs are similar in both trees, other Mg levels in the *Eucalypt* far

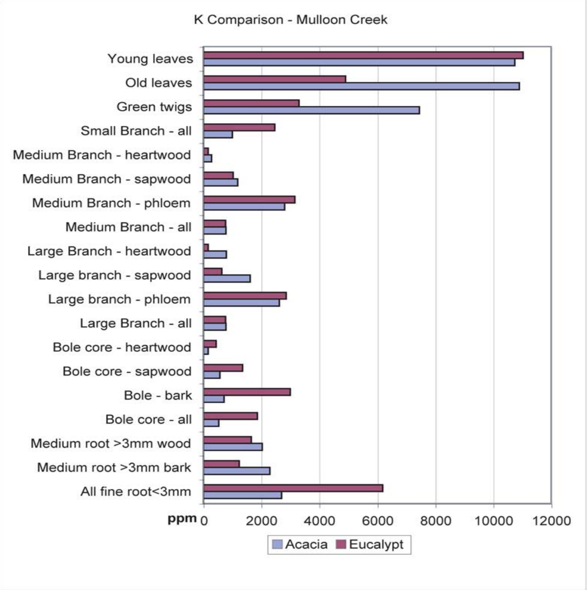

Figure 1: K distribution *Acacia* versus *Eucalypt.*

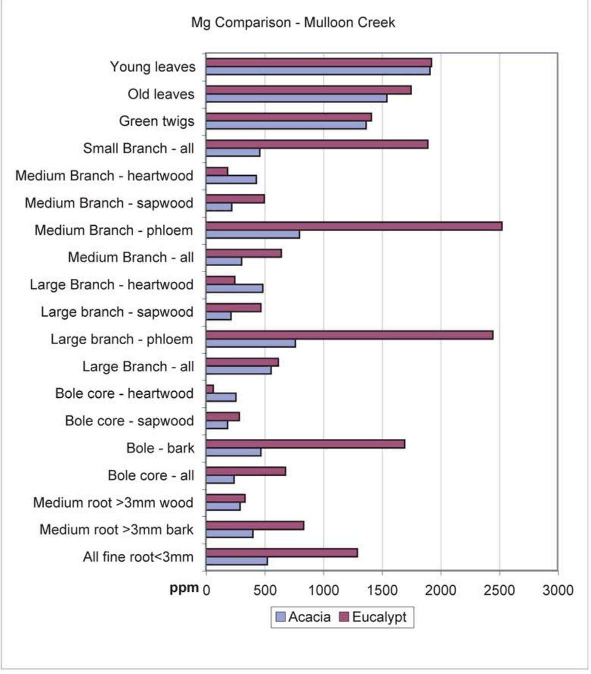

Figure 2: Mg distribution *Acacia* versus *Eucalypt.*

exceed those present in the *Acacia*. The pattern of Mg distribution in the soil beneath these trees showed very little difference along the transect (Leonard & Field 2003), either spatially, or with depth.

Calcium (Figure 3), a meso-nutrient, and Sr, sometimes considered a micro-nutrient, show an almost identical pattern of distribution in both plant and soil. This could be expected as they have similar valence and ionic radius and substitute readily for each other in minerals. In the soil, there are very high levels concentrated in the root zone of the *Acacia*, and no pattern of concentration below the *Eucalypt* (Leonard & Field 2003). Ca is required by plants for membrane stability and cell division and for normal growth of root tips. Ca is generally located in cell vacuoles and cell wall, and, according to Dell (1996) is not readily transported in the phloem. At "Mulloon Creek", the highest concentrations in the plants are in the phloem followed by the young growing points—the leaves, twigs and fine roots. Values in the *Eucalypt* are almost double those of the *Acacia*, while the concentration of Ca in the hard wood of the *Acacia* generally exceeds that of the *Eucalypt*. This pattern also appears in Sr distribution, but with much lower values, reflecting the lower values in the soil. Values of Ca in the soil are 15-20 times higher than Sr, while values of Ca in the *Acacia* are 100-120 times higher than Sr. In the *Eucalypt*, Ca is 75-140 times higher than Sr, suggesting concentration or accumulation of Ca, or exclusion of Sr. Magnesium, Ca and Sr all belong to Group IIA of the Periodic Table, and therefore could be expected to perform similarly. Given that Ca, as a meso-nutrient, is required in greater quantity in the plant, this is generally consistent with their behaviour in this study.

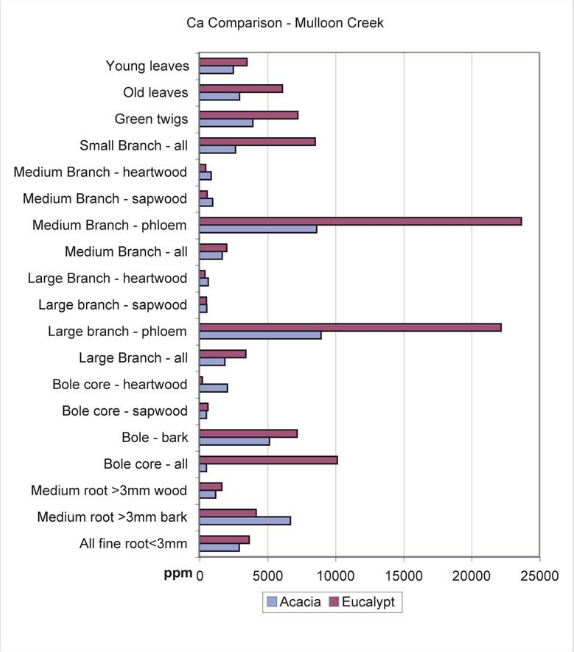

Figure 3: Ca distribution *Acacia* versus *Eucalypt.*

Iron (Figure 4) is the most common element in Group 3 and is sometimes considered to be a micronutrient. It is associated with the redox reactions of respiration and photysynthesis and the synthesis of chlorophyll. In the soils at "Mulloon Creek", Fe is evenly distributed along the transect, increasing with distance away from the tree and with depth from the surface, with slightly elevated values immediately beneath each tree. The pattern in the vegetation shows highest levels in the hard wood of the plants, though there is a marked difference between trees. The *Acacia* shows highest values in the largest wood parts, decreasing with size—bole > large branch > small branch > leaves and twigs. The *Eucalypt* has lower values in the bole than in the branches, and generally low values in the leaves and twigs. In both trees values in the roots are high compared to the rest of the plant. There is a slight rise in concentration of Fe in the root zone of both plants, which could indicate the plant is limiting uptake of this nutrient.

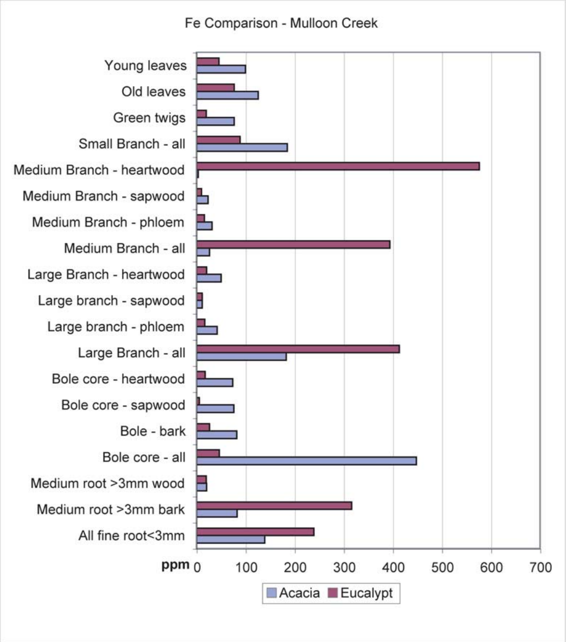

Figure 4: Fe distribution *Acacia* versus *Eucalypt.*

Aluminium (Figure 5) is the most common element in Group 4 Distribution within each plant shows a wide range. Aluminium is generally considered not to be a plant nutrient and, in fact, some authors consider that plants exclude it. Both plants have a similar pattern of distribution with highest readings in the roots, but with different concentrations. The *Acacia* shows some low levels throughout the plant, with highest concentration in the root bark, decomposing root and larger woody parts of the tree, (not all shown on this graph) followed by medium concentrations in the leaves and twigs. The *Eucalypt* has some much higher and much lower readings in the plant parts, with the highest reading being in the root bark—ten times higher than elsewhere in the plant. The next highest readings are in the fine root, seedpod (not shown here), and the woody parts of the plant. There is very little concentration in the active growing and transport mechanisms of both species. Aluminium distribution in the soil is constant along the transect, increasing with depth and distance from the tree (Leonard & Field 2003).

Zinc (Figure 6) is the most common element in Group 5 and is considered a micronutrient. It is required by the plant for stem elongation and photosynthesis; is part of many enzymes and is required for the activity of many others. Zinc deficiency may increase phosphorous uptake (Dell 1996). At "Mulloon Creek", Zn has an irregular distribution in the soil and the plant. This could be accentuated by the low values present in both soil and vegetation. Leonard & Field (2003) found a strong anomalous value in the soil pattern very close to a decomposing root of the *Acacia*. When this root was analysed there was no correspondingly high Zn level, however. It returned 2 ppm, in keeping with other woody parts of the tree. The highest reading for Zn was in the heartwood of the *Acacia*, which at 410 ppm, exceeded by tenfold any other readings in the tree. These ranged from 0 ppm to 35 ppm. The highest readings of Zn from the *Eucalypt* occurred in the wood of branch and bole, followed by root bark and fine root.

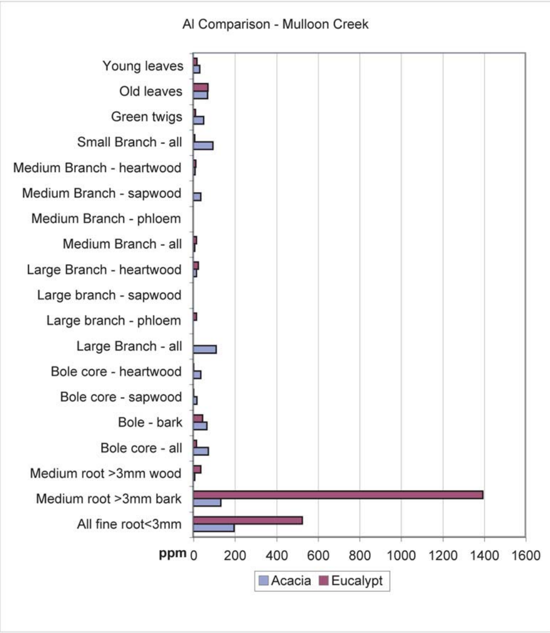

Figure 5: Al distribution *Acacia* versus *Eucalypt.*

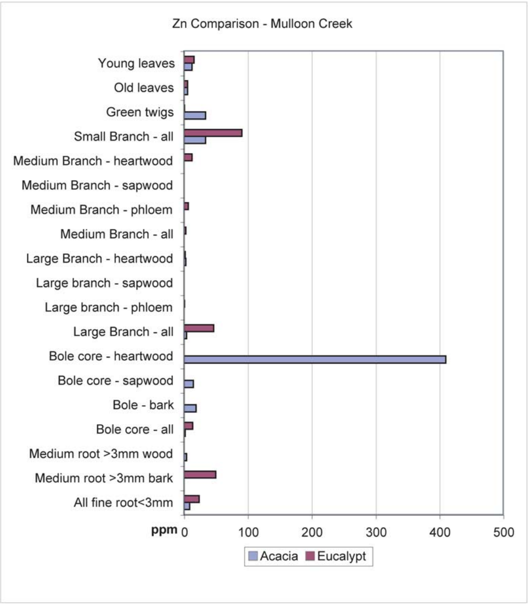

Figure 6: Zn distribution *Acacia* versus *Eucalypt.*

DISCUSSION

This study observed two different trees on one site. From this initial assessment it seems that the pattern of distribution of cations differs between the plants and could be related to: a combination of cation reactivity, (valence, ionic ratio, position in the Periodic Table etc); plant nutrient requirements; and, a ratio of plant nutrient requirements and the availability of nutrients in the regolith. Baker (1981) showed that plants behave differently towards cations, accumulating some and excluding others. Baker called others "indicators", where uptake and transport of metals to the shoot reflect external levels. Bhatia *et al.* (2003) agree that metal concentrations in hyper-accumulator plants follow the general trend of leaf > stem > root, but this study shows that this pattern does not apply to all cations or all trees. The observation by Judd *et al.* 1996, that foliage contains the highest concentration of nutrients, with the lowest in stemwood, (with the exception of Ca which is greatest in bark) cannot be supported by our results either. The results from "Mulloon Creek" may support an argument that these two plants have either a greater tolerance or a greater need for particular cations.

CONCLUSIONS

There is increasing interest in the field of metal distribution in plant matter, often stimulated by the use of plants for prospecting for new mineral bodies, for phytomining or for the remediation of contaminated lands. This research is often based on northern hemisphere crop and wetland species, and often under manipulated laboratory situations. To support this research, further study is needed in metal uptake of plants in natural field conditions. Southern hemisphere research may identify very effective hyper-accumulators in our native vegetation, as they are often adapted to nutrient-poor environments.

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REFERENCES

BAKER A.J.M. 1981. Accumulators and excluders – strategies in the response of plants to heavy metals. *Journal of Plant Nutrition* **3(1-4)**, 643-654.

BANKS J. 2003 Personal comment at field site.

DELL B. 1996. Diagnosis of nutrient deficiencies in eucalypts. In: ATTIWELL P.M. & ADAMS M.A. eds. *Nutrition of Eucalypts*. CSIRO.

BHATIA N.P., ORLIC I., SIEGELE R., ASHWATH N, BAKER A.J.M. & WALSH K.B. 2003. Elemental mapping using PIXE shows the main pathway of nickel movement is principally symplastic within the fruit of the hyperaccumulator *Stackhousi tryonii*. *New Phytologist* **160**, 479-488.

JUDD T.S., ATTIWELL P.M. & ADAMS M.A. 1996. Nutrient concentrations in eucalyptus: a synthesis in relation to differences between taxa, sites and components. In: ATTIWELL P.M. & ADAMS M.A. eds. *Nutrition of Eucalypts*. CSIRO.

KOCHIAN L.V., PENCE N.S., LETHAM D.L.D., PINEROS M.A., MAGALHAES J.V., HOEKENGA O.A. & GARVIN D.F. 2002. Mechanisms of metal resistance in plants: aluminium and heavy metals. *Plant and Soil* **247**, 109-119.

LACLAU J.P. BOULLET J.P. & RANGER J. 2000. Dynamics of biomass and nutrient accumulation in a clonal plantation of Eucalyptus in Congo. *Forest Ecology and Management* **128**, 181-196.

LEONARD J.A. & FIELD J.B. 2003. The effect of two very different trees on soil and regolith characteristics. *In:* ROACH I.C. ed. *Advances in Regolith*. CRC LEME, pp. 263-266.

MISHRA A., SHARMA S.D. & KHAN G.H. 2003. Improvement in physical and chemical properties of sodic soil by 3, 6 and 9 years old plantation of *Eucalyptus tereticornis*: biorejuvenation of sodic soil. *Forest Ecology and Management* **184**, 115-124.