

# POST-HARVEST ALUMINUM TOXICITY IN PODZOLIC SOILS OF THE SUNSHINE COAST, B.C.

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## Abstract

Most forest soils in the Georgia Basin – Puget Sound area are acidic and naturally high in aluminum (Al). This element is toxic to most terrestrial biota, and after leaching into drainage waters, to aquatic biota. This study investigates the changes in Al geochemistry following forest harvesting.

We collected soil samples from undisturbed plots, and compared them to samples from neighbouring plots that were clear-cut 1 to 15 years prior to sampling.

In logged plots we observed a slight increase in labile Al. However, labile calcium (Ca) levels also increased after harvesting and may help alleviate Al toxicity in these soils. The Ca/Al molar ratio, a useful predictor of Al toxicity in soils, is remarkably constant across control and logged plots.

## Introduction

Aluminum is considered to be the main factor limiting plant productivity on very strongly to strongly acidic soils (Alvarez et al., 2005). However, symptoms of Al toxicity are not well correlated to the Al content in soil or soil solution (Delhaize and Ryan, 1995). Many chemical and biochemical factors play an important role in modifying the response of plants to Al. A decrease in Al toxicity with increasing Ca concentration has been widely reported. The Ca/Al molar ratio has shown potential as an indicator of Al stress risk (Cronan and Grigal, 1995).

We investigated the changes in labile cations concentrations following forest harvesting, with special attention devoted to Ca and Al.

## Material and methods

### *Site*

The sampling area is located in the Roberts Creek Study Forest on the Sunshine Coast, about 40 km northwest of Vancouver, BC. The area is situated on the south-western flank of Mount Elphinstone and is characterized by low elevation (ranging from 350 to 500 m above sea level) and gentle slopes (average gradient of 15%). It lies within the Pacific Range Drier Maritime variant of the Coastal Western Mountain Hemlock biogeoclimatic zone (CWHdm). Douglas fir

dominates the overstory. The climate is characterized by warm, relatively dry summers and moist, mild winters with little snowfall. Drainage occurs through zero and first order creeks. A zero order creek is ephemeral, while first order creeks are perennial and have several zero order tributaries (Green and Klinka, 1994; D'Anjou, 2002; Hudson and Tolland, 2002).

We collected soil samples from undisturbed plots (control), and compared them to samples from neighbouring plots that were clear-cut 1 to 15 years prior to sampling (fig. 1).



*Figure 1: an example of a control plot (left) and a treatment plot clear-cut 2 years ago (right). Note that large amounts of woody debris are left on the ground after harvesting.*

### ***Soil profile***

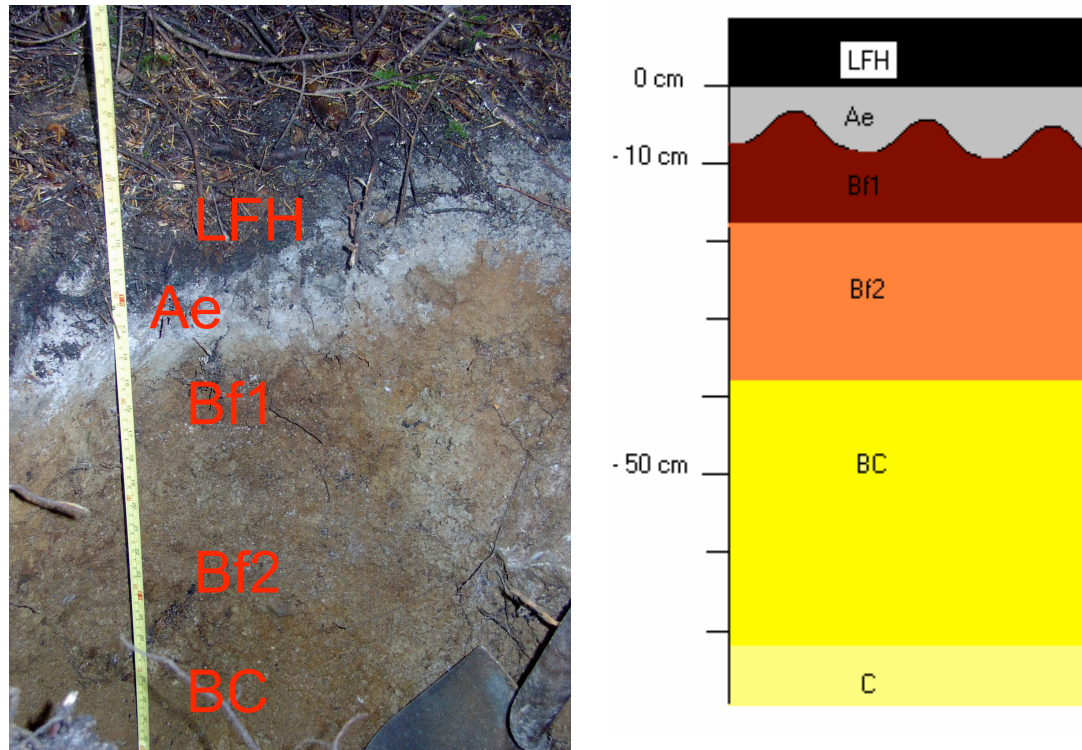
The soils of the study site are classified as humo-ferric podzols (fig 2). The soil profile comprises, from top to bottom:

- (1) organic layer LFH (3-15 cm in thickness). The forest humus form is usually a mor, indicating that little mixing occurs between the organic and the top mineral layers. Occasional moder and mull forest humus forms are observed, where soil animals such as mites and earthworms mix the organic and mineral layers together.
- (2) eluvial horizon Ae (2-15 cm thickness). This horizon is light in colour and contains less base cations, Al, and Fe than the parent material. The organic matter content is very low and the texture is sandy.
- (3) Bf horizon (25-35 cm thickness). This horizon shows a red colour and is enriched in Fe and Al. It contains a high concentration (up to 40g/kg soil) of poorly crystalline minerals such as

imogolite-type material. The Bf1 sub-horizon accumulates organic matter leached down from the surface organic layer.

(4) BC horizon (20 to 40 cm thickness). This transition horizon is sandy in texture and shows mottling, a sign of periodic intense anaerobic conditions caused by a fluctuating water table.

(5) C horizon. The parent material consists in compact basal till with little sign of soil development. Tree roots do not penetrate this horizon but instead run parallel to it.



*Figure 2: Actual soil profile (left) and simplified diagram (right) showing the average thickness of horizons.*

Most soil horizons are very strongly acidic. pH is below 5.5 in the LFH and Ae horizons, and averages 5.5 in the Bf to C horizons. The potential for these soils to be Al toxic is considerable.

### ***Extraction and analysis***

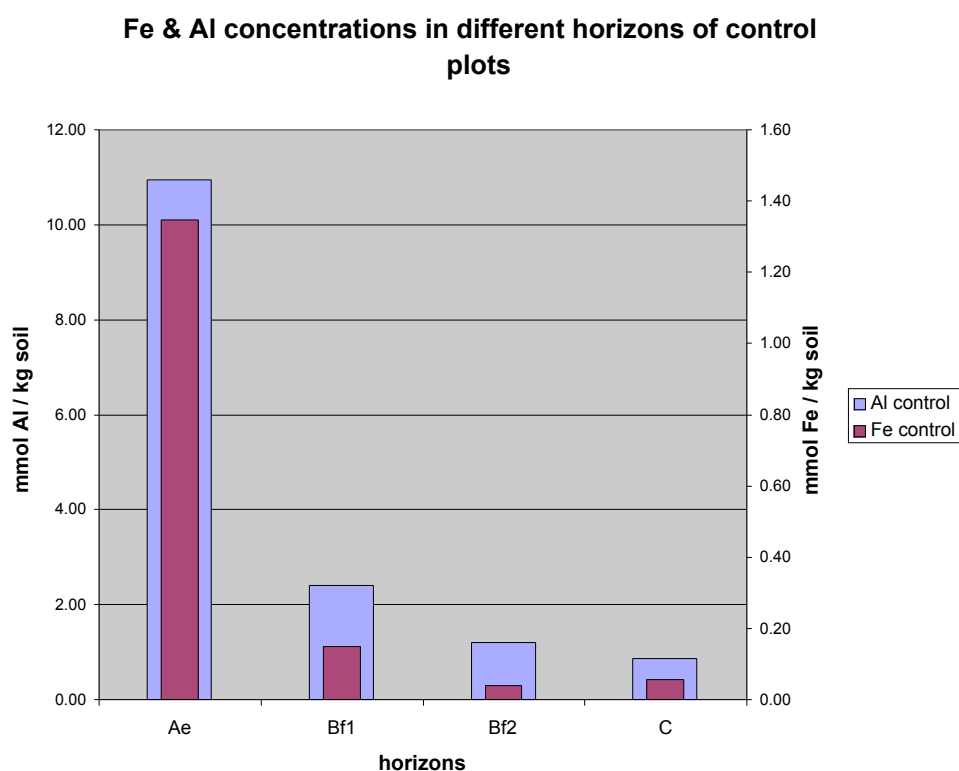
Labile cations were extracted with a 0.02 M BaCl<sub>2</sub> solution and extracts concentrations of aluminum (Al), iron (Fe), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), silicon (Si), and phosphorus (P) were measured using an AES-ICP (atomic emission spectroscopy – inductively coupled plasma).

## Results

### *Cation distribution by horizon*

Overall, the most abundant cations are Al and Ca, followed by K and Mg. This result is in accordance with the lyotropic series, which describe the ease of removal of exchangeable cations from exchange sites. Ca and Al have a small hydration radius and are strongly attracted to negatively charged surfaces found on soil colloids.

Al concentration is greatest in the Ae horizon, which is also the most acidic (fig. 3). Al and Fe concentrations show a similar distribution pattern and decrease with depth in both control and treatment plots. Labile Al concentration show a 10-fold variation in the soil profile, exceeding 10 mmol/kg soil in the Ae horizon and reaching a low of less than 1 mmol/kg soil in the deepest horizon (C).



*Figure 3: Distribution of Fe and Al in different horizons of control plots. The most superficial mineral horizon (Ae) is displayed on the left, followed by horizons of increasing depth.*

The base cations (Ca, Mg, K, and Na) also tend to decrease in concentration with increasing depth. A weak trend of accumulation in the Bf2 horizon is observed in few samples. Labile silicon concentrations are low in Ae and increase 4-folds in the B & C horizons (data not shown).



### Effects of logging on different horizons

After logging we observe a decrease of Al and Fe in the Ae horizon and a slight increase in the Bf horizons (fig. 4).

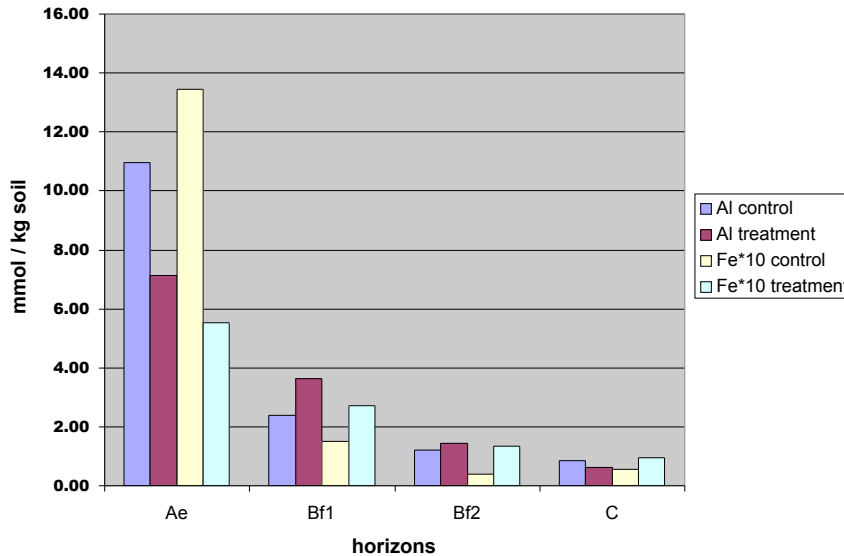


Figure 4: Distribution of Fe and Al in different horizons of control and logged plots. Please note that Fe concentrations have been multiplied by 10 for ease of display on the graph.

Si and base cations show a slight decrease in Ae, a slight increase in Bf1, and an inconsistent trend in Bf2 after logging.

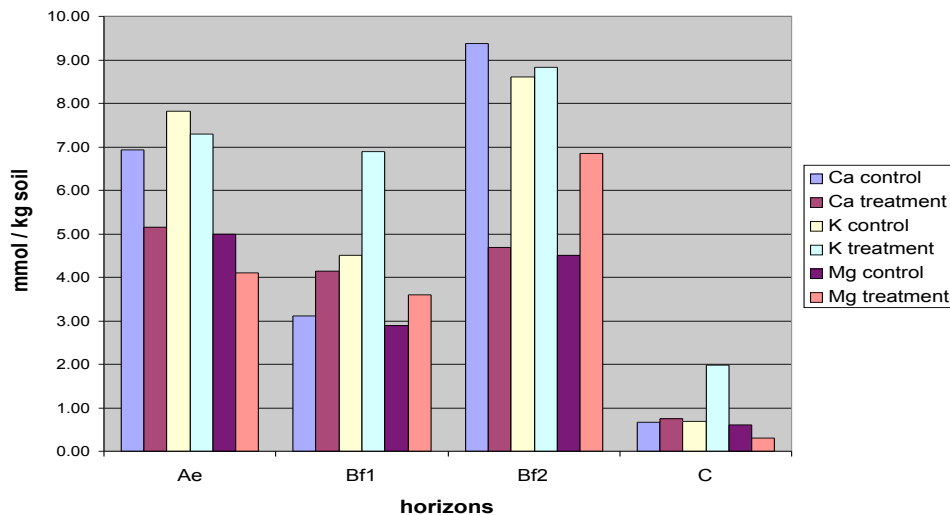


Figure 5: distribution of base cations in different horizons of control and logged plots. Please note that K and Mg concentrations have been multiplied by 10 for ease of display on the graph.

The calcium to aluminum molar ratio (Ca/Al), a valuable indicator of Al stress risk (Cronan and Grigal, 1995), is below 1 for Ae, greater than 1 for Bf2 (few data points), and approximately equal to 1 for Bf1 and C horizons (figure 6).

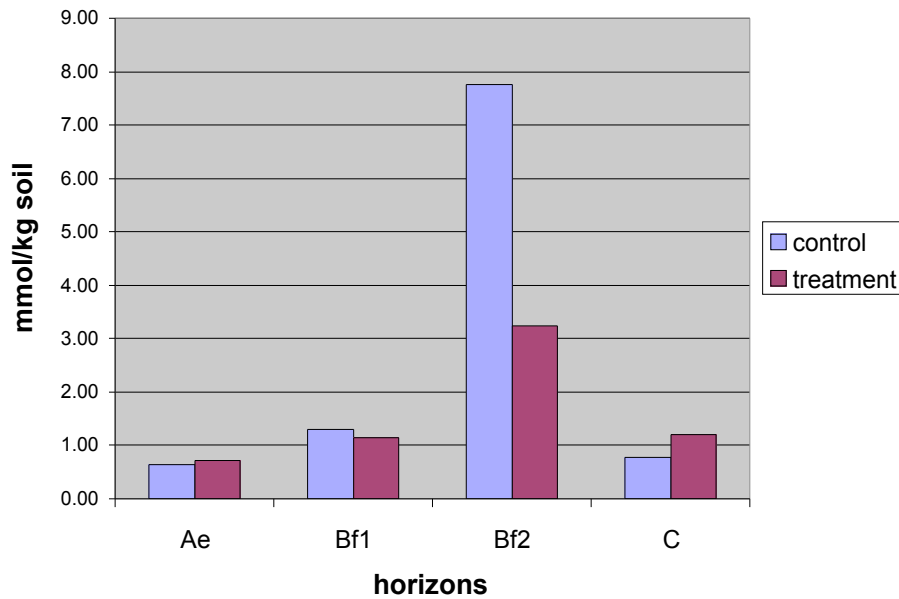


Figure 6: the Ca/Al ratio in different horizons of control and logged plots

#### ***Detailed study of the effect of logging on the Bf1 horizon***

The first Bf horizon is a key horizon in podzolic soils. Its chemical characteristics reflect the podzolization process, in which Al, Fe, organic matter and clays are leached from the Ae horizon and accumulate in the underlying Bf horizon. Forest harvesting is likely to disrupt the podzolization process and change the chemical conditions in the Bf1. The Bf1 horizon is also important for plant nutrition due to its relatively high pH, nutrient-rich status, and organic matter accumulation. For these reasons we studied the response of the Bf1 horizon to logging in more details.

In the Bf1 horizon, the treatment average is higher than the control average for all cations except for Na and P. The concentration of these elements is very low and near the instruments detection limit. The observed trend may not be significant.

Overall, cations concentrations are low in control plots, show rather random spikes after logging, and return to low initial levels after about 10 years following logging (fig. 7).

The increase in Al is counterbalanced by a coincident increase in base cations. The Ca/Al ratio is fairly constant. It increases slightly after logging to values slightly greater than 1, then after 12 years following logging decreases to values lower than those observed in the original control (fig. 8).

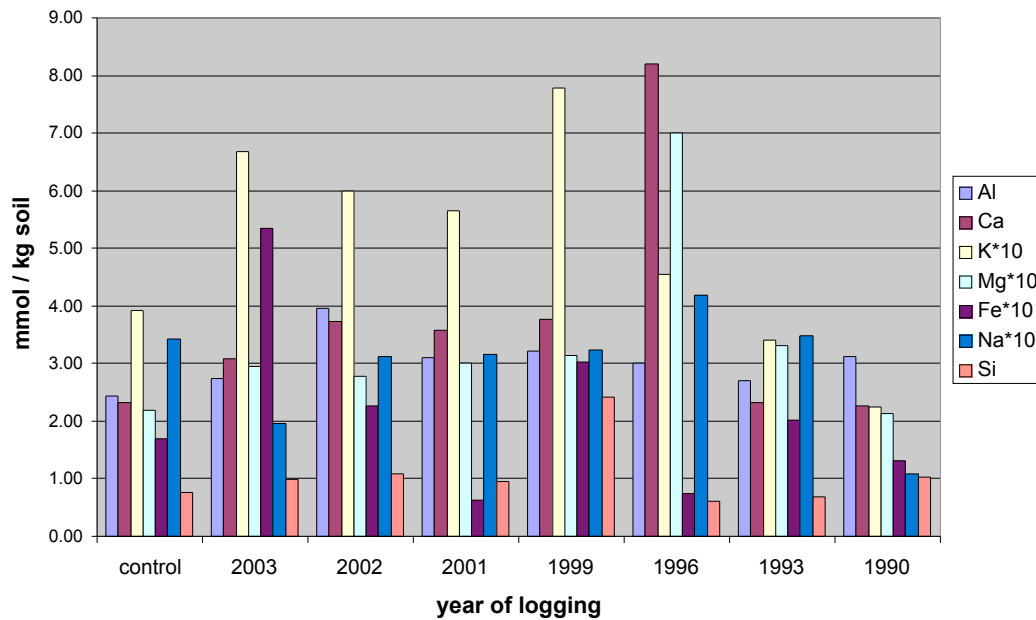


Figure 7: cations concentrations in Bf1 horizons of control plots and plots logged 1 to 15 years prior to sampling (in 2005)

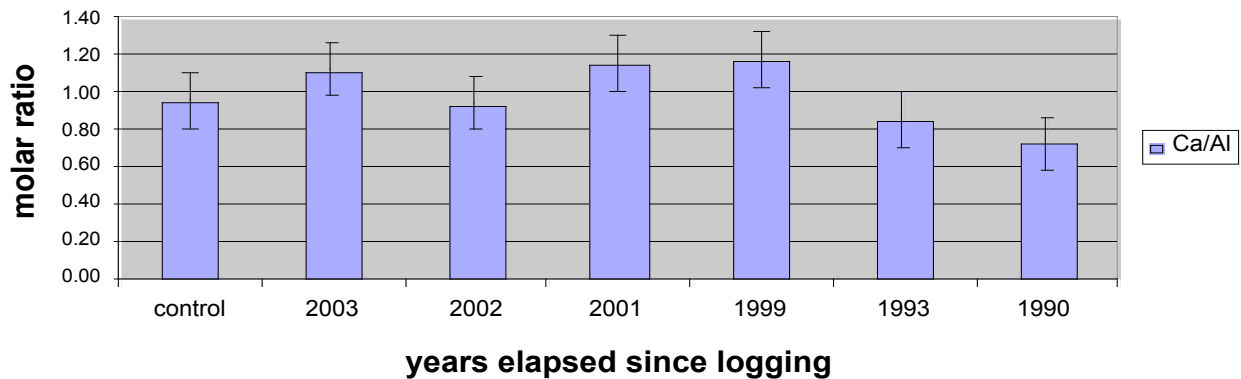


Figure 8: Ca/Al ratio in Bf1 horizons of control plots and plots logged 1 to 15 years prior to sampling (2005)

## Discussion

Major cations are not distributed evenly across the different soil horizons. Both acid and base cations show a 10 fold variation between the Ae and the C horizon of the profile. The Ae horizon is the most acidic and correspondingly shows the highest concentrations of labile Al. The Ca/Al ratio is below 1 in this horizon and shallow roots are likely to experience Al related stress.

After logging we observe an overall increase in cation concentrations in the Bf1 horizon, an important horizon for plant nutrition and soil forming processes. At approximately 10 years after logging vegetation becomes re-established and cations return to their base levels. The pH is constant in control and logged plots and does not explain the observed variations in labile Al and base cations.

The Ca/Al molar ratio remains fairly constant (around 1) between control and logged plots.

The increase in Al after harvesting is not believed to cause immediate additional Al toxicity. Ca levels increase concomitantly and may help alleviate Al stress.

However, the Ca/Al ratio seems to drop below 1 at approximately 10 years following logging. According to Cronan & Grigal (1995), the risk of forest damage due to Al toxicity is then greater than 50%. This unexpected finding warrants further investigation to confirm the trend and study mechanisms responsible for this change.

## Conclusion

We observed an increase in soil base cations and Al concentrations from 2 to 10 years following clear-cut harvesting. At 12 years after logging exchangeable cations returned to their base level. The increase in Al after harvesting is not believed to cause immediate Al toxicity. Ca levels increase concomitantly and may help alleviate Al stress for at least the first 10 years following clear-cutting. Al distribution after 10 years following logging should be investigated further.

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