The impact of CCA-treated posts in vineyards on soil and ground water

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Abstract Grapes in Marlborough are typically grown on a vertical shoot positioned trellis system (VSP). For this purpose *Pinus radiata* posts are treated with CCA, a mixture of copper (Cu), chromium (Cr) and arsenic (As), giving a wood concentration of 1,730, 3,020 and 2,410 mg/kg, respectively on a dry matter basis. The CCA levels around the posts in different soils were investigated and assessed for the potential leaching of CCA into ground water. An initial survey showed leaching of all three heavy metals from the treated posts into the soil surrounding the posts (0.2% of the total vineyard area) compared with the control, depending on vineyard age and soil type. The rate of movement out of the posts was calculated from posts placed in lysimeters. HortResearch's Soil Plant Atmosphere Model (SPASMO) was used to predict the leaching rate of CCA. For As, leaching was found to be 5 mg/post/month, with the Cr rate being about twice that. Further modelling revealed a steady plume of As moving downwards after about 200–300 years. However, long-term hydrogeological modelling showed that sufficient aquifer water flow prevented the accumulation of CCA in the ground water. The modelling approaches are discussed.

Keywords Arsenic; chromium; copper; leaching; vineyard posts; viticulture

Introduction

The area of producing vineyards in Marlborough, New Zealand, has increased from about 2,000 ha in 1996 to 15,000 ha in 2006. Grapes in Marlborough are typically grown on a vertical shoot positioned trellis system (VSP), using treated timber posts to support wires. Post spacing is generally 7.2 m within the row (one post per four vines), resulting in approximately 580 posts per ha. Over 95% of vineyard posts in Marlborough are made from pine timber (*Pinus radiata*) that is treated with a mixture of copper, chromium and arsenic (CCA) to prevent fungal rot and insect damage. This treatment typically results in a wood concentration of copper (Cu), chromium (Cr) and arsenic (As) of 1,730, 3,020 and 2,410 mg/kg, respectively, on a dry matter basis. With an average post weight of 12 kg, each hectare of vineyard has a CCA loading of 12, 21 and 17 kg, respectively. Research by hydrologists had found lightly elevated levels of arsenic in groundwater in one small area. Despite this area being known for the presence of geogenic arsenic, the Council needed to ascertain the sustainability of using CCA-treated timber as support structures in vineyards. HortResearch was asked by the Marlborough District Council to survey CCA levels around the posts in different soils and to assess the possible long-term effects of any potential leaching of CCA into ground water.

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Survey materials and methods

Six sites were selected to represent a range of post ages and soil types from around the Marlborough Region. The soils varied from clay loams, through shallow silt loams to very gravelly soils with high winter water levels. The vineyard ages varied from 2 to 16 years old. The posts were levered out of the ground for sampling to cause minimal soil disturbance around each post. For each class of posts, three replicates were taken.

Soil samples were taken adjacent to the posts, (A), at 50 mm horizontal distance (B) and immediately and 100 mm below the post (C and D respectively). A reference soil sample (E) was collected from the inter-row (Figure 1).

Approximately 20 g (dry weight) samples of wood were removed from both the above- and below-ground portions of the post using a chisel. For the half-round and quarter-round posts, wood was removed to approximately 15 mm deep at the intersection between the flat face and the circumference. An additional six samples were taken from new posts. The samples were sent to a commercial laboratory for dry-weight determinations of copper, chromium, arsenic and boron.

Survey results and discussion

The results from this survey clearly show the appearance in the adjacent soil of all three heavy metals, with significantly higher concentrations of CCA in the soil surrounding the posts compared with the control soil. Across all sites, 25% of the samples contained more than 100 mg/kg As (As threshold for agricultural soils set by the Australian National Environmental Protection Council; ANEPC). If the investigation levels were the NZ Timber Treatment Guideline value of 30 mg/kg, then nearly half the soil samples would have exceeded the investigation level. Some 10% of the samples were above ANPEC guidelines for chromium (100 mg/kg). None of the copper values exceeded the ANPEC guideline of 1,000 mg/kg (Figure 2, compare with Table 1). However, 33 samples were above 200 mg/kg, a level shown to cause plant toxicity in other studies

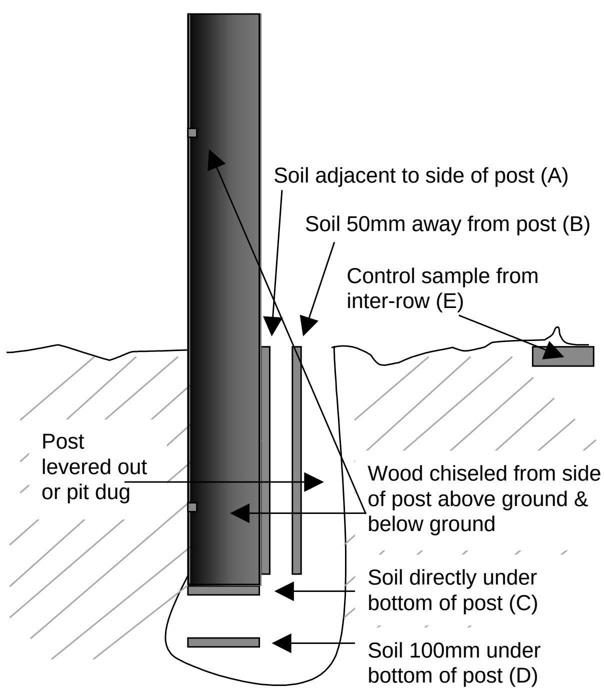

Figure 1 Locations of soil and wood samples taken from around each post

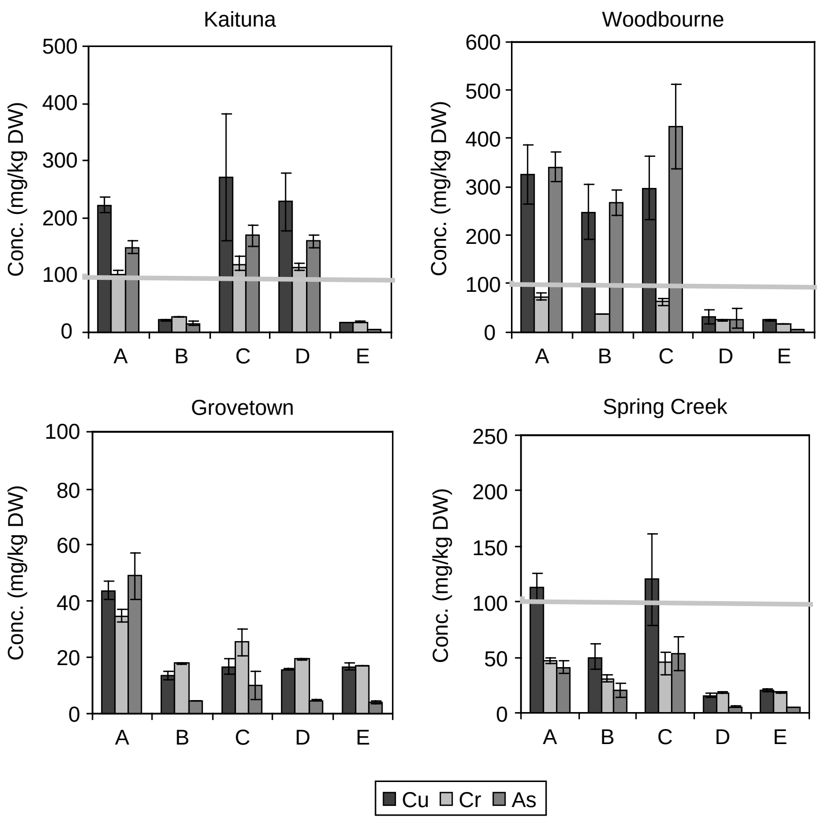

Figure 2 Soil copper (Cu), chromium (Cr) and arsenic (As) concentrations (mg/kg Dry Weight) at various locales throughout the Marlborough Region. Bars represent the standard error of the mean ($n = 3$). The **horizontal grey line** is the Australian National Environmental Protection Council (ANPEC) guideline for arsenic in soil

(Thayalakumaran *et al.*, 2003). However, this was very localised and only happened in the area immediately around the posts, which covers about 0.2% of the total vineyard area. Earlier studies on treated posts also showed that soil CCA concentrations decreased rapidly with increasing distance from the post, especially for copper and chromium, which approached background levels at 50 mm. Arsenic is more mobile and has been found 500 mm out from posts, and 1 m below (Zagury *et al.*, 2003). The average soil

Table 1 The effect of soil type on the fate of arsenic leaching from a treated timber post after 30 years, averaged over a vineyard area (kg/ha). The initial mass of arsenic was taken to be 9.9 g per post and the post density was assumed to be 600 posts/ha. Based on historic climate data, the accumulated leaching to 1 m, 2 m, and 3 m depth is given

Soil series	Description	Loss (kg/ha)	@ 1 m (kg/ha)	@ 2 m (kg/ha)	@ 3 m (kg/ha)
Rarangi	Pea gravel	2.66	1.37	0.65	0.41
Fairhall	Shallow silt loam	2.66	0.41	0.16	0.09
Rapaura	Shallow silt loam	2.66	0.63	0.26	0.13
Brancott	Deep silt loam	2.66	0.33	0.10	0.03
Spring Creek	Clay loam	2.66	0.33	0.11	0.03
Kaituna	Silt loam, high C	2.66	0.07	0.02	0.01
Woodbourne	Deep silt loam	2.66	0.02	0.00	0.00
Grovetown	Deep clay loam	2.66	0.06	0.00	0.00

CCA concentrations in our study were consistent with the findings of many overseas studies (Hingston *et al.*, 2001; Chirenje *et al.*, 2003; Zagury *et al.*, 2003).

Lysimeter trial materials and methods

To study the leaching of CCA from vineyard trellis posts under controlled conditions, a trial was set up in which six round and six half-round 1.5 m long CCA-treated posts were placed in 75 L lysimeters that were filled with soil from one of the areas in Marlborough, most at risk from CCA leaching. Before posts were installed in the lysimeters, samples of the soil and water were taken to determine the background levels of CCA. Similarly, samples of the above-ground and below-ground portions of the posts were obtained prior to installation. Six of the soil-containing lysimeters (three with round, and three with half-round posts) were permanently drained, keeping the posts relatively dry, while in six other similar lysimeters, the posts were kept saturated to imitate elevated groundwater levels.

In addition, three replicates of half-round and three of full round 500 mm posts were suspended in buckets filled with water with 400 mm of posts under water to simulate a worst-case scenario when the bottoms of the posts dip into shallow ground water. Lids were placed on these buckets to prevent rainfall entering and to reduce evaporation. The water levels in these lysimeters were maintained throughout the experiment. Drainage was collected weekly, the volume measured, and a sub-sample sent away for CCA analysis. Wood samples from the water-filled lysimeters were initially collected monthly but after three months were collected only every third month. By monitoring the CCA rise in the water, we could parameterise a first-order model for the soil-to-solution transfer.

The meteorological station on site recorded daily rainfall and other pertinent climatic variables throughout the experiment.

Lysimeter trial results and discussion

Results from this trial showed a clear movement of CCA from the post both into the water, and into the soil (Figure 3). The lateral and depthwise penetration depends on the permeability of the soil and the capacity of the soil to bind these heavy metals. Allinson *et al.* (2000) reported that once in soil, the movement of the copper component of CCA is strongly retarded by exchange with the soil, even in sandy soils. Monthly analysis of the leachate gave us the parameters to calculate the rate of movement out of the posts. These values were used in HortResearch's Soil Plant Atmosphere Model (SPASMO) to

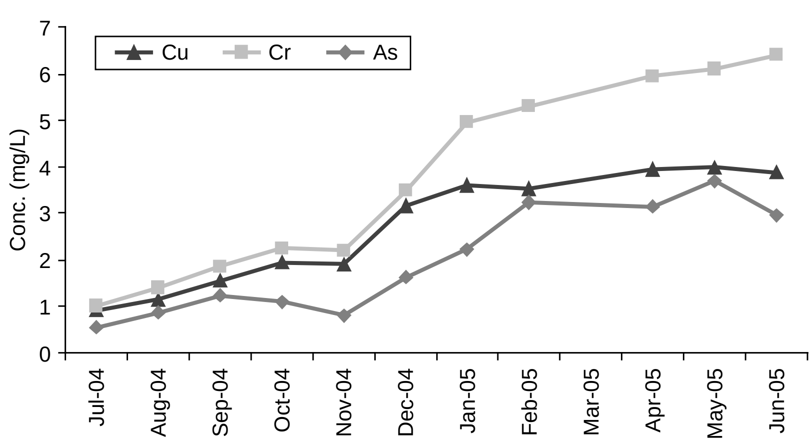

Figure 3 Monthly measured concentration showing the impact of the leaching of Cu, Cr and As from CCA-treated posts submerged into water

predict the movement of these heavy metals through, and out of these posts into the water and the soil, for eight different sites in the Marlborough vineyard area. The leaching rate for As was found to be 5 mg/post/month, with the Cr rate being about twice that. During the treatment process, the end-grain penetration of CCA is 40 times higher than lateral penetration (Morgan and Purslow, 1973). It can therefore be expected that, in reverse, the end-grain leaching would also be considerably higher than lateral leaching because of the wood's longitudinal vascular structure. Leaching measured from CCA-treated posts that had their ends sealed with paint showed $>50\%$ reduction of CCA concentration in the water compared with non-sealed posts (Ko *et al.*, 2006).

Using our knowledge of the soils in Marlborough and their related climates, as well as the measurements from the lysimeters, it has been possible to model the likely flow of Cu, Cr and As out of the posts into the surrounding soil and down through the profile. The results from this modelling exercise corresponded with the actual field results found in the leaching survey of several Marlborough vineyards (Robinson *et al.*, 2005). This gives us confidence that our modelling has given us good insight into the potential leaching risks for the different soils around Marlborough.

Using locally obtained vineyard posts revealed enormous variation in concentrations of CCA (Greven *et al.*, 2005). For example, the concentration of arsenic between posts [As] varied from 1,100 to 5,300 mg/kg, with a median [As] of 2,150 mg/kg. The variation of [As] within the posts ranged from 1,850–3,000 mg/kg, with the higher concentrations at the pointed end. The ratio of As, Cu and Cr in the posts was always similar, but varied from the industry standard of Cu:Cr:As = 1,700:3,000:2,400 mg/kg. However, in this particular experiment, chemical concentrations between the posts were consistent ([Cu] = 2,500 mg/kg, [Cr] = 6,000 mg/kg and [As] = 3,600 mg/kg). It is on the basis of these concentrations that the modelling was carried out. Figure 3 shows the leaching of CCA from the treated timber into water. The SPASMO model for describing treatment-chemical fate was run only for arsenic.

The chemicals leached out of the posts are transported in the water through the profile depending on: a) the permeability of the soil to the water carrying the CCA, and b) the capacity of the soil and organic matter particles to adsorb these chemicals. "The amount and rate at which arsenic leaches varies considerably depending on numerous factors, such as local climate, acidity of rain and soil, age of the wood product, and how much CCA was applied" (US EPA, 2002). With our knowledge of the various soil properties, it has been possible to calculate the amount of chemical that will leach over a period of 30 years based on weather information taken from historic meteorological data 1974–2004. The results of these calculations are shown in Table 1 for eight dominant soil profiles in Marlborough.

It is calculated that after 30 years, 44% of the As will have leached from the posts, i.e. 7.9 g As/post. This rate is controlled, we assume, by the diffusive nature of the wood, and the fraction of the soil's volume that is filled with water and in direct contact with the post. Movement of this amount of arsenic through the soil, however, depends very much on the soil type. Soil conditions, especially pH, organic matter and clay contents, play an important role in leaching and movement of CCA (Carey *et al.*, 1996; Hingston *et al.*, 2001). From the calculations (Table 1), we see that in heavy soils (e.g. the Grovetown, deep clay loam) most of the chemical will bind to the soil particles close to the post. Virtually all the As in these soils ends up being bound to the soil, raising the level of As in these soils rapidly (within 8 years) to levels exceeding the ANPEC guideline value of 100 mg-As/kg. However, with about 600 posts/ha this equates to only 0.05% of the vineyard surface area, and therefore the spatially averaged loading at depth needs to be weighted accordingly. Because most As is bound in the top part of the soil, little leaches much beyond 1 m depth over this 30-year timescale (Table 1). Other more free draining soils adsorb sufficient As to avoid risk to the groundwater. Table 1 shows the kg/ha of As that can be expected at depths of 1, 2 and 3 m in eight Marlborough soils after 30 years.

Only the Rarangi gravels could pose some risk (Green *et al.*, 2001). These stony soils have a low absorption capacity, low water content, and they are extremely free draining. This causes the As to move deep down into the profile at high concentrations of around 0.025 mg/L. This value is 2.5 times the New Zealand Drinking Water Standard (NZDWS). Furthermore, at times, the Rarangi shallow aquifer reaches close to the soil surface, inundating the bottom part of the posts. This increases the risks of CCA removal from the post and brings it directly into the groundwater.

Further modelling was based on soil type and climatic conditions in order to elucidate the potential for CCA to contaminate the underlying aquifers (Figure 4). Modelling over 500 years, but now with the expected post replacement every 20 years, revealed that after about 200–300 years, depending on soil type, a steady plume of As moved downwards (Clothier *et al.*, 2006). It was found that As, which is more mobile in the soil than Cu or Cr, potentially could move through the soil into the local aquifers after the adsorption capacity of the soil was filled. Spatially averaged, the concentration of As was found eventually to reach 0.0125–0.0175 mg/L at 2 m depth, which just exceeds the NZDWS. However, when combined with ground water flow results measured by the Regional Council, long-term hydrogeological modelling showed that in Marlborough, even at Rarangi, despite the high density of vineyards and hence posts, sufficient aquifer water flow prevented the accumulation of these heavy metals in the ground water. Long term, As concentrations will stay an order of magnitude below the NZDWS.

This work has shown that the use of CCA-treated posts will result in some levels of leaching of CCA into the soil. How much CCA accumulates in the soil is dependent on

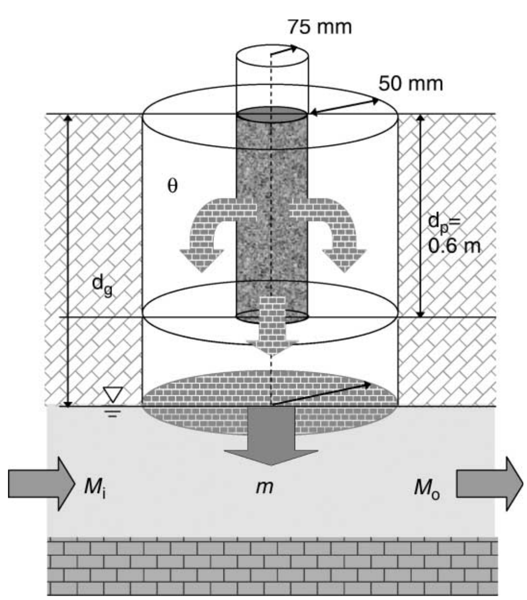

Figure 4 The Cu, Cr and As leaching processes described in the SPASMO (Soil Plant Atmosphere Model) model. Here dg is the depth to groundwater, θ is the soil water content, m [mg As/post/month] is the flux of As leaving the post, and Mi and Mo [mg As/yr] are the arsenic fluxes into and out of the ground water upstream and downstream of the posts

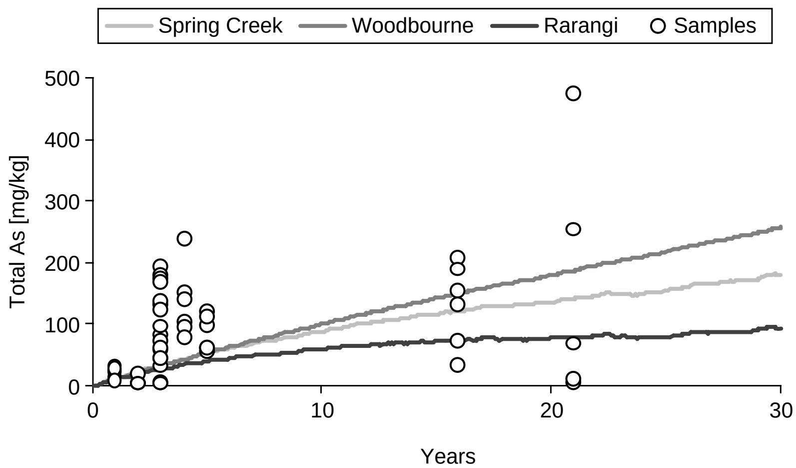

Figure 5 The effect of soil type on soil arsenic concentration immediately under the post predicted by SPASMO (Soil Plant Atmosphere Model) modelling (lines). The symbols represent samples collected within 50 mm of posts of various ages on a range of Marlborough soils (Robinson *et al*., 2005)

soil type (Figure 5). However, the steady downward flow in the long term depends mainly on the leaching rate from the post, not the soil type.

Conclusions

The three timber treatment chemicals of copper, chromium and arsenic (CCA) do move out of the vineyard support posts into the surrounding soils and then eventually they move down towards ground water. Chromium is the most mobile in the soil of the three elements, followed by arsenic and copper, yet there is great variability in CCA concentrations between posts. Soil type, stoniness and organic carbon in the soil are important factors controlling the speed and depth of movement of CCA through the soil.

CCA has the potential to accumulate in the soil over time and reach levels that are above guideline values. However, in Marlborough, some 95% of the vineyards are in areas where the subterranean aquifers have sufficient capacity to dilute the descending plume of copper, chromium and arsenic down to levels that are only 0.1 to 0.05 times the drinking water standard. Furthermore, naturally occurring geogenic arsenic levels in the aquifers are well above that contributed by the treated-timber posts.

Further work on CCA loss from paint-sealed end-grains of the post found a reduction of leaching by more than 50%.

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