Exposure to Pesticides and Metal Contaminants of Fertilizer among Tree Planters

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In British Columbia, Canada, harvested forests are manually replanted by seasonal workers. The work is known to be physically demanding and ergonomically difficult, and recently, there have been concerns over chemical exposures due to pesticide residues on seedlings, fertilizers (often applied alongside seedlings), and potential metal contamination of these fertilizers. This study aimed to characterize metal and pesticide exposure among a sample of British Columbia tree planters. Between May 2006 and April 2007, exposure measurements were taken from 54 tree planters at five geographically disperse worksites throughout British Columbia. Four worksites were using fertilizer and one was not. Metal concentrations were measured by inductively coupled plasma mass spectrometry on post-shift hand wipes, full-shift personal air sample, bulk soil, seedling root balls, and fertilizer samples. Pesticides were measured on post-shift hand wipes and on bulk seedling samples. Seedling nursery pesticide application records were used to focus pesticide analyses on pesticides known to have been applied to the seedlings at the study sites. Carbamate pesticides were analyzed by high-performance liquid chromatography/mass spectrometry and all other pesticides by gas chromatography mass spectrometry. No evidence was found that tree planters who worked with fertilizer were at an elevated risk of exposure to arsenic, lead, cadmium, chromium, and nickel relative to tree planters who did not. Pesticide residues were found on seedlings taken from worksites early in the tree planting season in April 2007. At these worksites, the fungicides chlorothalonil and iprodione were found on the skin of workers at low levels (range 0.37–106.3 ng cm$^{-2}$ and 0.48–15.9 ng cm$^{-2}$, respectively), providing evidence for exposure potential. Very poor hygiene conditions were observed at all tree planting work sites. Hand washing facilities were not available at work sites and only 5.6% of subjects reported hand washing during the work day, including prior to eating or smoking. Gloves were worn by all subjects but no personal protective equipment programs existed to train workers in the correct use or selection of gloves, and consequently, many glove choices were inappropriate. The lack of hand washing facilities combined with incorrect glove use could increase the duration of dermal exposure and increase the risk of hand-to-mouth ingestion exposure.

Keywords: dermal exposure; fertilizers; forestry; metals; pesticides

INTRODUCTION

In British Columbia (BC), Canada, harvested forests are replanted manually by seasonal ‘tree planters’. Up to 5000 workers are employed each year by 250–300 independent tree planting contractors that in turn are hired by forestry companies. Tree planting work sites are typically geographically dispersed and in remote rural locations. The seasonal workers usually live in tents in wilderness camps or in motels in nearby towns. The tree planting season begins at snowmelt...
(February in coastal regions and May for inland regions) and continues until October. Each planter (usually 10–50 per worksite ‘crew’) loads two or three bags worn on a hip belt with up to 200 or more seedlings (taken from storage boxes) and fertilizer sachets (in a separate bag or container) for planting in a clear-cut area (Fig. 1). Tree planters are potentially exposed to pesticide residues on seedlings, fertilizer dust from the fertilizers that they apply to planted seedlings, and possible fertilizer contaminants including heavy metals (United States Environmental Protection Agency 1999a).

Personal hygiene conditions are expected to be poor, particularly at wilderness camps, which could exacerbate dermal exposure (Tesluk, 2003). The work is very physically demanding and the high work rate has been shown to be sufficient to cause an elevated heart rate during the work day, muscle strain, and decreased body mass (Robinson et al., 1993; Trites et al., 1993; Roberts, 2002; Hodges et al., 2005). This could lead to an elevated rate of inhalation and consequent increase in uptake of contamination by the inhalation route. Roberts (2002) found elevated levels of resting cortisol and mild hypoglycemia among tree planters and suggested that this could lead to immunosuppression. Even at low levels of exposure, there may be potential for health effects among this group of workers.

**Fertilizer and fertilizer contaminants**

It is common practice in BC to fertilize seedlings with nitrogen, phosphorus, and potassium (NPK) fertilizers at the time of planting to promote survival and growth. The fertilizers are contained in perforated paper sachets and one sachet is applied per tree. Common chemical constituents of NPK fertilizers include urea, phosphoric acid, potash, ammonium phosphate, potassium chloride, and potassium sulfate. Some fertilizers also contain ‘micronutrients’ that are typically metals, such as iron, boron, copper, manganese, and zinc. The fertilizer is partially polymer coated to allow slow release over the first few months of growth.

Fertilizer sachets are shipped in plastic bags of ~100 units and after opening are carried in a separate hip bag along with the seedlings by the tree planter until use. Tree planters typically carry 200 sachets each containing ~25 g of fertilizer. Although the polymer coating limits the dispersion of fertilizer dust, there are anecdotal reports of exposure to fertilizer dust, including when sachets are broken or when opening new boxes, and of leaching of chemicals when sachets get wet.

Fertilizers may also contain non-essential heavy metal contaminants including arsenic (As), lead (Pb), cadmium (Cd), chromium (Cr), and nickel (Ni). Natural phosphate ore contains measurable amounts of Cd, Pb, and Ni and these metals may be present in the source material of the fertilizer. In some fertilizers, metal contaminants are unintentionally added to fertilizer along with desired ‘micronutrients’ sourced from industrial wastes or by-products such as electric arc furnace dust (US EPA, 1999a) but it is unknown whether this is the case with fertilizers used in BC tree planting. Canadian regulation requires product labels to list nitrogen, phosphorus, potassium, and micronutrient content but not non-essential metals (Department of Justice Canada, 2010). There has been little research on the exposure of fertilizer users to fertilizer contaminants (Group, 1999a,b; Pecqueiro, 1999) and none on the exposure of tree planters to fertilizers or fertilizer contaminants.
Pesticides

Seedlings are supplied by >40 seedling nurseries that are geographically dispersed throughout BC. Many nurseries apply pesticides during the growing period (typically insecticides) or before cold storage (typically fungicides), though some stock is not treated. Typically, pesticides are mixed with water and applied through sprinkler systems. The pesticide treatment is part of an integrated pest management program and is targeted to threats specific to the region, tree species, and local environment. To our knowledge, pesticides are never applied at the time of seedling planting in British Columbia. There are no insects or fungi in the region that threaten planted seedlings that can be treated with pesticides. Pesticides are only used seedling nurseries.

Seedlings intended for spring planting are grown the summer before and removed from growing trays (‘lifted’) in October to December and then stored at −2°C until use. The fungicides captan, chlorothalonil, iprodione, and benomyl and the insecticides malathion, diazinon, permethrin, and cypermethrin are in common use in BC forest nurseries. Seedlings grown for summer and autumn planting are grown earlier the same year and are not kept in cold storage nor treated with fungicides.

Although pesticides are applied months before planting, pesticide residues may still be present on seedlings at the time of planting. Alleyne et al. (1988) detected captan and chlorothalonil in personal air samples and captan, chlorothalonil, and benomyl on the skin of BC tree planters. Robinson et al. (1993) showed cholinesterase inhibition in tree planters suggesting exposure to organophosphate or carbamate compounds. However, these studies were conducted >15 years ago and were limited by small sample sizes among a single crew and a lack of geographical variability. Two studies have investigated acute health effects (including respiratory, dermal and ocular irritation; numbness, and nausea) following exposure to permethrin and cypermethrin among tree planters in Sweden; however, work and hygiene conditions vary widely between tree planters in Sweden and British Columbia and the results of the Swedish studies are unlikely to be representative of pesticide exposures and associated health effects among BC tree planters (Elfman et al., 2009; Kolmodin-Hedman et al., 1995).

Research objectives

The specific objectives of this research were to measure personal exposure levels of pesticide residues and metal contaminants of fertilizer among tree planters and to examine the determinants of these exposures. A further aim of the study was to improve on the design of previous studies of pesticide exposure among tree planters with a large sample size across several crews and geographic locations.

METHODS

Site and subject recruitment

Sampling was conducted between May and August 2006 and in April 2007. A convenience sample of five BC tree planting operations was selected. At each site, sampling was completed over the course of 2 days. The objective was to obtain exposure measurements for 10 subjects at each worksite, five each on two consecutive days. All workers actively engaged in tree planting at the study sites were eligible (crews consisted of between 9 and 51 tree planters).

Workers were informed about the study at least 48 h before the on-site visit. Volunteers were requested at an information meeting on the first day of sampling. Subjects were compensated for lost production during their participation in the study, but no other incentive was paid. All subjects gave signed informed consent. The study protocol was approved by the University of British Columbia Clinical Research Ethical Review Board (Certificate number H06-70039).

Skin wipes

Skin wipes were taken from the ‘seedling hand’ (the hand that contacts seedlings and fertilizer sachets). Skin wipe methods were adapted from Brouwer et al. (2000) and the OSHA Technical Manual (OSHA, 2008). Wipes were taken for each participant on two consecutive days, one to assess exposure to pesticides and the other metals. For each sample, three wipes were taken from (i) the back of the hand, (ii) inside the forearm, and (iii) perimeter of hand and fingers. Samples from the hand and forearm were made with 12 wipes of consistent force of an area prescribed by a 1.5" × 1.5" plastic template. Three wipes were made in an initial direction followed by three in the opposite, three more at 90°, and a final three opposite to wipes 7–9. After every three wipes, the swab was turned to expose an unused area. Samples from the perimeter of the fingers were made with two continuous passes, the first pass starting at the distal end of the radius and working around each finger to reach the distal end of the ulna and the second pass tracing the same pathway in the opposite direction (Fig. 2). Pesticide wipes used three 1.5" × 1.5" cotton batten swabs premoistened with 70% ethanol and metals wipes used a proprietary cloth wipe (Ghostwipe)
premoistened with deionised water (Environmental
Express, Mt Pleasant, SC, USA). Skin wipes were
taken by three trained occupational hygienists wearing
clean nitrile gloves. At each site, one field blank sam-
piece was taken. Each wipe sample was stored in a glass
vial, kept on ice or refrigerated at 4°C and transported to the analytical labora-
tory within 1 week of sampling. A trace of the perimeter
of each subject’s ‘seedling hand’ was taken to deter-
mine the surface area of the perimeter (finger) wipe.

Following collection of skin wipe samples, sub-
jects were asked about production, personal protec-
tive equipment use, and personal hygiene pertinent
to that shift.

**Air samples**

Subjects wore SKC Model 224-44XR air pumps
(SKC, Eighty Four, PA, USA) attached to a GSP
inhalable sampler (Stroehlein, Kaarst, Germany)
with mixed cellulose ester (MCE) filters, fitted at
the lapel. Flow rate was 3.5 l.p.m. Ten percent of
samples were laboratory and field blanks.

**Bulk samples**

Seedling, soil, and fertilizer samples were taken
from each site. At least one sample was taken of each
tree species (and nursery provider) and fertilizer type
that was used during each sampling day. Seedlings
were placed in plastic bags, stored on ice in dark con-
tainers or refrigerated at 4°C, and transported to the analy-
tical laboratory within 1 week. Seedling samples
were divided into ‘green’ (stems and foliage) and
‘rootball’ (soil) subsamples. Nursery pesticide applica-
tion records were obtained for each seedling collected.
Bulk soil (~500 g) was collected from randomly se-
lected undisturbed sites around the worksite.

**Chemical analysis**

Bulk soil, fertilizer, and seedling rootball samples,
deionized water dermal wipes, and MCE filters were
analyzed for As, Cd, Cr, Pb, and Ni by inductively
coupled plasma mass spectrometry. Air sample analy-
sis was based on Workers’ Compensation Board of
British Columbia method 1051 using acid digestion
of the filter (Workers’ Compensation Board of British
Columbia, 1989). Metals in soil analysis was based on
Canadian Society of Soil Science Methods, using a de-
ionized water leach with measurement by pH meter.
Bulk fertilizers were acid digested from a dry state.

Pesticide analysis of stems and foliage was targeted
to pesticides identified on the nursery pesticide applica-
tion records for the seedlings collected as well as pesti-
cides known to be in common use in British Columbia.
Analyses were based on US EPA methods 507, 525,
Samples were solvent extracted and quantified using
gas chromatography mass spectrometry or high perfor-
mance liquid chromatography/mass spectroscopy.

All samples were stored on ice in dark containers or
refrigerated at 4°C and transported to the analytical labora-
tory within 1 week. Analysis was completed
within 1–2 weeks of sample submission. These storage
conditions and time frames were based on the guidance
of the sample collection, preservation, and handling
guidance of the analytical methods used.

**Statistical analysis**

For both pesticides and metals, the data distribution
was highly skewed and therefore, data were log trans-
formed. Concentrations that were below the limit of
chemical detection were recorded as half the detection
limit (Hornung and Reed, 1990). Statistical analysis
was completed in Intercooled Stata Version 9.2 for
Windows (Stata Corp LP, College Station, Tx, USA).

To investigate the relationship between fertilizer
use and dermal exposure to metals, linear regression
analysis was performed for Pb, Ni, and Cr with log-
transformed dermal metal exposure as the outcome
variable and fertilizer use (yes or no), concentration
of metal in soil, and concentration of metal in seed-
ling rootballs as determinants of exposure. Models
were controlled for smoking status. Student’s t-test
was used to assess the effect of chemically protective
gloves (rubber, nitrile, neoprene, or latex) on dermal
exposure.

To investigate factors that might influence pesti-
cide residue levels on seedlings, linear regression
analysis was performed with seedling pesticide resi-
due concentration as the outcome variable and number
of days between application and lifting, number of
days between lifting and planting, and concentra-
tion of pesticide applied per unit area (active pesti-
cide ingredient per hectare) as determinants of exposure.
RESULTS

Characteristics of the five participating sites and sampling conditions are provided in Table 1. Site ‘M’ was considered the control site for fertilizer contaminant sampling as fertilizers were not used at this site. ‘Inland’ site locations were warmer, and sampling at these sites occurred in a different planting year and later in the year. On average, a greater number of seedlings were planted at inland sites. Fifty-four subjects participated in the study; ~30% were female and 53% were smokers at the time of sampling.

Fertilizer contaminants (metals)

The four sites using fertilizers used four different fertilizer brands from two different manufacturers. Principal constituents (N, P, and K) ranged from 18 to 26%, 9 to 12%, and 6 to 10%, respectively. All the fertilizer types also contained elemental nutrients (micronutrients) including sulfur (up to 6%) and combinations of magnesium, boron, zinc, copper, manganese, and iron all at levels of <1%.

Forty-two air samples and 51 dermal metal wipes were obtained. Five air samples were lost at Site R due to rain damage; one air sample per site was lost at Sites B, N, and M due to pump problems. Samples with pre- and post-flow variations >15% were excluded from analysis (this range of acceptable flow variation was set to account for flow fluctuations seen likely as a result of the high flow rate, 3.5 l.p.m., and the high rate of physical activity of the workers).

Concentrations of metals in air samples were low; only seven samples (17%) had detectable levels. Lead was measured at detectable levels on one sample at Site R (0.05 \(\mu\)g m\(^{-3}\)), Ni on one sample each at Sites N and M (0.07 and 2.8 \(\mu\)g m\(^{-3}\), respectively), and Cr on one sample each at Sites G and R (0.07 and 0.11 \(\mu\)g m\(^{-3}\), respectively) and on two samples at Site N (both 0.15 \(\mu\)g m\(^{-3}\)). All exposures were below the 8-h time-weighted average BC regulatory limits (10 \(\mu\)g m\(^{-3}\) for As, Cd, and Cr and 50 \(\mu\)g m\(^{-3}\) for Ni and Pb) (WorkSafeBC, 2010a). It was clear that there were minimal differences between the exposed and control sites and for at least one metal (Ni) airborne levels were higher at control Site M than at the other sites.

Skin exposures are shown in Table 2 (units are nanograms per square centimeter skin). As and Cd were found at detectable levels in 5 of the 51 samples; therefore, only ranges of As and Cd concentrations are shown. Cr, Ni, and Pb were detected on all samples. The ranges seen for these three metals were similar across all five sites and in linear regression analysis, controlling for smoking status and metals in soil and seedling rootballs, Cr, Ni, and Pb on skin were not significantly elevated in the group that used fertilizer. The control site (M) had the second lowest level for Cr, but the second to highest level for Pb and Ni. Dermal lead exposure was significantly higher at the control site where fertilizer was not used.

Bulk fertilizer, soil, and seedling samples

Results for bulk samples of fertilizer, soil, and root ball material are shown in Table 3. Bulk fertilizer data were only available from Sites G and R but for comparative purposes, four other fertilizer types were obtained from fertilizer suppliers and assayed although these had not been used at any of the sites tested. Among the solid samples (soil, rootball, and bulk fertilizer), ranges of concentrations for each metal were similar across exposed and control sites with the exception of cadmium which was found at detectable levels only in fertilizer samples and in soil at Site R.

Pesticide residues

Pesticide-treated seedlings were planted at all five sites. At coastal sites, all seedlings were pesticide treated but at inland sites, not all species had been

Table 1. Site characteristics for the five tree planting work sites

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Region</th>
<th>Mean temperature over two sampling days (°C)</th>
<th>Occurrence of rainfall over two sampling days</th>
<th>Mean number of seedlings planted per employee per day (SD)</th>
<th>Month/year of sampling</th>
<th>Seedling species planted</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Inland</td>
<td>15.1</td>
<td>Both days</td>
<td>1000 (167)</td>
<td>May/2006</td>
<td>Cedar and spruce</td>
</tr>
<tr>
<td>G</td>
<td>Inland</td>
<td>17.9</td>
<td>1 day</td>
<td>934 (137)</td>
<td>June/2006</td>
<td>Cedar, spruce, pine, douglas-fir, and hemlock</td>
</tr>
<tr>
<td>N</td>
<td>Coastal</td>
<td>6.9</td>
<td>1 day</td>
<td>708 (312)</td>
<td>April/2007</td>
<td>Pine and fir</td>
</tr>
<tr>
<td>R</td>
<td>Coastal</td>
<td>8.2</td>
<td>1 day</td>
<td>790 (218)</td>
<td>April/2007</td>
<td>Cedar, spruce, fir, and hemlock</td>
</tr>
<tr>
<td>M (control)</td>
<td>Inland</td>
<td>12.8</td>
<td>Both days</td>
<td>1214 (669)</td>
<td>June/2006</td>
<td>Spruce and pine</td>
</tr>
</tbody>
</table>

*Site M was used as control for fertilizer contaminant exposure. No seedlings were fertilized at site M and 100% of seedlings were fertilized at Sites B, G, N, and R.*
treated. Pesticide residues were detected on all the seedlings taken from coastal sites in April 2007, while no pesticides were detected on seedlings taken from inland sites in May and June of 2006 (Table 4). Fungicides detected were captan, chlorothalonil, and iprodione. Insecticides detected were permethrin and diazinon. The concentrations of pesticide residues detected ranged from 0.06 to 1090 \text{ \textmu g g}^{-1} \text{ seedling mass. The highest concentration (1090 \text{ \textmu g g}^{-1}) found was of chlorothalonil on a Douglas-fir seedling taken from Site N.}

Among the seedlings that were pesticide treated, the amounts applied were generally equivalent; however, less than half the amount of permethrin was applied to 2006 seedlings compared to 2007 seedlings.

Two inconsistencies between nursery records and chemical analyses were found. Captan was detected on a Sitka Spruce seedling taken from Site R although captan application was not recorded in the nursery records. Chlorothalonil and iprodione were detected on a Coastal Douglas-fir seedling taken from Site N while records do not show pesticide application on this batch of seedlings.

The natural log of pesticide residue concentration was used in modeling because the underlying data distribution was lognormal. It was assumed that the seedling that was labeled pesticide free yet carried chlorothalonil and iprodione residue had erroneous application records. For the sake of modeling, it was assumed that this seedling received the application of chlorothalonil and iprodione typical of the nursery where it was grown. Captan was only detected on one seedling so captan residues were not modeled.

Results of the linear regression modeling (Table 5) demonstrate that pesticide residue on seedlings increases with the amount of active ingredient applied per hectare. Pesticide residue decreased with the increasing days between pesticide application and seedling lifting (removal from growing trays) and increasing days between lifting and planting.

Forty-seven dermal pesticide wipes were obtained. Pesticides were not detected on the skin of workers at Sites B, G, and M. Pesticide residues were detectable on the skin of tree planters at Sites N and R. At Site R, chlorothalonil and iprodione were found on the majority of skin samples, while at Site N, chlorothalonil was found on 9 of 10 samples and iprodione on a single sample. Where detected, chlorothalonil levels ranged from 0.37 to 106 \text{ ng cm}^{-2} of skin and iprodione levels ranged from 0.7 to 15.9 \text{ ng cm}^{-2} (Table 6).
Most subjects wore gloves and some wore two pairs in combination. Eighteen of the 54 subjects wore nitrile, neoprene, rubber, or latex gloves, 34 subjects wore either a cotton glove or a gardening style glove (rubberized palm of hand and cotton back of hand), 1 subject wore no gloves, and the personal protective equipment (PPE) use of the remaining subject was not reported. Only 3 of the 54 subjects (5.6%) reported hand washing during the workday. Student’s t-test was used to assess the effect of chemically protective gloves (rubber, nitrile, neoprene, or latex) on dermal exposure to nickel, lead, chromium, and chlorothalonil. As chlorothalonil was only detected at Sites N and R, chlorothalonil analysis was restricted to these sites. Histograms of the data distributions appeared to be lognormal in shape and the exposure data were log transformed prior to analysis. The geometric mean dermal exposure to nickel, lead, and chromium was lower among those who used chemically protective gloves (although the differences were only statistically significant for nickel). The use of chemically protective gloves was not related to lower exposure to chlorothalonil (Table 7). An insufficient number of workers (three) reported hand washing during the workday so similar analyses to assess the effect of hand washing on exposure were not possible.

**DISCUSSION**

**Exposure to metals**

There was no apparent evidence linking increased exposure to the metals investigated and work with fertilizers. All airborne exposure levels for metals were below their respective regulatory limits and there was no consistent association between the use of fertilizer and elevated levels of dermal or inhalation exposure to metals. While the threshold of acceptable pump flow rate fluctuation was 15%, potentially decreasing the precision of the flow rate estimates, the measured masses were sufficiently low that uncertainty in flow rate estimates would not change the conclusion.

**Pesticides on seedlings**

Despite application being 4–12 months prior to collection for this study, pesticide residues were found on 8 of the 19 seedlings collected. These contaminated seedlings were all collected from the two
coastal worksites that were sampled in April 2007 (Sites N and R). Pesticides were not detected on seedlings at the sites visited in the inland regions of BC in May and June of 2006. The length of time between pesticide application and planting of seedlings was greater for the 2006 samples than for the

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Species</th>
<th>Pesticide</th>
<th>Days from application to planting</th>
<th>Days from application to lifting</th>
<th>Days from lifting to planting</th>
<th>Date planted</th>
<th>Pesticide concentration (µg g⁻¹)¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Hybrid Spruce</td>
<td>Iprodione</td>
<td>224</td>
<td>35</td>
<td>189</td>
<td>23 May 2006</td>
<td>&lt;1</td>
</tr>
<tr>
<td>B</td>
<td>Hybrid Spruce</td>
<td>Pesticide free</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>24 May 2006</td>
<td>All &lt;LODb</td>
</tr>
<tr>
<td>B</td>
<td>Western Red Cedar</td>
<td>Iprodione</td>
<td>220</td>
<td>61</td>
<td>159</td>
<td>23 May 2006</td>
<td>&lt;1</td>
</tr>
<tr>
<td>B</td>
<td>Western Red Cedar</td>
<td>Benzimidazole</td>
<td>220</td>
<td>61</td>
<td>—</td>
<td>Not tested</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Western Red Cedar</td>
<td>Pesticide free</td>
<td>—</td>
<td>—</td>
<td>199</td>
<td>5 June 2006</td>
<td>All &lt;LOD</td>
</tr>
<tr>
<td>G</td>
<td>Interior Douglas-fir</td>
<td>Pesticide free</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>216</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Interior Douglas-fir</td>
<td>Permethrin</td>
<td>318</td>
<td>114</td>
<td>204</td>
<td>6 June 2006</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>G</td>
<td>Interior Douglas-fir</td>
<td>Cypermethrin</td>
<td>262</td>
<td>58</td>
<td>—</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Interior Douglas-fir</td>
<td>Chlorothalonil</td>
<td>215</td>
<td>11</td>
<td>—</td>
<td>&lt;1</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Interior Douglas-fir</td>
<td>Fenhexamid</td>
<td>226</td>
<td>22</td>
<td>—</td>
<td>Not tested</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Lodgepole Pine</td>
<td>Pesticide free</td>
<td>—</td>
<td>—</td>
<td>207</td>
<td>5 June 2006</td>
<td>All &lt;LOD</td>
</tr>
<tr>
<td>G</td>
<td>Lodgepole Pine</td>
<td>Iprodione</td>
<td>285</td>
<td>77</td>
<td>208</td>
<td>14 June 2006</td>
<td>&lt;1</td>
</tr>
<tr>
<td>G</td>
<td>Hybrid Spruce</td>
<td>Iprodione</td>
<td>363</td>
<td>221</td>
<td>142</td>
<td>6 June 2006</td>
<td>&lt;1</td>
</tr>
<tr>
<td>G</td>
<td>Hybrid Spruce</td>
<td>Permethrin</td>
<td>349</td>
<td>207</td>
<td>—</td>
<td>&lt;0.05</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>Lodgepole Pine</td>
<td>Pesticide free</td>
<td>—</td>
<td>—</td>
<td>196</td>
<td>13 June 2006</td>
<td>All &lt;LOD</td>
</tr>
<tr>
<td>M</td>
<td>Lodgepole Pine</td>
<td>Iprodione</td>
<td>285</td>
<td>77</td>
<td>208</td>
<td>14 June 2006</td>
<td>&lt;1</td>
</tr>
<tr>
<td>M</td>
<td>Hybrid Spruce</td>
<td>Iprodione</td>
<td>363</td>
<td>221</td>
<td>142</td>
<td>6 June 2006</td>
<td>&lt;1</td>
</tr>
<tr>
<td>M</td>
<td>Hybrid Spruce</td>
<td>Permethrin</td>
<td>349</td>
<td>207</td>
<td>—</td>
<td>&lt;0.05</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Douglas-fir</td>
<td>Chlorothalonil</td>
<td>No record</td>
<td>No record</td>
<td>101</td>
<td>2 April 2007</td>
<td>604</td>
</tr>
<tr>
<td>N</td>
<td>Douglas-fir</td>
<td>Iprodione</td>
<td>119</td>
<td>14</td>
<td>105</td>
<td>2 April 2007</td>
<td>1090</td>
</tr>
<tr>
<td>N</td>
<td>Douglas-fir</td>
<td>Iprodione</td>
<td>138</td>
<td>33</td>
<td>—</td>
<td>83.3</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Western White Pine</td>
<td>Benzimidazole</td>
<td>297</td>
<td>186</td>
<td>111</td>
<td>2 April 2007</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>N</td>
<td>Western White Pine</td>
<td>Diazinon</td>
<td>358</td>
<td>247</td>
<td>—</td>
<td>1.59</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Western White Pine</td>
<td>Permethrin</td>
<td>315</td>
<td>204</td>
<td>—</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Western White Pine</td>
<td>Captan</td>
<td>394</td>
<td>283</td>
<td>—</td>
<td>&lt;0.05</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Western Red Cedar</td>
<td>Chlorothalonil</td>
<td>146</td>
<td>68</td>
<td>78</td>
<td>12 April 2007</td>
<td>10.1</td>
</tr>
<tr>
<td>R</td>
<td>Western Red Cedar</td>
<td>Iprodione</td>
<td>146</td>
<td>68</td>
<td>—</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Western Red Cedar</td>
<td>Permethrin</td>
<td>324</td>
<td>246</td>
<td>—</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Western Red Cedar</td>
<td>Chlorothalonil</td>
<td>146</td>
<td>80</td>
<td>66</td>
<td>12 April 2007</td>
<td>29.6</td>
</tr>
<tr>
<td>R</td>
<td>Western Red Cedar</td>
<td>Iprodione</td>
<td>146</td>
<td>80</td>
<td>—</td>
<td>3.14</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Western Red Cedar</td>
<td>Permethrin</td>
<td>324</td>
<td>258</td>
<td>—</td>
<td>&lt;0.05</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Douglas-fir</td>
<td>Chlorothalonil</td>
<td>146</td>
<td>76</td>
<td>70</td>
<td>12 April 2007</td>
<td>28.4</td>
</tr>
<tr>
<td>R</td>
<td>Douglas-fir</td>
<td>Iprodione</td>
<td>146</td>
<td>76</td>
<td>—</td>
<td>1.15</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Douglas-fir</td>
<td>Permethrin</td>
<td>324</td>
<td>254</td>
<td>—</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Western Hemlock</td>
<td>Chlorothalonil</td>
<td>142</td>
<td>20</td>
<td>122</td>
<td>12 April 2007</td>
<td>48.7</td>
</tr>
<tr>
<td>R</td>
<td>Western Hemlock</td>
<td>Iprodione</td>
<td>142</td>
<td>20</td>
<td>—</td>
<td>6.49</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Western Hemlock</td>
<td>Permethrin</td>
<td>324</td>
<td>202</td>
<td>—</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Sitka Spruce</td>
<td>Chlorothalonil</td>
<td>147</td>
<td>34</td>
<td>113</td>
<td>13 April 2007</td>
<td>6.4</td>
</tr>
<tr>
<td>R</td>
<td>Sitka Spruce</td>
<td>Iprodione</td>
<td>147</td>
<td>34</td>
<td>—</td>
<td>1.28</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Sitka Spruce</td>
<td>Permethrin</td>
<td>325</td>
<td>212</td>
<td>—</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Sitka Spruce</td>
<td>Captan</td>
<td>No record</td>
<td>No record</td>
<td>—</td>
<td>34.5</td>
<td></td>
</tr>
</tbody>
</table>

¹µg g⁻¹ = p.p.m. or parts per million.

bAll <LOD = all pesticides tested below LOD.

cNo record means that application is not recorded in nursery application records.
2007 samples, likely allowing for greater decay of pesticide residues. This hypothesis is supported by the linear regression analysis (Table 5). Of the pesticides detected on seedlings, the fungicides chlorothalonil and iprodione were found on the most seedlings and at the highest concentrations. Fungicides were applied later than insecticides, just prior to lifting and cold storage. This later application time and subsequent cold storage are likely reasons for the high residual concentrations of fungicides relative to insecticides.

The results suggest that pesticide residues are most likely to be present on seedlings early in the tree planting season in the coastal region of BC. However, further work is necessary to fully understand the factors that contribute to the persistence of pesticide residue on seedlings at the time of planting. During this study, the investigators were unable to obtain information on the number of pesticide applications. Many nurseries only recorded the date of last application so the impact of repeated application on residue level is unknown. Further work would be

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>95% Confidence interval</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>3.97</td>
<td>1.78–6.16</td>
<td>0.001</td>
</tr>
<tr>
<td>Active ingredient per hectare (g)</td>
<td>0.00049</td>
<td>0.00023–0.00075</td>
<td>0.001</td>
</tr>
<tr>
<td>Number of days between last pesticide application and liftinga</td>
<td>−0.019</td>
<td>−0.027 to −0.012</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Number of days between lifting and planting</td>
<td>−0.027</td>
<td>−0.038 to −0.016</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Degrees of freedom = 31; adjusted $R^2 = 0.7693$.
aLifting is the removal of seedlings from growing trays.

<table>
<thead>
<tr>
<th>Sitea</th>
<th>N</th>
<th>% Detectable</th>
<th>Pesticide (ng cm$^{-2}$)</th>
<th>GM</th>
<th>GSD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Chlorothalonil</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range of LOD</td>
<td></td>
<td>4.8–6.3</td>
<td>0.48–0.63</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range of detectables</td>
<td></td>
<td>9.5–106.3</td>
<td>3.97</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td></td>
<td>Iprodione</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range of LOD</td>
<td></td>
<td>5.0–6.6</td>
<td>0.50–0.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range of detectables</td>
<td></td>
<td>0.37–7.8</td>
<td>0.70–15.9</td>
</tr>
</tbody>
</table>

Pesticides were not detected on skin at Sites B, G, and M. Captan, malathion, permethrin, cypermethrin, diazinon, and benzimidazole were not detected on skin at any site.

ng cm$^{-2} = $ nanograms of pesticide per square centimeter of skin wiped.

LOD = limit of detection. Ranges are presented because the LOD varied with surface area wiped.

<table>
<thead>
<tr>
<th>Agent</th>
<th>Glove type</th>
<th>N</th>
<th>Dermal exposure (ng cm$^{-2}$)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>GM</td>
<td>GSD</td>
</tr>
<tr>
<td>Chrome</td>
<td>Chemically protectivec</td>
<td>17</td>
<td>3.8</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>34</td>
<td>5.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Lead</td>
<td>Chemically protective</td>
<td>17</td>
<td>2.7</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>34</td>
<td>3.6</td>
<td>2.4</td>
</tr>
<tr>
<td>Nickel</td>
<td>Chemically protective</td>
<td>17</td>
<td>1.5</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>34</td>
<td>2.9</td>
<td>1.6</td>
</tr>
<tr>
<td>Chlorothalonil</td>
<td>Chemically protective</td>
<td>10</td>
<td>9.2</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>10</td>
<td>4.7</td>
<td>2.6</td>
</tr>
</tbody>
</table>

N, number of observations; GM, geometric mean; GSD, geometric standard deviation.

P-value from independent samples t-test, equal variances not assumed.

All gloves made of rubber, neoprene, nitrile or latex have been classified as chemically protective.
required to determine the conditions that are necessary to ensure that pesticides on seedlings have completely decayed by the time that tree planters plant the seedlings and to eliminate exposure to pesticides among tree planters.

**Dermal exposure to pesticides**

Chlorothalonil and iprodione, the most frequently detected pesticides on seedlings, were detected on the hands of workers working at the sites where pesticide residues were also found on seedlings. In 1988, Alleyne et al. (1988) measured chlorothalonil on seedling hands of tree planters at the end of a shift and found masses <0.6 µg on most hands; the highest mass they found was 12.5 µg. The masses detected on seedling hands in the current study were 0.06–22 and 0.14–2.5 µg for chlorothalonil and iprodione, respectively. Although Alleyne et al. did not correct their measurements for surface area wiped, they report that they wiped the entire hand. During the current study, only a portion of the hand was wiped. The masses detected by Alleyne et al. are similar to those seen in the current study despite the larger surface area wiped.

While there are no exposure limits for pesticide residue levels on seedlings, it may be valuable to compare another similar regulatory level. In some cases, the pesticide levels detected on the seedlings were above the Canadian maximum residue limits for foods (Department of Justice Canada, 2002). The maximum residue limits for chlorothalonil range from 0.1 to 15 p.p.m. dependent upon the food type. Concentrations of chlorothalonil of 29.6, 48.7, and 1090 p.p.m. (equivalent to micrograms per gram) were detected on three seedlings. A concentration of 34.5 p.p.m. of capitans was detected on a Sitka Spruce seedling, exceeding the maximum residue limit for foods of 5.0 p.p.m. Iprodione was detected at a concentration of 83.3 p.p.m. on a Douglas-fir exceeding the maximum residue limits of 0.3–60 p.p.m. Although seedlings are not foods, dermal contact with seedlings could lead to ingestion of pesticides by the hand-to-mouth route. During the workday, tree planters periodically return from the planting area to a roadside ‘base’ to reload with seedlings/fertilizer; meals and snacks are usually taken at this reload time. The tree planters surveyed during this study generally did not wash their hands during the workday and as a result, it is possible that chlorothalonil and iprodione on the skin were transferred to food, drinks, or cigarettes and ingested. However, it is unknown how much chlorothalonil or iprodione was ingested by the tree planters.

Of the two pesticides detected on skin, chlorothalonil is the most toxic and was detected at the highest concentrations. The health effects of chlorothalonil include contact dermatitis, kidney damage, and it has been linked to cancer of the kidneys (US EPA, 2001; IARC, 1999). The highest measured concentration of chlorothalonil on skin was 106.3 ng cm⁻². A chlorothalonil oral dose of $\sim 7.9 \times 10^{-4}$ mg kg⁻¹ day⁻¹ has been estimated based on the conservative assumption that the amount ingested is equivalent to the amount found on the seedling hand of the worker with the highest dermal exposure (106.3 ng cm⁻²). This estimate is based on a 70 kg person, a hand surface area of 520 cm², and an even distribution of chlorothalonil on the hand. The actual amount ingested for the typical tree planter is likely to be lower as the estimate was based on the highest observed dermal chlorothalonil exposure and because although no hand-to-food transfer efficiencies were found in the literature, it is unlikely that 100% of the contamination on the hand transfers to the food. Despite the conservative assumptions used, the estimate of $7.9 \times 10^{-4}$ mg kg⁻¹ day⁻¹ is below the US EPA toxicological endpoint of $3 \times 10^{-3}$ mg kg⁻¹ day⁻¹ to assess health risk from oral exposure to chlorothalonil and the endpoint of $7.33 \times 10^{-3}$ mg kg⁻¹ day⁻¹ used to assess risk of cancer from any exposure to chlorothalonil (US EPA, 2001, 2009) indicating that the health risk from ingestion of pesticides is likely to be low. The US EPA has not reported a reference dose for dermal exposure to chlorothalonil; however, no observed adverse effects level from a dermal toxicity study of rats was reported (0.06 mg kg⁻¹ day⁻¹). An uncertainty factor of 100 gives a dermal reference dose of $6 \times 10^{-4}$ mg kg⁻¹ day⁻¹. Again, assuming a dose of $7.9 \times 10^{-4}$ mg kg⁻¹ day⁻¹ for a 70 kg person (the amount on the seedling hand), the dose is above the reference dose (US EPA, 2001, 2009) suggesting that there may be some risk of toxicity from the dermal route of exposure. Due to the nature of tree planting, work exposures may be exacerbated. Tree planting is an extremely physically strenuous occupation (Trites et al., 1993). On a typical day, a tree planter can hike 16 km over difficult terrain, while bending and digging to plant 150–200 trees h⁻¹ (Roberts, 2002). The strenuous nature of tree planting work suggests that metabolic rates are increased, potentially increasing uptake of exposures. Furthermore, tree planting work is generally performed in remote locations where there are limited opportunities for hand washing and bathing. Only 1 in 20 of the tree planters surveyed in this study reported hand washing during the workday. Tree planters live in camp sites or hotels during the planting season and laundry facilities are often only available on days off. The unsanitary conditions could result in contaminants (including pesticides).
that are present on the skin remaining present for extended periods of time.

As a result of performing manual labour in a physically harsh outdoor working environment, tree planters frequently experience dermal cuts and abrasions. These cuts and abrasions could cause chemicals present on the skin to be more likely to cross the dermal barrier. While >95% of the workers wore gloves, only 33% wore gloves that provide chemical resistance (nitrile, neoprene, rubber, or latex). The use of chemically resistant gloves appeared to be related to lower dermal exposure to metals, although the relationships were not statistically significant for all metals. The use of such gloves was not associated with decreased chlorothalonil exposure. The employers did not have PPE programs at worksites to guide selection and maintenance of gloves. Improper glove selection and use can lead to contamination of the interior of the glove that can cause contaminants to be held against the skin. This may partially explain the lack of statistically significant reductions in exposure to all contaminants with the use of chemically resistant gloves.

These hygiene conditions are in contrast to Swedish tree planting hygiene conditions. The majority of the tree planters studied by Elfman et al. (2009) lived in their normal home and commuted to the tree planting work site. All had access to showers and washing facilities in their homes. The employers provided PPE including gloves and long trousers and most of the Swedish tree planters reported washing their hands before eating, smoking, or using snuff.

CONCLUSIONS

No evidence was found to suggest that tree planters who work with fertilizers are at greater risk of exposure to metals than tree planters who do not work with fertilizers. Low levels of pesticides (particularly chlorothalonil and iprodione) were found on seedlings and on the skin of tree planters. Although the risk of health effect of pesticide exposure at the levels measured appears to be low, the tree planting work conditions in BC may exacerbate exposures. The strenuous nature of the job may increase the uptake of exposures and the poor hygiene conditions could lead to prolonged dermal exposure and increased risk of ingestion exposure from the hand-to-mouth route or from contamination of food. Low levels of exposure may be of concern for this work group.

RECOMMENDATIONS

BC regulation requires that employers provide on-site wash facilities and suitable clothing and personal protective equipment to workers who are exposed to pesticide residues (WorkSafeBC, 2010b). Hand washing stations must be implemented to allow hand washing during the workday to decrease the dermal load of pesticides and decrease the risk of ingestion exposure. Tree planters should also be educated about the importance of hand washing before eating, wearing clean clothes each work day to prevent buildup of contaminants on clothing, and appropriate use of PPE. Inconsistencies were found between nursery application records and pesticides detected on seedlings. Owing to these nursery record inconsistencies, tree planters should exercise caution even when working with seedlings labeled pesticide free.

Further work should be conducted in cooperation with seedling nurseries to fully understand the factors that influence the concentration of pesticides on seedlings at the time of planting. This may allow nurseries to ensure that seedlings are grown and stored in such a way that no pesticides are present at the time of planting.

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