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Impact of chromated copper arsenate (CCA) in wood mulch

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Abstract

The production of landscape mulch is a major market for the recycling of yard trash and waste wood. When wood recovered from construction and demolition (C&D) debris is used as mulch, it sometimes contains chromated copper arsenate (CCA)-treated wood. The presence of CCA-treated wood may cause some potential environmental problems as a result of the chromium, copper, and arsenic present. Research was performed to examine the leachability of the three metals from a variety of processed wood mixtures in Florida. The mixtures tested included mixed wood from C&D debris recycling facilities and mulch purchased from retail outlets. The synthetic precipitation leaching procedure (SPLP) was performed to examine the leaching of chromium, copper and arsenic. Results were compared to Florida's groundwater cleanup target levels (GWCTLs). Eighteen of the 22 samples collected from C&D debris processing facilities leached arsenic at concentrations greater than Florida's GWCTL of 50 $\mu\text{g/l}$. The mean leachable arsenic concentration for the C&D debris samples was 153 $\mu\text{g/l}$ with a maximum of 558 $\mu\text{g/l}$. One of the colored mulch samples purchased from a retail outlet leached arsenic above 50 $\mu\text{g/l}$, while purchased mulch samples derived from virgin materials did not leach detectable arsenic (<5 $\mu\text{g/l}$). A mass balance approach was used to compute the potential metal concentrations (mg/kg) that would result from CCA-treated wood being present in wood mulch. Less than 0.1% CCA-treated wood would cause a mulch to exceed Florida's residential clean soil guideline for arsenic (0.8 mg/kg).

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1. Introduction

The production of mulch represents a major market for a number of recovered solid wastes. Wastes traditionally used for mulch include land-

clearing debris, yard trash, and vegetative wastes produced during landscaping and land maintenance activities. Scrap manufactured wood products are also recycled into mulch. Examples of scrap wood products include manufactured product debris (e.g. scrap from furniture production), discarded pallets and spools, and wood recovered from construction and demolition (C&D) debris. Discarded wood is often less desirable as a source of mulch because of its color, but the advent of coloring agents

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designed to dye wood to more aesthetically acceptable colors has opened this market. In addition to landscaping applications, processed wood is also used at times for playground buffering material and animal bedding. The source and characteristics of the wood are important, since the presence of foreign materials (e.g. nails) and hazardous chemicals may limit the value and market for the mulch. Lead is one example of a hazardous chemical that has caused problems with reuse of scrap wood products, as a result of wood painted with lead-based paint (Beebe and England, 1998).

The presence of pressure treated wood in processed wood mulch may also pose a problem. The most common wood preservative used in recent years has been chromated copper arsenate (CCA) (AWPA, 1999; Solo-Gabriele et al., 1998). CCA contains chromium, copper and arsenic, and all three heavy metals have potential adverse impacts on human health and the environment (Weis et al., 1995; Weis and Weis, 1999; Brown et al., 2001; Decker et al., 2002; Gordon et al., 2002). Arsenic and chromium are regulated in the US as primary drinking water standards (50 and 100 $\mu\text{g}/\text{l}$, respectively) while copper is regulated as a secondary drinking water standard (1000 $\mu\text{g}/\text{l}$). A discussion of drinking water standards is appropriate because many US states have adopted them as groundwater standards or guidelines. Florida, for example, developed groundwater cleanup target levels (GWCTLs) for arsenic, chromium and copper that are the same as the drinking water standards. When evaluated as part of the clean-up of contaminated sites and the reuse of wastes in the environment, both arsenic and chromium (Cr^{6+}) are considered carcinogens, and copper poses a chronic toxicity risk (FAC, 2000). Copper also represents a chemical of concern when discussing toxicity to aquatic organisms (Flemming and Trevors, 1989).

CCA-treated wood has been documented to occur in wood recovered from C&D debris recycling facilities in Florida (Tolaymat et al., 2000). The two primary markets for recovered wood in Florida are industrial boiler fuel and landscape mulch. While the C&D debris recycling facilities are encouraged to separate treated wood from untreated wood prior to use for mulch, CCA-treated wood still finds its way into the mixed

wood stream. This results from either the lack of understanding by C&D debris facility operators that treated wood should not be included in mulch or the difficulty to distinguish CCA-treated wood from untreated wood. When wood is painted, weathered, or dirty, identification of CCA-treated wood from other non-preserved wood is very difficult. In 1997, mulched C&D debris wood from 12 facilities in Florida was found to contain up to 20% CCA-treated wood by weight, with an average of 6% (Tolaymat et al., 2000). During 1999, woodpiles at three Florida C&D debris recycling facilities contained between 9 and 30% CCA-treated wood (Townsend et al., 2001). During 2001, wood waste was found to contain 22% CCA-treated wood for an extensive study conducted at one Florida C&D debris recycling facility (Solo-Gabriele et al., 2001). The situation is further complicated by the anticipated increase in CCA-treated wood entering the waste stream over the coming decades (Solo-Gabriele and Townsend, 1999). It is estimated that approximately 140 000 m^3 of CCA-treated wood product were disposed in Florida during the year 2000. This quantity is forecasted to increase to 900 000 m^3 by 2015 (Solo-Gabriele and Townsend, 1999).

Two possible impacts of CCA-treated wood in landscape mulch are discussed here. The first is the possible impact on human health from direct exposure to the mulch (ingestion, dermal contact, inhalation). The second is the leaching of heavy metals from the mulch. While the metals in the wood are often described as being fixed or bound to the wood, small concentrations of metals do leach out over time when exposed to rainfall or soil moisture (Cooper and Ung, 1997; Stilwell and Gorny, 1997; Hingston et al., 2001). It may be argued that if CCA-treated wood is permitted for its intended use (e.g. a fence post in the environment), then its presence in landscape mulch should represent no more of a risk. A few notable differences between the presence of CCA-treated wood as mulch and its presence in its intended use are worth discussing. First, the surface area available for leaching is much greater once the wood is mulched. A greater CCA-treated wood surface area results in greater heavy metal leaching (Townsend et al., 2001). The smaller particle size also makes

the direct human exposure pathway a realistic scenario. Direct human exposure can be in the form of dislodgeable chemicals that rub off on hands and are then inadvertently ingested through hand-to-mouth contact, or from direct consumption of small wood particles (Wester et al., 1993; Rahman and Hughes, 1994; Hughes et al., 1995). The wood treating industry recommends that small particles of CCA-treated wood such as sawdust generated from cutting the wood, be cleaned up and disposed of properly (AWPI, 1995). Second, the placement of mulch represents the final disposition of the wood. The wood under most circumstances will remain where placed and will ultimately become integrated into the underlying soil, providing for the ultimate disposal of the wood. At the end of its usable life, a fence post or a deck board will be removed and disposed in a different location. The wood treating industry recommends that CCA-treated wood taken out of service should be disposed in a lined sanitary landfill or a waste-to-energy facility (AWPI, 1995).

Research was conducted to examine the possible environmental impacts of CCA-treated wood occurring in uses such as landscape mulch in Florida. Two pathways were examined: leaching to groundwater and direct human exposure. To examine leaching to groundwater, samples of C&D debris wood mulch previously analyzed to determine the presence of CCA-treated wood (Tolaymat et al., 2000) were further tested using the synthetic precipitation leaching procedure (SPLP). Additional samples, both from C&D debris and from commercial mulch products, were collected and analyzed. The SPLP leachate concentrations of arsenic, chromium, and copper were measured in the leachate and compared to Florida's GWCTLs. The direct exposure pathway was examined by performing mass balance calculations and determining the amount of CCA-treated wood that could be present in mulch before it exceeds risk-based direct exposure concentrations.

2. Methodology

Samples of processed C&D debris wood collected from 12 C&D debris recycling facilities in

1997 were leached using the synthetic precipitation leachate procedure (SPLP) (Tolaymat et al., 2000). While the 1997 processed woodpiles may not have been all destined for landscape mulch (some were likely being sold as boiler fuel at the time), they do represent similar materials as those being colored and used as mulch. One additional sample of processed wood mulch was collected from a C&D debris recycling facility in 1999. Two samples of commercial colored mulch (source of wood unknown) were also tested. Samples of other commercial landscaping mulch products made from virgin wood (pine bark, cypress) were tested as controls. The methods performed as part of this study included a collection of processed wood mulch samples, sample preparation, sample leaching, and analysis of leachate for arsenic, chromium, and copper.

2.1. Sample collection and preparation

The methods used for collection and processing of samples collected in 1997 have been described previously (Tolaymat et al., 2000). Composite samples of processed wood from large woodpiles were collected in 120-l plastic containers. While some additional size reduction was performed in the laboratory, this was only conducted to mix the wood and size-reduce oversized pieces. The final size of the wood chips used in the laboratory was not substantially different than that sold as mulch. During the time period between sample collection in 1997 and the leaching analysis in 1999 and 2000, the wood samples were stored in plastic containers at 4 °C.

Mulched wood from an additional C&D debris recycling facility was sampled in the summer of 1999 (southeast Florida). At this facility, operators removed wood manually from incoming loads of C&D debris and stockpiled it. A horizontal grinder was employed to size-reduce the wood and the wood was then colored (red) and sold as landscape mulch. Two composite samples from a large pile of colored processed wood were collected in plastic bags. Mulch from a yard waste processing facility was also collected. This site accepted yard waste from local residents and processed the material into mulch using a tub grinder. One composite

Table 1
Description of the samples tested

Sample ^{a,b}	Sample source description
A1, A2 B1	Processed wood waste: source separated C&D and pallets. Processed C&D wood waste from recycling facility. Wood separated up front in manual recovery system.
C1, C2 D1, D2, D3, D4	Processed wood waste: source separated C&D and pallets. Processed C&D wood waste from recycling facility. Wood separated up front in mechanical recovery system. D2 and D4 were largely yard waste.
E1, E2, F1, G1, H1, H2, I1, I2, J2, K1, M1, N1, N2 P1	Processed C&D wood waste from recycling facility. Wood separated up front in manual recovery system.
Q1, Q2	Commercial colored mulch purchased from garden supply store in north Florida. Commercial colored mulch purchased from garden supply store in southeast Florida.
R1	Vegetative mulch from yard waste and land clearing in north Florida.
S1	Pine bark mulch from north Florida.
T1	Cypress mulch purchased from garden supply store in north Florida.
U1	Cypress mulch purchased from garden supply store in north Florida.

^a Different letters indicate different sites, numbers indicate samples collected from a particular site.

^b Samples A–M were leached in triplicate, and samples N–U were leached in duplicate.

sample of an onsite pile was sampled. Colored wood samples (red) from different vendors were purchased from two different retail stores. The original source of the wood (C&D debris, yard waste, virgin wood) was not identified on the packaging. In addition to the red-colored mulch, mulch samples made of natural pine bark mulch and cypress mulch were also purchased from a retail store. A summary of all samples tested is presented in Table 1. Samples with the same initial letter came from the same facility. The number of samples collected from each facility ranged from 1 to 4.

2.2. Leaching tests

All mulch samples were leached using US EPA Method 1312, the Synthetic Precipitation Leaching Procedure (SPLP). This test was developed as a tool to evaluate the leaching of chemical constituents from waste materials or contaminated soils into ground and surface waters. Unlike the more common toxicity characteristic leaching procedure (TCLP), which simulates leaching in a municipal solid waste landfill, the SPLP uses a simulated rainwater leaching solution and is designed to assess leaching in environments exposed to rain

water. This method provides a more realistic assessment of metal mobility under field conditions, (i.e. what happens when it rains) (Hageman et al., 2000; Jang and Townsend, 2001). The SPLP test starts with the preparation of a sulfuric acid/nitric acid solution (60 g sulfuric acid and 40 g of nitric acid). This solution is then used to prepare the SPLP extraction fluid by diluting the sulfuric/nitric acid mixture in reagent water (0.4–0.5 ml into 2 l) so that the pH of the resulting extraction fluid is at 4.22 ± 0.5 . A 100-g mulch sample is weighed and then placed in a 2-l polyethylene extraction vessel. Two liters of SPLP extraction fluid are added to the sample. The samples are then rotated for 18 ± 2 h. After rotation, samples are removed from the agitator and filtered. The filtrate is collected in plastic bottles and nitric acid is added until the pH of the solution is below 2.0 (US EPA, 1996a).

2.3. Leachate digestion and analysis

Prior to analysis, the leachate samples were digested according to US EPA SW-846 method 7060A for arsenic and method 3020 for copper and chromium (US EPA, 1996a). Both methods are open vessel methods that require the addition

of concentrated nitric acid to a 100-ml sample of SPLP extract. The arsenic method also calls for the addition of 30% hydrogen peroxide. The analysis of arsenic, copper, and chromium was conducted using a Perkin–Elmer Atomic Absorption (AA) graphite furnace Spectrophotometer Model 5100 equipped with Zeeman Background Correction. The detection limit for the three metals was 10 µg/l. Samples M–U were reanalyzed for arsenic at the lower detection limit of 5 µg/l in order to compare the virgin mulch sample results to the new arsenic drinking water standard (10 µg/l). Samples A–M were leached in triplicate while the rest of the samples were leached in duplicate. Laboratory blanks, blank spikes, matrix spikes and duplicate samples were digested and analyzed for quality control purposes.

3. Results and discussion

3.1. Final leachate pH

Many factors control the extent to which a heavy metal leaches from a waste material into an aqueous medium, but perhaps none more than pH (Sposito et al., 1982; Van der sloot et al., 1997). It is thus important to report the final pH of the leaching fluid. Even though the initial pH of the SPLP extraction fluid is acidic (4.22), the amount of acid is small. A small amount of alkalinity in the sample causes the pH of the leaching fluid to increase and thus impacts the concentration of metals that leach. Table 2 presents the final pH of the leaching test fluids.

An examination of Table 2 indicates that the samples collected from C&D debris processing facilities possessed a higher pH than the virgin mulch (samples S, T and U). The final leaching pH values for the C&D debris wood mulch (samples A–N) ranged from 5.7 to 7.8, with only site C being less than 6.5. The pH values of the virgin mulch samples were all less than 6.0 (4.50–5.96). C&D debris wood mulch is likely to contain other impurities such as dirt, concrete, and gypsum. Such impurities can provide mineral buffering capacity to raise the final pH of the leaching fluid.

Table 2
Heavy metal concentrations in SPLP leachates

Name	Final pH	Metal concentration (µg/l)		
		As	Cr	Cu
A1	7.69	52.3	49.4	41.9
A2	7.80	56.2	54.0	44.6
B1	6.83	182	82.2	96.1
C1	5.71	275	118	340
C2	6.03	176	110	136
D1	7.23	41.9	67.5	148
D2	6.65	<10.0	<10.0	94.4
D3	7.25	165	39.3	94.9
D4	7.34	<10.0	<10.0	<10.0
E1	7.05	73.8	55.3	35.5
E2	7.32	71.0	43.2	49.9
F1	7.27	68.5	38.3	25.8
G1	7.20	160	112	66.2
H1	6.83	80.6	35.8	42.8
H2	6.56	153	45.1	64.2
I1	7.22	158	68.1	43.3
I2	7.10	94.8	39.1	24.2
J2	7.38	49.0	30.1	34.5
K1	6.67	558	229	217
M1	7.06	347	170	633
N1	6.82	173	85.9	35.1
N2	6.79	156	73.8	56.2
P1	5.81	<5.00	<10.0	11.1
Q1	8.11	65.0	24.0	17.7
Q2	8.16	65.8	26.1	16.8
R1	7.56	56.7	117	36.1
S1	5.85	<5.00	<10.0	19.7
T1	5.96	<5.00	<10.0	<10.0
U1	4.50	<5.00	<10.0	<10.0

3.2. Leachate metal concentrations

All of the leachate samples were analyzed for arsenic, chromium, and copper. The metals were analyzed as the total of all species of metal occurring, not for individual species (e.g. trivalent chromium vs. hexavalent chromium). The results for all three metals are presented in Table 2. The concentrations presented for samples A–M represent the average of three leaching tests and the values for samples N–U represent the average of two leaching tests. Histograms of the leached concentrations of these three metals are presented in Fig. 1. The histograms reflect all of the individual samples collected from C&D debris processing facilities (including triplicates and duplicates). When looking at the entire sample data set, the

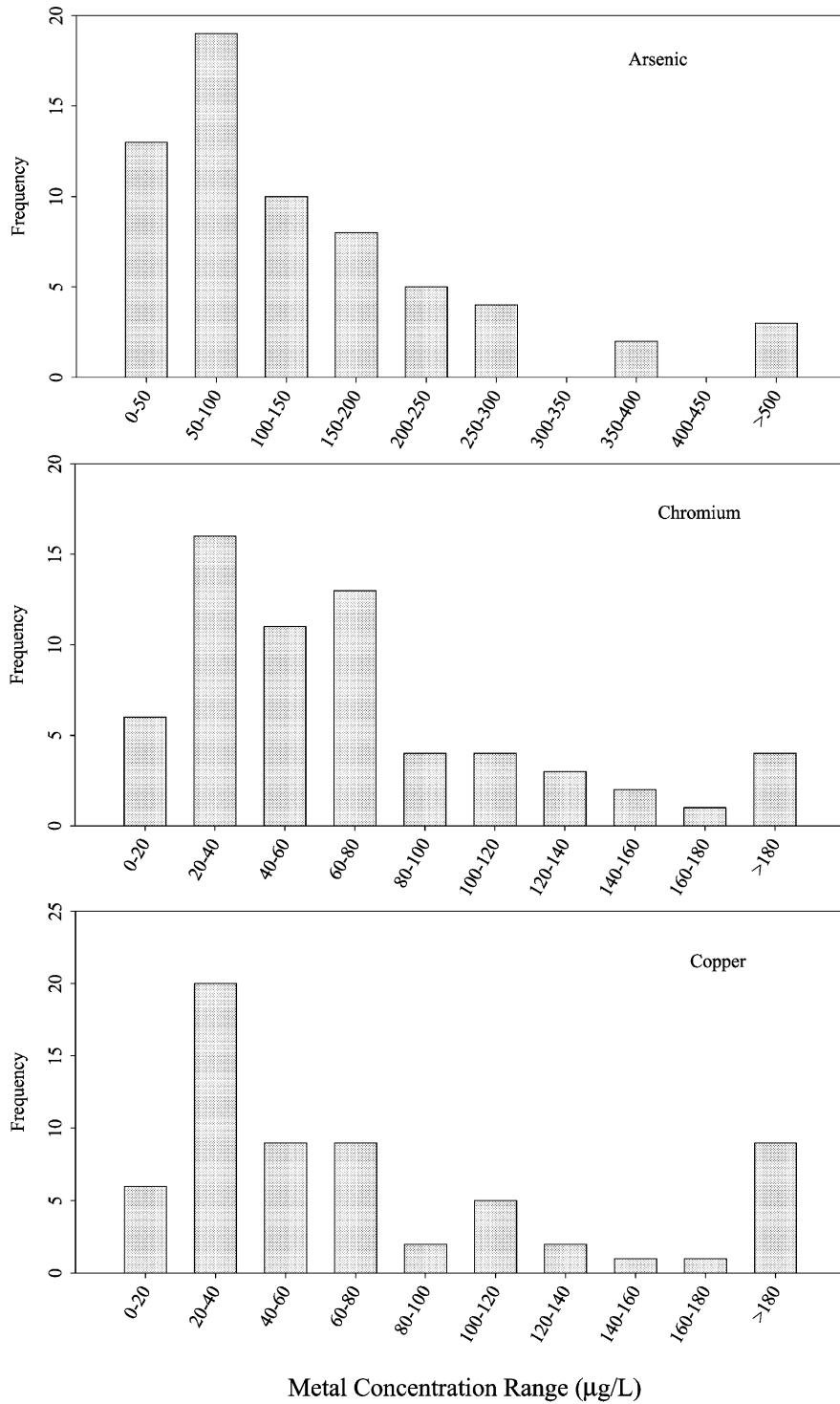


Fig. 1. Distribution of arsenic chromium and copper concentrations in leachates from processed C&D debris.

Table 3
Mean metal concentrations in SPLP leachates

Sample	As ($\mu\text{g/l}$)	Cr ($\mu\text{g/l}$)	Cu ($\mu\text{g/l}$)
1997 C&D debris samples (sites A–M)	153	73.4	113
1999 C&D debris mulch sample (site N)	164	79.8	45.7
Yard waste facility (site R)	56.7	117	36.1
Commercial mulch (pine bark, cypress) (sites S, T, U)	<5.0	<10.0	6.56
Colored mulch 1 (site P)	<5.0	<10.0	11.1
Colored mulch 2 (site Q)	65.4	25.0	17.2

concentration of arsenic ranged from below detection limit (5 or 10 $\mu\text{g/l}$) to 558 $\mu\text{g/l}$. The chromium concentrations ranged from below detection limit (10 $\mu\text{g/l}$) to 229 $\mu\text{g/l}$, while the copper concentrations ranged from below detection limit (10 $\mu\text{g/l}$) to 340 $\mu\text{g/l}$.

Arsenic was found to have the highest mean concentration of all three metals analyzed in the SPLP leachates from the C&D debris wood samples. The average arsenic concentration (arithmetic) in the SPLP leachates from the 1997 C&D debris samples was 153 $\mu\text{g/l}$ (see Table 3), while the 1999 sample was 164 $\mu\text{g/l}$. For purposes of calculating mean concentrations, values below detection limit were treated as one-half of the detection limit. The two C&D debris facility samples with SPLP arsenic concentrations below detection limit (D2 and D4) were piles identified as primarily yard trash. Many C&D debris recycling facilities also accept and grind yard trash and land clearing debris. The average chromium concentration was 73.4 $\mu\text{g/l}$ for the 1997 samples and 79.8 $\mu\text{g/l}$ for the 1999 sample, and the average copper concentration was 113 $\mu\text{g/l}$ for the 1997 samples and 45.7 $\mu\text{g/l}$ for the 1999 sample. Heavy metals were for the most part absent in the SPLP leachates from the pine bark and cypress mulch samples (arsenic and chromium were below detection limits; copper was measured above the detection limit in one of three virgin mulch samples). The yard trash sample (R1) and one of the commercial colored mulch sources (Q1, Q2) leached detectable levels of all three metals. The other commercial colored mulch source did not leach detectable levels of either arsenic or chromium.

In the majority of the C&D debris samples, arsenic leached a greater amount than chromium and copper. This is illustrated in Figs. 2 and 3. Both figures include all individual samples collected and leached (the triplicates and duplicates). Fig. 2, for example, is a plot of arsenic concentration vs. chromium concentration from the C&D debris facilities samples. Included in this plot are the lines representing As/Cr ratios of 1:1, 2:1 and 4:1. In Fig. 2, the majority of the data lie above the 1:1 line. While the As/Cr ratio in type C CCA-treated wood (the most common formulation) is 0.9, arsenic typically leaches more than chromium. Previous studies have found the leachable As/Cr ratio for new wood to range from 3.0 to 16.7 (Cooper, 1991; Lebow, 1996; Townsend et al., 2001). Samples with high As/Cr ratios are likely more indicative of wood mulch containing new CCA-treated wood (construction scrap). Samples with lower arsenic to chromium ratios probably contain more weathered wood samples (demolition) where much of the arsenic has already leached. Despite the variability, the constant presence of all three metals gives good indication that the major source is CCA-treated wood.

Total metal concentrations (mg/kg) in the mulch were not measured; size reduction of the mulch would have been required to obtain a homogenous sample. The previously estimated CCA-treated wood content of samples A–M ranged from below background to 20%, with a mean of 6% (Tolaymat et al., 2000). If a wood mixture contained 6% type C CCA-treated wood at a standard retention value of 4.0 kg CCA/m³ wood, the mixture would have arsenic, chromium

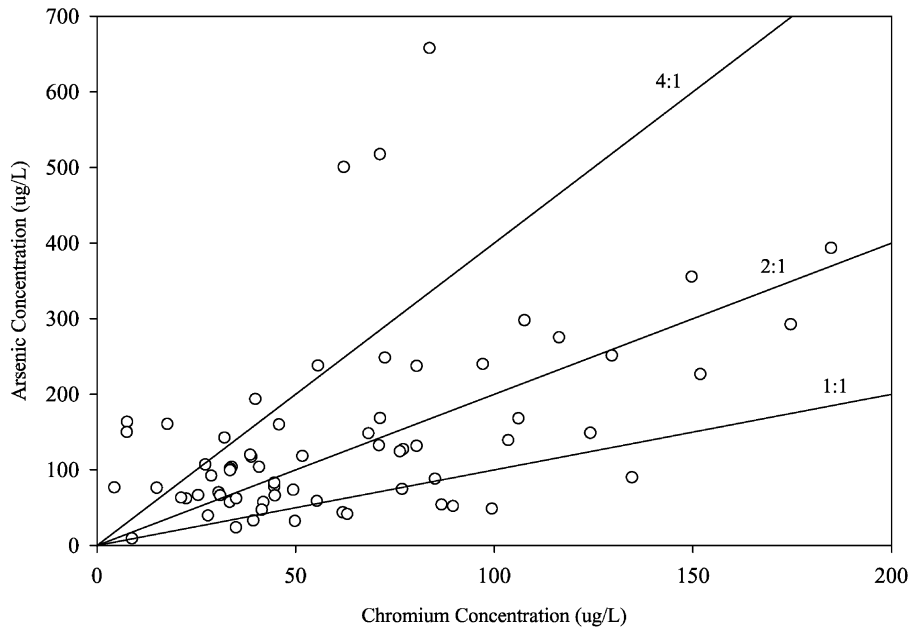


Fig. 2. Arsenic and chromium concentrations leached from C&D wood waste.

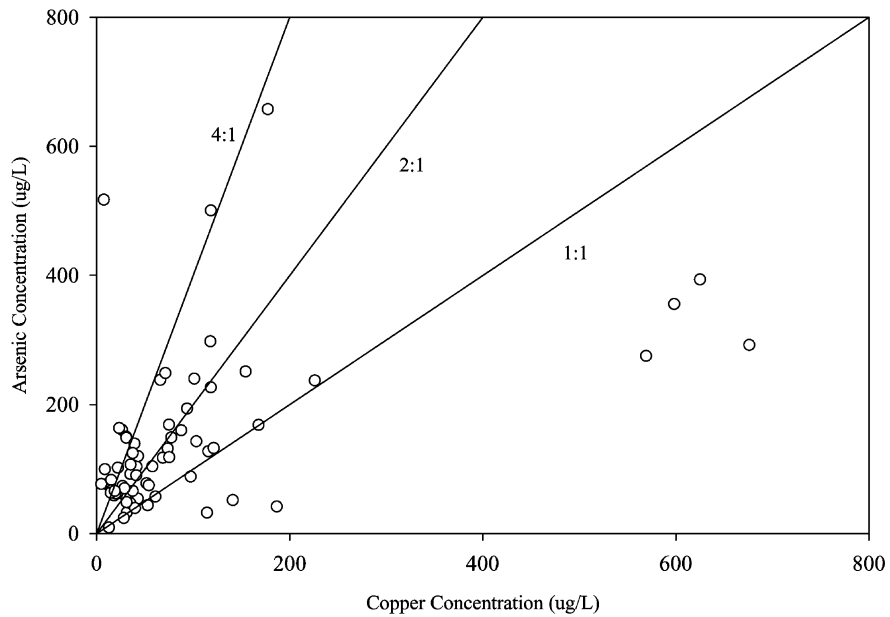


Fig. 3. Arsenic and copper concentrations leached from C&D wood waste.

Table 4
Samples exceeding Florida GWCTL for As and Cr

Samples	No. of samples	Samples exceeding GWCTL	
		As	Cr
1997 C&D debris samples (sites A–M)	20	16	5
1999 C&D debris mulch sample (site N)	2	2	0
Yard waste facility (site R)	1	1	1
Commercial virgin mulch (pine bark, cypress) (sites S, T, U)	3	0	0
Colored mulch 1 (site P)	1	0	0
Colored mulch 2 (site Q)	2	2	0

and copper concentrations of 84, 114 and 66 mg/kg, respectively.

3.3. Comparison to groundwater guidance concentrations

The metal concentrations in the SPLP leachates were compared to the Florida Groundwater Cleanup Target Levels (GWCTLs) for arsenic, chromium and copper. The GWCTLs for arsenic, chromium and copper are 50, 100 and 1000 $\mu\text{g}/\text{l}$, respectively. The GWCTLs for arsenic and chromium represent risk-based concentrations that were adopted from the US Safe Drinking Water Act (SDWA) Primary Drinking Water Standards. The copper GWCTL was adopted from the SDWA secondary drinking water standard (due to aesthetic impact on drinking water). It is a common practice to compare the results of a batch leaching test such as the SPLP directly to groundwater standards to determine whether a contaminated soil or land-applied waste will present a risk of groundwater contamination (Saranko et al., 1999). When this comparison is made, arsenic presented the greatest risk to groundwater.

Table 4 presents the number of samples that exceeded the arsenic and chromium GWCTLs by sample category. The arsenic GWCTL was exceeded in the majority of the C&D debris wood samples (18 out of 22). Arsenic was detected

above the GWCTL in the one sample of yard trash collected (sample R). While this sample was collected to represent a control for natural vegetation, it is plausible that CCA-treated wood could have been mixed with yard trash. The authors have observed CCA-treated wood in piles of yard trash waiting to be mulched and have on occasion, observed lumber and timbers and portions of fences with the piles. The commercial colored mulches behaved differently. The samples purchased from a store in south Florida leached arsenic at an average concentration of 64.5 $\mu\text{g}/\text{l}$ (above the GWCTL), while the one purchased in north Florida showed no detectable arsenic. This indicates that the south Florida sample was likely derived, at least in part, from C&D debris wood, while the north Florida one was not. This is not surprising considering the large number of C&D debris recycling facilities in south Florida. The pH results also corroborate this observation. The north Florida colored mulch was in the same range as the pine bark and cypress mulches, while the south Florida mulch leachate pH was in the range of the C&D debris wood. The authors note that the US EPA lowered the primary drinking water standard to 10 $\mu\text{g}/\text{l}$ in 2002, with drinking water facilities required to be in compliance by 2006. The Florida Department of Environmental Protection will in all likelihood, follow suit and lower the GWCTL. When results for the C&D debris facilities are compared to an arsenic threshold of 10 $\mu\text{g}/\text{l}$, only the two C&D debris facility samples that were clearly from yard waste piles (D2 and D4) are lower.

Chromium concentrations in the SPLP leachates exceeded the GWCTL in five samples out of the 20 collected during 1997, and in sample R. However, based on the final extraction pH it is likely that the chromium was in the trivalent form rather than the more toxic hexavalent form. Chromium is added to CCA-treated wood in the hexavalent form. The hexavalent chromium reduced to trivalent chromium and in the process ‘fixes’ the CCA to the wood. Even if small amounts of hexavalent chromium were still present in the wood, it is only stable in oxidizing conditions and at high pH values (Barnhart, 1997).

Table 5
Percentage of CCA-treated wood needed for mulch to exceed risk-based direct exposure standards

Regulatory standard or guideline for direct exposure (mg/kg)				% CCA-treated wood that must be present for a metal to exceed guideline or standard ^a		
	As	Cr	Cu	As	Cr	Cu
US EPA soil screening level	0.4	NA ^b	NA	0.02	NA ^a	NA ^a
Residential Florida soil cleanup target level	0.8	210	110	0.04	7.0	6.1
Industrial Florida soil cleanup target level	3.7	420	76 000	0.18	14	Cannot exceed
US EPA domestic wastewater sludge rule (EPA 503)	41	NA	1500	1.9	NA	83

^a Based on 6.4 kg CCA/m³ wood, type C CCA-treated wood.

^b Not applicable; no standard or guideline exists.

The comparison with the GWCTL may or may not reflect a realistic risk to the environment. The actual concentration in the groundwater will depend on factors such as how much mulch is applied, how often, the type of soil underneath the mulch, the depth to the groundwater table, and the degree of dilution in the groundwater. Thus, actual impact on the groundwater would require additional investigation. It can be said, however, that arsenic does leach from C&D debris wood mulch at concentrations that would limit its application if current Florida policy practices for waste materials were applied. It is also likely that the continued application of this type of mulch will result in increased soil arsenic concentrations.

3.4. Direct exposure

The assessment of direct exposure risk is usually carried out by measuring the total concentration of a chemical in a soil or waste (mg/kg) and comparing to an appropriate risk-based concentration. These risk-based concentrations are developed using an assumed pathway of exposure and appropriate toxicological data. The US EPA has developed a set of soil screening levels (SSLs) for different chemicals using this approach (US EPA, 1996b), and many states such as Florida (FAC, 2000) have modified this approach with state-specific assumptions. Thus, to examine the risk of

direct exposure to a given metal, total metal concentrations (mg/kg dry mass) are compared to Florida's soil clean-up target levels (SCTL). The Florida residential SCTLs for arsenic, chromium, and copper are 0.8, 210 and 110 mg/kg, respectively (FAC, 2000).

While no measurements of the total concentration of arsenic, chromium and copper were conducted as part of this study, the concentration of various mixes of untreated mulch with CCA-treated mulch can be compared to the risk-based pollutant concentrations because the concentration of arsenic, chromium and copper are defined for different grades of treated wood. For example, type C CCA-treated wood (the most common formulation) at a standard retention value of 6.4 kg/m³ (kg of CCA/m³ of wood) would have arsenic, chromium and copper concentrations of 2100, 3000 and 1800 mg/kg, respectively. Assuming that untreated wood has negligible concentrations of these three metals, the amount of CCA-treated wood that must be present within a mulch mix to surpass various risk-based standards can be calculated as presented in Eq. (1). M_x represents the concentration of metal x (As, Cu or Cr) in CCA treated wood (mg/kg). $SCTL_x$ is the SCTL of metal x . While Eq. (1) calculates the allowable fraction of CCA-treated wood that will meet Florida's SCTLs, this value can be substitut-

ed for other risk-based concentrations (see Table 5).

$$\% \text{CCA}_{\text{allowed}} = \frac{\text{SCTL}_x \left(\frac{\text{mg}}{\text{kg}} \right)}{M_{x\text{CCA}} \left(\frac{\text{mg}}{\text{kg}} \right)} \times 100 \quad (1)$$

As was the case with the leaching-to-groundwater pathway, arsenic was the most problematic. When considering Florida's residential SCTL for arsenic (0.8 mg/kg), a wood mixture containing 0.04% CCA-treated wood would exceed the SCTL. While Florida's residential SCTL for arsenic is relatively low, it is not out of line with many other locations. In a survey of state arsenic soil standards, residential arsenic standard concentrations ranged from 0.1 mg/kg (for the state of Arkansas) to 250 mg/kg (for the state of Montana), with 14 out of the 21 states surveyed being less than 10 mg/kg. States with high risk-based standards used different risk assumptions or set the standard to background arsenic concentrations (AEHS, 1998). Florida's background arsenic concentration (geometric mean) has been reported to be 0.42 mg/kg (Chen et al., 1999). It should be noted that untreated wood could have arsenic concentrations somewhat above 0.8 mg/kg. But even when comparing to a higher risk-based standard, such as 10 mg/kg, the amount of CCA present that would cause the mulch to exceed would still be less than 1%.

Perhaps the greatest uncertainty in the application of risk-based standards such as those used for assessment of contaminated soils and soil-like waste materials (e.g. compost, cement kiln dust) are the exposure assumptions. Risk-based regulatory levels such as Florida's SCTLs are based on direct exposure to soil-like particles. However, exposure from touching CCA-treated wood, especially larger particles may be different. This warrants further investigation. Also, processed wood has different physical and chemical characteristics as compared to soil. Certainly, the average particle size of wood is greater than that for soil, and thus the input assumptions to the risk equations would differ. However, the long-term fate of the mulch is that it will become part of the soil as the material breaks down over time.

3.5. Recommended management practices

The results of this study and previous work (Tolaymat et al., 2000) indicate that CCA-treated wood does have a strong potential to become part of processed wood mulch produced at C&D debris recycling facilities. While the extent of the risk posed by land application of this material may be debated, the results presented herein warrant caution. Several steps can be taken to minimize introduction of CCA-treated wood into landscaping mulch and playground buffer. Regulatory agencies should develop clear policies and regulations that prohibit inclusion of CCA-treated wood in mulch. Wood mulchers need to be educated as to the need to separate out treated wood prior to grinding. While visual identification can prove difficult, several strategies may be employed. New CCA-treated wood can usually be recognized by color and removed. Weathered wood is more difficult, but certain types of wood loads contain large amounts of CCA-treated wood and can be disposed of in separate areas. These include deck, dock and fence demolitions, and distinct items such as utility poles. Stains that react with CCA-treated wood can be also utilized as spot checks (Blassino et al., 2002). Future technologies may include portable or conveyor-fixed sensors to identify CCA-treated wood (Solo-Gabriele et al., 2001). CCA-treated wood diverted from mulching should be disposed of properly or recycled if markets exist.

4. Conclusion

Processed wood samples collected from C&D debris facilities in Florida were found to leach arsenic, copper and chromium as a result of the presence of CCA-treated wood. Select samples of virgin wood mulch products (pine bark, cypress mulch) were found to leach little, if any, of the three metals tested. Arsenic presented the biggest problem when the results were compared to Florida's risk-based target concentrations for groundwater. Since contamination of groundwater would depend on many factors such as underlying soil type, rate of mulch application, extent of application, and depth of groundwater, the results do not

directly indicate that groundwater contamination will occur. They do, however, indicate that this practice warrants further examination and control. When looking at direct exposure risks, mass balance calculations showed that less than 0.1% CCA would cause the mulch to exceed Florida's clean soil levels for arsenic. Steps were outlined to minimize the inadvertent disposal of CCA-treated wood through applications such as mulch.

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