COPPER MIGRATION FROM TREATED WOOD GARDEN BOXES INTO SOIL AND VEGETABLE BIOMASS PART I: THE FIRST TWO GROWING SEASONS AFTER INSTALLATION

*G. N. Presley**
Assistant Professor
E-mail: gerald.prelsey@oregonstate.edu

M. J. Konkler
Senior Faculty Research Assistant II
Department of Wood Science and Engineering
Oregon State University
3180 SW Jefferson way
Corvallis, OR 97331
E-mail: matthew.konkler@oregonstate.edu

(Received November 30, 2023)

Abstract. Pressure-treated wood is a commonly used material for constructing garden boxes and concerns about metal leaching into garden soils and garden vegetables persist among the public. This study describes efforts to quantify copper migration from copper azole-treated garden bed frames into garden soil and vegetable biomass. Two garden bed frames were constructed from copper azole 2 × 12-inch nominal Douglas-fir lumber and two were constructed with untreated Douglas-fir lumber before filling with a mixture of native soil and compost. An assortment of common garden vegetables was planted in identical patterns in each of the beds for two growing seasons. During this 2-yr study, we found no difference in copper concentrations between identical vegetables grown in beds constructed with treated or untreated lumber. After 1 and 2 yr, average copper concentrations in soil 0-25 mm from the bed frames were about 23 ppm and 21 ppm higher than soils in the same location in untreated beds, respectively ($p < 0.05$, Tukey's HSD). Elevated copper levels were not detected in beds constructed with treated lumber at 76-102 inches from the frames or the bed center, indicating that metal migration was limited. This study shows use of treated wood garden beds did not lead to increases in copper concentrations in vegetables grown in those beds. Treated bed materials did lose some copper to garden soil but increases in copper are limited to about 20 ppm immediately next to the treated wood frames and were not detectable at any greater distances from the wood.

Keywords: Metal leaching, bioaccumulation, wood durability, copper azole.

INTRODUCTION

Wood is commonly used in the construction of garden boxes for residential flower beds and vegetable gardens but suffers severe decay risk in this environment due to frequent wetting by irrigation and contact with nutrient-rich soil. Using pressure-treated lumber can improve the lifespan of wooden garden boxes and is economically desirable. However, concerns over chemical contamination of garden soils and vegetables persist among the public.

Some of the concerns arise from the past use of chromated copper arsenate (CCA) as a wood preservative for residential applications and the associated fears of arsenic contamination of vegetable matter. It has been over 20 yr since CCA-treated lumber was voluntarily removed from the residential market in the United States (EPA 2002). Since then, nonarsenical copper-based preservative systems such as copper azole (CA-C), micronized CA-C, and alkaline copper quaternary have been used for residential applications including ground contact applications like the construction of garden boxes. Despite the absence of arsenic in current preservative formulations, many online blogs recommend avoiding pressure-treated wood in garden boxes because of the risk of contaminating produce with hazardous

* Corresponding author

chemicals. The United States Department of Agriculture Organic regulations also exclude the use of pressure treated wood in new construction on organic certified land (NOP 2016). This suggests regulators believe the use of treated wood will impact the quality of organic produce.

Excessive copper exposure to plant tissues can be detrimental to plant growth if present at sufficient levels in the growth medium or plant tissues. High levels of heavy metals in vegetables originating from plants grown in contaminated soils are potentially hazardous to human health if accumulated in plant biomass at high levels (Intawongse et al 2006). Given these risks of metal accumulation observed in some hydroponic copper exposure experiments, it is important to assess the impact of treated wood garden boxes on garden soils that come into contact with edible vegetables (Shabbir et al 2020). There is a surprisingly small amount of published scientific investigation into the impacts of pressure-treated wood on garden vegetables specifically. A study done at Oregon State University investigated this topic using CA-C-treated Douglas-fir as a test material (Love et al 2014). This study showed that there was no difference in the metal content of the edible portions of vegetable biomass whether it was grown in a treated or untreated box. There was, however, a significant increase in the copper content of carrot tops sourced from treated boxes as compared with untreated boxes, indicating that there may be the potential for metal exposure for the aboveground portions of carrots.

The risk of vegetable contamination from treated wood has also been assessed in a controlled culture where metals are intentionally introduced into growth media and results vary by plant. Grapevines exposed to copper, chromium, and arsenic in a hydroponic growth medium did not accumulate metals above those of the controls, indicating that the plants regulated metal uptake via their roots (Ko et al 2007). Another study showed that CCA-treated wood sawdust amendment of soil led to increases in CCA metal concentration in the fibrous root portion of beetroot but less so in the large edible portion of the root (Speir et al 1992). Other studies show metal accumulation in plant parts in hydroponic and soil cultures where high copper loadings in the form of soluble copper are added to plant cultures (Shabbir et al 2020). These studies are not representative of the real-world use of treated wood bed material and further investigation of metal accumulation potential in a representative system would be beneficial for uncovering the true impact of treated wood's use in garden boxes.

In this study, metal migration from treated wood used in vegetable garden construction was investigated in a multiyear study. Garden boxes were constructed with CA-C-treated Douglas-fir lumber as well as untreated wood to quantify the migration of copper out of the treated boxes. Copper content in soils and vegetable biomass were measured at equivalent locations and plant types in each garden box. This study summarizes the first 2 yr of soil and vegetable data in an ongoing study.

METHODS

Garden Box Construction and Planting

Two garden box frames were constructed out of untreated or pressure-treated 5.1 × 30.5 cm (2 × 12-inch) nominal Douglas-fir lumber (Fig 1). The treated frame boards were pressure-treated to ground contact retention (2.4 kg/m^3) with CA-C. The raised beds were 1.2 × 3 m, constructed from a single 2.4-m piece of lumber that was halved for the box ends and two 3 m pieces of lumber for the sides which were held together with exterior screws. No additional remedial treatment was applied to the cut surfaces of the pressure-treated lumber. After the beds were constructed, the native soil was excavated to about 45 cm depth to loosen and layered into the beds with compost. The raised beds were then topped with a ∼5-cm layer of compost before planting.

The four beds were planted in patterns identical to one another in each growing year. A different group of vegetables was selected for planting in years 1 and 2 and the planting plan is diagramed in Figs 2 and 3. Vegetable varieties used are summarized in Table 1. A mixture of common vegetables was seeded or planted into the beds at appropriate times based on their hardiness. The beds were watered by drip irrigation fed by 12.5 mm

Figure 1. Raised bed construction from the construction of boxes (top left) to bed digging (top right) to finished (bottom left) and in the first summer of growth with tomato trellising installed (bottom right).

irrigation tubing. Watering was done in response to weather and during the summer months was done daily. Trellising made from either galvanized 8-foot cattle panels, repurposed steel shelves, or untreated Douglas-fir trellising was used to support tomatoes and other vining plants (Figs 1 and 4). No copper input was expected from any of the trellising materials that would confound results.

Vegetable and Soil Collection

Produce was collected from the gardens as it matured. For each type of vegetable, a comingled sample of vegetable biomass was collected from each of the four beds. This was done to ensure that enough biomass was available for each bed for metal analysis. The size and productivity of vegetables varied in different boxes and because of

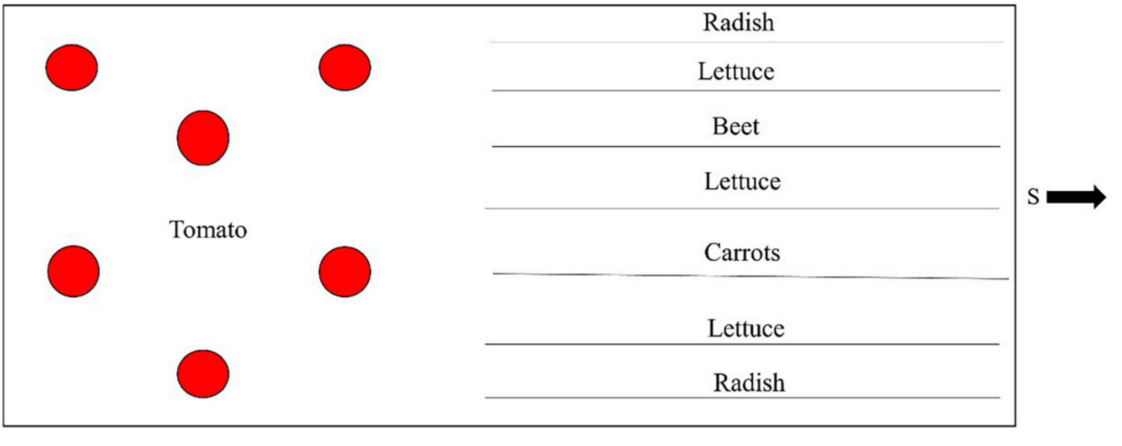

Figure 2. Planting diagram for year 1 for treated and untreated raised beds. Varieties grown for each vegetable are listed in Table 1 and circles indicate an individual plant. Basil was succession planted after beets were harvested in year 1.

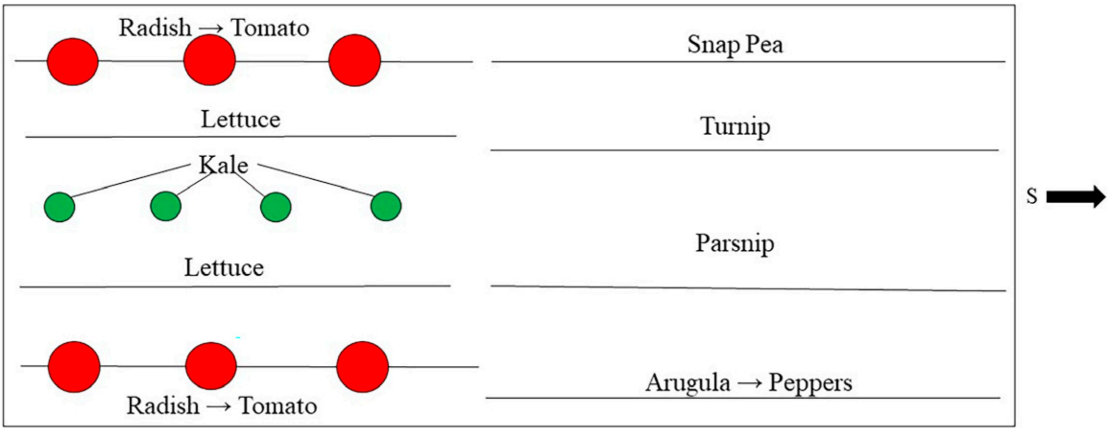

Figure 3. Planting diagram for year 2 for treated and untreated raised beds. Varieties grown for each vegetable are listed in Table 1 and circles indicate an individual plant. Arrows denote succession planting after the harvest of the first crop.

this, the total number of each plant harvested for analysis differed in some cases. For root crops such as carrots, beets, and parsnips, the leafy tops were separated from the roots and were analyzed separately. In some cases, inedible portions of non-root vegetables were analyzed in addition to the edible portion.

Soil samples were collected from the bed centers upon installation to serve as background. A single comingled sample of four samples was collected for each bed. At the end and start of each season (after fresh compost addition), soil samples were collected using a 25 × 305 mm soil corer from 0 to 25 mm from the bed edge, 76-102 mm from the bed edge, and the bed center (Fig 5). A total of four soil samples of each type were taken from each bed at each sampling point according to the diagram shown in Fig 5. The four equivalent samples at each sampling point were comingled and homogenized before analysis except for samples taken at the end of year 2 which consisted of four separate soil cores for each location in each bed. Soil samples were collected from the top of the soil surface to the full depth of the wood border.

Measurement of Copper

Soil or vegetable biomass was microwave digested in triplicate from comingled samples and analyzed for copper content using inductively coupled plasma mass spectrometry (ICP-MS). Soil or plant biomass samples were homogenized, oven-dried, and microwave-digested according to EPA method 3052. Briefly, 0.25 g of soil or 0.5 g of plant biomass was placed into PTFE microwave extraction tubes and 10 mL of concentrated nitric acid was added. Samples were digested for 9.5 min at 180°C with a total microwave digestion time of about 15 min. The resulting digestate was rinsed from the tube with DI water and brought up to a volume of 35 mL with DI water and analyzed for Cu using ICP-MS and expressed on a µg/g (PPM) basis.

Copper in extracts was measured using a Thermo-Elemental iCAP RQ ICP-MS. Each ICP-MS analytical session began by allowing the ICP-MS to warm up for 30 min before being tuned first in standard robust and then in kinetic energy discrimination robust (KEDR) modes utilizing a multiple element 1 part per billion (ppb) standards prepared in a 2% HNO_3 + 0.5% HCl matrix. Calibration standards were prepared from single-element standards and were spiked with 0.5 ppb indium for use as an internal standard. Calibration curves generated for 65Cu included nine standards and a blank. All standards and blanks were prepared using ultra-pure 2% HNO_3. Samples were spiked with 0.5 ppb indium as an internal standard and diluted 10-fold using laboratory-grade water. The analyte 65Cu was analyzed in KEDR mode. Each analysis

Table 1. Description of vegetable samples harvested from the raised beds in years 1 and 2 and which plant parts were analyzed.

Vegetable	Part analyzed	Variety	Seed source	Planting year
Basil	Leaf	Sweet Italian	Burpee	1
Basil	Stem	Sweet Italian	Burpee	1
Beet	Root	Early Wonder Tall top	Territorial Seed Co.	1
Beet	Tops	Early Wonder Tall top	Territorial Seed Co.	1
Carrot	Root	Carrot, Giants of Colmar	Territorial Seed Co.	1
Carrot	Tops	Carrot, Giants of Colmar	Territorial Seed Co.	1
Lettuce	Leaf	Mixed greens gourmet	Burpee	1
Radish	Leaf	Cherry Belle	Territorial Seed Co.	1
Radish	Root	Cherry Belle	Territorial Seed Co.	1
Tomato	Fruit	Rutgers	Territorial Seed Co.	1
Tomato	Vine	Rutgers	Territorial Seed Co.	1
Basil	Leaf	Sweet Italian	Burpee	1
Basil	Stem	Sweet Italian	Burpee	1
Beet	Root	Early Wonder Tall top	Territorial Seed Co.	1
Beet	Tops	Early Wonder Tall top	Territorial Seed Co.	1
Carrot	Root	Carrot, Giants of Colmar	Territorial Seed Co.	1
Carrot	Tops	Carrot, Giants of Colmar	Territorial Seed Co.	1
Lettuce	Leaf	Mixed greens gourmet	Burpee	1
Radish	Root	Cherry Belle	Territorial Seed Co.	1
Tomato	Fruit	Rutgers	Territorial Seed Co.	1
Tomato	Vine	Rutgers	Territorial Seed Co.	1
Arugula	Leaf	Roquette	Territorial Seed Co.	2
Radish	Root	Cherry Belle radish	Territorial Seed Co.	2
Radish	Leaf	Cherry Belle radish	Territorial Seed Co.	2
Turnip	Root	Turnip purple top globe	Territorial Seed Co.	2
Turnip	Greens	Turnip purple top globe	Territorial Seed Co.	2
Lettuce	Leaf	Lettuce Bibb	Burpee	2
Kale	Leaf	Kale Prism	Territorial Seed Co.	2
Pea	Pod	Super Sugar Snap	Territorial Seed Co.	2
Parsnip	Root	Gladiator F1	Territorial Seed Co.	2
Parsnip	Tops	Gladiator F1	Territorial Seed Co.	2
Tomato	Fruit	Rutgers	Territorial Seed Co.	2
Pepper	Fruit	Gold Star	Territorial Seed Co.	2

consisted of five 80 sweep runs with 65Cu analyzed with 10 ms dwell times. Quality control and internal precision were monitored by repeated measurements of the prepared standards following every 25th sample.

Statistical comparisons were made between copper levels in treated and untreated beds using a single factor ANOVA and a Tukey's honestly significant difference post hoc test, $\alpha = 0.05$.

RESULTS AND DISCUSSION

Copper concentration was measured on a dry weight basis for vegetables grown in years 1 and 2 are shown in Figs 6 and 7, respectively. There was no obvious difference in plant growth among the different beds although yields were not measured as part of this study. Copper levels are shown as averages for material sourced from treated and untreated beds are treated or untreated garden bed and little difference was detected among vegetables sourced from different bed types. There was no clear pattern of higher or lower copper levels based on bed type. In some instances, such as some radish roots and tomatoes, untreated beds produced vegetables with slightly higher copper content while in others such as some lettuce, treated beds may have had slightly higher copper

Figure 4. Progression of vegetable growth in the second growing season March (left), April (center), and May (right).

levels. However, none of these differences were statistically different than one another ($p > 0.05$, Tukey's HSD).

This is contrary to previous observations where carrot tops were identified as a potential accumulator of copper from garden bed materials (Love et al 2014). This study shows no difference in copper levels found in carrot tops grown in treated garden boxes or untreated garden boxes. Another study has shown that some plant tissues in beans, particularly roots, can show increased copper concentrations in soils when grown in copper-amended soils (Apodaca et al 2017). Intawongse and Dean (2006) showed that copper can accumulate in lettuce, spinach, and radish roots grown in copper-contaminated compost. However, copper levels in the growing medium in that study were over 10 times higher than those found in the current study and represent a severely metal-contaminated growing medium. Regardless, no increase in copper concentrations for root crops was measured in this study.

Copper levels in vegetables grown in year 2 followed a similar pattern where most average copper values in produce grown in treated or untreated beds were similar. Average copper levels in tomato fruit grown in treated beds trended slightly higher than in untreated beds, but the difference was not significant ($p > 0.05$, Tukey's HSD). Average copper levels trended higher in arugula and turnip greens grown in untreated boxes, but these were also not significantly different from levels in vegetables grown in untreated beds ($p > 0.05$, Tukey's HSD). These data indicate that for both years, copper levels in vegetables grown in treated and untreated beds were indistinguishable from one another.

Copper levels in soils were measured at the installation of the boxes, at the end of the first growing season, after the addition of compost for the second growing season, and after the second growing season (Fig 8). Copper concentrations in soil taken from treated garden boxes were about 23 ppm higher than equivalent samples taken from untreated boxes after the first year and the difference was statistically significant ($p < 0.05$, Tukey's HSD). This was a much lower increase in copper content than was observed in soils in direct contact with CCA-treated vineyard posts which increased by about 7-fold on average (Robinson et al 2006). No difference was seen in soils from the two-bed types at the 76-102 mm sampling point or the center bed sampling point, indicating that copper migration was limited to a small distance from the bed.

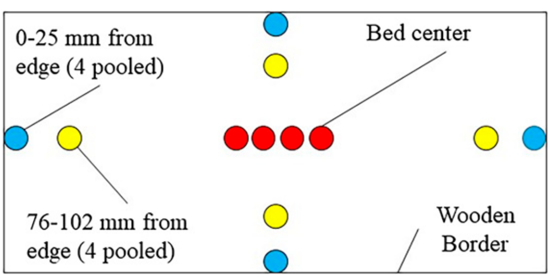

Figure 5. Sampling diagram for soil samples taken at the beginning and end of each growing season.

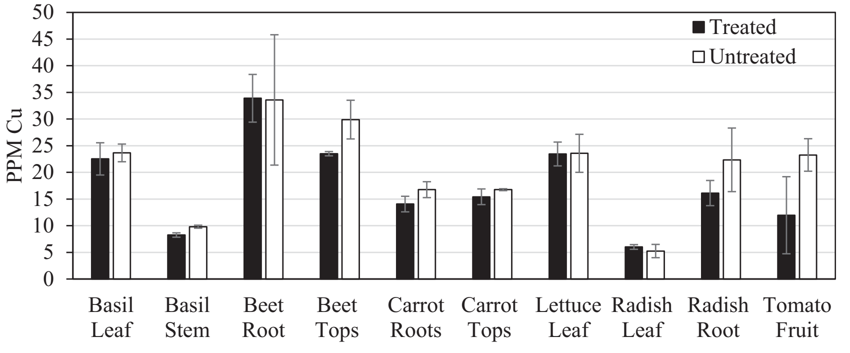

Figure 6. Copper levels were found in vegetable biomass taken from the raised beds in year 1. Error bars are plus or minus one standard deviation of three replicate extracts of two comingled pools of biomass.

Soil samples taken after compost addition at the start of the second year of growth did not show the same pattern and all equivalent samples taken from treated and untreated beds were indistinguishable from one another. This suggests that the compost addition washed out the copper signal from the treated bed by diluting the bed soil with fresh material. At the end of the second year, a nearly identical pattern to the first year emerged where average copper levels 0-25 mm from the bed edge were 21 ppm higher in the treated beds and the difference was statistically significant ($p < 0.05$, Tukey's HSD). No other sampling locations showed elevated copper levels in treated beds vs untreated beds, indicating that copper migration remained limited to the bed margins in the second year as well.

Copper levels measured are well within normal soil levels for the south Willamette Valley, OR which averages 38 PPM with a standard deviation of 30 PPM (Oregon Department of Environmental Quality 2013). Soil copper levels found in this study also fall well within normal ranges observed around the world which can range up to 495 PPM in the United States and even as high as 1508 PPM in the United Kingdom (Rehman et al 2019). The highest average Cu levels measured near treated wood boxes in this study was about 57 PPM and this is well within a range that would be considered statistically indistinguishable from natural copper levels in the Willamette Valley, OR. It is important to note that a fungal attack was observed on the untreated bed material as early as one year after installation whereas it was not on pressure-treated

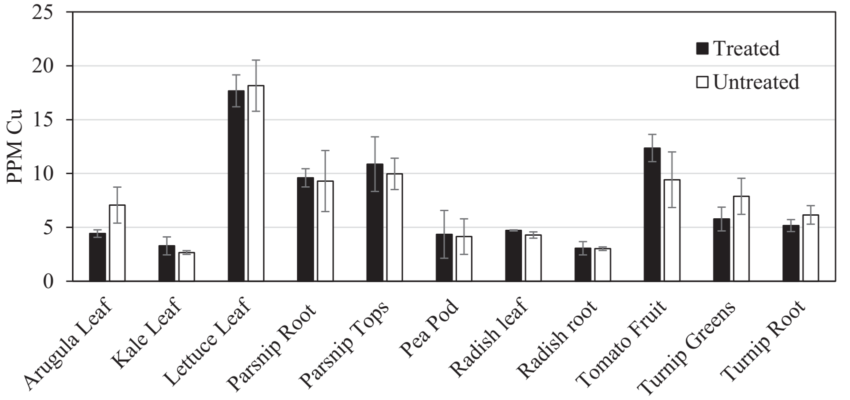

Figure 7. Copper levels were found in vegetable biomass taken from the raised beds in the year 2 season. Error bars are plus or minus one standard deviation of three replicate extracts of two comingled pools of biomass.

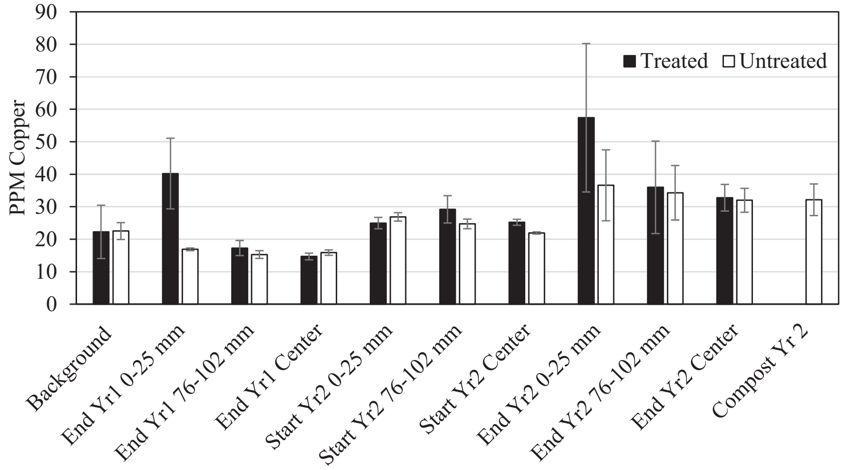

Figure 8. Copper levels were found in soils taken from treated and untreated garden boxes at the start of the study, the end of the first season, and the start of the second season of growth. Error bars are plus and minus one standard deviation three replicate extracts of two comingled pools of biomass, except for the end second-year sampling which consisted of four separate core samples from each bed extracted once.

beds. This illustrates the durability improvement from the use of pressure-treated bed material. While some increase in copper levels was observed within 25 mm of the treated wood beds, it was not enough to cause concern and it appeared to be limited to within a short distance from the bed material.

Copper migration from CA-C-treated wood has previously been studied using several different experimental methods. The potential for copper migration from CA-C treated decking to impact soil was studied by capturing decking runoff and applying it to columns packed with soil (Kennedy and Collins 2001). The previous study found that the amount of copper lost in runoff from the decking was insufficient to increase copper levels in the soil above their initial values. Soils in direct contact in this study showed an increase of about 20 PPM throughout a growing season. This is likely due to higher chemical loadings for wood in ground contact used in this study as opposed to decking and sustained contact of the wood with the soil to facilitate diffusion of the metal into the soil.

Another study that measured copper migration from CA-C treated wood stakes in soil-filled pots showed that soil immediately around the stakes increased in copper concentration by about 53-182 PPM Başkal et al (2023). These levels are about 2.5-9 times higher than observed in this study, but it is important to note that the CA-C retention levels in wood tested by Başkal and colleagues were 4.7-9.2 times higher than the 2.4 kg/m^3 ground contact retentions used for treated bed materials in this study. With that said, our results appear to show a proportional decrease in copper migration with the lower retention levels produced for the western United States market that are in line with previously observed migration rates.

This study analyzed copper migration from two treated or untreated garden boxes. While replication was built into the study through replicate sampling around each bed, the study would have benefited from greater replication. Soil as well as wood is a highly variable matrix of organic and inorganic matter and metal migration through these matrices can be highly varied from one location to another. Greater replication in the number of beds per treatment would have provided a better understanding of how copper migration varies among a greater population of treated wood. Subsequent studies on this topic should include a greater number of smaller beds.

Soils from the end of year 1 were extracted and analyzed for propiconazole and tebuconazole using high-performance liquid chromatography. Neither of these compounds were found in the initial sampling where the detection limit for propiconazole and tebuconazole was about 10 PPM in the soil (data not shown). No further analyses were done because it was determined that azoles were unlikely to be identified in any subsequent sampling. In CA-C, azoles are present at only 4% of the mass of copper. Even if migration is occurring in this system, it is likely entering soil at concentrations that are below the detection limits of our method.

CONCLUSION

This study shows that no increase in copper concentration was detectable in vegetables grown in garden boxes made with CA-C treated wood over vegetables grown in untreated beds. No effect of the treated beds was observed over two growing seasons. Treated wood garden bed material does increase copper concentrations in soils within 25 mm of the bed edge about 20 ppm above levels measured in untreated garden boxes. These increases were seen in both years of the study within 25 mm of the bed edge but were not measured at other locations farther from the bed edge. Increases in soil copper concentration near the bed edge were minor and did not increase copper levels beyond the natural range for the area.

ACKNOWLEDGMENT

This work was funded by the Oregon State University Environmental Performance of Treated Wood Research Cooperative.

REFERENCES

Apodaca SA, Tan W, Dominguez O, Hernandez-Viezcas JA, Peralta-Videa JR, Gardea-Torresdey JL (2017) Physiological and biochemical effects of nanoparticulate copper, bulk copper, copper chloride, and kinetin in kidney bean (*Phaseolus vulgaris*) plants. Sci Total Environ 599-600:2085-2094.

Başkal KŞ, Yalçın M, Akçay Ç, Sargıncı M (2023) The effect of soil type on copper leaching from wood treated with three copper-based wood preservatives. Wood Mater Sci Eng 1-7. https://doi.org/10.1080/17480272.2023.2293174

Environmental Protection Agency (2002) Notice of Receipt of Requests to Cancel Certain Chromated Copper Arsenate (CCA) Wood Preservative Products and Amend to Terminate Certain Uses of CCA Products. Federal Register February 22, 2002, OPP-66300.

Intawongse M, Dean JR (2006) Uptake of heavy metals by vegetable plants grown on contaminated soil and their bioavailability in the human gastrointestinal tract. Food Addit Contam 23(1):36-48.

Kennedy MJ, Collins PA (2001) Leaching of preservative components from pine decking treated with CCA and copper azole, and interactions of leachates with soils. *in* Proceedings of the IRG annual meeting, IRG/WP 01-50171, 14 pp.

Ko B, Vogeler I, Bolan NS, Clothier B, Green S, Kennedy J (2007) Mobility of copper, chromium and arsenic from treated timber into grapevines. Sci Total Environ 388(1-3):35-42.

Love CS, Gardner B, Morrell JJ (2014) Metal accumulation in root crops grown in planters constructed from copper azole treated lumber. Eur J Wood Prod 72(3): 411-412.

NOP 5036 (2016) Treated lumber (draft guidance). United States Department of Agriculture Agricultural Marketing Service National Organic Program, Washington, D.C.

Oregon Department of Environmental Quality (2013) Development of Oregon Background Metals Concentrations in Soil, Technical Report.

Rehman M, Liu L, Wang Q, Saleem MH, Bashir S, Ullah S, Peng D (2019) Copper environmental toxicology, recent advances, and future outlook: A review. Environ Sci Pollut Res Int 26(18):18003-18016.

Robinson B, Greven M, Green S, Sivakumaran S, Davidson P, Clothier B (2006) Leaching of copper chromium, and arsenic from treated vineyard posts in Marlborough, New Zealand, Sci Total Environ 364:113-123.

Shabbir Z, Sardar A, Shabbir A, Abbas G, Shamshad S, Khalid S, Murtaza G, Dumat C, Shahid M, Natasha (2020) Copper uptake, essentiality, toxicity, detoxification and risk assessment in soil-plant environment. Chemosphere 259: 127436, p. 1-28.

Speir TW, August JA, Feltham CW (1992) Assessment of the feasibility of using CCA (copper, chromium and arsenic) treated and boric-acid treated sawdust as soil amendments. Plant Soil 142(2):235-248.