Copper migration from treated wood garden boxes into soil and vegetable biomass Part II: The third and fourth growing seasons after installation

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Abstract: Concerns about the safety of preserved wood as a garden box frame material persist in the public stemming from fears about chemical contamination of homegrown food. This study describes the third and fourth years of a long-term study to measure copper migration from copper azole-treated garden bed frames into garden soil and vegetable biomass (Presley and Konkler 2024). Garden bed frames made of Douglas-fir lumber untreated or pressured treated with copper azole were planted with common garden vegetables over two growing seasons. Vegetables and soil samples were collected and analyzed for copper concentration. Average copper levels in vegetables collected from treated or untreated beds were not distinguishable, except for radish roots grown in year 4 which contained higher copper levels (7.5 PPM) when grown in untreated wood beds compared to those grown in treated wood beds (3.7 PPM; $p < 0.05$ Tukey's HSD). At the end of each growing season, average copper concentrations in soil were significantly elevated in soil in direct contact (0–25 mm) with the treated wood (77.8–101 PPM) over copper levels found at equivalent locations in untreated wood beds (21.1–33.2 PPM) ($p < 0.05$, Tukey's HSD). No differences in average copper concentrations were observed in soils taken from any other sampling location, indicating that measurable copper accumulation was limited to within 25 mm of the bed edge. This study shows that the use of treated wood as a bed frame material has no impact on vegetable copper content and the impacts of copper migration are small and spatially limited.

Keywords: Metal leaching; Bioaccumulation; Wood durability; Copper azole.

Introduction

Wood is a popular material for the construction of raised beds for vegetable gardens because of its wide availability, workability, and ease of construction. However, wood is susceptible to biodegradation by wood-destroying fungi, particularly in a ground-contact application with regular wetting, such as a garden box frame. Pressure treatment of wood commodities with copper containing biocides is commonly used to improve the resistance of wood to decay by fungi in residential applications such as garden box frames (Kirker and Lebow 2021).

The use of chemical preservatives for the protection of raised bed garden frames has raised concern among the general public because of the proximity of these materials to homegrown vegetables. These concerns have arisen from the past use of chromated copper arsenate (CCA) as a wood preservative for residential applications and from concerns of arsenic contamination in gardens and bioaccumulation in food. While these concerns have not been substantiated by scientific data (Quarles et al. 2004), CCA was voluntarily discontinued as a residential-use wood preservative over 20 years ago (EPA 2002). Today, arsenic-free copper-based wood preservatives such as copper azole (CA-C), micronized copper azole (MCA), and alkaline copper quaternary (ACQ) dominate the residential pressure-treated wood market. Despite this, fears in the

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general public remain about the risks of metal contamination of produce grown in close proximity to pressure-treated wood.

Fears of copper contamination from treated wood in garden boxes are based on concerns related to human and plant health. High levels of metals in soil or hydroponic growth medium can inhibit the ability of common vegetables to grow and result in poor vigor. These problems are cited in relation to chemically contaminated soils with relatively high levels of copper (over 200 PPM), often exceeding those found in soil naturally (Yang et al. 2002; Chiou and Hsu 2019). Additionally, many vegetables can bioaccumulate copper when grown in soil with copper levels that are high enough to consider it a contaminant (Sharma et al. 2021).

Chemical migration from wood-preservative systems currently available in the residential market in the United States has been widely studied and, in the case of modern residential wood preservatives, copper is the primary chemical component that has the potential to migrate from the wood (Kennedy and Collins 2001). It is well known that measurable copper migrates from these treated wood commodities when exposed to water. Whether or not these losses translate into physiological changes in plants in the context of a vegetable garden box is another question. The impacts of CCA and copper alone have been assessed on grapevines grown in hydroponic chambers with mixed results showing no metal accumulation (Ko et al. 2007) or measurable copper accumulation when soluble copper was added to plant cultures (Shabbir et al. 2020). Amending soil with CCA-treated sawdust resulted in some increases in metal concentrations in beetroot, albeit at levels below toxic thresholds for animals (Speir et al. 1992). While informative, these in vitro studies do not represent treated wood's impact as it is used by residential consumers.

A previous study of the impact of treated wood on metal concentration in garden vegetables showed mixed results and had a limited sample size (Love et al. 2014). A recent study that reported the impacts of copper azole-treated wood on copper content in garden soils and vegetables over 2 years of planting showed that the only measurable impact of treated wood in this context was a small increase in copper concentrations in soil in direct contact with the bed material (Presley and Konkler 2024). The study presented here is a continuation of a long-term investigation of the impact of copper azole-treated wood on garden soil and vegetable metal content when it is used as a bed frame material. Data for the third and fourth growing seasons after garden bed construction are described below.

Methods

Garden box planting and maintenance

Previously constructed garden box frames were maintained and planted for a third and fourth growing season of a long-term study started in 2021 in Albany, Oregon (Presley and Konkler 2024) (Figure 1). The study included two beds made with wooden frames of each type: untreated or pressure-treated 5.1 × 30.5 cm (2 × 12-inch) nominal Douglas-fir. The treated beds were incised and pressured treated to American Wood Protection Association standard ground contact retentions of 2.4 kg/m^3 with copper azole type C (AWPA 2024). Before planting commenced for each growing season, the beds were all topped with a ~5 cm layer of compost, which was mixed in with the top layer of garden soil.

The four beds were planted in patterns identical to one another in each year, and planting diagrams showing the distribution of vegetable types in each planting year are shown in Figures 2 and 3. Vegetable types and the varieties grown in years 3 and 4 of this study are summarized in Table 1. Vegetables were either seeded into the beds directly or were planted as juvenile plant starts that were raised from seed indoors prior to being planted. Vegetables were planted at appropriate times for USDA hardiness zone 8b, in which the study area resides. The beds were watered using treated municipal water by drip irrigation fed through 12.5 mm polyethylene tubing in response to seasonal weather patterns. Trellising for peas consisted of a wooden lattice made of strips of untreated Douglas-fir. Trellising for tomatoes in year 3 consisted of the same wooden lattice, and in year 4 it consisted of a 4.8 m galvanized cattle panel bent over the beds and affixed to either side of the beds (Figure 1). No copper input was expected from any of the trellising materials.

Vegetable and soil collection

Vegetables were collected from the garden beds throughout the growing season as they reached harvestable sizes. Three replicate samples of each vegetable large enough to provide sufficient test material were collected from each bed, for a total of 6 replicates per bed type. This was the case for all vegetables except for radishes grown in untreated beds in year 4, which only had a total of four replicates due to crop failure in one untreated bed. The number or total mass of vegetables collected for each replicate sample varied because of variation in vegetable size and the total number of available plants for each vegetable type. Sufficient biomass was collected in each replicate to make three replicate extracts for copper analysis.

Figure 1. Treated and untreated garden boxes in October of the third (left) and September of the fourth (right) growing seasons.

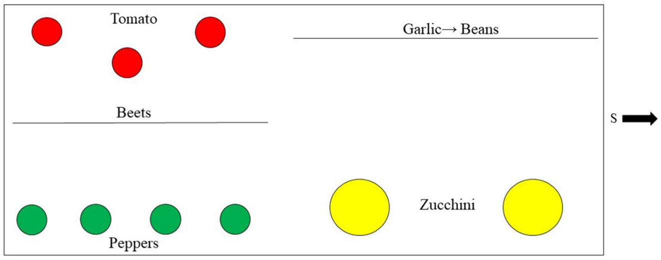

Figure 2. Planting diagram for year 3 for treated and untreated raised beds. Varieties grown for each vegetable are listed in Table 1 and circles indicate an individual plant. Beans were succession planted after garlic.

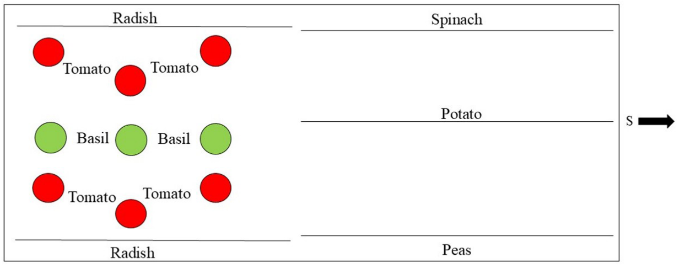

Figure 3. Planting diagram for year 4 for treated and untreated raised beds. Varieties grown for each vegetable are listed in Table 1 and circles indicate an individual plant.

In most cases the edible portion of the plant was reserved for analysis of copper concentration only. For root crops beets and radishes, the leaves were also analyzed for copper concentration.

Soil samples were collected from each bed at the beginning and end of each growing season. At the start of each growing season, compost was added to each bed and worked into the top layers of soil prior to planting, as noted above. A sample of the compost was retained for analysis of copper concentration. Soil samples for the start of the season were collected after the compost addition. A soil corer of 25 × 305 mm was used to collect samples 0–25 mm from the bed edge, 76–102 mm from the bed edge, and at the bed center. The corer was plunged into the soil to capture a ~305 mm soil core representative of soil held by the bed frames. Four soil samples from each location were taken per bed, and these were analyzed as replicate samples (Figure 4).

Measurement of copper

Soil or vegetable biomass was microwave digested in triplicate from comingled samples and analyzed for copper content us-

Table 1. Description of vegetable samples harvested from the raised beds in year 3 and year 4 and which plant parts were analyzed.

Vegetable	Part analyzed	Variety *
Planting year 3		
Garlic	Bulb	Russian Red
Garlic	Leaves	Russian Red
Beet	Root	Early Wonder Tall Top
Beet	Leaves	Early Wonder Tall Top
Zucchini	Fruit	Mexicana
Bush bean	Fruit	Oregon 91G bush bean
Bell pepper	Fruit (flesh only)	Wonder Bell F1
Tomato	Fruit	Carmello
Planting year 4		
Basil	Leaf	Emily
Pea	Pod	Sugar Daddy Snap Pea
Potato	Tuber	Vivaldi
Radish	Leaf	Cherry Belle
Radish	Root	Cherry Belle
Spinach	Leaf	Lakeside F1
Tomato	Fruit	Pozzano

* Seed source for all plantings: Territorial Seed Company.

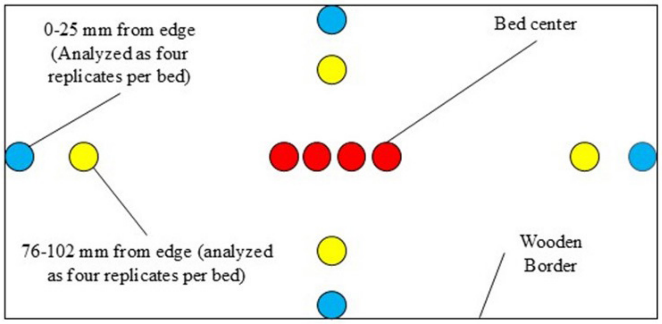

Figure 4. Sampling diagram for soil samples taken at the beginning and end of each growing season adapted from Presley and Konkler (2024).

ing atomic absorption spectrophotometry (AAS). Soil or plant biomass samples were homogenized, oven dried, and digested according to EPA method 3052 (EPA 1996). 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 minutes at 180°C, with a total microwave digestion time of about 15 minutes. Each replicate sample was digested in triplicate to generate three separate technical replicates per replicate sample. The resulting digestate was rinsed from the tube with DI water and brought up to a volume of 35 mL with DI water. It was then analyzed for copper using AAS and as µg/g (PPM) in the original oven-dried biomass.

Samples were loaded onto a Shimadzu AA-7000 and analyzed using Flame Atomic Absorption Spectroscopy for copper. Copper analysis was performed at 324.8 nm. The lamp current was set to 6mA, the slit width was 0.7 nm, the flame type was a mixture of air and acetylene (atomic absorption grade) with an acetylene flow rate of 1.8 liters per minute, and the burner height was 7 mm. Each sample was analyzed four times with a total per sample analysis time of approximately 1 minute. The recorded absorbance was plotted against a five-point standard curve to calculate concentration. The detection limit using this method for copper was 0.006 PPM for the liquid extracts.

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 concentrations for vegetables harvested in years 3 and 4 after bed installation are shown in Figures 5 and 6, respectively. Copper concentrations in the vegetable biomass were the same in vegetables grown in treated and untreated beds in most cases, with no statistically significant differences ($p > 0.05$, Tukey's HSD). One exception was for radish roots grown in year 4, where radishes harvested from the untreated beds had significantly higher average copper levels (7.5 PPM) than those harvested from treated beds (3.7 PPM; $p = 0.027$, Tukey's HSD). Higher average copper levels in radishes grown in the untreated beds was not expected, but it may be due to the lower sample size for radishes obtained in year 4, due to a poor crop during that growing season. Additionally, it is important to note that the copper levels measured here may just represent natural variation in the plant biomass. The United State Department of Agriculture (USDA) Food Central database for food nutrients lists radishes as having about 10.6 PPM copper on a dry weight basis (USDA 2019). Levels measured here are lower than the USDA's typical average copper level for radishes and, despite some variability between populations, copper levels measured in this study are not of concern for human consumption.

Similarity among copper concentrations from vegetables originating from treated or untreated beds is in line with previous observations from earlier growing seasons that were part of this study (Presley and Konkler 2024). Some prior observations suggested that copper may accumulate in carrot tops when grown in treated wood beds (Love et al. 2014), but none of the root crops grown in years 3 and 4 of this study showed increased copper levels resulting from the treated bed frame materials. Other studies have shown that vegetables will accumulate copper if grown in soils amended with or contaminated with copper, but generally copper levels required to generate that effect are much higher than are observed in soils found in treated wood garden beds (Apodaca et al. 2017; Intawongse and Dean 2007; Presley and Konkler 2024).

Copper levels taken from soils at three locations in each bed were measured at the beginning and the end of years 3 and 4 after installation (Figure 7). At the start of year 3, average copper levels in soil from untreated and treated beds were similar, and no statistically significant differences were detected ($p > 0.05$, Tukey's HSD). At the end of year 3, soil samples taken 76–102 mm from the bed edge and the bed center similarly showed no significant differences in average copper concentrations. At the 0–25 mm sampling point taken at the end of year 3, soils taken from treated beds had higher average copper concentrations (101 PPM) compared with soil samples from equivalent locations in untreated boxes (33.2 PPM). This pattern was consistent with what was observed

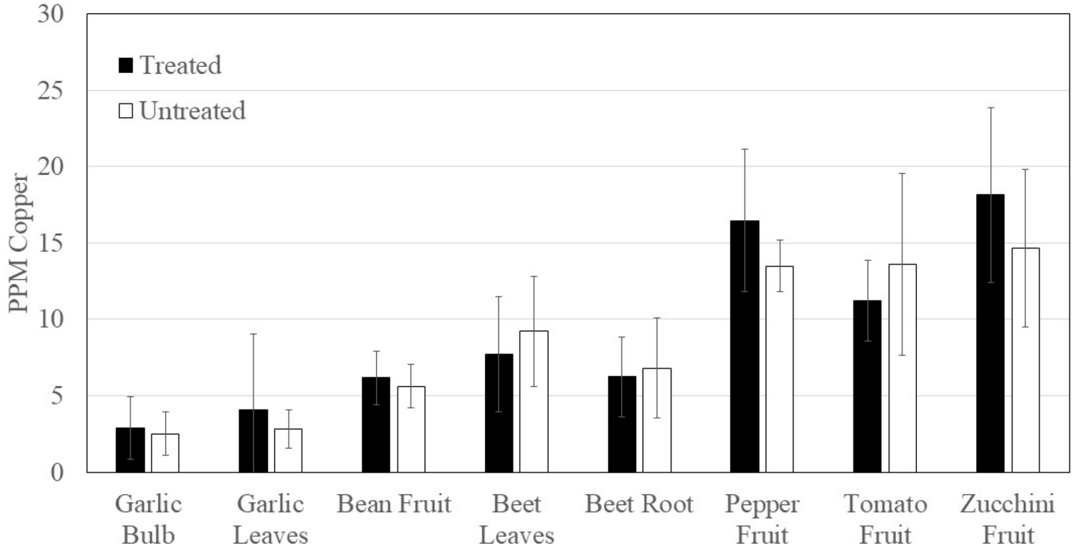

Figure 5. Copper levels found in vegetable biomass taken from the raised beds in year 3. Error bars are plus or minus one standard deviation of six replicate extracts, three taken from each replicate bed of each type.

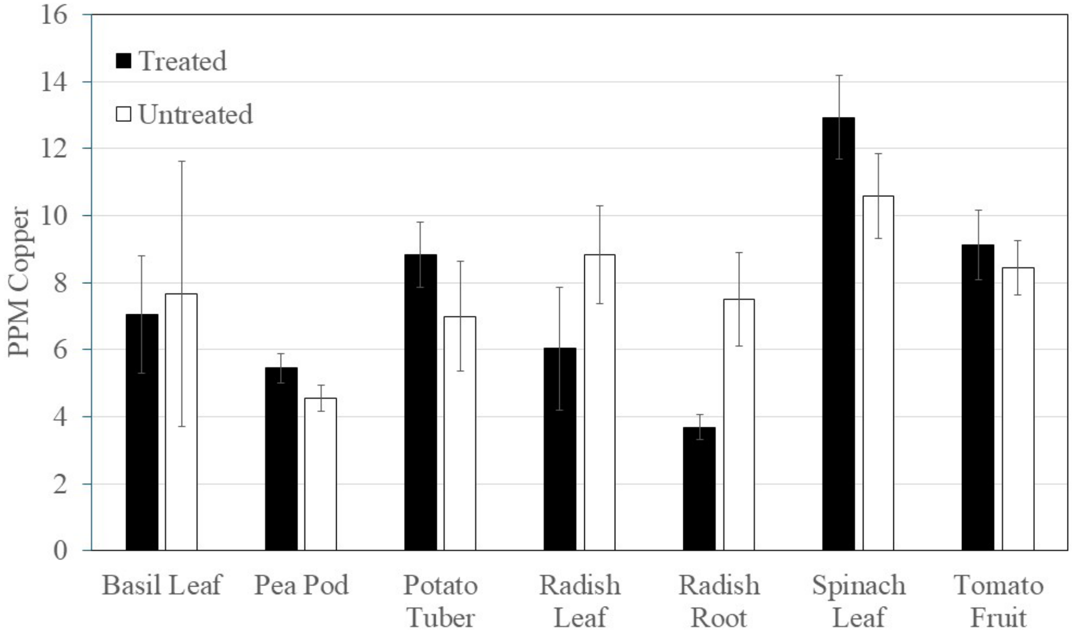

Figure 6. Copper levels found in vegetable biomass taken from the raised beds in the year 4 season. Error bars are plus or minus one standard deviation of six replicate extracts, three taken from each replicate bed of each type, except for radishes from untreated beds, which only had four replicates in total due to crop failure in one bed.

in the first two growing seasons, where copper accumulation was only measurable in soils in direct contact with the treated wood bed frame (Presley and Konkler 2024).

At the start of the fourth growing season, soil isolated from 76–102 mm from the bed edge and the bed center showed no significant differences in average copper concentrations between equivalent samples taken from treated and untreated beds ($p > 0.05$, Tukey's HSD; Figure 7). Soils taken from the 0–25 mm sampling location in the treated beds showed significantly higher average copper concentrations (44.4 PPM) compared to the same location in untreated beds (26.2 PPM; $p < 0.05$, Tukey's HSD). Compost addition reduced the average

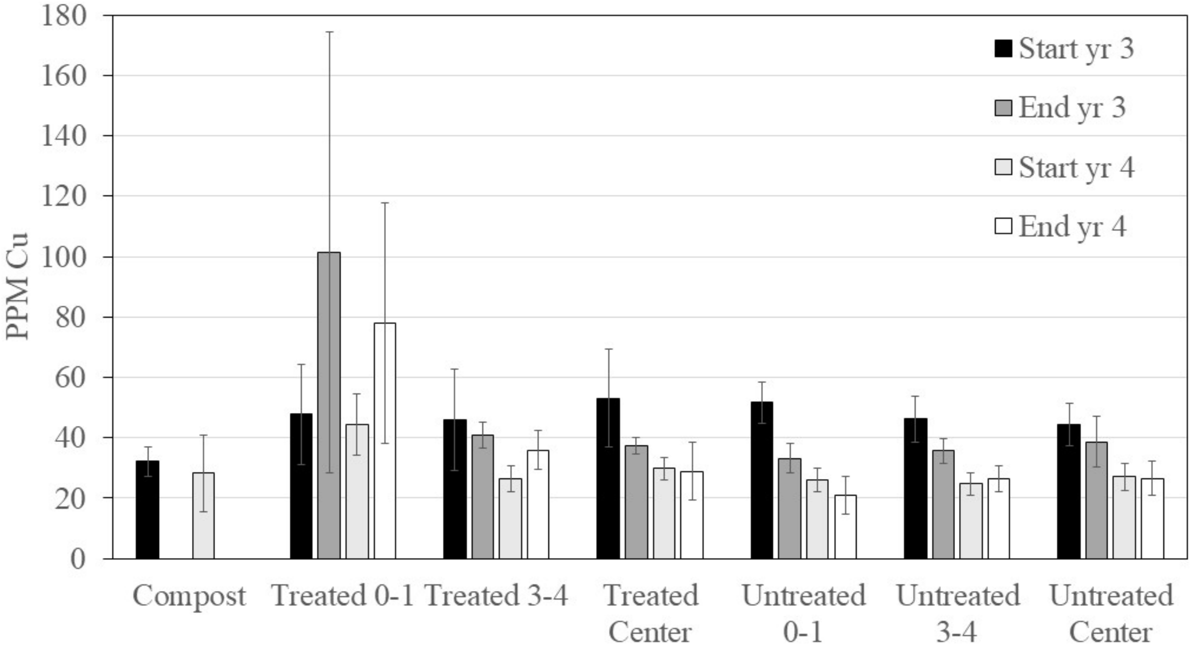

Figure 7. Copper levels found in soils taken from treated and untreated garden boxes at the start and the end of the third season, as well as the start and the end of the fourth season of growth. Error bars are plus and minus one standard deviation of eight replicate extracts, four from each of two garden beds of each type. Figure labels 0–1 for both treated and untreated boxes refer to the 0–25 mm sampling locations; labels 3–4 refer to the 76–102 mm sampling locations.

copper concentration from 101 to 44.4 PPM from the end of the third growing season to the start of the fourth. However, in year 4, average copper levels in soils from the 0–25 mm sampling location in treated beds were still higher than the 0–25 mm sampling location in untreated beds. In earlier sampling points, compost addition was enough to equalize copper average copper concentrations after a year of accumulation in soils in direct contact with the bed edges (Presley and Konkler 2024). At the end of year 4, soils taken 76–102 mm from the bed edges as well as those from the bed center were similar in the treated and untreated beds ($p > 0.05$, Tukey's HSD). Average copper concentrations were higher in soils taken from the 0–25 mm sampling location in treated beds (77.8 PPM) than those found at the same location in untreated beds (21.1 PPM; $p < 0.05$, Tukey's HSD).

Data from years 3 and 4 are consistent with previous observations in years 1 and 2 of this study (Presley and Konkler 2024). Treated wood results in copper increases in soil only in direct contact with the bed material and is not widely observed throughout the garden bed soil.

Additionally, average copper concentrations in soils measured in years 3 and 4 ranged from 21.1 to 101 PPM across all bed types and sampling locations, which fall well below 140 PPM, the level considered elevated above natural soil levels found in the Willamette Valley (DEQ 2013). Soils in other parts of the United States naturally can contain up to about 500 PPM copper (Rehman et al. 2019). While treated wood does result in copper increases in some of the garden box soil, levels measured in this study to date are not unnaturally high.

The primary issue among those who are concerned about treated wood's impact on garden vegetables centers on bioaccumulation and downstream health impacts. Copper concentration in soil is important in determining whether or not vegetables grown in that soil bioaccumulate levels of copper and copper that can impact human health (Sharma et al. 2021). Contaminated soils levels that may cause issues with crop contamination are much higher than have been observed in this study. In a study performed in Italian agricultural soils, soil with copper concentrations as high as 217 PPM showed no dietary risks to consumers (Fagnano et al. 2020). Another study of bioaccumulation of copper in Chinese cabbage, pakchoi, and celery showed that soil concentrations of total copper must reach 430–835 PPM before bioaccumulation becomes a health risk (Yang et al. 2002). The highest average copper levels observed in soils in this study to date (101 PPM) are much lower than those that have been shown to result in copper bioaccumulation in food crops.

Another concern centers on the impact of copper on the viability and vigor of garden vegetables. Copper contaminated soils can also result in changes to plant physiology and reduced crop vigor. Soil copper levels above 250 PPM have been shown to reduce the growth of four different leafy vegetables (Chiou and Hsu 2019). The copper threshold in soil at which Chinese cabbage, pakchoi, and celery showed growth inhibition is about 150 PPM (Yang et al. 2002). Previous observations indicate that toxicity thresholds for many vegetable crops are considerably higher than the highest copper levels measured in this study. Additionally, the highest copper levels observed in the treated wood garden boxes in this study were limited to a thin, ~25 mm band around the bed margins.

The sampling regime for the third and fourth growing seasons was changed to include greater sampling replication (four soil samples per bed per location and triplicate extracts of each soil sample). This change resulted in improved data quality compared with the previous report (Presley and Konkler 2024) and enables greater confidence in the findings. Soil, as well as wood, is a highly variable matrix of organic and inorganic matter; metal migration through these matrices can be highly varied from one location to another. Still, this study only included two beds of each material type, and future long-term studies are needed to provide a greater sampling of the conditions gardeners face.

Conclusion

This shows that use of copper azole-treated wood as a garden bed frame material does not cause an increase in copper concentrations in vegetables grown in those garden boxes. Copper accumulation in soil was limited to within a ~25 mm distance from the treated wood bed material, up to an average of just over 100 PPM at the end of year 3. The magnitude of copper accumulation was modest, with the highest concentrations still falling within natural copper levels for the region in which the beds are located.

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