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Roadside soils show low plant available zinc and copper concentrations

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ABSTRACT

Vehicle combustion and component wear are a major source of metal contamination in the environment, which could be especially concerning where road ditches are actively farmed. The objective of this study was to assess how site variables, namely age, traffic (vehicles day^{-1}), and percent carbon (%C) affect metal accumulation in roadside soils. A soil chronosequence was established with sites ranging from 3 to 37 years old and bioavailable, or mobile, concentrations of Zinc (Zn) and Copper (Cu) were measured along major highways in North Carolina using a Mehlich III extraction. Mobile Zn and Cu concentrations were low overall, and when results were scaled via literature values to “total metal”, the results were still generally lower than previous roadside studies. This could indicate farming on lands near roads would pose a low plant toxicity risk. Zinc and Cu were not correlated with annual average traffic count, but were positively correlated with lifetime traffic load (the product of site age and traffic count). This study shows an often overlooked variable, site age, should be included when considering roadside pollution accumulation. Zinc and Cu were more strongly associated with %C, than traffic load. Because vehicle combustion is also a carbon source, it is not obvious whether the metals and carbon are simply co-accumulating or whether the soil carbon in roadside soils may facilitate previously overlooked roles in sequestering metals on-site.

1. Introduction

Roadside soils are known to have elevated heavy and trace metal concentrations (*e.g.*, Wheeler and Rolfe, 1979; Turer et al., 2001). Copper (Cu) and Zinc (Zn) in roadside soils are attributed to tire abrasion (Li et al., 2001; Legret and Pagotto, 1999), lubricating oil (Christoforidis and Stamatis, 2009), vehicular exhaust (Cadle et al., 1999) and break pad degradation (Westerlund, 2001; Thorpe and Harrison, 2008). Additionally, galvanized metal from roadside guard rails and automotive parts has been shown to contribute Zn to roadside soils and dusts (Blok, 2005).

The adverse health effects due to heavy and trace metal contamination are well known. Because of their toxicity and ability to accumulate in the environment, research has focused on metals and their fate in the roadside soils and dust (Lagerwerff and Specht, 1970; Turer et al., 2001; Nabulo et al., 2006; Christoforidis and Stamatis, 2009). Roadside soils may pose a health risk in urban and peri-urban areas as road dust re-suspension and particulate matter threaten human respiratory health (Valavanidis et al., 2006). Contaminated soils are also an environmental hazard if they are mobilized and transported to other parts of the landscape. The mobility of metals in roadside soils is influenced by soil pH, organic matter, flow patterns, de-icing agents, and weather patterns (Turer et al., 2001; Kluge and Wessolek, 2011; Roulier et al., 2008; Bäckström et al., 2004a,b). Copper, lead (Pb), and Zn contaminated roadside soil particles can be eroded or mobilized by wind, deposited throughout the landscape and washed into nearby water bodies, leading to adverse aquatic and terrestrial impacts (Sutherland et al., 2000; Trombulak and Frissell, 2000; Chen et al., 2010). Werkenthin et al. (2014) provides a thorough review of roadside metal contamination, mobility, and environmental concerns.

In addition, in rural areas it is not uncommon for road right-of-ways to be farmed especially for hay production (*e.g.*, Overstreet

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2013; Martinson undated). Although agricultural production is often discouraged due to safety concerns (*e.g.*, Wilkinson, 2015), it is increasingly common in many areas (*e.g.*, Overstreet 2013) and some local governments are considering rules to allow the practice (*e.g.*, "Commissioners clarify 'road ditch planting", 2014). Interestingly, we could find no peer-reviewed research on road right-of-way farming despite copious online evidence of the practice and associated issues. Additionally, as city populations continue to grow subsistence farming on marginal land and urban farming is expected to increase (Huang et al., 2006; Säumel et al., 2012) and these soils are likely to have similar metals-related problems. Consequently, it is important to understand the distribution of bioavailable metals in roadside soils for potential agricultural implications, human health impacts, and environmental protection.

Trends surrounding metal accumulation in roadside soils are lacking. Populations are expected to increase, especially in cities, leading to greater traffic volume (vehicles day^{-1}) and pollutant loading in the future (United Nations, 2014). Previous research has examined traffic volume and metal concentration trends, but it has neglected to account for the accumulation of metals over time. Increased traffic volume is generally assumed to increase roadside soil metal concentrations (Chen et al., 2010). However, some studies have failed to find a correlation between traffic volume and elevated soil metal concentrations (Pérez et al., 2008). A recent meta-analysis of roadside soils found a strong correlation between traffic volume and Cd, Cr, moderate correlation for Zn and Cu, and no correlation for Pb (Werkenthin et al., 2014). Some ambiguity surrounds Zn's and Cu's relationships to traffic volume. For instance, Chen et al. (2010) noted that the most contaminated soils were located near the highest traffic volume roads, but only Pb was significantly correlated with traffic volume, while the other metals (Cd, Cu, and Zn) were not. Garcia and Millan (1998) and Nabulo et al. (2006) reported no significant relationships between traffic volume and Zn or Cu.

The goal of this research was to quantify plant available (mobile) concentrations of Zn and Cu in roadside soils of the Southeastern U.S. This study used the Mehlich III extraction to quantify mobile Zn and Cu, which includes the exchangeable fraction (we will refer to this fraction as mobile throughout the rest of the paper). The Mehlich III extraction is commonly used to rapidly and inexpensively assess plant available nutrients (Sims et al., 1991; Vadas et al., 2005; Mehlich, 1984). The U.S. Department of Agriculture National Resource Conservation Service (USDA NRCS) requires that soil fertility tests be completed following state land grant recommendations (NRCS, 2012) and the accepted soil test extractant in North Carolina is Mehlich III extraction, which is used to determine mobile nutrients and metals, consequently this extraction was used herein.

Many researchers report that the form of metal, rather than total concentration, is needed to evaluate phytotoxic risk (Vega et al., 2004; Remon et al., 2005; Zhuang et al., 2009). Plant species also effect crop uptake of potentially toxic metals from soils, and measuring plant tissue concentrations for varying species on the same soil could produce vastly different results (M. B. McBride, 2003; Peris et al., 2007). Therefore, we present mobile soil concentrations in an effort to highlight the availability of these metals – should crops be planted in the future – to mobilize and be accumulated within the plant. Thus the overall objectives of this study were to (1) characterize mobile Cu and Zn in the roadside soils of North Carolina, and (2) determine what soil characteristics and traffic patterns were related to the observed metals accumulation. This information could better predict how additional vehicles on roads over time may impact metal accumulation, and contamination risk via soil mobilization.

2. Materials and methods

2.1. Study site

Vegetated filter strips that border four lane highways in the Piedmont physiographic region (Griffith et al., 2002) of central North Carolina (NC) were the focus of this study. The annual temperature for this area is 15.7 °C (NCDC 2012; 1981–2010 dataset of annual normals). Seasons are rather pronounced with the average temperatures in December–February (winter) and June–August (summer) of 3.8 °C and 25.6 °C, respectively. The region receives 1175.4 mm yr^{-1} of rainfall, which falls fairly uniformly throughout the year: 1175.4 mm yr^{-1} (NCDC, 2012; 1981–2010 dataset of annual normal).

Utilizing a soil chronosequence, 20 roadside sites (Fig. 1) of different ages were sampled to evaluate carbon (C), Zn, and Cu accumulation within the soil. It was assumed that each site started with similar soil characteristics at time = 0 (*i.e.*, no sites were amended with additional C or contaminated with metals during construction). Using ArcGIS, each site was identified prior to sampling and systematically sampled from May to July 2011. The site age was determined from NC Department of Transportation (NCDOT) Geographical Information System (GIS) data (NCDOT, 2011). Site age was assigned based on date of road construction or date of last major road overhaul as this practice was assumed to significantly disrupt the site and effectively 're-set' potential soil C or metal stocks to initial site levels. Sites were selected based on age, but the 2011 NCDOT GIS data did not report the average annual daily traffic volume (vehicles day^{-1}) for each site. Therefore, daily traffic volume was determined from 2014 NCDOT GIS data (NCDOT, 2014). As traffic patterns do not vary widely from year-to-year, it is assumed that the traffic volume reported in 2014 is consistent with that of 2011. In this paper 'traffic volume' refers to the NCDOT average annual daily traffic volume (vehicles day^{-1}). To better estimate how the lifespan and exposure to traffic pollution over time affects soil metal concentrations, an estimate of lifetime 'traffic load' refers to the yearly traffic volume (vehicles day^{-1} x 365 days year^{-1}) multiplied by the site age (years).

2.2. Experimental design

Experimental design is discussed in detail in Bouchard et al. (2013). Each of the 20 roadside sites consisted of two replicate transects, 1 m apart. Four evenly-spaced sample locations were identified along each transect until reaching the right-of-way swale invert. Soil samples were collected at each roadside site (n = 8 per site) for a total of 160 samples. One sample was lost and therefore the sample set was 159 samples. At each sample location individual soil cores were taken at 0–0.1 m depth using an AMS hammer corer (AMS American Falls, Idaho, USA).

2.3. Soil analysis

Chemical analyses were performed on individual soil cores. Soil samples were analyzed for Zn and Cu by means of the Mehlich III (0.2N CH_3COOH + 0.25N NH_4NO_3 + 0.013N HNO_3 + 0.015N NH_4F + 0.001M EDTA) extraction (Mehlich, 1984) and inductively coupled argon plasma atomic emission spectroscopy (ICAP-AES) on a volume basis, which is the standard method of the NC Department of Agriculture and Consumer Services (NCDA). The NCDA method does not quantify other heavy metals of concern such as lead or cadmium. Zinc and Cu results (mg dm^{-3}) were divided by the specific soil density (g cm^{-3}) to yield metal concentrations mg kg^{-1}. For comparisons to previous studies that reported total Zn or Cu concentrations based on complete metal removal (*e.g.*,