Trace Metal Bioavailability in New Jersey Vineyard Soils

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Introduction

New Jersey houses a burgeoning vineyard industry and is currently the seventh-leading domestic wine producing state in the American Viticulture Area (Frank et al., 2017). In 2018, more than 690,000 gallons of wine were sold, and by 2019, grape bearing acres went from 1,283 to 1,582 acres (Vigna, 2019). Soils in the Outer Coastal Plain, a physiographic province with soils formed from sandy fluviomarine sediment, are favorable for grapevine growth due to their coarse texture, and unique acidity from inputs of coniferous vegetation litter. The Downer series is a common vineyard soil, found at the vineyard sampled, consisting of loamy sand that offers numerous agricultural commodities. The taxonomic name for the Downer series is Coarse-loamy, siliceous, semiactive, mesic Typic Hapludults, consisting of mostly sands (Average: 70 to 90%) alongside silts (Average: 10 to 30%), and clays (Average: 10 to 15% clay) ; (NRCS, 2007).

As of 2021, the current New Jersey population density is approximately 1,220 persons/mi^2 (U.S Bureau, 2021). With an increasingly dense population, there is the potential for increased traffic throughout the state, which can lead to an increased risk for trace metal contamination. A common source of trace metals in urban and suburbanized areas is vehicle emissions, storm water runoff, and commercial grade soil amendments. These sources of pollutants are detrimental to our natural systems because they introduce metals that can be retained in soils and can be bioavailable to vegetation with the addition of commercial grade amendments. If bioavailable, vegetation can uptake metals through roots and bioaccumulate in biomass. The presence of trace metals can be problematic in wine products by impacting quality, causing haziness, negative scents and taste attributes, increased browning, turbidity, and astringency (Cacho et al., 1995 ; Galani Nikolakak et al., 2002).

Lead (Pb) is a common trace metal found in New Jersey vineyard soils in urbanized settings. It can be problematic from an agricultural standpoint because it is typically well retained on colloids at the soil surface and remain for long durations of time. With the addition of commercial grade amendments, such as phosphate fertilizers, Pb may solubilize and become bioavailable. This is also particularly problematic for crops, including grapes, that may be ingested by consumers. The FDAs calculated current Interim Reference Level (IRL) for Pb in farmland is 12.5 μg per day for adults (FDA, 2021). Lead is one of the most toxic metals in our environment and poses numerous health concerns, such as neurotoxicity, anemia, kidney/brain damage and in high concentrations fatality. This work focuses on analyzing vineyard soils total and soluble Pb content, along with properties that may impact Pb solubility and bioavailability to grapevines neighboring roadways.

Objectives

(1) Examine variation in vineyard levels of total soil Pb content, roadway proximity, and grape Pb content.
(2) Examine variation in total Pb and soluble Pb retention in relation to roadway contaminants and phosphate fertilizers.
(3) Correlate soil total Pb with soil physicochemical properties in order to identify areas of concern.

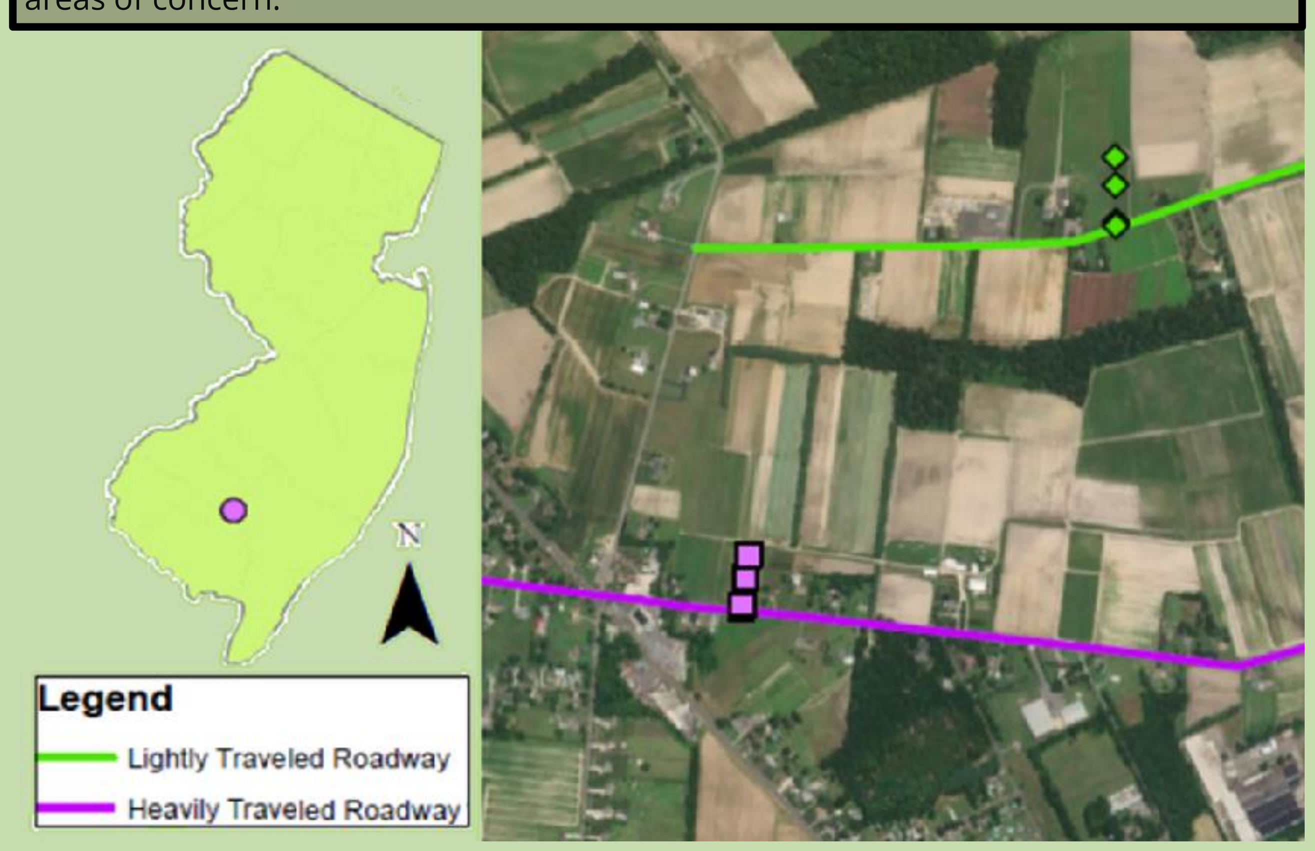


Figure 1. Map of plots and sampling points located on two roadways differing in amount of traffic based daily.

Methodology

SAMPLING

Soil and grape samples were collected (Depth: 0–20 cm) at 5 points located along linear transects at a vineyard located in Buena Vista, NJ. Grapevine plots were established by the owner along two roadways, 1 lightly and 1 heavily traveled by vehicles. Soils were sampled nearest to roadways, in between grapevines and roadways, and 3 points along rows of grapevines (Figure 2). Each transect extended 350m+ to the end of the grapevine plots.

- Transect 1: Plot along heavily traveled roadway.
- Transect 2: Plot along lightly traveled roadway.

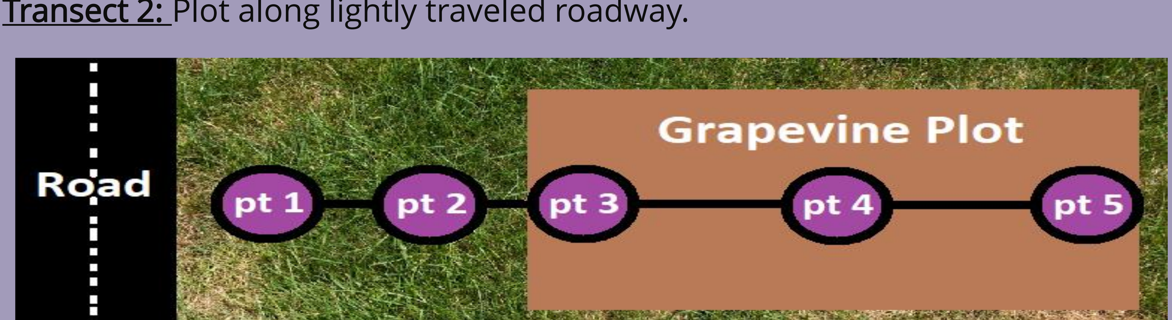


Figure 2. Diagram of transects established at a vineyard on two roadways.

SOIL PHYSIOCHEMICAL PROPERTIES

Soil samples that were collected were analyzed for additional physiochemical properties used to identify any influences in Pb retention and migration.

- Particle Size Analysis (PSA) – Measured using Ro-Tap sieve shaker for sands and the hydrometer sedimentation method for silts and clays
- Mass Moisture (MM) – Samples were weighed for moisture removal following oven drying at 105 °C.
- Soil Organic Carbon/Matter (SOC/M) – Measured using loss on ignition in a muffle furnace.
- Soil Acidity – Measured in a 1:1 soil to water ratio using a pH meter.

Total Metals Digestion

- Soil total Pb was determined using aqua regia digestion (EPA 3050B procedure) and analyzed using flame atomic absorption spectroscopy (FAAS).
- Soil soluble Pb was determined using water extraction, and samples were shaken for 24 hours.
- Grape Pb content was determined through digestion with concentrated nitric acid (HNO_3) and analyzed using FAAS.

Statistics

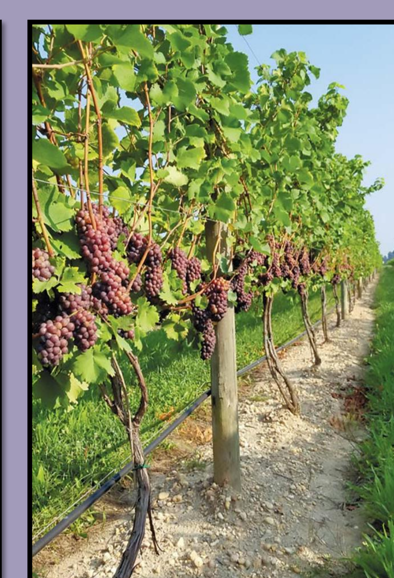
Using Microsoft Excel, simple linear regression was employed to identify a correlation between:
(1) Levels of total soil Pb content, roadway proximity, and grape Pb content,
(2) Migration of Pb along grapevine plots, and
(3) Soil properties that assist in Pb retention in vineyard soils.

Results

Table 1. Total Pb content, soluble Pb content in soil, and Pb content in grapes sampled along 5 linear transects located on two roadways (*see Figure 2*).

Pb Determination				
Soil Samples	Roadway Position	Total Pb (mg/kg^{-1})	Soluble Pb (mg/kg^{-1}) in Soil	Soluble Pb (mg/kg^{-1}) in Grapes
Heavily Traveled Roadway	1	62.7	<BLD*	N/A
	2	61.7	<BLD*	N/A
	3	55.3	<BLD*	2.5
	4	50.0	<BLD*	3.0
	5	47.8	<BLD*	2.6
Lightly Traveled Roadway	1	38.4	0.03	N/A
	2	33.2	0.01	N/A
	3	35.2	0.02	2.7
	4	37.8	0.02	2.1
	5	35.8	0.03	2.2
NJ Farm Soil Background Level Range (mg/kg)*	16.4-24.8			

<BLD* Readings were below level of detection
N/A - no grapes were present at this roadway position
* Comparison data obtained from Fields et al. (1993)



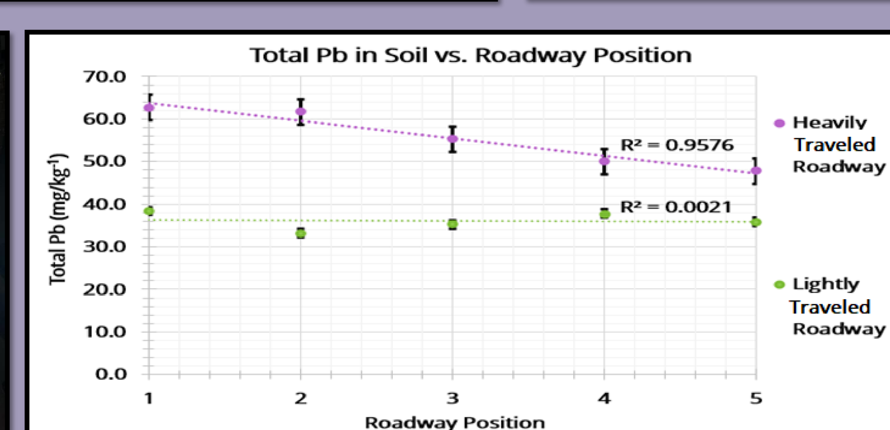


Figure 3. Simple linear regression indicating a strong relationship between the total in soil and roadway proximity (*see Figure 2*).

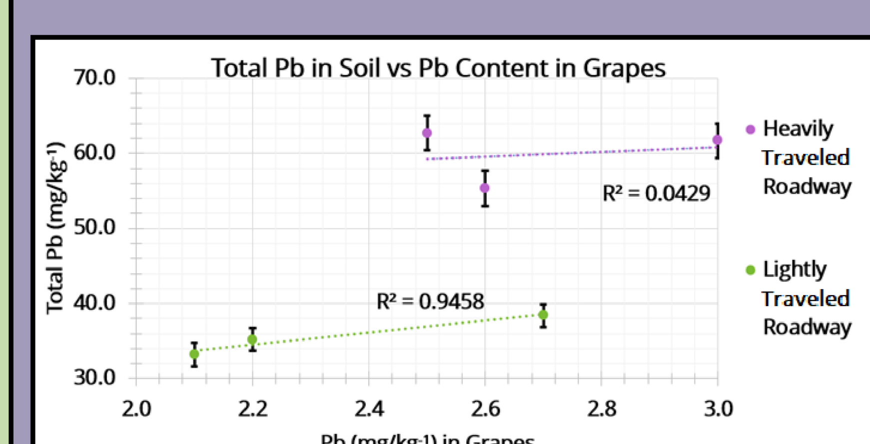


Figure 4. Simple linear regression indicating a strong relationship between the total Pb content in soil samples and Pb content in found in grapes samples.

Table 2. Particle size analysis and chemical properties (pH, EC, MM, SOM) sampled at 5 plots from a vineyard located on two roadways (*see Figure 2*).

Physiochemical Site Properties							
Roadway Position	Particle Size Analysis			Chemical Analysis			
	Clay (%)	Sand (%)	Silt (%)	pH	EC (ds m-1)	Moisture (%)	SOM (%)
1	13.3	56.7	30.0	6.5	129.4	1.7	15.1
2	18.2	57.8	24.0	6.3	156.5	2.6	13.2
3	17.8	57.0	25.2	6.6	206.0	1.1	1.2
4	11.0	60.0	29.0	6.5	124.7	0.8	1.3
5	11.2	61.8	27.0	7.0	109.0	1.4	1.1

Site chemical properties averaged among sampling sites

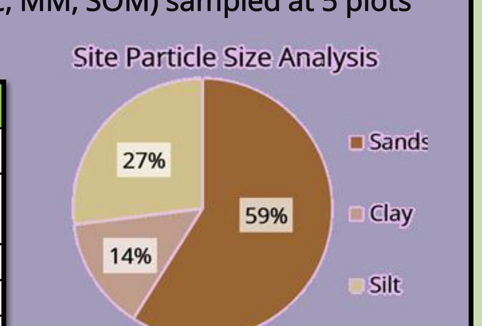


Figure 5. Abundance of sands, clays and silts for the vineyard where samples were collected.

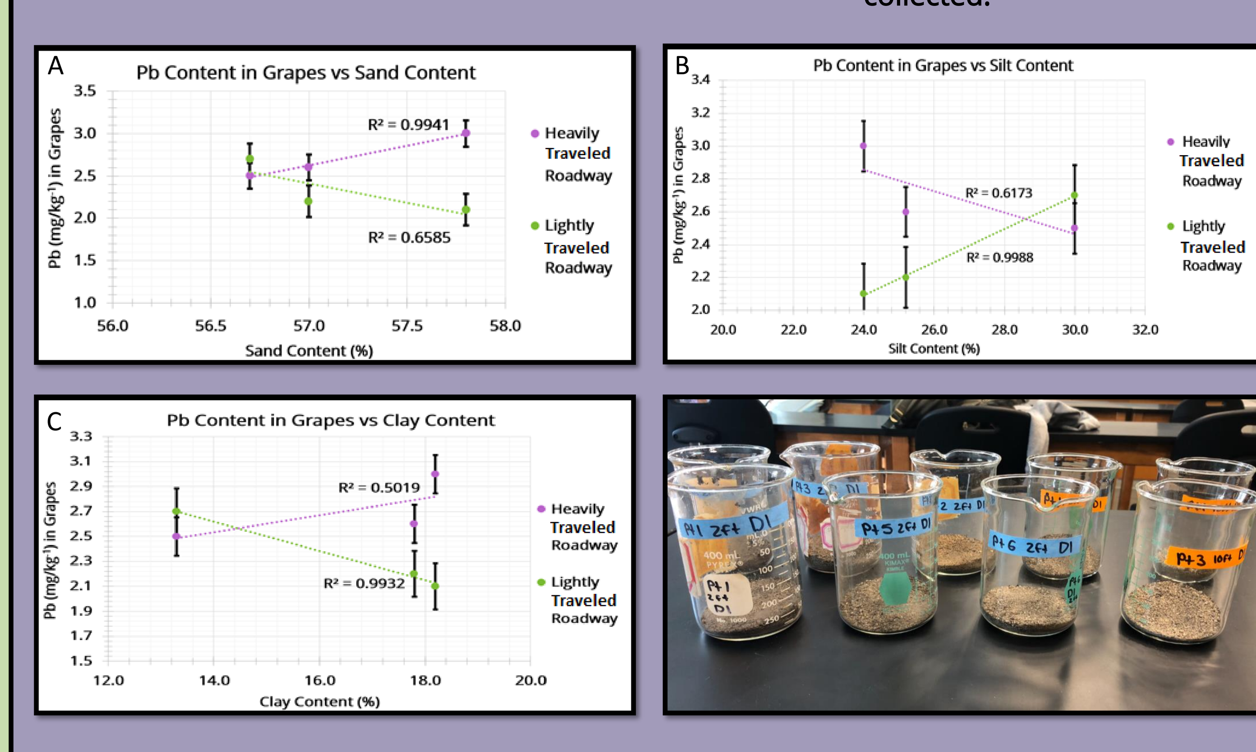


Figure 6. Simple linear regression models relating particle size analysis of samples (A. Sand Content, B. Silt Content, C. Clay content) with Pb content in grapes. Based on the correlation coefficients, there is a strong relationship between the particle size and the mobility and bioavailability of Pb found in the grape samples.

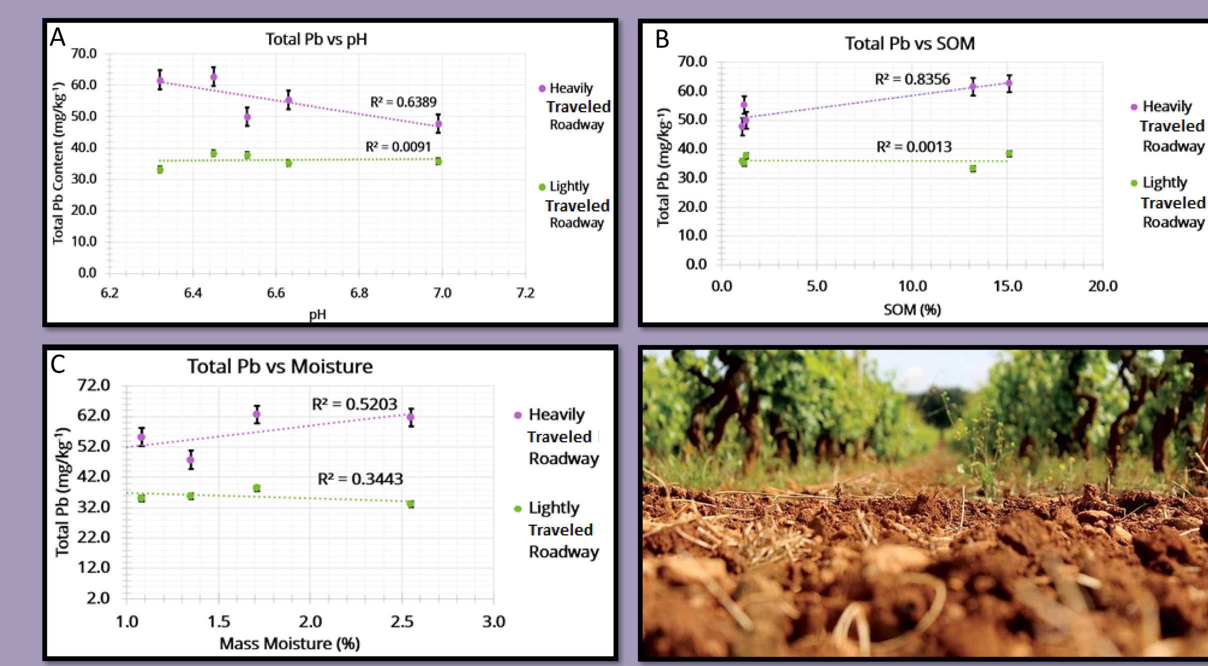


Figure 7. Simple linear regression models relating physicochemical properties (A. pH, B. SOM, C. Moisture) with total Pb in soil. Based on the correlation coefficients, there is a strong relationship between the pH, SOM, and total Pb; and there is a moderate relationship between moisture and the bioavailability of total Pb for the heavily traveled roadway.

Summary

NOTABLE CORRELATIONS

- Areas that retained high amounts of Pb in the soil, correlated to higher Pb found in grapes, and higher amounts of soluble Pb retained in the soil.
- Clay content had a strong relationship with Pb content in grapes, indicating clay could potentially reduce the amount of Pb retained in the soil.
- Correlation between particle size and Pb content in grapes showed opposite trends between heavily traveled roadways and lightly traveled roadways.
- Areas of soil with an acidic pH, and higher SOM retained more total Pb in the soil then compared to areas with a basic pH and less SOM.

Conclusion

In conclusion, soil total Pb (33.2 – 62.7 mg kg^{-1}) and grape Pb (2.1 – 3.0 mg kg^{-1}) were determined to be elevated in a local vineyard, likely related to agricultural practices and influenced by roadways. Strong relationships between high Pb content and roadway proximity indicate a potential influence of roadways on total Pb, soluble Pb, and grape Pb content. As expected, total Pb was strongly related to grape Pb content and soluble Pb in soil, which is also considered to be the bioavailable form of Pb.

In terms of physicochemical properties, soil samples consisted of a sandy loam texture, comprising of mostly sands (Average: 59%), followed by silts (Average: 27%), and clays (Average: 14%). Increases in sand content with proximity to roadways may be due to influences from soil compaction and impervious surfaces related to roadways that promote water runoff and soil erosion. Soils with increased clay content exhibited a strong relationship with grape Pb content, indicating that clays could potentially assist in lead retention and uptake in plants through a process known as Cation Exchange Capacity (CEC). Additionally, soil organic matter content was considered high for samples and well above average soil content (5%). This parameter was moderately correlated to soil total Pb and may represent an additional mechanism of retention and contribution to soil CEC. Alongside, pH is an important controller of strong adsorption of trace metal cations and exhibited moderately-strong correlation with total Pb. Soil samples were determined to be slightly acidic to neutral pH, likely related to lime additions. As soil pH increases above neutral, lead will be strongly adsorbed in soil. Only moderate to low correlations were noted for soil moisture and electrical conductivity.

Future work will necessitate additional samples in order to obtain a more robust dataset to confirm the influence of roadways on soil Pb and uptake by grapevines. We will be expanding this work to additional vineyards throughout NJ, examining additional soil properties that influence trace metal behavior and bioavailability, and further examining the bioavailability of Pb in grapevines and other crops.

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