Non-industrial wood ash chemistry and its biogeochemical effects on sugar maple (*Acer saccharum*, Marsh.) in three central Ontario sugar-bushes

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ABSTRACT

Non-industrial wood ash chemistry and its biogeochemical effects on sugar maple (*Acer saccharum*, Marsh.) in three central Ontario sugar-bushes

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Nutrient losses from forest soils caused by decades of acid deposition and intensive tree harvesting have affected tree growth and forest health in North America and Europe. Non-industrial wood ash (NIWA), a substance rich in macronutrients, may be a potential remediation strategy to return lost nutrients to forest. However, the chemical composition of NIWA and its effects on soil and tree growth are poorly understood. This thesis evaluated the chemical variability of non-industrial wood ash, and its short-term effects on soil properties, sugar maple (*Acer saccharum*) foliar chemistry, tree growth, and understory vegetation community composition at three sugar bushes in Muskoka, Ontario. The chemical analysis of NIWA samples obtained from the residents of Muskoka, showed that NIWA contains high levels of macro nutrients such as calcium, magnesium, and potassium and contains relatively low concentrations of trace metals. Ash mixtures amalgamated in the field were relatively homogenous in their chemical composition and metal concentrations were generally below Ontario NASM regulation guidelines for land application. Concentrations of copper and zinc exceeded CM1 guidelines, however, were always below restricted metals land application limits (CM2). Ten months after NIWA application to three sugar bush sites, soil pH and exchangeable base cations increased significantly in the litter and FH horizons at all treatment plots compared with control plots. Few treatment effects were recorded for the surface (0 – 10 cm) mineral horizon, with only potassium increasing in mineral soil at all three study sites. Elevated concentrations of most metals and metalloids (aluminum (Al), boron (B), cadmium (Cd), copper (Cu), Iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), zinc (Zn)) were recorded in soil at all treatment plots, however these effects were generally restricted to the litter horizon. Diagnosis and recommendation integrated system analysis (DRIS) conducted on the sugar maple foliage indicated that potassium was the most limiting nutrient at all three study sites, and significant increases were recorded in foliar potassium concentrations ten months after ash application in sapling and mature trees at all treatment plots. Increases in foliar calcium and magnesium concentrations were small and variable amongst the study sites. No significant treatment effects of NIWA application were observed on sugar maple tree growth two years after ash application, while changes in understory composition were generally limited, but these also varied among sites.

Keywords: Acer saccharum, Base cations, Calcium decline, Forest soil amendment, Trace metals, non-industrial wood ash.

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List of Abbreviations

Acid Neutralizing Capacity.......ANC

Ammonia.......NH_3

Ammonium.......NH_4

Aluminum.......Al

Arsenic.......As

Basal Area.......BA

Basal Area Increment.......BAI

Base Saturation.......BS

Below Detection Limit.......BDL

Boron.......B

Cadmium.......Cd

Calcium.......Ca

Calcium Carbonate.......$CaCo_3$

Calcium Magnesium Carbonate.......$CaMg(CO_3)_2$

Calcium Nitrate.......$Ca(NO_3)_2$

Cation Exchange Capacity.......CEC

Carbon.......C

Chromium.......Cr

Cobalt.......Co

Coefficient of Variance.......CV

Copper.......Cu

Diagnosis and Recommendation Integrated System.......DRIS

Diameter at Breast Height.......DBH

Dissolved Organic Carbon.......DOC

Exchangeable Cations..EC

Fibric and Humic..FH

Friends of the Muskoka Watershed...FOTMW

Gypsum..$CaSO_4$

Hydrogen..H^+

Hydroxide..OH^-

Inductively Coupled Plasma-Optical Emission Spectrometry ....ICP-OES

Industrial Wood Ash...IWA

Iron..Fe

Lead...Pb

Litter Horizon..L

Loss on Ignition...LOI

Magnesium..Mg

Manganese..Mn

Mercury..Hg

Molybdenum...Mo

Nickel..Ni

Nitrate...NO_3

Nitrogen..N

Nitric Acid..HNO_3

Nitrogen Oxides...NOx

Nitrous Oxide...N_2O

Non-agricultural Source Material...NASM

Non-industrial Wood Ash...NIWA

Organic Horizon..LFH

Organic Matter...OM

Phosphorus..P

Potassium..K

Reactive Nitrogen...Nr

Selenium...Se

Shannon's Diversity..H

Simpson's Diversity..D

Sodium..Na

Standard Deviation..SD

Sulphur...S

Sulphur Dioxide...SO_2

Sulphate...SO_4

Vanadium..V

Whole Tree Harvesting...WTH

Zinc...Zn

1. General Introduction

1.1 Acid deposition and its effects on the forests of northeastern North America.

Industrialization has greatly affected the biogeochemistry of forests in Europe and eastern North America by increasing the atmospheric deposition of sulphur (S) and nitrogen (N) (Talhelm et al., 2012). The problem has been compounded by climate change, and forest harvesting accelerating base cation losses, and calcium (Ca) in particular, from forest soils (Akselsson et al., 2007; Cleavitt et al., 2018; Driscoll et al., 2001; Fernandez et al., 2003). Losses of base cations and associated increases in soluble aluminum (Al) concentration have been linked to a decline in the health of sugar maple (*Acer saccharum*) (Horsley et al., 2000; McDonough et al., 2021), red spruce (*Picea rubens*) (DeHayes et al., 1999), and potentially changes in forest composition (Lawrence et al., 2018).

Acidic deposition occurs when nitrogen oxides (NO_x) and sulphur dioxide (SO_2) are emitted into the atmosphere from anthropogenic activities such as the combustion of fossil fuels, and smelting of sulfide ores (Greaver et al., 2012; Likens et al., 1979). Once released, SO_2 and NO_x react with the water, oxygen, and other chemicals in the atmosphere to form sulfuric and nitric acid, and if significant quantities are reached, precipitation pH can drop below 5.6 units, causing acid rain (Likens et al., 1979). Sulphur and N deposition can occur as wet deposition via precipitation and as dry deposition in the form of gases and particles of S and N (Greaver et al., 2012). In some regions dry deposition can be a major component of total acidic deposition (Likens et al., 1979).

Sulphate is associated with H^+ ions (Gorham, 1958; Lefohn & Krupa, 1988) and as acidic rainwater percolates through soil the base cations in soil are replaced by positively charged hydrogen ions that bind more tightly to soil particles (Hedin & Likens, 1996). As such, these soil particles sequester H^+ ions and so the acidity of the water flowing through the soil stays low (Hedin & Likens, 1996). The behaviour of N in soils is more complex. Nitrogen is generally a limiting nutrient for terrestrial ecosystems; as it is usually found in its molecular form or nonreactive form (N_2) in the atmosphere (Galloway et al., 2003). Nonreactive N is generally "fixed" into reactive forms (Nr) naturally through lightning (Navarro-González et al., 1998) and biological N fixation via microorganisms (Hayatsu et al., 2008; Vitousek & Hobbie, 2000). Gaseous N is fixed when N is bonded to hydrogen or oxygen to form inorganic compounds (Navarro-González et al., 1998; Vitousek et al., 1997), while nitrification is carried out by a range of heterotrophic bacteria and fungi that oxidize ammonia into nitrite and nitrate (Hayatsu et al., 2008). Reactive forms of N include ammonia [NH_3] and ammonium [NH_4^+], inorganic oxidized forms (nitrogen oxide [NO_x], nitric acid [HNO_3], nitrous oxide [N_2O]), and nitrate [NO_3^-] (Galloway et al., 2003).

Anthropogenic activities such as combustion of fossil fuels that converts atmospheric N_2 into reactive NOx, cultivation of legumes, rice and other crops that support symbiotic relationships with N fixing bacteria (Ladha & Reddy, 2003; Phillips, 1980) and industrial processes that produce N fertilizers (Cherkasov et al., 2015) have almost doubled the transfer of N from the atmosphere into the land based biological N cycle (Vitousek et al., 1997). Inorganic N loading can eventually cause N saturation in ecosystems (Huang et al., 2015; Williams et al., 1996) whereby ammonium in soil is converted to nitrate by bacteria in a process which releases hydrogen ions thus acidifying soil (Vitousek et al., 1997). This process leads to decreases in soil pH and declines in soil exchangeable base cations (Perakis et al., 2013). Furthermore, as the terrestrial ecosystem experiences an increase in base cation leaching it leads to higher concentrations of H^+ ions in forest soils and the lower pH increases the mobilization of aluminum (Al) ions (Bache, 1986; Li et al., 2022). Mobilization of Al can also exacerbate Ca leaching by 1.) reducing uptake of Ca from the mineral soil to be cycled into the forest floor, 2.) increasing the supply of reactive Al, that once transported into the forest floor, exchanges with Ca, causing Ca leaching, and 3.) as Al saturation occurs, Ca is reduced at soil exchange sites for adsorption, due to the latter's poor ability to displace adsorbed Al (Lawrence et al., 1995).

Soils generally maintain a baseline concentration of essential nutrients such as Ca, magnesium (Mg) and potassium (K) that is supplied by mineral weathering and deposition of windblown dust (Hedin & Likens, 1996). However, ecosystems that are naturally poor in base cations, such as those dominated by siliceous bedrocks like granite, gneiss, and quartz sandstones, are particularly sensitive to acidification (Likens et al., 1979). These substrates are resistant to dissolution through weathering causing the surface waters in these areas to have low buffering capacity against additions of acids (Likens et al., 1979).

1.11 Clean Air Act and its impacts

In eastern North America a reduction in atmospheric S and N deposition has occurred over the last 40 years due to the implementation of polices including the Clean Air Act enacted in 1970s (Carlson, 2014). Within Canada, the provinces of Ontario and Quebec have experienced the largest reductions in acidic deposition (Jeffries et al., 2003), however chemical recovery in lake surface water chemistry and forest soils has been less than expected. For example, at Plastic Lake in central Ontario, a reduction in SO_4 deposition led to an increase of 0.8 pH units in bulk precipitation since the 1980s, however stream Al and pH depressions were comparable to values recorded in the 1980s and this lack of recovery was attributed to soil acidification and mobilization of SO_4 following summer droughts (Watmough et al., 2016). Meanwhile Lawrence et al. (2011) studied the recovery of lakes in the western Adirondacks, New York and reported that there was only a 0.28 pH unit increase and a 13 ueq/L increase in acid neutralizing capacity (ANC) in 12 streams over 23 years despite records showing large decreases in stream SO_4 concentrations over the past 24 years. This was attributed to an almost equivalent decrease in base cation concentrations as well as an increase in organic acidity in streams (Lawrence et al., 2011). Chemical recovery in soils in response to decreased acidic deposition has also been limited (McHale et al., 2017). For example, in the southeastern Catskill Mountains, in New York, significant reductions in acid deposition were measured from 1992 to 2014, however almost no recovery in soil chemistry was recorded (McHale et al., 2017).

Several reasons have been highlighted as the potential cause for slow recovery from acidic deposition. These include the release of previously deposited SO_4 from soil (Driscoll et al., 1995), continued net losses of base cations from forest soils (Watmough & Dillon, 2003), and intensive forest harvesting which reduces the supply of soil base cations (Futter et al., 2014). The intensity of forest harvesting, such as whole tree harvesting (WTH) which is the removal of all above ground biomass (Vanguelova et al., 2009), can also affect the magnitude of base cation losses from soils (Akselsson et al., 2007). For example, a study conducted in Sweden reported that mass balance calculations after stem harvesting and WTH resulted in net losses of nutrients in both, however WTH led to substantially higher net losses of K and Ca in forest soils (Akselsson et al., 2007). Additionally, in a regional meta-analysis reviewing data from Nordic and UK coniferous forests similarly reported higher reductions in soil nutrient concentration, total N, and soil organic carbon in forest soils after WTH as compared with stem only harvesting (Clarke et al., 2021).

1.2 Impact of atmospheric deposition on sugar maple

Over the past half century sugar maple has experienced significant dieback throughout its eastern range and this decline has been linked to soil acidification (Bal et al., 2015; Duchesne et al., 2002; Horsley et al., 2000; McLaughlin, 1998). Sugar maple is of substantial importance due to its dominance within hardwood forests, and its economic value in terms of lumber and maple syrup production (Duchesne et al., 2005). For example, 70% of the world's production of maple syrup comes from the province of Quebec, and approximately 17% of commercial forests in Quebec are dominated by sugar maple (Duchesne et al., 2005). In 2020, Canadian maple producers harvested 14.3 million gallons of maple syrup that amounted to $558.5 million in total sales, while maple products accounted for 6.4% of all Canadian horticulture farm receipts for 2020 (Crops and Horticulture and Division Agriculture and Agri-Food Canada, 2021).

Reports of sugar maple decline go back to the 1970s (Ouimet & Camire, 1995) sporadically throughout its range in eastern United States (Miller et al., 1989), Ontario, and Quebec (McLaughlin, 1998; Payette et al., 1996). The most severe declines were observed in regions with thin nutrient poor soils, that received elevated levels of atmospheric acid deposition (Watmough, 2002). Sugar maple decline is characterized by branch dieback, loss of crown vigor, and reduction in radial growth, eventually leading to death (Horsley et al., 2000). The severity of decline symptoms varies dramatically among individuals within the same stand (Ouimet et al., 1995). However, crown condition may be used as a predictor for tree death, with risk of mortality increasing with declining crown condition (Tominaga et al., 2008).

There are various explanations for sugar maple decline that include biotic and abiotic stressors and they are likely not mutually exclusive (Pitel & Yanai, 2014). Nevertheless, soil base cation depletion (Long et al., 2009), metal toxicity from metals such as manganese (Mn) and Al (Schaberg et al., 2006; Schier & Mcquattie, 2000), and natural disturbances such as drought and insect infestation (Payette et al., 1996) have all been suggested as possible contributing factors to sugar maple decline.

1.3 Remediation techniques to counter the effects of acid deposition

Soil fertilization through Ca additions and liming have shown promising results to mitigate impact of decline on sugar maple (Huggett et al., 2007). The use of liming to counter the effects of soil acidification has been employed through-out Europe since the 1980s (Schaaf & Huttle, 2006) while experimental liming dates to the 1950s (Tamm, 1974). Liming has been shown to decrease soil acidity, increase soil base saturation and, the concentration of exchangeable Ca leading to higher Ca/Al ratios in soil that are less harmful for vegetation (Huettl & Zoettl, 1993; Schaaf & Huttle, 2006).

Liming materials that are most used for soil amelioration include oxides, hydroxides, carbonates and silicates of Ca or Ca-Mg mixtures such as calcitic limestones (calcium carbonate; $CaCO_3$), and dolomitic lime (calcium-magnesium carbonate; $CaMg(CO_3)_2$) (Uchida & Silva, 2000). However, other materials such as wollastonite ($CaSiO_3$), calcium nitrate ($Ca(NO_3)_2$), and gypsum ($CaSO_4$) have also been used (Reid & Watmough, 2014). The relative neutralizing value or the amount of acid a given quantity of lime will neutralize once dissolved (expressed as a percent of the neutralizing value of pure $CaCO_3$) varies based on the material used and its purity (Uchida & Silva, 2000). Calcitic limestone, for example, has a relative neutralizing value of a 100 while dolomitic lime ranges from 95 to 108 (Uchida & Silva, 2000). Lime works to neutralize the effects of acid deposition by dissolving to produce Ca^{2+} and hydroxide (OH^-) ions. Newly produced Ca^{2+} exchanges with toxic Al^{3+} and H^+ ions on soil surface, while OH^- will react with Al^{3+} and H^+ to form solid $Al(OH)_3$ or H_2O (Uchida & Silva, 2000). Lime also provides added Ca and Mg to soil (Uchida & Silva, 2000).

Liming of forest soils has led to increases in soil base saturation, and an increase in the concentrations of foliar nutrients such as K, Ca, and phosphorus (P) (Wilmot et al., 1996). For example, a large-scale liming trial in south-west Germany, resulted in an increase of soil pH of 1.2 – 1.3 units and an increase in base saturation of 40 to 70%, after lime ($CaCO_3$) was applied at a dosage rate of 2.5 – 3 Mg ha^{-1} in 1985, followed by a 2nd application of 6 Mg ha^{-1} of dolomite in 2003 (Jansone et al., 2020). Additionally, in another study, four mature Scots pine (*Pinus sylvestris*) stands received a single lime application with varying doses between 3 and 15 Mg ha^{-1} resulting in increases in needle nutrient concentrations of Ca and decreases in Mn, Al, and iron (Fe), 35 years after application (Borja & Nilsen, 2009). In North America, Long et al. (1997) reported significant improvement in crown vigor of overstory sugar maple and an increase in diameter growth on lime treated plots. Furthermore, liming increased exchangeable base cations in the upper 15 cm of soil and reduced levels of exchangeable Al and Mn (Long et al., 1997). These changes in soil chemistry were reflected in the overstory sugar maple foliar chemistry (Long et al., 1997) and increases in foliar concentrations of Ca and declines in foliar Mn were linked to healthier crown conditions (Juice et al., 2006). Like liming, industrial wood ash has also been used as a soil amelioration method to mitigate the effects of atmospheric acid deposition.

1.4 Wood ash properties, use and effects

Biomass accounts for ~14% of the world's primary energy consumption (Balat & Ayar, 2005), the equivalent of 25 million barrels of oil per day (Hall, 1991). Approximately, 35% of biomass energy consumption comes from developing nations

(Balat & Ayar, 2005), while biomass accounts for about 4% of energy consumption in the United States (Hall, 1991), and 15% of Canada's renewable energy (Hannam et al., 2018). Globally, biomass production is estimated to be 146 billion metric tons per year (Balat & Ayar, 2005). Pressure to mitigate the harmful effects of climate change and find alternative sources of energy, have increased global interest in use of bioenergy as an alternative to fossil fuels (Demirbas et al., 2009). Biomass fuels can be classified under four broad categories, 1.) waste material, which can be classified as all organic materials that accumulate at specific locations and carry disposal costs, 2.) residue material resulting from plant materials left in the fields after harvesting of crops or timber, 3.) energy crops cultivated for fuel content, such as short rotation tree farms, and hydrocarbon plants (e.g. plants from the Euphorbiaceae family), and 4.) an integrated biomass system where multiple products are combined (Benemann, 1980).

Biomass is a renewable source of heat production, accounting for 7.1% of heat produced in power plants and 27.1 % of heat directly consumed at end sectors, such as homes and businesses (Lamer et al., 2018). Most of the biomass energy produced is from wood and wood waste (Demirbas et al., 2009), resulting in substantial amounts of wood ash residue (Obernberge & Supancic, 2009). In Germany, 400 to 650 kt of wood ash is created from energy production; if household wood combustion were to be added the figure would exceed 1000 kt (Lamer et al., 2018). Meanwhile, Sweden produced 528 kt of wood ash annually, mostly from paper and pulp mill residue (Lamer et al., 2018). In Canada, more than a 1000 kt of wood ash is produced primarily from the paper and pulp mill industry (Lamer et al., 2018).

1.41 Wood ash composition and production

Wood and wood waste are the most important biomass energy sources, accounting for 64% of biomass energy (Demirbas et al., 2009). Increases in energy derived from biomass have contributed to an increase in the amount of biomass combustion residue such as wood ash (Obernberger & Supancic, 2009). Wood ash is the organic and inorganic residue generated from the combustion of wood and wood products such as saw dust, wood chips and/or bark (Siddique, 2012). Wood ash chemical composition, properties and the quantity produced, can vary greatly; and are dependant upon numerous factors such as tree species, type of plant tissue used, climate and soil of feedstock, and wood burning temperature (Pitman, 2006). For example, ash yield tends to decrease as combustion temperatures are increased (Etitgni & Campbell, 1991). Ash derived from branch and root wood typically have higher concentrations of many elements than ash derived from stem-wood, and ash derived from bark and foliage elemental concentrations are even higher (Pitman, 2006).

Wood ash tends to be rich in macronutrients such as Ca and Mg, however it also contains heavy metals such as Mn, cadmium (Cd), zinc (Zn) and lead (Pb) (James et al., 2014). Additionally, N concentrations in ash are usually very low as N is lost to the atmosphere during combustion (Demeyer et al., 2001). Calcium is generally the most plentiful element found in wood ash (Reid & Watmough, 2014). Calcium present in wood ash is usually in the form of $CaCO_3$ (Reid & Watmough, 2014), and can account for approximately 16 to 20% of the ash by weight (Pitman, 2006). Additionally, wood ash also contains high levels of other important nutrients such as K and P (Campbell, 1990; Naylor

& Schmidt, 1986). Wood ash pH can range between 7.5 to 13.6 (Hannam et al., 2018) making it a substance with a high neutralizing capacity, which can be attributed to the Ca and K carbonates and hydroxides present within the ash (Campbell, 1990).

1.42 Industrial Wood Ash

Most of the wood ash produced in eastern North America originates from industrial sources (Hannam et al., 2018). Industrial wood ash is created from sources, that include sawmills and the pulp and paper industry (Elliott & Mahmood, 2006). Fly ash and bottom ash are two forms of industrial ash that are classified, based upon their origin within the boilers (Hannam et al., 2018). Fly ash which can be further grouped as cyclone fly ash or filter fly ash (Narodoslawsky & Obernberger, 1996), is the fine particles of ash scrubbed from the flue gases before they enter the atmosphere (Hannam et al., 2017), while bottom ash is ash that accumulates at the base of the boilers (Elliott & Mahmood, 2006). Fly ash tends to have a higher surface to volume ratio and is more reactive than bottom ash (Hannam et al., 2017). It is light weight, small (~200 μm) and usually contains higher levels of dioxins and heavy metals than bottom ash except for Zn (Pitman, 2006). Metals like Cd, Pb, molybdenum (Mo) and Zn, concentrate in cyclone and filter fly ash, due to the temperature at which ash flows are precipitated (Nardoslawsky & Obernberger, 1996). Fly ash is usually precipitated at temperatures between 100 to 200°C while bottom ash is usually between 600 to 1000°C (Nardoslawsky & Obernberger, 1996). Lower temperatures allow for the de-sublimation and condensation of volatile metals, resulting in higher concentrations (Nardoslawsky & Obernberger, 1996). However, metals with low volatility such as nickel (Ni), Chromium (Cr) and vanadium (V) concentrate in bottom ash along with nutrients such as Ca, Mg, and P (Nardoslawsky & Obernberger, 1996).

1.43 Non-Industrial wood ash

In comparison to industrial wood ash, less is known about nonindustrial wood ash (NIWA) originating from residential properties. On average, 18,000 tonnes of wood ash are generated from residences in Ontario annually (Azan, 2017). Furthermore, since it originates from numerous sources it is thought to have a wide range of variability in its chemical composition (Azan et al., 2019). Azan et al. (2019) found that the mean Ca concentrations of NIWA ash samples from Muskoka ranged between 26.8% to 31.9% while K concentrations were between 6.1% and 10.4%. Variations in residential wood ash chemical composition can also be attributed to the tree species being burned (Deighton & Watmough, 2020). For example, ash from yellow birch has 12 times more Zn, 9 times more As and 6 times more Cd and Pb than ash from sugar maple and white pine, while nutrient concentrations were found to be generally more similar among the three tree species (Deighton & Watmough, 2020).

Fragments of wood charcoal are often found intermingled within finer ash. Wood charcoal is a by product of incomplete wood combustion (Antal & Gronli, 2003). Similar to the chemical composition of wood ash, wood charcoal's chemical composition is heavily dependent upon tree species (Pluchon et al., 2014), however, it can differ from that of finer ash. Based on existing literature, wood charcoal tends to have lower pH and nutrient content than finer wood ash (Pluchon et al., 2014). Furthermore, wood charcoal particle size can be larger than finer ash which can influence ash chemical composition (Etitgni & Campbell, 1991; James et al., 2014; Nocentini et al., 2010). There is limited research on the chemical composition of wood charcoal produced within NIWA, and if NIWA is to be used as a soil amendment more research is needed to understand the chemical composition of wood charcoal, and if it should be removed from ash mixtures before land application.

1.44 Wood ash effects on soil, water, and forest biota

Wood ash is enriched with base cations such as Ca, K, and Mg and thus has the potential to be used as a soil amelioration substance for forest soils (Pitman, 2006). However, due to its high alkalinity and elevated concentrations of some trace metals such as Cd, Ni, and Pb it may be harmful to sensitive components of forest ecosystems (Moilanen et al., 2006; Pitman, 2006). Numerous studies have been carried out in Europe and North America to study the effects of wood ash on forest ecosystems, evaluating application dosages, different wood ash types and combined applications with fertilizers rich in N (Hytönen & Hökkä, 2020; Jacobson et al., 2004, 2014).

Wood ash effects on soil

Wood ash application generally leads to an increase in pH and base saturation in surface soil horizons, with effects persisting beyond the first year (Jacobson et al., 2004; Saarsalmi et al., 2001). Prolonged changes have been observed in the organic and mineral layers, several years after application that is attributed to the slow downward transfer of base cations (Saarsalmi et al., 2001). The chemical response of soil to ash can be affected by ash type and application rates (Pitman, 2006; Saarsalmi et al., 2006). For example, loose ash releases K, and Na (sodium) more rapidly than granulated ash that is less soluble (Nieminen et al., 2005). However, due to the lower solubility of nutrients from granulated ash, fertilization effects may last for a longer period than that of loose ash (Hytönen & Hökkä, 2020).

A significant increase in exchangeable Ca and Mg concentrations has been observed in soil after ash application along with an increase in the effective cation exchange capacity (CEC) and base saturation (BS) (Saarsalmi et al., 2001). In a study by Ludwig et al. (2002), exchangeable Ca in the organic and mineral soil (combined) increased by 411 kg ha^{-1} while Mg increased by 39 kg ha^{-1}, nineteen months after application. Vance (1996) estimated that a single dose of 10 Mg ha^{-1} of fire boiler wood ash application to soils could replace nutrient losses caused by WTH with the notable exception of N. Wood ash contains low concentrations of N and thus does not directly contribute to N availability (Pitman, 2006). However, wood ash application can contribute to the decomposition of recalcitrant organic matter, thus increasing available N in soil (Mortensen et al., 2019), though this is dependent upon pre-existing N availability in the system (Mortensen et al., 2019; Rosenberg et al., 2010).

While the application of wood ash can improve soil quality and replace lost nutrients, elevated levels of potentially toxic metals have been observed in the short term after ash application. In general, these effects have been mostly restricted to the upper soil horizons and dissipated relatively quickly over time (Arvidsson et al., 2003; Ozolincius & Varnagiryte, 2005). Researchers in Lithuania for example, measured the concentrations of several metals two years after wood ash application and found increases in concentrations of Cr, Cu, Ni, and Zn in ash-treated plots, but only in the O (LFH) horizons, while a significant downward transport was reported only for Zn and Ni (Ozolincius and Varnagiryte, 2005). Meanwhile, (Pugliese et al., 2014) found that ash application did not significantly change metal concentrations in soil and decreased available Pb presumably due to an increase in soil pH. Exchangeable Al concentrations have similarly been observed to decrease in the humus and mineral layers after ash application (Saarsalmi et al., 2001).

Wood ash effects on soil water and surface water chemistry

Wood ash application can alter soil water chemistry (Deighton et al., 2021; Kahl et al., 1996; Pitman, 2006; Ring et al., 2020), with many parameters changing in response to ash application. Soil water response however vary depending on ash type, soil depth and time (Ludwig et al., 2002; Ring et al., 2020). For example, elevated Ca concentrations in soil solutions, collected at the mineral soil surface (0 cm), were observed for 15 months after a single 4.8 Mg ha^{-1} wood ash addition in northern Germany (Ludwig et al., 2002). Potassium and Mg concentrations in soil water similarly increased, with peak K concentrations recorded in the first year after application and decreased continuously into the second year of the study (Ludwig et al., 2002). In a study in an acidic forest in West Enfield, Maine, Kahl et al. (1996) observed a slight increase in dissolved organic carbon (DOC) in soil solution chemistry after an application of 13 and 20 Mg ha^{-1}, while in another study in Germany, Rumpf et al. (2001) found no changes in DOC in soil water. Short-lived decreases in soil water pH following ash application have been reported

(Ludwig et al., 2002; Rumpf et al., 2001). These changes were attributed to the desorption of Al followed by Al hydroxide precipitation (Rumpf et al., 2001). However, increases in soil pH after wood ash application have also been recorded. For example, in an incubation study, on acidic soils in central Cameroon, Voundi Nkana et al. (2002) found wood ash induced increases in soil solution pH after a 60-day incubation period. In that study, wood ash application rate was based upon the calcium carbonate equivalence of the ash corresponding to 1 and 2 times the level of exchangeable Al.

The response of soil water chemistry to wood ash addition is dependent upon ash dosage (Ring et al., 2020). Higher doses can temporarily cause large increases in base cations, pH, and anions in soil solution that are related to the initial dose applied (Kahl et al., 1996). Kahl et al. (1996) for example, reported minimal chemical response in soil solution to a wood ash treatment of 6 Mg ha^{-1}, while dosages of 13 and 20 Mg ha^{-1} showed large and rapid increases in Ca, Mg, Cl, NO_3 and SO_4 in soil solution. The response was temporary at 13 Mg ha^{-1}, however at 20 Mg ha^{-1} pH, ANC, and concentrations of K, Na and SO_4 remained elevated in soil solution several months after application (Kahl et al., 1996).

Current research indicates that slight increases in metal concentrations in soil solution can occur after wood ash application, but the increases are usually not significant (Ludwig et al., 2002; Ring et al., 2020; Rumpf et al., 2001). Rumpf et al. (2001) reported no significant changes in concentrations of Pb and Cr in soil water solution 19 months after an ash application of 2.4 Mg ha^{-1} and although there was an increase in Cd and Zn concentrations, the amount remained below Germany’s legal limit for drinking water (0.18 μmol 1^{-1}) and limits for soil conservation (7.6 μmol 1^{-1}). Similarly, over a 17-year period in Sweden, Ring et al. (2020), found no significant changes in the concentration of arsenic (As), Cu, Mn, Pb, V and Zn in soil water chemistry following an ash application of varying dosages (3 to 9 Mg ha^{-1}). Increases in Cd concentrations in the plots receiving the highest ash dosage were observed during the first 9 years of the study, but during the latter part of the study no treatment effects for Cd were found (Ring et al., 2020).

Few studies have looked at the impact of wood ash addition on surface water chemistry. Tulonen et al. (2002) studied the effects of wood ash application on the sub-catchments of two small humic head water lakes in southern Finland and reported slight increases in pH, alkalinity, conductivity, and concentrations of K, SO_4, and Cl^- in inflowing waters and lake waters after an application dosage of 6.4 Mg ha^{-1}. Based on the limited results it appears that although wood ash application may not cause significant changes in water quality on a small scale, but changes may be more dramatic at higher application rates, however, further research is needed in this area (Tulonen et al., 2002).

Wood ash impact on aquatic and terrestrial biota

Wood ash has been reported to adversely affect terrestrial biota (Pitman, 2006). Visible damage to bryophytes has been observed after application of crushed ash, with the damage being most severe the first year after application (Jacobson & Gustafsson, 2001). At high wood ash doses (9 Mg ha^{-1}), bryophyte cover was significantly reduced after application (Jacobson & Gustafsson, 2001), however no visible negative effects were recorded at lower doses (3 Mg ha^{-1}) (Arvidsson et al., 2003). A potential cause for bryophytes damage is the high concentrations of neutral salts and high pH that can lead to visible damage such as 'burning' (Jacobson & Gustafsson, 2001). Dwarf shrub cover was also negatively affected and was postulated to be caused by changes in soil chemistry caused by ash application (Jacobson & Gustafsson, 2001). Similarly, in another study in southwestern Lithuania, Ozolinčius et al. (2007), reported significant reduction in moss cover after an ash application of varying dosages (1.25, 2.5, and 5.0 Mg ha^{-1}), with moss cover decreasing with higher wood ash dosage rates. However, no significant effects on bryophytes were found following treatment with pelleted ash (Jacobson & Gustafsson, 2001).

Following ash application, Olsson & Kellner, (2002) observed a positive correlation between the pH of the humus layer and the number of established ground flora species in a Norway spruce (*Picea abies*) stand in southern Sweden. The study suggested that germination could be affected by ash induced pH changes (Olsson & Kellner, 2002). Researchers also tested for metal accumulation in forest berries and mushrooms after ash application and concluded that heavy metals were unlikely to accumulate in plants (Moilanen et al., 2006; Norström et al., 2012). Overall, literature suggests that ash application at low doses may have minimal to no effect on plant community composition (Arvidsson et al., 2003; Jacobson & Gustafsson, 2001).

Wood ash application can lead to an increase in tree growth, although growth responses are mixed (Moilanen et al., 2002; Saarsalmi et al., 2006). Published research regarding ash application effects on tree health and growth, is dominated by application effects on conifers (Pitman, 2006) even though hardwoods are expected to benefit more from ash application, due to their greater need for base cations such as Ca, Mg and K (Vance, 1996). A 20% increase in basal area increment (BAI) was measured in sugar maples in Quebec after an ash treatment of 20 Mg ha^{-1}, 3 years after application (Arseneau et al., 2021). Increases in tree growth were attributed to increases in soil Ca and Mg levels (Solla-Gullón et al., 2008) and decreases in Ca deficiencies in sugar maple seedlings and mature trees (Arseneau et al., 2021). Similarly, increases in height and diameter of Monterey pine (*Pinus radiata*) were observed after 5 years following the application of mixed wood bark ash at dosages of 5 and 10 Mg ha^{-1} (Solla-Gullon et al., 2008). Ozolinčius, Varnagiryte-Kabašinskiene, et al., (2007), also reported increased growth in the top and middle crown of Scots pines after a combined application of wood ash and nitrogen. Another long-term ash application study resulted in substantial stem growth increases in Scots pine after an application rate of 8 and 16 Mg ha^{-1} (Moilanen et al., 2002). Wood production in all ash treated plots was 13 to 17 times greater than in untreated plots (Moilanen et al., 2002). Additionally, trees in untreated plots were found to suffer from continuous foliar P and K deficiencies while trees in ash treated plots (16 Mg ha^{-1}) showed no nutrient shortage (Moilanen et al., 2002).

Wood ash has been shown to increase salamander abundance one year after application of fly and bottom ash at Haliburton Forest in central Ontario (Gorgolewski et al., 2015). The response was attributed to increased soil pH and soil moisture; however, it was noted that salamander abundance may have occurred only after pH had equilibrated with the soil. Additionally, application of fly and bottom wood ash at a dosage of 10 Mg

ha^{-1} resulted in no significant effects on short-term earthworm survivorship or growth (McTavish et al., 2020). Although the study found earthworm behavior (habitat avoidance and reduced surface activity) changed, these changes were likely influenced by highly scenario-specific circumstances, including wood ash type, application site, and timing of application (McTavish et al., 2020). There are several studies on the effects of liming on key fauna and amphibians (Moore et al., 2014) but limited research exists on effects on fauna from wood ash application (Gorgolewski et al., 2015).

In southern Finland, Tulonen et al. (2002) carried out laboratory tank experiments using humic lake water to understand the immediate effects of wood ash application (6.4 Mg ha^{-1}) on aquatic biota. The results showed decreased growth of phytoplankton biomass after only 1.5 weeks with an application rate of 6.4 Mg ha^{-1}. Meanwhile in field experiments, where 19% of the catchment was treated with the same ash dosage as the tank experiments, resulted in an increase in phytoplankton biomass relative to the reference lake (Tulonen et al., 2002). An increase in zooplankton (rotifers) biomass was also observed suggesting enhanced lake productivity. The dissimilarity between the results of the tank experiment and the field study was associated to rapid increases in water pH in the tank experiments. Further research is required to gain a more comprehensive understanding of the impacts of wood ash application to aquatic ecosystems.

1.45 Wood ash regulations

Numerous policies are in place to manage the substantial amount of ash created, which range from using ash as a binding agent in cement, land filling or recycling it back into forests or for agricultural uses (Siddique, 2012; Hannam et al., 2018). However, due to the differences in ash chemical composition and quality, most countries usually landfill their residual ash (Hannam et al., 2018; Pitman, 2006). For example, the United States paper and pulp mills create ~3 to 5 million Mg of wood ash annually, of which 90% is landfilled (Pitman, 2006; Pugliese et al., 2014). In contrast, in Denmark there is a strong push to reuse biomass ash. A tax deterrent was implemented charging a fee of ~64 Euros for every ton of ash landfilled (Lamer et al., 2018). This has resulted in a limited amount of ash landfilled while most is used as fertilizer or soil amelioration product, although the process is heavily regulated (Lamer et al., 2018). Before application, an analysis of forest soils is mandatory and the calculation of proper dosage rate to ensure trace elemental concentrations remain below pre-set limits is required (Stupak et al., 2008).

In Canada, industrial and non-industrial wood ash is generally considered a hazardous waste material and is usually landfilled (Hannam et al., 2018). In 1995, 84% of the ash produced by Canadian pulp and paper industry was landfilled and only 3% was applied towards beneficial uses (Elliott & Mahmood, 2006). By 2002, the amount of ash landfilled dropped to 78%, while overall beneficial use increased to 22%, 9% of which was allocated towards land spread (Elliott & Mahmood, 2006). Policies regarding ash management differ greatly among provinces, as they mainly fall under provincial and territorial jurisdiction (Hannam et al., 2016). Due to a lack of formal guidance designed specifically for the use of wood ash as a forest soil amendment, wood ash has been categorized under regulations set for various other waste products, such as compost, hazardous waste material or biosolids (Hannam et al., 2016).

The use of wood ash as a soil amelioration substance varies significantly among the provinces and territories; some allow wood ash to be recycled while others landfill. Wood ash undergoes an approval process for land application, where it is analysed to determine concentrations of As, Cd, Cr, cobalt (Co), Cu, mercury (Hg), molybdenum (Mo), Ni, Pb, selenium (Se) and Zn (Hannam et al., 2016). The soil receiving the application must also undergo analyses to ensure metal levels do not already exceed limits (Hannam et al., 2016). All provinces, with few exceptions (BC, ON, and QC), use the trace metal limits set out for compost by the Canadian Council of Ministers of the Environment. Since BC, ON, and QC use different guidelines, their concentration limits also vary (Hannam et al., 2016). For example, in Quebec, wood ash is categorized as a fertilizer residual and has an upper limit for Pb of 300 $mg.kg^{-1}$ but in BC, the upper limit is 500 $mg.kg^{-1}$ when ash is used as a soil amendment (Hannam et al., 2016). Regardless, if any wood ash sample being tested exceeds prescribed limits, then it cannot be land applied and must instead be treated as a hazardous waste, to avoid soil and or water contamination (Hannam et al., 2016).

With wood ash management policies in their current form, wood ash originating from industry is easier to recycle. Industrial wood ash originates at a single point source thus making it easier to test for trace metal content before land application per regulations. Meanwhile, it can be inferred that nonindustrial wood ash will require significantly more testing, as smaller quantities are generated at various locations. However, this barrier may be removed if NIWA's chemical variability can be characterized in detail, to ensure that existing guideline are not exceeded and that there are no adverse effects on ecosystem health after ash application.

1.46 Friends of the Muskoka Watershed wood ash study

Friends of the Muskoka Watershed (FOTMW) is a not-for-profit organization which promotes the protection, wise management and, the remediation of Muskoka lakes, rivers, and watersheds through applied research (https://ashmuskoka.ca/). AshMuskoka is a project initiated by the FOTMW with the aim of demonstrating that NIWA is a chemically safe and biologically appropriate forest soil amendment, through collaborative work between scientists, municipal officials, and property owners (https://ashmuskoka.ca/about-hatsoff/). As part of the AshMuskoka project, NIWA is collected from residents and small businesses for the purposes of implementing a wood ash recycling study. Ash is collected from volunteers throughout the Muskoka region, where participants drop off their residual ash in seasonal ash drives throughout the year. The ash is stored in specified locations until ready to be processed for land application and chemical analyses. All NIWA used in this study was provided by FOTMW.

1.5 Thesis Objectives and Hypothesis

The purpose of this study is to characterize the chemical variability of non-industrial wood ash, and its short-term effects on soil properties, sugar maple growth (>10 cm DBH) and understory vegetation community composition. The findings of this thesis are presented in two research chapters. The first research chapter (Chapter 2) presents the findings describing the variability in the chemical composition of non-industrial wood ash collected from the residents of the greater Muskoka region in Ontario. The second research chapter (Chapter 3) assesses the impact of ash used as a soil amendment one year after application at three sugar bushes in the district of Muskoka, Ontario.

In Chapter 2, 107 ash samples collected from the residents of Muskoka were analyzed for several chemical properties including pH, macronutrients and metal content (including some metalloids restricted under the NASM regulations; these elements will be grouped under metals for the remainder of this thesis), organic matter, and their Carbon-Nitrogen-Sulfur (CNS) content and variation in these measurements is described. In Chapter 3, the short term (1-year) response of ash application was assessed. Specifically, this study measured 1) soil properties (pH, organic matter, CNS, nutrient content, and metal concentrations 2) saplings and mature (> 10 cm DBH) sugar maple foliar chemistry (CNS, nutrient and metal content) 3) sugar maple growth, and 4) changes in understory vegetation communities up to two years after ash application.

The objective of Chapter 2 was to evaluate the variability of the chemical composition of NIWA and the potential for homogenization to address chemical quality concerns. It was predicted that once homogenized, wood ash would have relatively stable nutrient content and metal concentrations (Mn, Al, Cd, Ni, Fe, Cu, As, B, Zn, Pb) compared with unhomogenized ash. Furthermore, ash metal concentrations were predicted to remain below the soil metal limits set out in Ontario's Non-Aqueous Non-Agricultural Source Materials (NASM) regulation 267/03 CM2 guidelines.

The objective for Chapter 3 was to evaluate the short-term response of non-industrial wood ash application to three sugar bushes in Muskoka, Ontario. It was hypothesized that wood ash application would increase nutrient availability for plant growth with minimal or no harmful effects from metal toxicity. Wood ash treatments were expected to significantly increase pH and nutrient concentrations (Ca, Mg, K) and metal (metalloid) concentrations in the organic soil horizons one year after application. Nutrient (Ca, Mg, K) concentrations in foliage of both mature and sugar maple saplings were predicted to increase in ash treated plots, with little to no increases in trace metal concentrations. Over the 1-year post treatment, no differences in tree growth or understory composition were expected.

1.6 Research significance

Depletion of essential macronutrients from forest soils due to atmospheric acid deposition (Johnson et al., 1985) has been observed to impact tree health (Ouimet & Camire, 1995). This is especially true for forests growing on nutrient poor soils situated on Precambrian bedrock (McDonough et al., 2021). These nutrient deficiencies are exacerbated by the practice of whole tree harvesting, giving way to further nutrient losses (Duchesne et al., 2008). Of particular concern are the decline in health and vigor of sugar maple (Horsley et al., 2000). Sugar maple is an important species in northern hardwood forest due to its ecological importance and economic significance (Duchesne et al., 2005; Lovett & Mitchell, 2004).

Wood ash has been shown to raise pH, Ca and other base cation concentrations in soil (Saarsalmi et al., 2001) when used as a soil amendment. However, there are concerns over trace metal toxicity and accumulation in soil (Ludwig et al., 2002). An increase in demand for biomass as a source for renewable energy (Demirbas et al., 2009), will increase the amount of wood ash created as a by-product, subsequently increasing the amount of ash sent to landfill for disposal as per the wood ash regulations in Ontario (Elliott & Mahmood 2006; Hannam et al., 2018). Wood ash properties are dependent upon various factors such as tree species used, burning temperature, and part of tree used among others (Pitman, 2006). With so many factors at play wood ash originating from diverse residences, will have a greater variation in its chemical composition due to a lack of homogeneity (Azan, 2017) thus making it harder to implement a policy which can easily divert ash away from landfills and towards a more productive use.

This research aims to study the variability in NIWA composition and properties, the changes to that variability upon homogenization, and its effects on soil chemistry and sugar maple health when used as a soil amendment. Ultimately the research can address the variability and metal toxicity concerns of using wood ash as a soil amendment and assist policy makers to implement decisions with regards to incorporating NIWA use in forest management policies.

2. The chemical composition of non-industrial wood ash in Muskoka

2.1 Abstract

This study evaluated the chemical composition and variability of non-industrial wood ash (NIWA) and charcoal collected from the residents of Muskoka, Ontario. Both NIWA (n = 107) and wood charcoal (n = 10) contain high concentrations of macro nutrients (calcium (Ca), potassium (K), magnesium (Mg) and phosphorus (P)) and generally low levels of trace metals. The chemical composition of NIWA varied among individual samples, but for all analytes most of the test samples fell within a narrow range. Nutrient (Ca, Mg, K and P) concentrations were generally within or higher than previously reported values for industrial wood ash, while metal concentrations were lower than previously reported industrial wood ash values. Most of the samples were within the Non-Aqueous Non-Agricultural Source Materials (NASM) regulation 267/03 of the Nutrient Management Act guidelines, however concentrations of lead (Pb), arsenic (As), and copper (Cu) in a few samples were above CM2 limits. Once homogenized into an amalgamated ash mixture for field application, amalgamated ash samples were relatively consistent in their chemical composition. Concentrations of Cu and zinc (Zn) in amalgamated ash samples were often above CM1 limits, however all metal concentrations of all amalgamated samples fell below CM2 land application limits. Furthermore, a bootstrap analysis suggested that homogenization of wood ash samples from individual donors will generally produce bulk mixtures that are relatively consistent in their chemical composition.

2.2 Introduction

Biomass is a renewable energy source that is of increasing interest due to the progressive depletion of conventional fossil fuels and its importance as a more sustainable alternative (Demirbas et al., 2009). Approximately 35% of the energy demand in developing countries is met by biomass (Demirbas et al., 2009), while industrialized countries such as Finland (18%), Sweden (9%) and the US (3%) also derive a considerable amount of their energy requirements from biomass. The global expenditure on biomass programs exceeds 2 billion dollars per year (Hall & Moss, 1983). In Canada, approximately 15% of renewable energy generated is from biomass sources and the amount allocated for renewables is steadily increasing (Hannam et al., 2018). The pulp and paper industry is currently the largest user of biomass energy from wood, however the use of forest biomass energy is diversifying (Hannam et al., 2018). The increased use of wood biomass has resulted in an increase in production of its associated waste material, wood ash.

Wood ash is comprised of the inorganic and organic residue generated from the combustion of wood and wood by-products (Siddique, 2012), through commercial and domestic use (Azan, 2017; Hannam et al., 2018). Wood ash can be highly variable in both chemical composition and its physical properties (Hannam et al., 2018). Previous literature has reported a wide range in wood ash pH, organic matter, and nutrient and metal concentrations (Hannam et al., 2018; Pitman, 2006). These differences are due to factors such as differences in source material, the temperature at which wood was burned, and parts and species of tree used (Pitman, 2006). For example, Ca concentrations range between 15.4 to 461 g kg^{-1} among bark ashes from various species

(Elliott & Mahmood, 2006). Large variations in the chemical composition have been noted in ash derived from common Ontario tree species; with Ca concentrations ranging between 156 to 250 g kg^{-1}, being highest in white pine (*Pinus strobus*) and lowest in sugar maple (*Acer saccharum*) (Deighton & Watmough, 2020). Furthermore, combustion temperature can also significantly affect ash yield and metal concentrations. Ash quantity tends to decrease, and metal concentrations increase, at higher combustion temperatures (Etitgni & Campbell, 1991).

Wood ash can be characterized into two subcategories: 1) industrial wood ash (IWA), created through wood combustion in industries such as timber mills and pulp and paper (Hannam et al., 2018) and 2) non-industrial wood ash (NIWA) which is generated mainly through residential combustion but can also include commercial sources such as small businesses (e.g pizzeria) (Azan, 2017). Industrial wood ash can be further classified into two primary groups based upon its origin within boilers: fly ash and bottom ash (Hannam et al., 2018). Fly ash is less dense and contains higher levels of dioxins and heavy metals than bottom ash (Narodoslawsky & Obernberger, 1996; Pitman, 2006). Fly ash is collected from the flue gases of power or steam boilers by an electrostatic precipitator (Elliott & Mahmood, 2006). The pH of fly ash ranges between 8.6 and 13.8 pH units while Ca concentrations have been reported to range between 92.1 – 247.9 g kg^{-1} (Hannam et al., 2018). Bottom ash accumulates at the base of boilers (Elliot & Mahmood, 2006) and leaves the combustion chamber at higher temperatures than fly ash, which results in lower concentrations of heavy metals such as cadmium (Cd), and Pb (Narodoslawsky & Obernberger, 1996). Bottom ash is generally less alkaline (pH ranges

7.5 to 12.9) and has a lower range in Ca concentrations (3.9 – 211.0 g kg^{-1}) compared with fly ash (Hannam et al., 2018).

Additionally, often found intermingled within finer ash are fragments of wood charcoal. Wood charcoal is a by product of incomplete wood combustion (Antal & Gronli, 2003), and like wood ash, wood charcoal derived from different tree species can vary widely in its physical and chemical properties (Pluchon et al., 2014). However, the chemical composition of wood charcoal can differ from that of finer ash. For example, wood charcoal derived from nine different tree species had a pH range of 6.25 to 7.24, while total P ranged from 1131 mg kg^{-1} to 3982 mg kg^{-1} (Pluchon et al., 2014); these values are much lower than previously reported values of pH and total P for wood ash (see Hannam et al.,2018). Furthermore, wood charcoal particle size can be larger than 2.0 mm (Nocentini et al., 2010) while finer ash particles are generally less than 1.0 mm (Etitgni & Campbell, 1991). Particle size has been associated with differences in ash chemical composition. For example, pH, Ca, and Mg have been observed to increase as particle size decreases (James et al., 2014) and metal concentrations have been observed to decrease as particle size increases (James et al., 2014; Smołka-Danielowska & Jabłońska, 2022). While studies exist on the biogeochemical effects of naturally occurring wood charcoal (i.e. charcoal produced from wildfires) on forest soil and its chemical composition (DeLuca et al., 2006; Pluchon et al., 2014), the chemical composition of wood charcoal produced within NIWA is not well studied. Therefore, if NIWA is to be used as a soil amendment, more research is needed to understand the chemical composition of wood charcoal, and if it should be removed from ash mixtures before land application.

Although wood ash has been shown to have several beneficial uses such as filler material in building construction, cement manufacturing, and previous studies have shown that IWA can be used as a liming agent for nutrient deficient or acidic soils (Elliot & Mahmood, 2006; Norstrom et al., 2012), currently most of the wood ash produced in Canada is treated as a hazardous waste material and is landfilled (Hannam et al., 2018). There is no federal legislation related to the disposal of wood ash, and thus ash management policies vary among the provinces (Hannam et al., 2016). A commonality among the provinces is for the ash to undergo an approval process if it is to be applied to land; ash must be analysed for trace metal concentrations and if levels exceed limits set out by the provinces, then it cannot be used as a soil amendment (Hannam et al., 2016).

In Ontario, wood ash falls under the Non-Aqueous Non-Agricultural Source Materials (NASM) Regulation 267/03 of the Nutrient Management Act. There are two regulated metal content limits within 267/03, CM1 and CM2. CM1 when used in reference to NASM refers to the concentration of regulated metals that fall below the unrestricted limits as defined by the regulation and CM2 pertains to concentration of regulated metals that fall above the CM1 limits however below the restrict CM2 limits (Table 2.1) (O. Reg 267/03)(Nutrient and Management Act, 2002). If one or more trace metals within the ash exceeds CM2 limits then it cannot be applied to land under the NASM regulation (Hannam et al., 2016). Guidelines developed for manure, biosolids and other approved soil amendments have been adapted as best management practices for ash application. These guidelines encompass various criteria including proximity to surface water, depth to ground water, slope, application timing and site type among others that must be followed during ash spreading (Hannam et al., 2016).

Table 2.1 Ontario regulation 267/03 Non-Aqueous Non-Agricultural Source Materials Restricted metal limits

Regulated Metals	CM1 - Unrestricted	CM2 - Restricted
Arsenic $mg.kg^{-1}$	13	170
Cadmium $mg.kg^{-1}$	3	34
Chromium $mg.kg^{-1}$	210	2800
Cobalt $mg.kg^{-1}$	34	340
Copper $mg.kg^{-1}$	100	1700
Lead $mg.kg^{-1}$	150	1100
Mercury $mg.kg^{-1}$	0.8	11
Molybdenum $mg.kg^{-1}$	5	94
Nickel $mg.kg^{-1}$	62	420
Selenium $mg.kg^{-1}$	2	34
Zinc $mg.kg^{-1}$	500	4200

Commercial burning of wood can generate up to 1% of ash by weight, resulting in significant waste by product (Pitman, 2006). Canada produces about 1 million Mg of wood ash per year based on the total contribution from pulp and paper mills and forest biomass (Lamer at al., 2018). In Quebec 150,000 Mg of wood ash was landfilled in 2005 while BC landfilled 96% of about 235,000 Mg in 2014 (Hannam et al., 2017). While NIWA production is much smaller in Ontario, Azan (2017) reported that approximately 18,000 Mg of wood ash is generated annually from residences, usually destined for landfill.

Concerns over wood ash chemical variability and regulatory approval policies must be addressed before wood ash can become a common soil amendment (Hannam et al., 2017). This applies more so to NIWA, as it might be more variable in its composition than industrial wood ash because it is derived from multiple sources (Azan et al., 2019). This is primarily due to a lack of consistency in feedstock control, tree species and parts of tree burned and differences in combustion temperature and ash handling (Azan et al., 2019). Furthermore, if the chemical composition of NIWA is variable and concentrations of one or more metals exceed regulatory values in homogenized samples the use of NIWA as a soil amendment will remain limited. The objective of this study was to evaluate the variability of the chemical composition of NIWA and to determine whether provincial regulatory guidelines are exceeded in samples that were homogenized for field application. To that end, 107 ash samples and 10 wood charcoal samples were collected from the residents of Muskoka, Ontario for chemical analysis, and a further subset of 30 samples of amalgamated ash, consisting of three varying ash mixtures that were composited for field application, were similarly analyzed for their chemical composition.

It was hypothesized that NIWA would contain high concentrations of nutrients and have metal (Mn, Al, Cd, Ni, Fe, Cu, As, B, Zn, Pb) levels lower than Ontario's Non-Aqueous Non-Agricultural Source Materials (NASM) regulation 267/03 CM2 guidelines. It was also expected that the chemical composition of homogenized ash would be less variable than unamalgamated ash samples and metal levels would not exceed CM2 guidelines.

2.3 Methodologies

2.3.1 Study Area

The District of Muskoka is in south-central Ontario, Canada at the southern edge of the Canadian Shield. It spans about 6475 km^2 and encompasses six different municipalities, including the towns of Bracebridge, Gravenhurst, Huntsville, and the townships of Georgian Bay, Lake of Bays, and Muskoka Lakes (Gallant, 2017). The region has a permanent population of 60,599 (Statistics Canada., 2017) and it sees approximately 83,000 seasonal residents due to its popularity as a cottage destination (Gallant, 2017). Three percent of Muskoka's population heats their homes using wood biomass producing approximately 235 000 kg of ash annually (Azan et al., 2019). In a survey conducted by Azan (2017), 57% of the survey respondents reported using mostly hardwood for their heating needs and that the most common species used included maple (*Acer spp*.), beech (*Fagus grandifolia*), oak (*Quercus spp*.), birch (*Betula spp*.), ash (*Fraxinus spp*.), and cherry (*Prunus spp*.) (Azan, 2017).

2.3.2 Study design

All non-industrial wood ash analyzed for this study, originated from various residences and a few small businesses within the Muskoka region. None of the ash used in this study originated from industrial sources. Wood ash was collected from individual homes and businesses during seasonal ash drives. Home and business owners were requested to store their ash and then deliver it to specific drop off locations (https://ashmuskoka.ca/locations/). Individual ash samples collected were stored outside in large, galvanized metal bins with a lid (Figure 2.1a). The bins were further protected against various weather elements with a plastic tarp, until ready for homogenization and laboratory analyses. Care was taken to keep individually donated samples separate. From the donated ash samples, 107 samples were collected in October 2019 for laboratory analyses. Grab samples were collected and placed into small plastic zip-lock bags and an identification code was assigned to the individual bags unique to that sample (Figure 2.1b). Ash from bins which showed signs of rust were not used due to the possibility of metal contamination. Ten wood charcoal samples were also collected randomly from within the donated ash for laboratory analyses.

The 107 individual ash samples (unamalgamated ash) were then homogenized using a large cement mixer. Multiple smaller portions of unamalgamated ash were added to the mixer at random, while the mixer was on and rotating to create multiple homogenized bulk mixtures. After the homogenization process was completed the ash mixtures were divided into three contrasting ash groups (amalgamated ash mixtures A, B and C). Each group contained multiple bins, from which a further ten subsamples each were collected for laboratory analyses (total samples n = 30) (Figure 2.2). Sample collection was conducted in field while the amalgamated ash mixtures were being land applied to closely resemble real world application. Samples were collected and placed into small plastic zip-lock bags and marked with an identification code unique to that sample.

Figure 2.1: Photograph of a metal storage bin for unamalgamated nonindustrial wood ash (a), photograph of amalgamated ash samples for laboratory analyses (b)

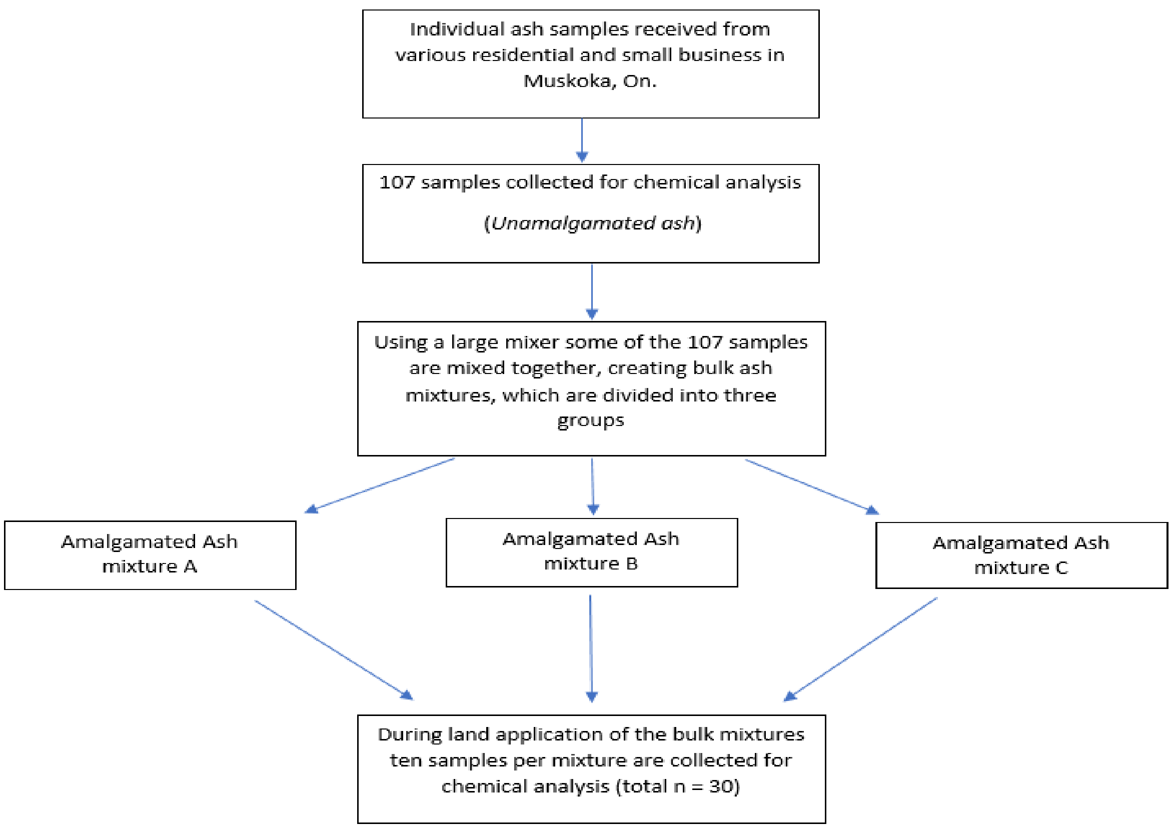


Figure 2.2: Flowchart for the homogenization process of three contrasting amalgamated ash mixtures, derived from individual ash samples collected from the residents of Muskoka, ON in 2019.

2.3.3 Laboratory Analyses

Ash and wood charcoal analyses

All ash samples were oven dried for 24 hours at 110°C and then sieved (2mm). Any foreign objects (e.g., metal nails, plastic parts, partially burned paper) were removed and discarded, and samples were then sieved again using a 0.25 mm soil sieve. Samples were analyzed for pH_{CaCl2}, loss-on-ignition (LOI), Carbon, Nitrogen, and Sulphur content (CNS), total metals (Zn, Pb, Ni, Mn, Fe, Cu, Cd, B, As, Al) and macro-nutrients (Ca, Mg, K, P). Wood charcoal samples were sieved using a 2 mm soil sieve, and any foreign objects were removed and discarded. Like the ash samples, wood charcoal samples were analyzed for pH_{CaCl2}, LOI, CNS, and total metals and macro-nutrients. Wood charcoal samples were ground using a mortar and pestle prior to analyses.

An OAKTON pH 510 series multimeter was used to measure pH of the ash and wood charcoal samples in a 0.01M $CaCl_2$ slurry at a ratio of 1:5 (ash:$CaCl_2$). All slurries were gently agitated for 45 mins and rested for an additional 45 min before taking a pH reading. Organic matter was determined using the LOI method (Ball, 1964). Five grams of sample was weighed out into porcelain crucibles and oven dried for 8 hours at 110°C to derive the moisture content using the equation ((wet mass – dry mass) / dry mass) x 100. Samples were then placed into a muffle furnace at 450°C for 8 hours to determine percent organic matter. Sample CNS content was determined using a CNS combustion analyzer (Elementar vario MACRO cube CNS). Standards (NIST-1515-SRM apple leaves) were included in every run to test for recovery. Total metal and nutrient concentrations (Mn, Al, Fe, Ni, Cd, Zn, Cu, As, B, Pb, Ca, Mg, K, P) were determined using inductively coupled plasma - optical emission spectrometry (Perkin Elmer ICP-OES) after hot digestion using concentrated nitric acid. Approximately 0.2 grams of ash and wood charcoal samples were weighed into 50 ml digiTUBEs, and 2.5 mL of 100% trace metal grade nitric acid was added using a precision repeater; each tube was appropriately labeled with the corresponding sample ID. Soil standards (EnviroMAT SS-1) and blanks were run at the beginning and end of every approximately 44 samples to test for accuracy and contamination (Recoveries were 95 to 100%). A hot plate was used to digest the samples for 8 hours at 100°C, after which they were further digested at room temperature for an additional 8 hours until the entire sample dissolved. Sample tubes containing the digestates were individually rinsed with B-pure water approximately 3 times and filtered into 25 mL volumetric flasks using a P8 Fast Flow Filter Paper. Solutions were further diluted to 25 mL with B-pure water and transferred into 50 mL Falcon tubes and refrigerated until analysed.

2.3.4 Statistical Analyses

To test the null hypothesis that amalgamated ash is similar in chemical composition to unamalgamated ash, comparisons were made between unamalgamated ash samples (n = 107) and amalgamated ash samples' (n = 30), pH, nutrient and metal concentrations, using a Kruskal-Wallis rank sum test since assumptions of normality (according to the Shapiro-Wilk's test) were not met. Significance level was set at $P = 0.05$. A post hoc Dunn's test, with a Bonferroni correction, was completed only on those variables where a significant difference was determined. Comparisons between unamalgamated ash samples and wood charcoal samples were also conducted using a Kruskal-Wallis rank sum test.

Spearman's correlation matrices were calculated to identify correlations between unamalgamated ash samples' metal and nutrient concentrations. Outliers were not removed to ensure the full range of unamalgamated ash chemistries was considered.

Nonparametric bootstrap analysis was conducted on unamalgamated ash samples' chemistry data to estimate the potential variability within the amalgamated ash's population parameters. Bootstrap sampling was done by randomly drawing data points (n = 20) from unamalgamated ash chemistry data and returning the drawn data values back for them to be available for the next draw. Multiple draws were conducted (n = 1000) to derive the mean and standard deviation for ash pH, nutrient, and metal concentration. All statistical analyses were performed with RStudio Version 4.1.0 (RStudio Team, 2021)

2.4 Results

2.4.1 Unamalgamated Non-Industrial Wood Ash Chemistry

Unamalgamated non-industrial wood ash chemistry varied considerably among the 107 samples; however, elemental concentrations were generally consistent with previously reported industrial ash values, with some notable exceptions (Table 2.2). Mean ash Ca and K concentrations were higher in our study samples (Ca: 141.62 – 676.96 g/kg^{-1}; K: 36.63 – 281.05 g/kg^{-1}) compared with reported ranges for industrial ash and mean Mg and P concentrations in the 107 samples (Mg: 10.02 – 59.59 g/kg^{-1}; P: 3.60 – 28.01 g/kg^{-1}) were comparable to the highest values reported for industrial wood ash

(Table 2.2). Furthermore, mean concentrations of most metals fell below or were at the lower end of reported industrial ash ranges. Nevertheless, mean Cd (3.0 mg kg^{-1}), Zn (502.1 mg kg^{-1}) and As (8.7 mg kg^{-1}) concentrations were above the unrestricted (CM1) NASM guidelines but were well below the restricted (CM2) NASM guidelines (Table 2.2). Ash S concentrations were below detection limits while reported ranges for industrial ash were generally higher. Mean ash pH was generally within the reported industrial ash values while C and N were found to be at the lower end of reported values (Table 2.2).

While mean values indicate that NIWA is generally rich in base cations and P concentrations, with low levels of trace metals compared with industrial ash, large variations in unamalgamated ash pH, nutrient and metal concentrations were observed. For example, ash pH in approximately 50% of sample was above 13 pH units, while the Ca concentration in approximately 35% of the sample was below 299 g kg^{-1} and approximately 79% were under 29.84 g kg^{-1} for Mg (median value for ash Ca and Mg were 316.5 and 24.3 g kg^{-1} respectively) (Figure 2.3). Trace metal concentrations in ash were similarly very variable with coefficients of variability for most metals exceeding 100% (Table 2.2). Importantly, concentrations of Pb, As and Cu in ash were below the restricted (CM2) limits in every test sample except three (out of 107) samples, whereas all 107 ash samples had Zn, Ni, and Cd concentrations under restricted (CM2) limits (Figure 2.4). Of the 107 ash samples analyzed 35% (Zn), 1% (Ni), 38% (Cd), 6% (Pb), and 7% (As) had concentrations above unrestricted (CM1) limits. Of the trace metals, Cu most consistently exceeded guidelines; Cu concentrations in 63% of samples exceeded the unrestricted (CM1; 100 mg kg^{-1}) limit (Table 2.2).

Table 2.2: pH, LOI, CNS, nutrient and metal concentrations of unamalgamated non-industrial wood ash (n=107), samples collected from residents of Muskoka District during 2019, as well as literature values for industrial bottom and fly ash generated in plants across Canada and previously reported literature values for NIWA from Muskoka, On. Also shown are the Ontario Regulation 267/03 of the Nutrient Management Act limits for unrestricted (CM1) and restricted (CM2) use of wood ash for land application as a non-agricultural non-aqueous source material are also shown.

	Unamalgamated Non-industrial Wood Ash				NIWA (Lit. values)	Industrial Bottom Ash	Industrial Fly Ash	NASM Limits**	
	Mean	*Median*	*SD*	*Cv (%)*				*CM Level 1*	*CM Level 2*
pH	11.0					7.5 - 12.9*	8.6 - 13.8*		
LOI	2.3	2.0	1.7	72.6					
C (%)	8.8	8.8	1.3	14.7		0.5 - 51.8*	2.7 – 43*		
N (%)	0.1	0.1	NA	NA		<0.01 - 0.3*	0.04 - 0.4*		
S (%)	BDL	BDL	NA	NA		<0.01 - 2.5*	<0.01 - 4.7*		
Ca (g.kg^{-1})	323	316	80.0	24.7		3.9 - 211 *	92.1 - 247.9*		
Mg (g.kg^{-1})	26.1	24.3	8.4	32.1		0.6 - 33.1*	6.4 - 29.4*		
K(g.kg^{-1})	120	115	44.2	36.7		0.8 - 50.8*	13.5 - 90.8*		
P (g.kg^{-1})	9.1	8.2	3.8	41.4		0.1 - 11.9*	3.2 - 10.6*		
Cd (mg.kg^{-1})	3.0	2.3	2.4	80.1	2.02†	0.4 - 0.7††	6 – 40††	3	34
As (mg·kg^{-1})	8.7	1.1	37.8	435	0.61†	0.2 – 3††	1 – 60††	13	170
Ni (mg·kg^{-1})	10.5	8.2	11.3	107	4.18†	40 – 250††	20 – 100††	62	420
Pb (mg·kg^{-1})	45.0	8.5	196	437	3.05†	15 – 60††	40 - 10^3††	150	1100
Cu (mg·kg^{-1})	163	109	259	158	100.49†	15 – 300††	~200††	100	1700
Zn (mg·kg^{-1})	502	416	355	70.9	500.6†	15 – 10^3††	40 – 700††	500	4200
Mn (mg·kg^{-1})	4853	5116	1743	35.9		(2 - 5.5) 10^3††	(6 - 9) 10^3††		
Al (mg·kg^{-1})	4177	3028	3238	77.5					
B (mg·kg^{-1})	239	222	71.9	30.1					
Fe (mg·kg^{-1})	2057	1306	2786	135					

*BDL: Below Detection Limit, AshNet – Ash Chemistry database *, Azan (2019)†, Pitman (2006) ††, Nutrient and Management Act 2002**,*

Figure 2.3: Distribution in nutrient concentrations of unamalgamated non-industrial wood ash (n = 107).

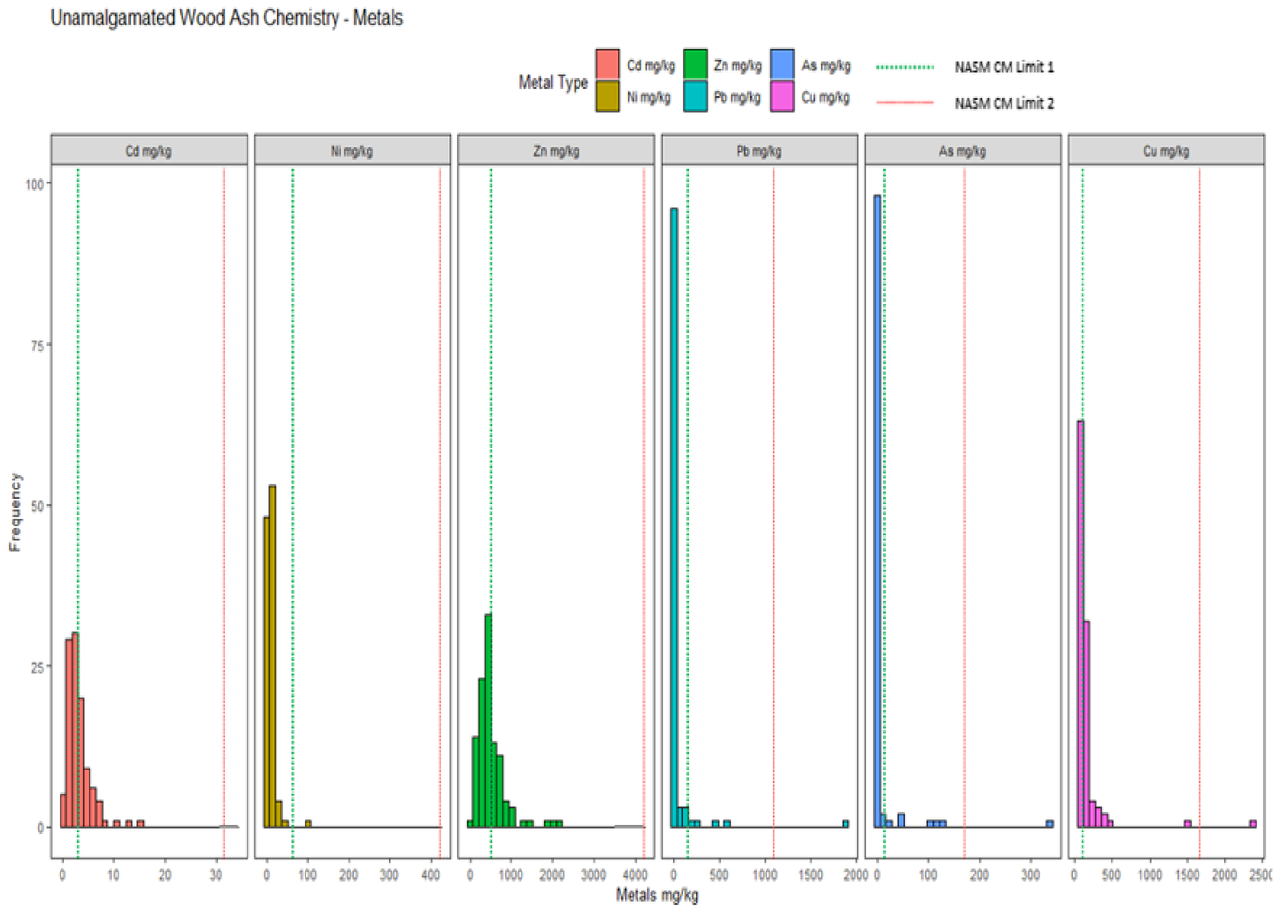


Figure 2.4: Distribution of metal concentrations in unamalgamated non-industrial wood ash (n=107) samples, and Ontario Regulation 267/03 of the Nutrient Management Act limits for unrestricted (CM1) and restricted (CM2) use of wood ash for land application as a non-agricultural non-aqueous source material are also indicated with dashed green and red lines respectively.

Spearman's correlation matrices indicated significant positive relationships between macronutrients (Ca, Mg, P, K) (Figure 2.5). Boron concentrations in ash were also positively correlated with K, Mg, and P but most metals were not significantly correlated with ash macronutrients.

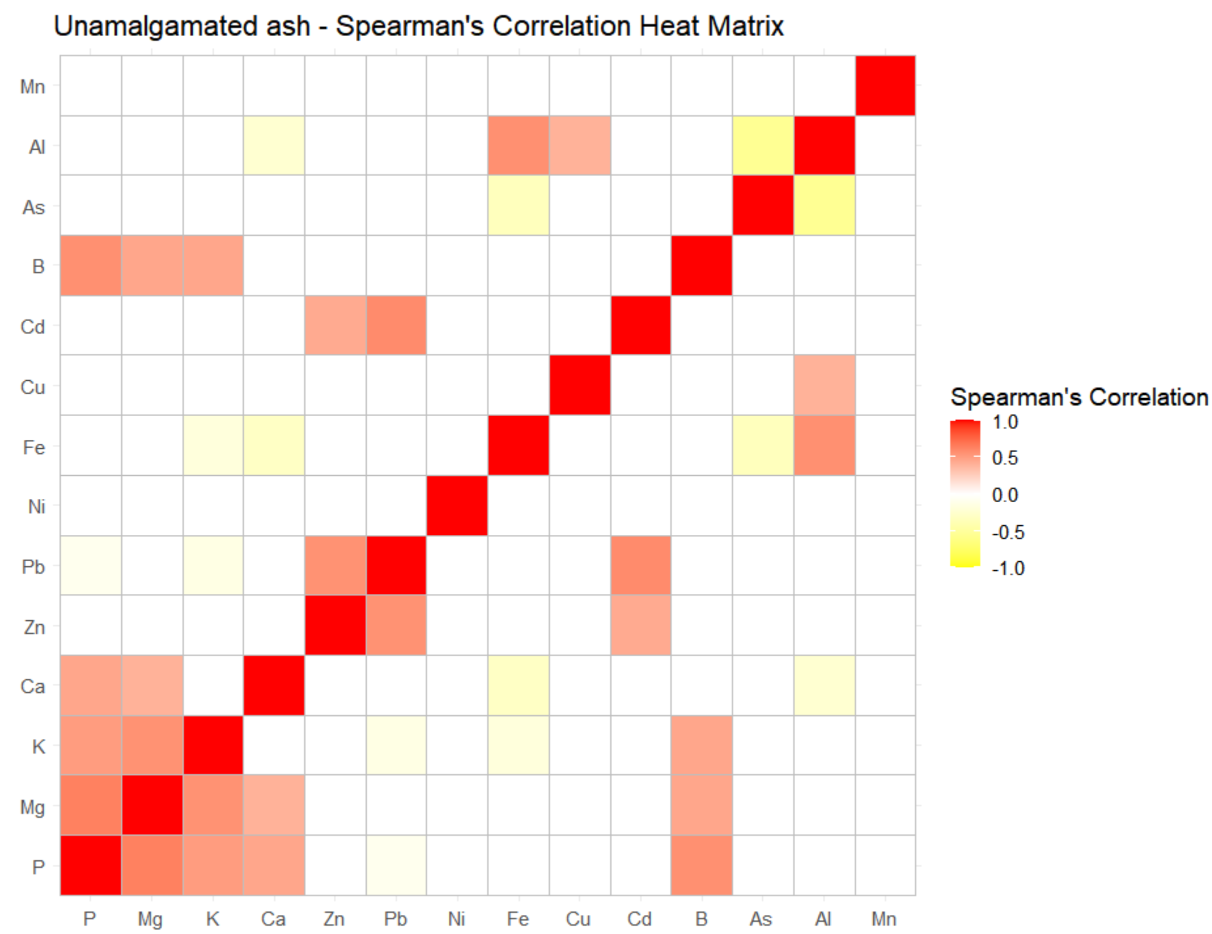


Figure 2.5: Spearman's correlation matrices of unamalgamated non-industrial wood ash samples, collected from residents in Muskoka, Ontario (n = 107). White boxes or those not included were not significant at $p < 0.05$.

2.4.2 Non-Industrial Wood Charcoal Chemistry

Like unamalgamated non-industrial wood ash, concentrations of nutrients and metals in wood charcoal were generally within the reported ranges for industrial wood ash, but some notable differences between charcoal and ash chemistry were observed

(Table 2.3). Mean wood charcoal K concentrations (134.7 g kg^{-1}) were higher than previously reported industrial ash values (Bottom ash: 0.8 – 50.8, Fly ash: 13.5 90.8 g kg^{-1}). Mean wood charcoal metal concentrations for Cd, As, Ni, Pb, and Cu fell below the reported values for industrial fly ash, and within the reported ranges of bottom ash except for Cd, which was higher in the study samples (Table 2.3). Like unamalgamated ash, metal concentrations in wood charcoal were generally lower than the NASM unrestricted (CM1) and restricted (CM2) limits. Wood charcoal concentrations for Cd, As, Ni, Pb, and Zn were below unrestricted (CM1) limits for all test samples. Wood charcoal Cu concentrations were the exception, as 80% of the samples were above the unrestricted (CM1) limit (100 mg kg^{-1}), however all samples were under the Cu restricted (CM2) limits (1700 mg kg^{-1}).

Mean wood charcoal pH and nutrient and metal concentrations tended to be lower than unamalgamated wood ash concentrations, but this difference was only significant for pH, Ca, and Mg (Table 2.3). For example, mean wood charcoal pH was 10.8 and mean concentrations for Ca, and Mg were 232 g kg^{-1}, and 21 g kg^{-1} respectively compared with 11.0, 323.7 g kg^{-1}, and 26 g kg^{-1} for unamalgamated ash. Mean wood charcoal concentrations for Cd, Ni, Pb, Cu, Zn, Fe, and Al were all generally lower than in unamalgamated ash except for Mn; however, the differences were not statistically significant.

Table 2.3: pH, LOI, CNS, nutrient and metal concentrations of non-industrial wood charcoal (n=10), collected from residents of Muskoka District during 2019. Literature values of industrial bottom and fly ash generated in plants across Canada and previously reported literature values for NIWA from Muskoka, On. Also shown are the Ontario Regulation 267/03 of the Nutrient Management Act limits for unrestricted (CM1) and restricted (CM2) use of wood ash for land application as a non-agricultural non-aqueous source material are shown for reference. Significant differences (***) to unamalgamated ash and wood charcoal were determined by a Kruskal Wallis test. P value significant at 0.05.

	Non-industrial Wood Charcoal				NIWA (Lit. values)	Industrial Bottom Ash	Industrial Fly Ash	NASM Limits**	
	Mean	*Median*	*SD*	*Cv (%)*				*CM Level 1*	*CM Level 2*
pH	**10.0*****▼					7.5 - 12.9*	8.6 - 13.8*		
LOI	14.8	14.0	7.5	50.7					
C (%)	18.6	16.0	6.8	36.6		0.5 - 51.8*	2.7 – 43*		
N (%)	0.2	0.2	0.1	50.0		<0.01 - 0.3*	0.04 - 0.4*		
S (%)	BDL	BDL	NA	NA		<0.01 - 2.5*	<0.01 - 4.7*		
Ca (g.kg^{-1})	**232*****▼	234	46.0	19.6		3.9 - 211 *	92.1 - 247.9*		
Mg (g.kg^{-1})	**21.0*****▼	19.7	7.0	33.3		0.6 - 33.1*	6.4 - 29.4*		
K(g.kg^{-1})	134	129	41.9	31.0		0.8 - 50.8*	13.5 - 90.8*		
P (g.kg^{-1})	8.0	7.0	4.0	50.0		0.1 - 11.9*	3.2 - 10.6*		
Cd (mg.kg^{-1})	1.8	2.0	0.7	38.9	2.02 †	0.4 - 0.7 ††	6 – 40 ††	3	34
As (mg·kg^{-1})	BDL	BDL	NA	NA	0.61 †	0.2 – 3 ††	1 – 60 ††	13	170
Ni (mg·kg^{-1})	8.0	8.0	3.7	46.3	4.18 †	40 – 250 ††	20 – 100 ††	62	420
Pb (mg·kg^{-1})	7.0	7.8	3.0	42.9	3.05 †	15 – 60 ††	40 - 10^3 ††	150	1100
Cu (mg·kg^{-1})	127	117	33.0	26.0	100.49 †	15 – 300 ††	~200 ††	100	1700
Zn (mg·kg^{-1})	408	407	124	30.6	500.6 †	15 – 10^3 ††	40 – 700 ††	500	4200
Mn (mg·kg^{-1})	5366	5759	1536	28.6		(2 - 5.5) 10^3 ††	(6 - 9) 10^3 ††		
Fe(mg·kg^{-1})	1412	1335	456	32.4					
B (mg·kg^{-1})	216	198	72.7	33.7					
Al (mg·kg^{-1})	2616	2425	1101	42.1					

*BDL: Below Detection Limit, AshNet – Ash Chemistry database *, Azan (2019) †, Pitman (2006) ††, Nutrient and Management Act 2002***

2.4.3 Non-Industrial Amalgamated Wood Ash Mixtures' Chemistry

Amalgamated wood ash mixtures were generally consistent in their chemical composition and mean values were similar to those measured in unamalgamated ash, however a few notable differences were found (Table 2.4). Ash pH and Cu concentrations were significantly lower for amalgamated ash mixture C when compared to mixtures A and B. Amalgamated ash mixture B contained lower concentrations of Pb than ash mixtures A and C. Meanwhile ash concentrations of Fe varied amongst all three sample sets. Mean ash concentrations of K and Ca were higher for all three amalgamated ash mixtures than the reported ranges for industrial ash. Mean concentrations of Cd, Cu, and Ni in ash were lower than the reported ranges for fly ash, while As and Zn concentrations were above the reported ranges for bottom ash but were within the reported ranges for fly ash.

Concentrations of Cd, As, Ni, and Pb in all three amalgamated ash mixtures were under unrestricted (CM1) limits. In contrast, a high proportion of samples from the three mixtures exceeded the CM1 limits for Zn and Cu, however no samples exceeded CM2 limits. For example, for amalgamated ash mixture A 80% of samples exceeded CM1 limits for Cu while 50% exceeded CM1 Zn limits. In comparison for amalgamated ash mixture B 90% of the samples exceeded CM1 Cu limits and 50% of samples exceeded CM1 Zn limits. For amalgamated ash mixture C 60% of ash samples exceeded CM1 Cu limits but all samples were under CM1 Zn limit.

Table 2.4 pH, LOI, CNS, nutrient and metal concentrations of 3 contrasting amalgamated NIWA mixtures (n=10 each), and literature values for industrial bottom, fly, and previously reported NIWA values. Ontario Regulation 267/03 of the Nutrient Management Act limits for unrestricted (CM1) and restricted (CM2) use of wood ash for land application as a non-agricultural non-aqueous source material are also shown. Significant differences among the 3 amalgamated ash samples determined by a Kruskal Wallis test with a post hoc Dunn's test indicated with different letters. P value significant at 0.05

	Amalgamated Non-industrial Wood Ash				NIWA (Lit. values)	Industrial Bottom Ash	Industrial Fly Ash	NASM Limits**	
	Mean	*Median*	*SD*	*Cv (%)*				*CM Level 1*	*CM Level 2*
Ash Mixture A									
pH	**13.5** ^{a}					7.5 - 12.9*	8.6 - 13.8*		
LOI	3.5	3.5	0.8	22.9					
C (%)	11.6	10.0	4	34.0		0.5 - 51.8*	2.7 – 43*		
N (%)	0.2	0.1	0.2	100		<0.01 - 0.3*	0.04 - 0.4*		
S (%)	BDL	BDL	NA	NA		<0.01 - 2.5*	<0.01 - 4.7*		
Ca ($g.kg^{-1}$)	305	305	15.2	5.0		3.9 - 211 *	92.1 - 247.9*		
Mg ($g.kg^{-1}$)	24.2	23.8	2.5	10.7		0.6 - 33.1*	6.4 - 29.4*		
K($g.kg^{-1}$)	109	108	13.0	12.0		0.8 - 50.8*	13.5 - 90.8*		
P ($g.kg^{-1}$)	8.8	8.5	1.2	13.4		0.1 - 11.9*	3.2 - 10.6*		
Cd ($mg.kg^{-1}$)	2.7	2.8	0.4	14.4	2.02 [†]	0.4 - 0.7 [††]	6 – 40 [††]	3	34
As ($mg{\cdot}kg^{-1}$)	3.9	0.2	6.0	153	0.61 [†]	0.2 – 3 [††]	1 – 60 [††]	13	170
Ni ($mg{\cdot}kg^{-1}$)	10.5	9.6	3.0	30.4	4.18 [†]	40 – 250 [††]	20 – 100 [††]	62	420
Pb ($mg{\cdot}kg^{-1}$)	**24.3** ^{a}	21.3	17.0	71.8	3.05 [†]	15 – 60 [††]	40 - 10^{3} [††]	150	1100
Cu ($mg{\cdot}kg^{-1}$)	**140** ^{a}	133	41.9	29.8	100.49 [†]	15 – 300 [††]	~200 [††]	100	1700
Zn ($mg{\cdot}kg^{-1}$)	523	495	109	20.9	500.6 [†]	15 – 103 [††]	40 – 700 [††]	500	4200
Mn ($mg{\cdot}kg^{-1}$)	6306	6373	683	10.8		(2 - 5.5) 10^{3} [††]	(6 - 9) 10^{3} [††]		
Fe ($mg{\cdot}kg^{-1}$)	**2793** ^{a}	2607	1150	41.0					
Ash Mixture B									
pH	**13.3** ^{a}					7.5 - 12.9*	8.6 - 13.8*		
LOI	5.8	5.0	1.0	17.7					
C (%)	8.8	8.5	0.8	9.0		0.5 - 51.8*	2.7 – 43*		
N (%)	0.1	0.1	NA	NA		<0.01 - 0.3*	0.04 - 0.4*		
S (%)	BDL	BDL	NA	NA		<0.01 - 2.5*	<0.01 - 4.7*		
Ca ($g.kg^{-1}$)	273	289	48.4	17.7		3.9 - 211 *	92.1 - 247.9*		
Mg ($g.kg^{-1}$)	22.1	22.7	3.5	16.0		0.6 - 33.1*	6.4 - 29.4*		
K($g.kg^{-1}$)	112	118	21.7	19.3		0.8 - 50.8*	13.5 - 90.8*		
P ($g.kg^{-1}$)	7.9	8.1	1.2	15.1		0.1 - 11.9*	3.2 - 10.6*		
Cd ($mg.kg^{-1}$)	2.5	2.5	0.6	24.7	2.02 [†]	0.4 - 0.7 [††]	6 – 40 [††]	3	34
As ($mg{\cdot}kg^{-1}$)	3.1	BDL	7.4	237	0.61 [†]	0.2 – 3 [††]	1 – 60 [††]	13	170
Ni ($mg{\cdot}kg^{-1}$)	8.8	8.9	2.0	22.5	4.18 [†]	40 – 250 [††]	20 – 100 [††]	62	420
Pb ($mg{\cdot}kg^{-1}$)	**12.7** ^{b}	13.5	3.8	30.3	3.05 [†]	15 – 60 [††]	40 - 10^{3} [††]	150	1100
Cu ($mg{\cdot}kg^{-1}$)	**154** ^{a}	129	92.1	59.8	100.49 [†]	15 – 300 [††]	~200 [††]	100	1700
Zn ($mg{\cdot}kg^{-1}$)	516	504	151	29.3	500.6 [†]	15 – 103 [††]	40 – 700 [††]	500	4200
Mn ($mg{\cdot}kg^{-1}$)	6837	7029	1023	15.0		(2 - 5.5) 10^{3} [††]	(6 - 9) 10^{3} [††]		
Fe ($mg{\cdot}kg^{-1}$)	**1322** ^{b}	1199	528	39.9					
Ash mixture C									
pH	**11.5** ^{b}					7.5 - 12.9*	8.6 - 13.8*		
LOI	5.6	5.5	1.0	17.8					
C (%)	9.1	8.8	0.9	9.8		0.5 - 51.8*	2.7 – 43*		
N (%)	0.1	0.1	NA	NA		<0.01 - 0.3*	0.04 - 0.4*		
S (%)	BDL	BDL	NA	NA		<0.01 - 2.5*	<0.01 - 4.7*		
Ca ($g.kg^{-1}$)	294	308	46.4	15.7		3.9 - 211 *	92.1 - 247.9*		
Mg ($g.kg^{-1}$)	22.5	23.0	3.8	16.9		0.6 - 33.1*	6.4 - 29.4*		
K($g.kg^{-1}$)	104	107	20.3	19.5		0.8 - 50.8*	13.5 - 90.8*		
P ($g.kg^{-1}$)	7.8	8.1	1.2	15.0		0.1 - 11.9*	3.2 - 10.6*		
Cd ($mg.kg^{-1}$)	2.6	2.7	0.4	15.2	2.02 [†]	0.4 - 0.7 [††]	6 – 40 [††]	3	34
As ($mg{\cdot}kg^{-1}$)	3.7	0.9	5.7	153	0.61 [†]	0.2 – 3 [††]	1 – 60 [††]	13	170
Ni ($mg{\cdot}kg^{-1}$)	7.9	8.4	1.5	19.1	4.18 [†]	40 – 250 [††]	20 – 100 [††]	62	420
Pb ($mg{\cdot}kg^{-1}$)	**48.5** ^{a}	20.9	64.2	132	3.05 [†]	15 – 60 [††]	40 - 10^{3} [††]	150	1100
Cu ($mg{\cdot}kg^{-1}$)	**106** ^{b}	102	15.2	14.3	100.49 [†]	15 – 300 [††]	~200 [††]	100	1700
Zn ($mg{\cdot}kg^{-1}$)	439	457	61.5	14.0	500.6 [†]	15 – 103 [††]	40 – 700 [††]	500	4200
Mn ($mg{\cdot}kg^{-1}$)	6329	6443	1215	19.2		(2 - 5.5) 10^{3} [††]	(6 - 9) 10^{3} [††]		
Fe ($mg{\cdot}kg^{-1}$)	**1872** ^{ab}	1691	634	33.9					

*BDL: Below Detection Limit, AshNet – Ash Chemistry database *, Azan (2019)[†], Pitman (2006) [††], Nutrient and Management Act 2002***

2.4.4 Unamalgamated Ash Samples and Amalgamated Ash mixtures Comparison

Some differences were observed between the chemical composition of unamalgamated and amalgamated ash samples (Table 2.5). The pH of amalgamated ash mixture C was lower than the unamalgamated ash and the pH of amalgamated ash mixture A was higher than the unamalgamated ash (Table 2.5). Furthermore, mean concentrations for Ca, Mg, K and P were lower (10 – 20%) than the unamalgamated ash. There were fewer differences in metal concentrations between amalgamated ash mixtures and unamalgamated samples although Mn was significantly higher for amalgamated ash mixture B and Fe was lower for amalgamated ash mixture A compared with the unamalgamated ash (Table 2.5). A bootstrap analysis conducted on unamalgamated ash data showed that the mean concentrations of all elements fell within the standard deviation indicating that field samples of amalgamated ash were within the range of unamalgamated values suggesting the methodological approach for field application of ash produces relatively consistent values that are within the expected range (Table 2.5).

Table 2.5: pH, nutrient and metal concentration values for non-industrial wood ash broken down by unamalgamated (n = 107) ash and amalgamated ash mixtures (n = 10 per mix). Significant differences determined by a Kruskal Wallis test with a post hoc Dunn's test indicated with different letters. P value significant at 0.05. Bootstrapped data for pH, nutrients, and metal concentrations of unamalgamated NIWA randomly selected with replacement (n = 20) with replications (Replicates =1000) are also shown.

	Unamalgamated Ash		*Amalgamated Ash A*		*Amalgamated Ash B*		*Amalgamated Ash C*			*Bootstrap Data*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*P value*	*Mean*	*SD*
pH	12.5^{c}		13.5^{a}		13.0^{ac}		11.5^{b}		< 0.001	12.5	1.0
Ca (g.kg⁻¹)	323.7^{b}	80.3	305.8^{a}	15.2	273.5^{a}	48.3	294.5^{a}	46.3	< 0.001	324.0	80.9
Mg (g.kg⁻¹)	26.1^{b}	8.3	24.1^{a}	2.5	22.0^{a}	3.5	22.5^{a}	3.8	< 0.001	26.0	8.0
K(g.kg⁻¹)	120.4^{b}	44.2	109.5^{a}	13.1	112.6^{a}	21.7	104.2^{a}	20.3	< 0.001	120.0	43.6
P (g.kg⁻¹)	9.1^{b}	3.7	8.8^{a}	1.1	7.9^{a}	1.2	7.8^{a}	1.1	< 0.001	9.1	3.7
Cd (mg.kg⁻¹)	3.0	2.4	2.7	0.4	2.5	0.6	2.6	0.4	0.724	3.0	2.0
As (mg·kg⁻¹)	8.6	37.8	3.9	6.0	3.1	7.4	3.7	5.7	0.642	8.8	38.0
Ni (mg·kg⁻¹)	10.5	11.2	10.5	3.1	8.8	2.0	7.9	1.5	0.3783	10.0	11.0
Pb (mg·kg⁻¹)	45.0^{b}	196.8	24.3^{a}	17.4	12.7^{a}	3.8	48.5^{ab}	64.1	< 0.001	45.0	195.7
Cu (mg·kg⁻¹)	163.5	259.4	140.8	41.9	154.1	92.0	106.1	15.2	0.146	164.6	263.0
Zn (mg·kg⁻¹)	502.1	355.8	523.5	109.5	516.0	151.2	439.6	61.5	0.221	504.0	355.0
Mn (mg·kg⁻¹)	4853.9^{b}	1751.3	6306.6^{ab}	683.7	6837.2^{a}	1023.1	6329.9^{ab}	1215.1	< 0.001	4859.8	1729.5
B (mg·kg⁻¹)	238.9	71.9	235.5	46.0	239.3	49.9	213.1	30.1	0.6676	239.6	71.9
Fe(mg·kg⁻¹)	2057.1^{b}	2777.1	2793.0^{a}	1150.0	1322.8^{b}	528.0	1872.8^{ab}	634.5	< 0.003	2056.8	2766.0
Al (mg·kg⁻¹)	4177.4	3238.6	4075.9	1031.8	3044.6	1019.2	3933.0	1261.5	0.438	4139.9	3206.8

2.5 Discussion

This study evaluated the chemical composition of NIWA generated from residential wood stoves in the district of Muskoka. We found that NIWA is rich in macro nutrients (Ca, Mg, K and P), and metal concentrations were generally within the NASM guidelines for land application. There was considerable chemical variability amongst individual wood ash samples, however once homogenized, the chemical composition of the bulk sample was relatively consistent and metal concentrations in each test sample were under CM2 levels. Additionally, NIWA metal concentrations were generally lower than the reported values for industrial wood ash, while base cation concentrations were higher.

2.5.1 Unamalgamated non-industrial wood ash

Wood ash samples tested in this study contained high concentrations of Ca, Mg, and K that were higher than previously reported industrial ash concentrations. For example, Hannam et al., (2018) examined the chemical properties of fly and bottom ashes generated in bioenergy plants across Canada and reported total Ca concentrations between 92.2 g kg^{-1} and 247.9 g kg^{-1} for fly ash and 3.9 g kg^{-1} to 211.0 g kg^{-1} for bottom ash, while our study sample range was 141.6 g kg^{-1} to 679.9 g kg^{-1}. Such high levels of macro nutrients can be attributed to factors such as the chemical composition of tree species, along with the parts of tree burned (Deighton & Watmough, 2020; Pitman, 2006). For example, Deighton & Watmough, (2020) reported yellow birch (*Betula alleghaniensis*) ash had higher concentrations of K than white pine. Furthermore, data from the national tree chemistry database in the northeastern United States, reported mean Ca concentrations for sugar maple bark (n = 118) were 24 g kg^{-1}, while values for yellow birch (n = 23), and white pine (n =22) bark were just 10.9 g kg^{-1} and 4.2 g kg^{-1}, respectively, such variability amongst tree species carry over into the chemical composition of their ash. Additionally, variations within the same species were noted in nutrient concentrations of bark, bole, branch, and foliage. Mean Ca concentrations in sugar maple branch were reported to be 7.0 g kg^{-1}, while mean Ca foliage concentrations were 10.4 g kg^{-1} (Pardo et al., 2005). Ash nutrient variability may also be influenced by variation in wood chemistry within the same species growing under different soil conditions. A dendrochemical survey of sugar maple in south central Ontario across 22 sites found that wood Ca concentrations varied from extremely low concentrations in trees on the Precambrian Shield (< 790 mg kg^{-1}) to between 811 and 1173 mg kg^{1} at sites south of the Shield (Watmough, 2002).

Hardwoods generally contain higher levels of macro nutrients than softwoods, while tree bark tends to be rich in Ca concentrations (Pitman, 2006). In this study, NIWA was dominated by hardwood ash, as most Muskoka residents who responded to a survey (n = 47 responses received) indicated (Table 2.6). Additionally, per the survey the respondents indicated that they mainly burned bark (70.2%) and trunk wood (85.1%) while a large number claimed to use mostly hardwood such as maple (70.2%), birch (51.1%) and/or oak (*Quercus spp.*) (27.7%). Only about 25% of participants reported using softwood species such as pine (*Pinus spp*.), spruce (*Picea spp.)* and or hemlock (*Tsuga canadensis*). Higher levels of K concentration in NIWA may also be attributed to the lower temperatures associated with home wood stoves, resulting in lower volatilization losses of K compounds as volatilization occurs at around 1300 °C (Naylor & Schmidt, 1986).

Table 2.6 Survey responses to wood ash questionnaire, conducted in January 2021, from the residents of Muskoka District. Respondents indicated tree species commonly used along with parts of tree burned. Total number of respondents (n = 47).

Tree species	Total occurrence per survey respondent	Percent %
Ash (*Fraxinus spp*.)	3	6.4
Basswood *(Tilia americana)*	1	2.1
Beech (*Fagus grandifolia*)	10	21.3
Birch (*Betula spp*.)	24	51.1
Cherry (*Prunus spp.)*	4	8.5
Hemlock (*Tsuga canadensis*)	3	6.4
Iron wood *(Ostrya virginiana)*	3	6.4
Maple (*Acer spp*.)	33	70.2
Oak (*Quercus spp*.)	13	27.7
Pine (*Pinus spp*.)	7	14.9
Poplar *(Populus spp.)*	3	6.4
Spruce (*Picea spp.)*	2	4.3
Hardwoods	10	21.3
Softwoods	3	6.4
Tree parts burned		
Bark	33	70.2
Trunk	40	85.1
Branches	35	74.5

Ash metal concentrations varied greatly within the test sample set. Such dissimilarities in ash metal concentrations are logical based on previously reported findings on NIWA. NIWA originates from various sources and there is a lack of consistency in feed stock, burn temperature, and parts of tree used (Azan et al., 2019); factors which contribute tremendously to ash chemical composition (Pitman, 2006). For example, Deighton & Watmough (2020) reported large differences in metal concentrations of the three most burned (for heating) tree species within Muskoka. Yellow birch ash had higher concentrations of metals compared with sugar maple and white pine ash. For example, ash Zn concentrations in yellow birch ash were 12 times higher than sugar maple and white pine ash, while As and Pb concentrations were 9 and 6 times greater, respectively. Additionally, metal concentrations have been found to vary significantly in nine commonly found tree species within Muskoka (Landre et al., 2010). For example, Al concentrations in foliage is significantly higher in hemlock (*Tsuga canadensis*), white pine and balsam fir (*Abies balsamea*) while red maple (*Acer rubrum*), birch and oak have elevated Cu concentrations; meanwhile birch has significantly higher Cd however lower levels of Al compared with the other species (Landre et al.,2010).

Ash metal concentrations were generally low compared with industrial wood ash, and concentration within individual samples were mostly within the NASM guidelines. For example, ash Cd and Ni concentrations reported by Pitman, (2006) ranged between 6 – 40 and 20 – 100 mg kg^{-1} respectively, for industrial fly ash while ash samples tested in our study had mean Cd and Ni concentrations of 3.0 and 10.5 mg kg^{-1} respectively. Ash metal concentrations for most of the samples tested were under the CM2 NASM guidelines for restricted use of wood ash, with a few notable exceptions for Pb, As, and Cu. Concentrations of Cd, Zn and Ni were under CM2 limits for all samples, however, some exceeded CM1 limits. The trace metal with the highest number of samples exceeding the CM1 limit was Cu. These results are like the findings of a previous NIWA study conducted in Muskoka by Azan et al., (2019), who also observed mean Cu concentrations along with ash Zn concentrations to be above CM1 limits in their study. However, their study contained a much smaller number of test samples compared with the present study. Elevated levels of Cu concentrations in NIWA could be a result of our test samples containing a higher percentage of tree species rich in this trace metal such as yellow birch. Deighton & Watmough (2020), reported yellow birch ash concentrations for Cu, Cd, and Zn to be above CM1 guidelines, and yellow birch ash contained 2 to 3 times more Cu than ash from sugar maple or white pine. Additionally, Cu is volatized at temperatures generally above 1000 °C (Misra et al., 1993), while most home stoves commonly fire below 1200°C (Pitman, 2006).

Concentrations of most metals in ash were positively correlated to each other but not macro-nutrients, indicating that ash that is rich in nutrients does not have similarly high metal concentrations. This is likely due to the variation in the chemical composition of the tree species and parts of tree used, along with feed stock growing conditions (Pitman, 2006; Landre et al., 2010). For example, high levels of Mn, Ni and Zn have been found in tree foliage (Landre et al., 2010), meanwhile Ca concentrations tend to be highest in tree bark (Elliott & Mahmood, 2006). Therefore, ash samples which originate mainly from bark will be higher in Ca while ash coming from mainly burning foliage will have higher levels of metals. Based on these results it can be inferred that if one sample is higher in metals that does not mean others will have similar levels of metal concentrations.

Concentrations of Mg in NIWA used in this study were generally consistent with previously reported industrial ash Mg concentrations (Pitman, 2006), however they were higher than mean concentrations reported by Deighton & Watmough (2020) for NIWA. Furthermore, large variations in Zn concentration among ash samples originating from sugar maple, white pine and yellow birch have been observed (Deighton & Watmough, 2020). Similarly, Naylor & Schmidt (1986), reported large variation in Zn concentrations in ash derived from home stoves using only hardwoods. Metal bins used for storage of NIWA, foreign objects (e.g. metal nails) found in the donated samples, and tools used for the homogenization of the ash, may also contribute to trace metal concentrations through leaching. Leaching of metals such as Zn, Fe, Cr, and Pb can occur overtime through corrosion and/or erosion (Ghada et al., 2015; Gonzalez et al., 2013; Verissimo et al., 2006).

2.5.2 Non-Industrial Wood Charcoal

The chemical composition of wood charcoal was similar to ash with the exception that pH, Ca and Mg concentrations were significantly lower in charcoal than in ash. However, concentrations of most macronutrients were generally within the range for previously reported industrial wood ash, except for K concentrations that was higher in our samples. Previous literature has reported that metal concentrations in ash decrease as particle size increases (James et al., 2014; Smołka-Danielowska & Jabłońska, 2022) and although mean ash metal concentrations were generally lower in wood charcoal compared with finer wood ash a significant difference was observed only in As concentrations. Concentrations of all regulated metals were found to be under CM1 limits except for Cu where most of the samples tested were above CM1 limits but still under CM2 limits. These results suggests that wood charcoal metal concentrations may not differ vastly from finer NIWA therefore they do not require to be removed from ash mixtures before land application.

2.5.3 Amalgamated Non-Industrial Wood Ash

The three-contrasting amalgamated non-industrial wood ash mixtures were generally similar in their chemical composition and mean values were within the standard deviation of a bootstrap analysis of the individual ash samples providing evidence that mixing ash in the field produced ash mixtures with a relatively consistent chemical composition, with a few exceptions. Only one out of the three amalgamated ash mixtures had significantly lower pH and ash Cu concentrations. A few other differences were observed among the three sites in ash Pb and Fe concentrations, however overall, the ash applied at all three sites was generally similar in its chemical composition.

These values however are dependent upon the original unamalgamated samples. For example, although ash nutrient and metal concentrations for amalgamated ash mixtures were mostly consistent with previously reported concentrations for individual samples of NIWA (Azan et al., 2019, Deighton & Watmough, 2020); our ash's trace metal concentrations were generally much lower than values reported by Smolka-Danielowska & Jablonska, (2021). These inconsistencies may be attributed to differing feed stock location and or tree species used in their study compared with ours. For example, only 25% of respondents to our survey indicated the use of beech (21.3%) or spruce (4.3%), while none used Alder. Nevertheless, these differences highlight the importance of variations in feed stock quality.

Macro and micro element concentrations in all three amalgamated ash mixtures were below the CM2 NASM limits, but a few samples were above restriction limits for Pb, Cu and As concentrations. Moreover, when compared to trace metal restriction values set out in five European countries for ash application to forest soils our samples' mean metal concentrations were generally below limits. A notable exception is Germany (Table 2.6), which has the most stringent restrictions. Additionally, ash metal concentrations in the three mixtures were below the restriction limits for trace metal concentrations in Alberta (AB), British Columbia (BC), Nova Scotia (NS) and Quebec (QC) (Table 2.7), indicating that the NIWA used in this study meets trace metal guidelines for land application in several other locations, both within Canada and internationally.

Table 2.7 Restriction values for trace metals tested in this study for biomass ash for forest soil application in 5 European countries and 4 Canadian provinces (Hannam et al., 2018), compared with mean metal concentrations of three contrasting amalgamated ash mixtures. Amalgamated ash mixtures' metal concentrations that failed to meet requirements are highlight as A = Amalgamated ash mixture A, B = Amalgamated ash mixture B, and C = Amalgamated ash mixture C.

	AB	BC	NS		Qc		Denmark	Finland	Germany	Lithuania	Sweden
Ash Metals	Wood Ash	Soil Amendment	Biosolids		Fertilizing Residual						
			Class A	Class B	C1	C2					
As mg kg^{-1}	-	75	13	75	13	41	-	40	40	30	30
Cd mg kg^{-1}	46	20	3	20	3	10/15	20	25	1.5$^{A/B/C}$	30	30
Cu mg kg^{-1}	-	2200	400	760	400	1000	-	700	-	400	400
Pb mg kg^{-1}	-	500	150	500	120	300	250	150	150	300	300
Ni mg kg^{-1}	-	180	62	180	62	180	60	150	80	70	70
Zn mg kg^{-1}	5500	1850	700	1850	700	1850	-	4500	-	700	7000

2.6 Conclusion

Potentially high trace metal concentrations, large variability in feedstock chemistry, and poor understanding of the effects of homogenization on ash chemical composition are some of the barriers associated with the use of NIWA as a forest soil amendment. This study tested NIWA samples collected from the residential wood stoves in Muskoka, Ontario and found that NIWA is rich in important macro nutrients including

Ca and K, and low in most trace metals. Furthermore, ash nutrient concentrations were not correlated with ash metal concentrations, indicating that high levels of nutrients may not always be a good indicator of ash metal concentrations. Although there was substantial variability in the chemistry amongst individual ash samples, concentrations of most elements were within a relatively narrow range. Ash mixtures, amalgamated in the field were relatively homogenous in chemical composition and metal concentrations were generally below NASM regulation guidelines. Only Cu and Zn exceeded CM1 guidelines consistently however these levels were always below restricted metals land application limits (CM2). This study suggests that once homogenized, NIWA chemical composition is within the regulatory guidelines set out by several European countries and other provinces in Canada,

3. Short-term effects of non-industrial wood ash application at three sugar bushes in central Ontario.

3.1 Abstract

Short term effects of nonindustrial wood ash (NIWA) application (0, 4 and 8 Mg ha^{-1}) were evaluated at three sugar bush stands in Muskoka, south central Ontario. Ten months after NIWA application there was a significant increase in pH and exchangeable base cations concentrations in the L and FH soil horizons at treatment plots, with few treatment effects observed in the mineral horizons at all study sites. Concentrations of several metals (and metalloids) (Cd, Fe, Pb, Ni, Cu, B, Mn, Al, Zn) were also significantly higher (two to twenty times more) in the L horizon at all treatment plots compared with control plots. Diagnosis and recommendation integrated system (DRIS) analysis indicated that the three sites were deficient in K prior to treatment and foliar K generally doubled resulting in significant increases in sugar maple saplings and mature trees post application. Ash application resulted in only small increases in foliar concentrations of Ca, Mg, and some metals (Cd, Zn), in saplings and mature trees however these were mostly not significant and not consistent among the three sites. In the two years post application, there was no significant effect of ash treatment on sugar maple tree growth and ground vegetation diversity and richness responses to ash application were small and variable among the three study sites.

3.2 Introduction

Acidic deposition has enhanced the leaching of base cations (Ca, K, Mg, Na), from forest soils in Europe and North America (Johnson et al., 1985). Exchangeable base cations are leached when H^+ ions in soil solution increase and displace cations from soil into soil solution (Talhelm et al., 2012). In poorly buffered soils, H^+ loading can enhance dissolution of reactive forms of soil Al, exacerbating base cation leaching, as it competes for adsorption at soil exchange sites (Lawrence et al., 1995). The magnitude of leaching loss is dependent upon the base concentrations of cations in the soil but typically, $Ca^{2+}>Mg^{2+}>K^+>Na^+$ (Haynes & Swift, 1986). Nutrient losses from soil can also be amplified by timber harvesting, given that tree biomass contains large pools of base cations (Olsson et al., 1996; Thiffault et al., 2011).

Declines in tree health linked to losses of soil nutrients have been observed throughout North America (Drohan et al., 2002; Duchesne et al., 2002). In eastern North America low levels of foliar K, Mg, and Ca have all been linked to sugar maple (*Acer saccharum*) decline (Bernier & Brazeau, 1988b, 1988c; Kolb & McMormick, 1993). Low soil exchangeable Ca was linked to hardwood forest canopy decline across southern Ontario (McDonough et al., 2021). Several studies have reported significant improvement in tree health following liming and Ca additions (Huggett et al., 2007; Juice et al., 2006; Long et al., 2011). For example, at Hubbard Brook Experimental Forest significant increases in foliar Ca concentrations, healthier crown conditions and significant increases in sugar maple seedling density were reported after an addition of 0.85 Mg Ca/ha in the form of wollastonite ($CaSio_3$) (Juice et al., 2006).

A potential remediation measure to replace base cations lost from soil is through the application of wood ash (Pitman, 2006, Ludwig et al., 2002, Saarsalmi et al., 2006). Wood ash is the inorganic and organic residue generated by the combustion of wood and wood by products (Siddique, 2012), through commercial and domestic use (Azan, 2017; Hannam et al., 2018). Wood ash has a high but variable alkalinity, which can be accredited to its large concentrations of base cations, especially Ca, usually in the form of oxides, hydroxides, and carbonates (Campbell, 1990; James et al., 2014).

Wood ash has been used as a soil amendment for decades in several European countries, but its use in North America is limited in comparison (Pitman, 2006). In Ontario, wood ash is considered a hazardous waste material and most of it is diverted to landfill (Hannam et al., 2016). There is increasing interest in studying the biogeochemical response of wood ash application in Canadian context. Wood ash has been reported to increase base saturation (Jacobson et al., 2004), increase extractable Ca and Mg concentrations in soil (Saarsalmi et al., 2001), and contribute to the decomposition of recalcitrant organic matter, thus increasing available nitrogen (N) pools (Mortensen et al., 2019). However, elevated levels of potentially phytotoxic metal concentrations within the upper soil horizons have also been reported (Ozolincius & Varnagiryte, 2005), while in other research exchangeable Al concentrations in soil have been observed to decrease after ash application (Saarsalmi et al., 2001).

Existing literature suggests that the application of wood ash in low doses (3 Mg ha^{-1}) has minimal to no adverse affect on plant community composition (Arvidsson et al., 2003; Jacobson & Gustafsson, 2001) and positive effects on tree growth have been observed (Solla-Gullon et al., 2008). Improvements in tree growth were attributed to increases in soil Ca and Mg (Solla-Gullon et al., 2008) and decreases in Ca deficiencies in sugar maple seedlings and mature trees (Arseneau et al., 2021). However, there are other studies which have recorded significant changes in understory vegetation composition with a complete transformation of the species, and significant decreases in bryophytes species number and cover after ash application (Moilanen et al., 2002; Okland et al., 2022).

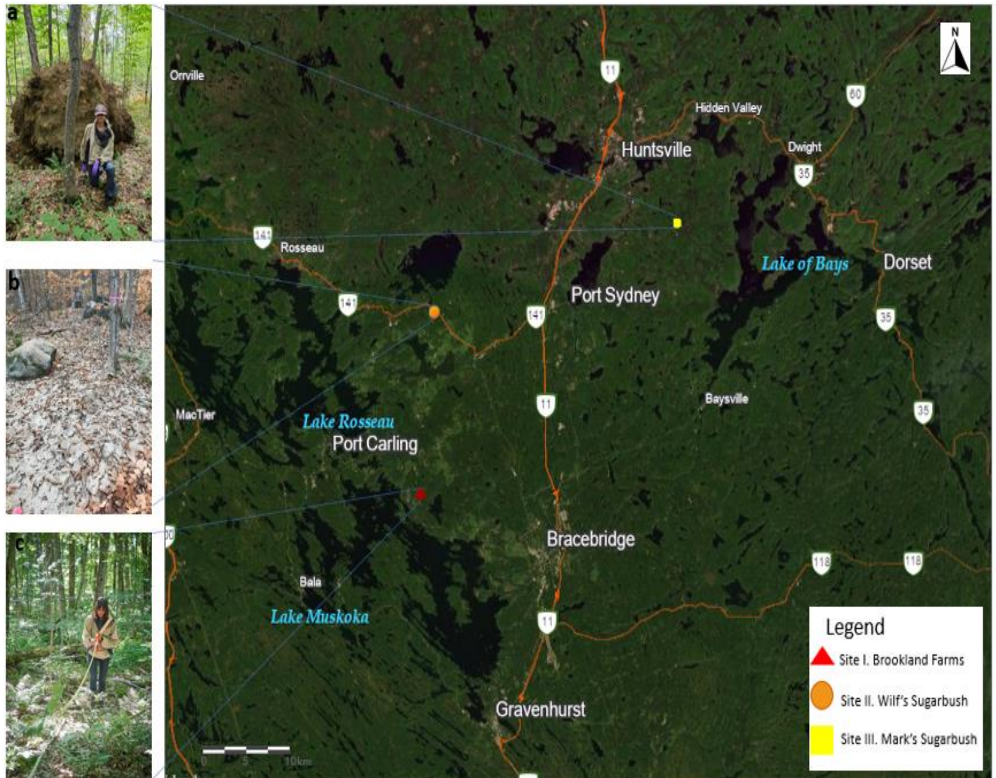
South central Ontario has received high levels of acidic deposition, leading to widespread soil and lake acidification (Dillon et al., 2007; Gorham & Gordon, 1960). Although large reductions in acidic deposition have been recorded, the recovery in soils from excessive nutrient depletion will likely take centuries, given that S and N deposition and forest harvesting levels remain consistent (Ott & Watmough, 2022). Therefore, the application of wood ash, a substance rich in base cations could replace lost nutrients and improve sugar maple health (Deighton & Watmough, 2020), a highly valued but Ca demanding tree species (Momen et al., 2015). Ontario produces approximately 18,000 tonnes of nonindustrial wood ash (NIWA) annually (Azan, 2017) that is rich in macro-nutrients and may be useful in countering the effects of acidification and nutrient losses in central Ontario, forests, and lakes (Azan et al., 2019; Deighton & Watmough, 2020). The objective of this study was to evaluate the short-term (< 2 yr.) response of non-industrial wood ash application applied to three sugar bushes in Muskoka, Ontario.

It was hypothesized, that wood ash application would increase nutrient availability to plants with minimal or no impacts on plant communities. Wood ash treatments were expected to significantly increase pH and nutrient concentrations (Ca, Mg, K) and metal concentrations in the organic soil horizons one year after application. Nutrient (Ca, Mg, K) concentrations in foliage of both mature and sugar maple saplings were predicted to increase in ash treated plots, with no increases in trace metal concentrations. No difference in tree growth or understory vegetation composition were expected due to the short study period.

3.3 Methods

3.3.1 Study Area

The study took place at three sugar bushes in the Muskoka River Watershed in south-central Ontario, Canada (Figure 3.1). The region is located on the southern end of the Canadian Precambrian Shield, overlain with weakly developed podzols and brunisols (Soil Classification Working Group, 1998), underlain with silicate bedrock (Reid & Watmough, 2015). The soils are acidic with slow mineral weathering rates and receive low levels (< 3 kg/ha/yr.) of atmospheric Ca deposition (Watmough & Dillon, 2003). Sixty-six percent of the region is comprised of forests, dominated by mixed hardwood, and some coniferous species (O'Connor et al., 2009; Reid & Watmough, 2015). Wetlands cover approximately 12% of the region, and 15% is covered by lakes (Reid & Watmough, 2015), of which 60% are in headwater reaches (O'Connor et al., 2009). The mean annual temperature reported for the period of 1981 – 2010 was 5.8°C, with an annual precipitation of 985 mm (Environment and Climate Change Canada, 2018).



This map was created by Batool Syeda using AcrGIS Online Software. Earthstar Geographics Esri Canada

Figure 3.1 Regional map of the study area and the three study sites, located in Muskoka, Ontario, Canada. Also featuring site photographs taken at a.) Mark's Muskoka Maple Sugarbush, b.) Wilfrid Creasor's Sugarbush, and c.) Brooklands Farm

Site I. Brooklands Farm [45'08 N, 79'46W]

Brooklands farm is a 400-acre farm located near Bracebridge, Ontario at an elevation of 304 m above sea level. The property consists of various wetlands, patches of farmlands and forests. The study site was located within a 60-acre sugarbush stand on the northeast corner of the property. The area consists of uneven terrain with several steep slopes and rocky outcrops. The mean thickness of the LFH layer was 3.05 cm. The soils were classified as Orthic Sombric Brunisols (Canadian System of Soil Classification, 1998). The average soil pH (top 0 to 15 cm) was 3.83. The site was dominated by sugar maple however also contained a mix of other hardwood forest species, and the basal area was measured at 26 m^2 ha^{-1} in 2019 (Table 3.1). The site is being actively used to produce maple syrup. Based on a 2016 study deficit levels of Ca and Mg were reported in the sugar maple leaf tissue on this site (Riley, 2017). Understory plant composition consists of naturally occurring hardwood forest species such as, sugar maple, wood fern *(Dryopteris),* Solomon's seal (*Polygnatum spp.),* trillium *(Trillium spp.)*.

Site II. Wilfrid Creasor (Wilf's) Sugarbush [45'21 N, 79'44W]

Wilfrid's sugarbush is near Huntsville, Ontario at an elevation of 291 m above sea level. The area is an 83-acre forest primarily dominated by sugar maple, along with other hardwood species (Table 3.1). The property also contained small ponds and wetlands. The study site was located on the northern end of the property, consisting of uneven terrain with gentle undulating slopes. The mean thickness of the LFH layer was 3.92 cm. The soils were coarse sandy loam, classified as Sombric Brunisols (Soil Classification Working Group, 1998). The mean soil pH (0 – 15 cm) was 3.96, and the basal area was measured at 31 m^2 ha^{-1} in 2019 (Table 3.1). The study area was used to produce maple syrup commercially however in more recent years the operation has been scaled down for private consumption. Understory plant composition consisted primarily of sugar maple saplings, wood fern, hobble bush *(Viburnum lantanoides),* wild raspberry (*Rubus occidentalis)*.

Site III. Mark's Muskoka Maple (Mark's) Sugarbush [45'28 N, 79'14W]

Mark's sugarbush is near Huntsville, Ontario at an elevation of 291 m above sea level. The area is a 49-acre forest dominated by sugar maple intermingled with other hardwood forest species. The study site was located on the northwestern end of the property and consists of relatively flat terrain. The soils were coarse sandy loam, classified as Sombric Brunisols (Soil Classification Working Group, 1998). The mean soil pH (0 – 15 cm) was 3.88, and the basal area was measured at 26 m^2 ha^{-1} in 2019 (Table 3.1). The study area was used to produce maple syrup since 1980. Understory plant composition comprised of common hardwood forest species including sugar maple saplings, Ground pine *(Lycopodium obscurum),* wild raspberry.

Table 3.1. Baseline site characteristics for the three sugar bushes in Muskoka, Ontario. Tree species relevant to each site marked by B (Brookland Farms) /W (Wilf's sugarbush) /M (Mark's sugarbush)

Year 2019	Brookland Farms	Wilf's Sugarbush	Mark's Sugarbush
Land cover (Hectares)	24	33	20
Elevation (m)	304	291	291
Mineral Soil pH (0 - 15 cm)	3.83	3.96	3.88
Basal Area All Species (m^2 ha^{-1})	26.08	30.67	26.21
Basal Area Sugar Maple (m^2 ha^{-1})	22.22	29.69	25.74
Stem Density (trees/ha)	635	577	677
Other Tree Species	Basswood (*Tilia americana*) B Balsam Fir *(Abies balsamea*) W/M Beech (*Fagus grandifolia*) B/W/M Black Cherry (*Prunus serotina*) B Red Maple (*Acer rubrum*) B/W/M Sugar Maple (*Acer saccharum*) B/W/M White Ash (*Fraxinus americana*) B/W White Pine *(Pinus strobus*) B/W/M Yellow Birch (*Betula alleghaniensis*) B/W		

Land cover data was obtained from the individual land owners, soil pH data was obtained from the soil samples collected in 2019, basal area and stem density data was calculated using the DBH data collected in 2019

3.3.2 Plot setup and study design

Three replicate experiments were conducted by establishing eighteen 10 x 10-metre plots at each site in August of 2019. Plots were randomly located within each sugar bush, but each plot had to contain a minimum of two mature (> 10 cm diameter at breast height (DBH)) sugar maple trees, and some sugar maple saplings. Sites were chosen with relatively flat topography to minimize runoff after ash application. Wooden stakes were used to mark the corners of each plot, and the stakes were labelled with the corresponding plot number. Special care was taken to leave a buffer area (>10m) between neighboring plots, to minimize the risk of cross contamination.

3.3.3 Field sampling and ash application

Ash samples were collected from residents in the Muskoka region. The ash was stored in large metal bins prior to field application. Before ash application in the field, the individual ash samples were amalgamated into a homogenous sample using a large cement mixer and distributed into multiple containers for ease of transport (For a more detailed description of ash collection, storage and mixing process please refer to Chapter 2 methods).

Baseline soil samples consisting of the litter layer (L), the fibric and humic (FH) layer and the mineral layer to a depth of 15 cm were collected at each plot, in late summer of 2019, prior to wood ash application. The samples were taken from all four corners, and the middle of each plot for a representative soil sample. Ten grab samples in total (Five from the L horizon and five from the FH horizon) were collected from each plot. Five mineral soil (0 – 15cm) samples were collected from each plot using a Dutch auger (Figure 3.2). Each sample was placed in a zip-lock bag and each bag was labeled with its corresponding site, plot number and soil layer ID code. Soil sampling was repeated in 2020, ten months after ash application.

Wood ash was applied in late fall of 2019, after leaf fall. Three treatment dosages were applied to each site, consisting of 8 Mg ha^{-1}(80 kg for a 10 x 10m plot), 4 Mg ha^{-1} (40 kg at a 10 x 10m plot), and a control (no ash). At each site, six plots per treatment were established for a total of 18 plots at each site - (Brooklands Farm was an exception, where there were six controls, six plots with 4 Mg ha^{-1} and five plots with 8 Mg ha^{-1}). Plots were assigned ash treatments at random. To minimize dosage application error, ash was poured from the larger metal bins into smaller 8 - L plastic buckets and each bucket was individually weighed in the field to ensure that every plot received the correct dosage (Figure 3.3). The application to plots took place by hand using small jugs, taking care to spread the ash as evenly as possible within each plot. Ash applied at each site was similar in its chemical composition, with only a few exceptions in differences between pH, Pb, Cu and Fe concentrations (Table 3.2). To confirm consistency in chemical composition, at each site sub samples of ash were collected at varying intervals throughout the application process (Table 3.2).

Table 3.2 pH, LOI, CNS, nutrient and metal concentrations of amalgamated nonindustrial wood ash applied to each study site (n=10 each) and Ontario Regulation 267/03 of the Nutrient Management Act limits for unrestricted (CM1) and restricted (CM2) use of wood ash for land application as a non-agricultural non-aqueous source material are also shown.

Study Sites	Amalgamated Non-industrial Wood Ash				NASM** Limits	
	Mean	*Median*	*SD*	*Cv (%)*	*CM Level 1*	*CM Level 2*
Brookland Farms						
pH	13.5					
LOI	3.5	3.5	0.8	22.9		
C (%)	11.6	10.0	4	34.0		
N (%)	0.2	0.1	0.2	100		
S (%)	BDL	BDL	NA	NA		
Ca (g.kg^{-1})	305	305	15	5.0		
Mg (g.kg^{-1})	24.2	23.8	2.5	10.7		
K(g.kg^{-1})	109	108	13	12.0		
P (g.kg^{-1})	8.8	8.5	1	13.4		
Cd (mg.kg^{-1})	2.7	2.8	0.4	14.4	3	34
As (mg·kg^{-1})	3.9	0.2	6	153	13	170
Ni (mg·kg^{-1})	10.5	9.6	3	30.4	62	420
Pb (mg·kg^{-1})	24.3	21.3	17	71.8	150	1100
Cu (mg·kg^{-1})	140	133	41.9	29.8	100	1700
Zn (mg·kg^{-1})	523	495	109	20.9	500	4200
Mn (mg·kg^{-1})	6306	6373	683	10.8		
Fe (mg·kg^{-1})	2793	2607	1150	41.0		
Wilf's Sugarbush						
pH	13.3					
LOI	5.8	5.0	1.0	17.7		
C (%)	8.8	8.5	0.8	9.0		
N (%)	0.1	0.1	NA	NA		
S (%)	BDL	BDL	NA	NA		
Ca (g.kg^{-1})	273	289	48.4	17.7		
Mg (g.kg^{-1})	22.1	22.7	3.5	16.0		
K(g.kg^{-1})	112	118	21.7	19.3		
P (g.kg^{-1})	7.9	8.1	1.2	15.1		
Cd (mg.kg^{-1})	2.5	2.5	0.6	24.7	3	34
As (mg·kg^{-1})	3.1	BDL	7.4	237.5	13	170
Ni (mg·kg^{-1})	8.8	8.9	2.0	22.5	62	420
Pb (mg·kg^{-1})	12.7	13.5	3.8	30.3	150	1100
Cu (mg·kg^{-1})	154	129	92.1	59.8	100	1700
Zn (mg·kg^{-1})	516	504	151	29.3	500	4200
Mn (mg·kg^{-1})	6837	7029	1023	15.0		
Fe (mg·kg^{-1})	1322	1199	528	39.9		
Mark's Sugarbush						
pH	11.5					
LOI	5.6	5.5	1.0	17.8		
C (%)	9.1	8.8	0.9	9.8		
N (%)	0.1	0.1	NA	NA		
S (%)	BDL	BDL	NA	NA		
Ca (g.kg^{-1})	294	308	46.4	15.7		
Mg (g.kg^{-1})	22.5	23.0	3.8	16.9		
K(g.kg^{-1})	104	107	20.3	19.5		
P (g.kg^{-1})	7.8	8.1	1.2	15.0		
Cd (mg.kg^{-1})	2.6	2.7	0.4	15.2	3	34
As (mg·kg^{-1})	3.7	0.9	5.7	153	13	170
Ni (mg·kg^{-1})	7.9	8.4	1.5	19.1	62	420
Pb (mg·kg^{-1})	48.5	20.9	64.2	132	150	1100
Cu (mg·kg^{-1})	106	102	15.2	14.3	100	1700
Zn (mg·kg^{-1})	439	457	61.5	14.0	500	4200
Mn (mg·kg^{-1})	6329	6443	1215	19.2		
Fe (mg·kg^{-1})	1872	1691	634	33.9		

*Nutrient and Management Act 2002**, BDL Below Detection Limit*

Figure 3.2 Site photograph of mineral horizon soil obtained using a Dutch auger, at Brookland farms.

In July 2020, foliage samples were collected from mature sugar maple trees (minimum of two trees, 3 when possible) and sugar maple saplings (trees under 10 cm DBH) from each plot. Samples from mature trees were collected from mid canopy using extendable pole pruners. The trees selected for sampling were dominant in the plot canopy, receiving direct sunlight. Sapling samples were collected by hand from each plot. All samples were placed in zip-lock bags; sapling and mature foliage tree samples were kept separate. Each bag was labeled with the corresponding site and plot number, along with an identification code to separate sapling foliage from tree foliage. Post ash application samples of soil were also collected in late summer of 2020, in the same manner as the baseline samples (Figure 3.3).

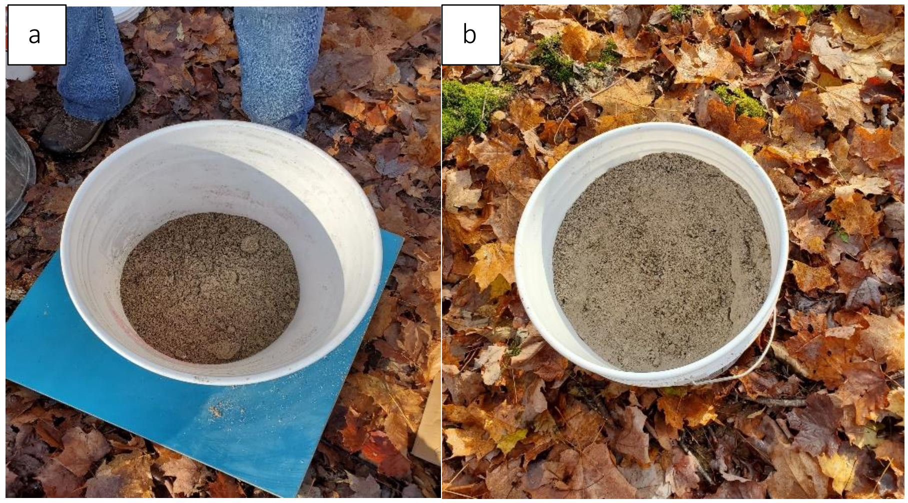


Figure 3.3 Site photographs of nonindustrial wood ash samples (a) being weighed in field before application to treatment plots, using a weigh scale and (b) 4-gallon plastic buckets. Wood ash collected from residents of Muskoka, Ontario in 2019.

An understory vegetation survey was conducted in July of 2020 (10 months post application) and 2021 (2-years post application). Three random understory vegetation surveys were conducted at each of the 18 plots using a 1 m^2 quadrat (Figure 3.4). Quadrat position within the plots were selected by a simple hand toss and species abundance and percent cover were recorded. Understory vegetation was classified as all vascular living plants (ferns, shrubs, grasses, various tree seedlings), less than two m in height and with a DBH of less than 10 cm. All vegetation was identified to species level; however, grasses were identified to family level only (Dickinson & Royer, 2014; Lawrence Newcomb, 1989). Tree DBH measurements were collected for all trees at or above 10 DBH at each plot in the summer of 2019 (prior to ash application), 2020 (1-year post application), and 2021 (2-years post application). Several trees were lost at Mark's sugar bush and a few at Brookland farm due to severe summer storms in 2020 and again in 2021.

Figure 3.4 Site photograph of vegetation survey, conducted using a 1x1-meter quadrat, at Wilf's sugarbush in the summer of 2020.

3.3.4 Laboratory Analyses

Soil analyses

Soil samples collected at each plot (4 corners, 1 middle) were combined into a single sample by horizon and oven dried for 24 hours at 110°C. Once dried the L and FH layer samples were grounded individually, into a powder using a Wiley mill machine, meanwhile the mineral layer was disaggregated by hand using a mortar and pestle and sieved to 2mm. All samples were analyzed for exchangeable cations (EC), pH, loss-on-ignition (LOI), total carbon, and nitrogen content (CN), and acid extractable metal concentration (Zn, Pb, Ni, Mn, Fe, Cu, Cd, B, Al).

Soil pH was measured using an OAKTON pH 510 series multimeter. A 0.01M $CaCl_2$ slurry was used at a ratio of 1:5. The slurries were shaken for 45 mins and rested for an additional 45 mins before a pH reading was taken. To determine the organic matter content of the soil, the loss on ignition method was used (Ball, 1964). A five-gram sample of mineral soil (two grams for organic) was placed into a crucible and oven dried at 105°C for 24 hours. Samples were reweighed and ashed in Fisher Scientific Isotemp Muffle Furnace at 450°C for 8 hours. Samples were placed in a desiccator and reweighed, and the difference in soil mass was determined to calculate percent organic matter.

To determine soil CN content, soil samples were packed into foil pellets and combined with tungsten, which helps with the oxidation of the elements during analysis (1:2 leaf litter: tungsten ratio), prior to analysis using an Elementar MAX Cube. Acid extractable metal concentrations were derived using inductively coupled plasma - optical emission spectrometry (ICP-OES) after hot digestion using concentrated trace metal grade nitric acid (67 – 70%). Approximately 0.2 grams of soil and ash samples were weighed into digiTUBEs (SCP Science, Quebec, CA), and 2.5 mL of 100% nitric acid added using a precision repeater. Samples were digested on a hot plate for 8 hours at a 100°C, then further digested at room temperature for an additional 8 hours until the entire sample dissolved. After the cold digestions, samples tubes containing the digests were individually rinsed with B-pure water approximately three times and transferred into 25 mL volumetric flasks via P8 Fast Flow Filter Paper. The solution was diluted to 25 mL with B-pure water and transferred into a 50 mL Falcon tube and refrigerated until analyses. Soil standards (EnviroMat SS-1) and blanks were used at the beginning and end of every 48-sample set to test for precision. All tubes were labelled with the appropriate site, plot, and soil layer ID codes.

A 1 M ammonium chloride (NH_4Cl) solution was used to determine the exchangeable cations for organic and mineral soils (Hendershot et al., 2008). Pulverized organic soils (1 g) and mineral soils (5 g) were weighed into 50 mL centrifuge tubes, and 25 mL of NH4Cl were added to each tube. Samples were placed on a shaker table overnight (16 hours), removed in the morning, and left to sit for an additional hour. Samples were filtered through Fisher P8 filter paper (fast flow, removes particles >20 µm) in a Buchner funnel using vacuum filtration. An additional 25 mL of NH_4Cl was added to the centrifuge tube to ensure removal of all soil from the tube walls and was passed through the filter. The filtrate was transferred from the flask into a new 50 mL centrifuge tube. Exchangeable cation samples were diluted by dispensing 1.0 mL of each solution into a 15 mL centrifuge tube, followed by the addition of 0.2 mL of trace metal grade nitric acid, and 8.8 mL of B-pure water. Analyses were performed using a Perkin Elmer Optima 7000 DV ICP-OES.

Foliage analyses

Foliage samples collected from multiple mature trees and saplings per plot were amalgamated into one larger sample (one for mature tree and one for saplings). Each bulk sample was oven dried for 24 hrs at 100°C. Each sample was then ground using a coffee grinder into a fine powder for analyses. Foliage samples from mature trees and saplings were analyzed for carbon, nitrogen, content (CN), and metals and macro-nutrients (Zn, Pb, Ni, Mn, Fe, Cu, Cd, B, Al, Ca, Mg, K, P) as described above.

Diagnosis and Recommendation Integrated System (DRIS) Calculations

DRIS indices were calculated for foliar Ca, Mg, K, P and N (Walworth & Summer, 1987), were,

Eq 1.)

$$\text{A index } = [\, f\ (A/B)\ +\ f\ (A/C)\ +\ f\ (A/D)\ +\ f\ (A/E)\,]\,/\,z$$

Eq 2.) where, when A/B =/> a/b,

$$F\left(\frac{A}{B}\right) = \left(\frac{(A/B)}{(a/b)} - 1\right) * \frac{1000}{CV}$$

Eq 3.) or where, when A/B < a/b,

$$F\left(\frac{A}{B}\right) = \left(1 - \frac{(a/b)}{(A/B)}\right) * \frac{1000}{CV}$$

A is the foliar concentration (%) of the element for which the index is being calculated while B, C, D and E are the foliar concentrations of the remaining elements. A/B is the value of the ratio of the two elements in the leaf tissue of the sugar maple foliage samples, while a/b is the optimum value or foliar ratio norms as described by Lozano & Huynh, (1989), and CV is the coefficient of variation associated with the norm, while z is the number of functions comprising the nutrient index. All indexes are balanced around zero and the sum of the nutritional indexes equal zero (Walworth and Sumner, 1987). Negative values indicate nutritional deficiency while positive value indicate excess in quantity as compared to the other nutrients. The lower the negative value the higher the deficiency, thus indicating the most limiting nutrient, while the highest positive value indicates the nutrient excess in relation to other nutrients.

3.3.5 Statistical Analyses

Comparison between pre and post ash application soil chemical and physical properties were made using a Kruskal Wallis rank sum test. To test the null hypothesis that wood ash application has no effect on soil pH, LOI, CNS content, nutrient and metal concentrations comparisons were made between treatment and control plots. A pairwise Wilcox post hoc test was used to compare treatment and control plots. Significance was determined as $P < 0.05$.

Comparison between treatment and control plot's sugar maple foliar nutrient and metal concentrations were made using a Kruskal Wallis rank sum test. Diagnosis and Recommendation Integrated System was used to derive foliage nutrient concentrations, ratios, and indices. The post hoc tests were completed only on variables where a significant difference was determined. Significance was determined as $P < 0.05$.

Tree growth assessment was performed by measuring percent change in basal area (BA) over a two-year period per plot, using the following equation,

$$\% \text{ change} = ((BA_{n} - BA_{n-2}) / BA_{n-2}) * 100$$

where BA is the tree basal area and n is the year of sampling. Only trees that survived during the study period were included in this calculation as some trees were lost due to storm damage in Mark's and Brookland sugar bushes. Comparison between time and treatments were made using a Kruskal Wallis rank sum test. Significance was determined as $P < 0.05$. Understory vegetation species diversity indices for all sites were calculated using Shannon's Diversity index (H) and Simpson's Diversity index (D). Comparison between treatment and time following ash application (1 and 2 years) were made for diversity indices and species richness were made using a Kruskal Wallis rank sum test and a pairwise Wilcox post hoc test. The post hoc tests were completed only on variables where a significant difference was determined. Significance was determined as $P < 0.05$. Significant differences between species abundance were tested using an Anosim test, followed by a Simper test to determine which species were most influential in driving the differences. Significance was determined as $P < 0.05$. Statistically analyses were performed in RStudio version 1.4.1106.

3.4 Results

3.4.1 Soil chemical and physical properties

Soil Nutrients

Prior to ash application there were no significant differences in soil chemistry among treatments plots per site. Ten months post application all three study sites exhibited similar responses to ash treatments. Increases in soil pH were measured at all plots, however these changes were most apparent in the litter and FH horizons of ash treated plots, where pH values increased to around 7.0 compared with < 5.0 in control plots (Figure 3.5). Plots that received ash at 8 Mg ha^{-1} also had a significantly higher soil pH than plots that received 4 Mg ha^{-1} (Figure 3.5). Small increases in the mineral soil pH were observed, however this was only significant in the 4 Mg ha^{-1} treatment plots at Brookland farms and 8 Mg ha^{-1} at Mark's sugarbush (Figure 3.5).

At all three study sites exchangeable soil base cation concentrations were highest in the litter horizon, followed by the FH horizon and the mineral soil horizon (Figure 3.6 – 3.8). Following ash application, exchangeable Ca and Mg concentrations increased in the litter and FH horizons, however no treatment effects were observed for K (Figure 3.6 – 3.8). Concentrations of soil Ca and Mg in the L and FH horizons were approximately double those observed in control plots in both ash treatments at all sites. There were significant increases in soil base cation concentration in the soil organic horizons in control plots compared with pre-treatment values however these were less pronounced than the treatment plots (Figure 3.6 – 3.8). Differences in mineral soil base cation concentrations were much less pronounced, but slight increases were observed, especially for K at Brookland farms and Wilf's sugarbush in the 8 Mg ha^{-1} treatment (Figures 3.6-3.8). Organic matter content as well as N and C concentration in the L horizons at all three sites were notably lower in the treatment plots compared with the control plots (Table 3.3).

Soil Metals (Metalloids)

At all three study sites, concentrations of most metals in the soil organic horizons were higher in the ash treated plots compared with the control plots post application (Table 3.4). Increases in metal levels were greatest in the litter horizon, followed by the FH horizon with the responses being generally consistent among the sites (Table 3.4). In the litter horizon concentrations of Al, Mn, Cd, Pb, Fe, Cu, B, Ni and Zn were highest in ash treated plots compared with the control plots and metal concentrations were generally higher in the 8 Mg ha^{-1} treatment plots than in the 4 Mg ha^{-1} treatment (Table 3.4). Metal concentrations in the litter layer were typically between two and ten times higher than control plots 10 months after ash application. For example, Pb concentrations increased from 1.8 mg kg^{-1} to 6 mg kg^{-1} at Wilf's sugarbush and 1.0 mg kg^{-1} to 20.9 mg kg^{-1} at Brookland farms after 4 Mg ha^{-1} ash application. There were very few treatment effects on mineral soil metal concentrations, with only slight increases recorded for Pb, Cd and Mn at most sites and a significant increase was only recorded for Cu concentrations at Mark's sugarbush.

Figure 3.5 Soil pH in litter, FH, and mineral (0 – 15 cm) horizons, before and 10 months after non-industrial wood ash application at three study sites in Muskoka, Ontario. Significant differences to control indicated by an asterisk (*). Significant differences between dosage amounts (4 and 8 Mg ha^{-1}) indicated by double asterisk (**). Significant differences were determined using the Kruskal Wallis test, with a post hoc pairwise Wilcox test. P value significant at 0.05.

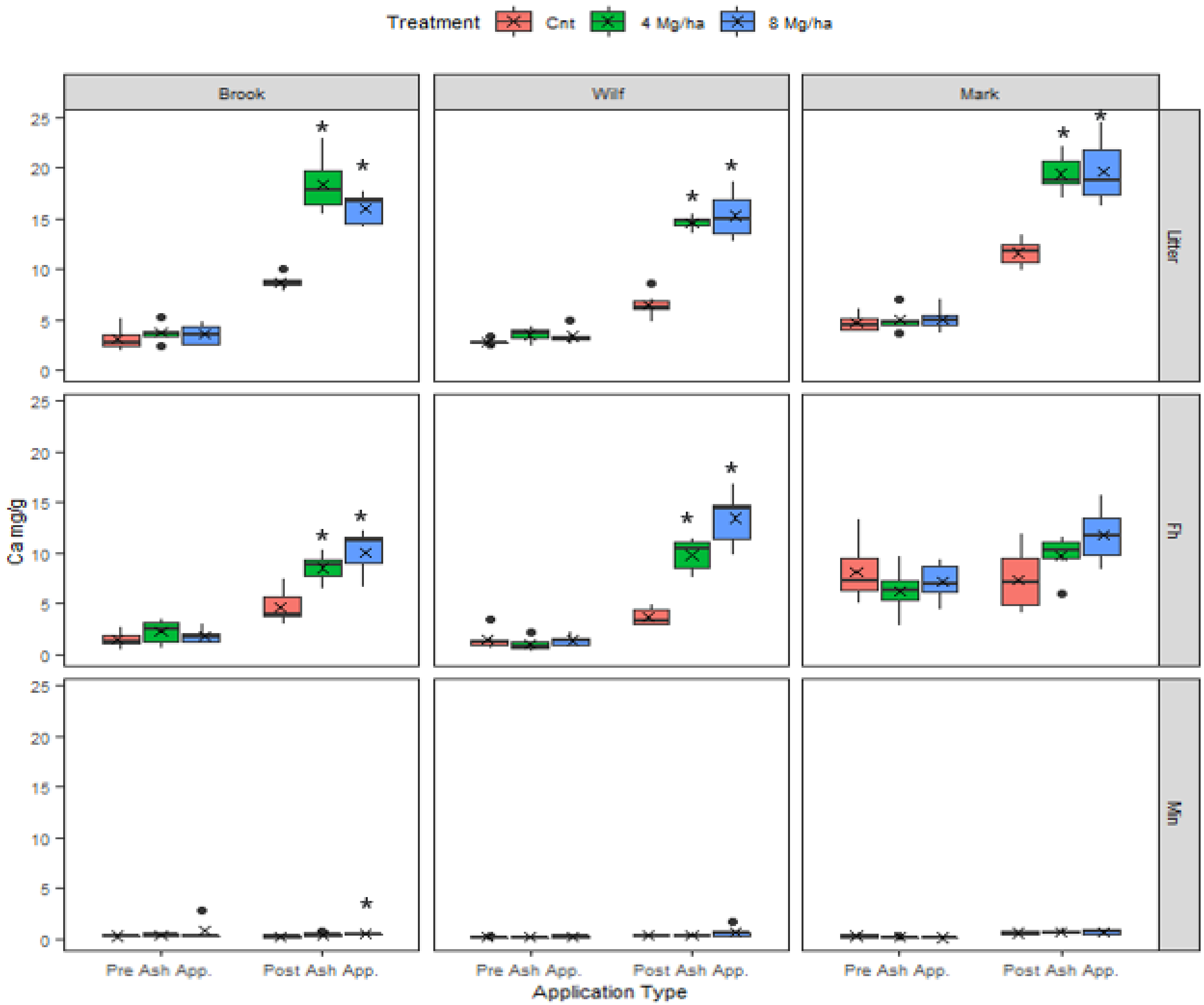


Figure 3.6 Soil exchangeable Ca concentrations in litter, FH, and mineral (0 – 5 cm) horizons before and 10 months after non-industrial wood ash application at three study sites in Muskoka, Ontario. Significant differences to control indicated by an asterisk (*). Significant differences between dosage amounts (4 and 8 Mg ha^{-1}) indicated by double asterisk (**). Significant differences were determined using the Kruskal Wallis test, with a post hoc pairwise Wilcox test. P value significant at 0.05.

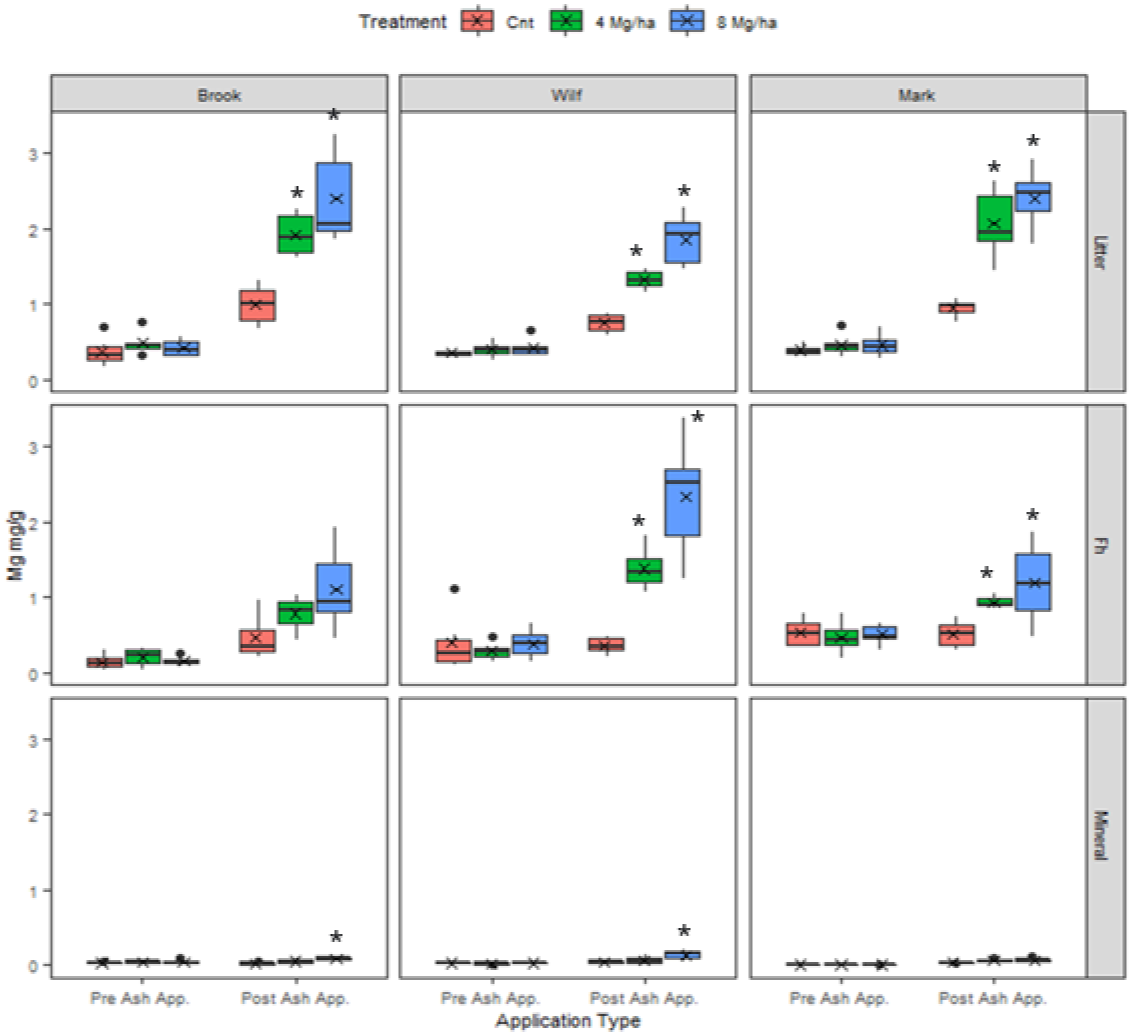


Figure 3.7 Soil exchangeable Mg concentrations in litter, FH, and mineral (0 – 15 cm) horizons before and 10 months after non-industrial wood ash application at three study sites in Muskoka, Ontario. Significant differences to control indicated by an asterisk (*). Significant differences between dosage amounts (4 and 8 Mg ha^{-1}) indicated by double asterisk (**). Significant differences were determined using the Kruskal Wallis test, with a post hoc pairwise Wilcox test. P value significant at 0.05.

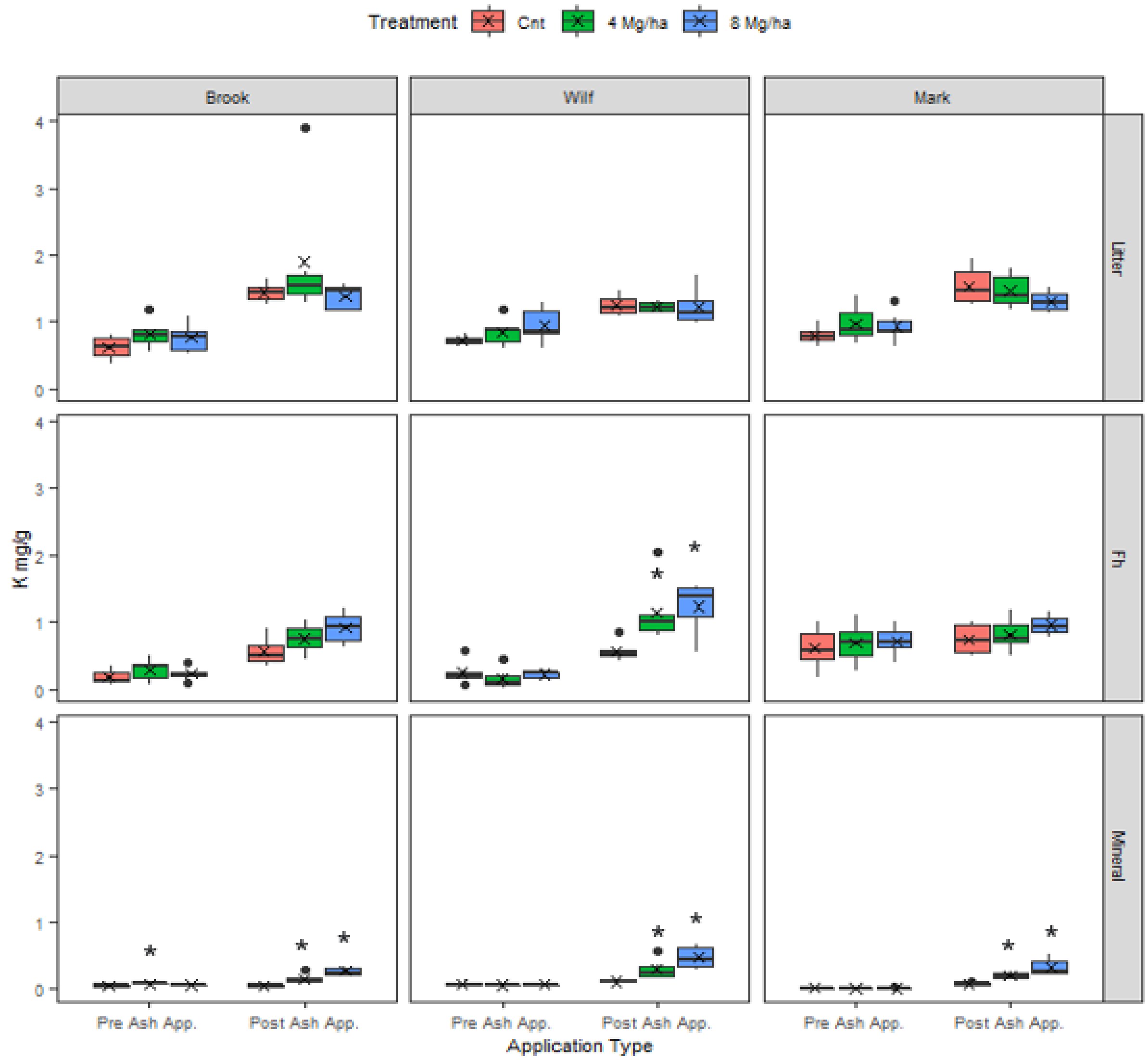


Figure 3.8 Soil exchangeable K concentrations in litter, FH, and mineral (0 – 15 cm) horizons before and 10 months after non-industrial wood ash application at three study sites in Muskoka, Ontario. Significant differences to control indicated by an asterisk (*). Significant differences between dosage amounts (4 and 8 Mg ha^{-1}) indicated by double asterisk (**). Significant differences were determined using the Kruskal Wallis test, with a post hoc pairwise Wilcox test. P value significant at 0.05.

Table 3.3 Soil CN and % OM concentrations before and 10 months after non-industrial wood ash application at three study sites in Muskoka, Ontario. Significant differences to control indicated by an asterisk (*). Significant differences between dosage amounts (4 and 8 Mg ha^{-1}) indicated by double asterisk (**). Significant differences between years indicated by differing letters. Significant differences were determined using a Kruskal Wallis test, with a post hoc pairwise Wilcox test. P value significant at 0.05.

	Carbon (%)		Nitrogen (%)		OM (%)	
	Pre Ash-Application	*Post Ash Application*	*Pre Ash-Application*	*Post Ash Application*	*Pre Ash-Application*	*Post Ash Application*
Litter Layer	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)
Brookland Farm						
Cnt.	45.0 (1.2)	46.0 (0.4)	2.0 (0.2)	2.0 (0.2)	88.0 (2.7)	88.0 (2.5)
4 Mg/ha	45.5 (1.0) a	39.0(2.0) b*	2.0 (0.1) a	1.7 (0.1) b*	90.3 (1.0) a	64.0 (8.2) b*
8 Mg/ha	44.0 (1.0) a	34.7(4.0) b*	2.0 (0.1) a	1.4 (0.1) b*	89.0 (1.4) a	48.0 (8.0) b**
Wilf Sugarbush						
Cnt.	45.1 (2.0) a	47.4 (8.4) b	2.0 (0.1)	1.8 (0.2)	91.0 (1.0)	92.0 (0.4)
4 Mg/ha	46.0 (1.5) a	40.0(3.0) b*	2.0 (0.1) a	1.6 (0.1) b*	90.0 (3.4) a	67.0 (6.0) b*
8 Mg/ha	46.0 (0.3) a	36.0(3.0) b*	2.0 (0.1) a	1.4 (0.2) b*	91.3 (0.4) a	47.0 (8.0) b**
Mark Sugarbush						
Cnt.	45.1 (0.3)	46.1 (0.6)	2.0 (0.1)	2.0 (0.1)	89.4 (1.0)	88.5 (2.1)
4 Mg/ha	45.4 (0.4) a	39.1 (5.0)b*	2.0 (0.1) a	1.5 (0.2) b*	89.0 (1.5) a	63.0 (10.0) b*
8 Mg/ha	45.5 (1.0) a	34.0 (5.3)b*	2.0 (0.1) a	1.4 (0.3) b*	90.0 (1.0) a	55.0 (9.4) b**
FH Layer						
Brookland Farm						
Cnt.	24.5 (9.0)	29.0 (8.0)	1.5 (0.4)	1.6 (0.3)	37.0 (16.0)	43.0 (11.0)
4 Mg/ha	31.0 (7.0)	33.0 (5.3)	1.8 (0.4)	1.8 (0.2)	54.3 (14.6)	48.2 (11.0)
8 Mg/ha	26.0 (5.3) a	35.0 (2.6) b	1.5 (0.2) a	2.0 (0.1) b	41.1 (11.0)	50.1 (10.1)
Wilf Sugarbush						
Cnt.	35.0 (7.5)	38.1 (3.3)	1.8 (0.4)	2.0 (0.2)	60.0 (16.2)	60.0 (8.2)
4 Mg/ha	29.4 (11.0)	38.2 (3.2)	1.5 (0.5)	2.0 (0.1)	49.0 (24.4)	60.0 (7.0)
8 Mg/ha	35.0 (5.0)	38.0 (4.0)	1.9 (0.2)	2.0 (0.2)	58.0 (9.8)	60.0 (11.0)
Mark Sugarbush						
Cnt.	36.3 (6.0)	39.2 (2.2)	2.0 (0.2)	2.0 (0.1)	60.0 (15.3)	59.0 (12.0)
4 Mg/ha	34.4 (6.2)	35.3 (7.3)	1.9 (0.3)	1.8 (0.3)	55.0 (16.8)	52.1 (13.4)
8 Mg/ha	30.4 (10.0)	33.0 (4.2) *	1.9 (0.5)	1.8 (0.2)	55.0 (14.8)	51.0 (9.4)
Mineral Layer						
Brookland Farm						
Cnt.	4.0 (1.0)	4.0 (1.0)	0.3 (0.1)	0.3 (0.1)	8.0 (1.4)	8.4 (2.0)
4 Mg/ha	6.7 (1.7) *	5.6 (1.3)	0.5 (0.1) *	0.4 (0.1)	9.1 (1.0)	9.4 (1.1)
8 Mg/ha	6.2 (1.6) *	5.0 (1.4)	0.4 (0.1)	0.4 (0.1)	9.0 (0.8)	9.1 (2.0)
Wilf Sugarbush						
Cnt.	5.7 (2.0) a	8.0 (2.0) b	0.4 (0.1)	0.5 (0.1)	11.2 (2.9)	15.2 (4.2)
4 Mg/ha	4.4 (1.0)	6.8 (2.3)	0.3 (0.1) a	0.5 (0.1)b	9.0 (2.0)	10.4 (2.6)
8 Mg/ha	5.7 (1.0)	9.8 (5.2)	0.4 (0.1)	0.5 (0.2)	11.2 (0.9)	12.0 (1.0)
Mark Sugarbush						
Cnt.	5.0 (1.0)	5.0 (2.0)	0.3(0.1)	0.4 (0.1)	9.0 (1.0)	10.0 (1.2)
4 Mg/ha	3.7 (0.4) a	8.2 (3.1) b	0.3(0.1) a	0.5 (0.2)b	8.0 (0.4) a	10.0 (1.2) b
8 Mg/ha	4.0 (0.5) a	7.5 (2.5) b	0.3(0.1)a	0.5 (0.1)b	8.3 (0.8)	9.4 (1.4)

Table 3.4 Soil metal concentrations before and 10 months after non-industrial wood ash application at three study sites in Muskoka, Ontario. Significant differences to control indicated by an asterisk (*). Significant differences between dosage amounts (4 and 8 Mg ha^{-1}) indicated by double asterisk (**). Significant differences between years indicated by differing letters. Significant differences were determined using a Kruskal Wallis test, with a post hoc pairwise Wilcox test. P value significant at 0.05. BDL (Below detection limit)

	Mn (mg.kg $^{-1}$)		Al (mg.kg $^{-1}$)		Cd (mg.kg $^{-1}$)		Pb (mg.kg $^{-1}$)	
	Pre Ash-Application	*Post Ash Application*	*Pre Ash-Application*	*Post Ash Application*	*Pre Ash-Application*	*Post Ash Application*	*Pre Ash-Application*	*Post Ash Application*
Litter Layer								
Brookland Farm								
Cnt.	2124	2176	443	351	0.8	0.9	1.8	3.0
4 Mg/ha	2425^{a}	4247^{b}*	216^{a}	1538^{b}*	0.9^{a}	1.0^{b}*	1.0^{a}	20.9^{b}*
8 Mg/ha	2273^{a}	4960^{b}*	283^{a}	2365^{b}*	0.8^{a}	2.0^{b}**	2.0^{a}	18.0^{b}*
Wilf Sugarbush								
Cnt.	1904	1830	441	199	0.7	0.7	1.0	1.6
4 Mg/ha	2156^{a}	4827^{b}*	294^{a}	1323^{b}*	0.7^{a}	1.5^{b}*	1.8^{a}	6.0^{b}*
8 Mg/ha	2031^{a}	5882^{b}*	900	2066**	0.8^{a}	2.0^{b}**	1.9^{a}	11.9^{b}**
Mark Sugarbush								
Cnt.	1950	2056	190	287	0.8	0.9	0.8^{a}	1.9^{b}
4 Mg/ha	1829^{a}	4351^{b}*	205^{a}	1788^{b}*	0.8^{a}	1.6^{b}*	1.0^{a}	27.6^{b}*
8 Mg/ha	2009^{a}	4702^{b}*	171^{a}	1988^{b}*	0.7^{a}	1.8^{b}*	0.6^{a}	2.0^{b}*
FH Layer								
Brookland Farm								
Cnt.	1307	1547	3898	2522	0.6	0.9	26.0	27.0
4 Mg/ha	1777	1519	2027	1693	0.8	0.7	29.0	28.9
8 Mg/ha	1545	1699	3397	1366	0.7	1.0	29.8	19.0
Wilf Sugarbush								
Cnt.	859	844	3996	2743	0.6	0.7	19.0	18.9
4 Mg/ha	1245	1621	2909	1384	0.6	0.7	18.0	17.0
8 Mg/ha	918	1369	3344	1985	0.7	0.8	21.6	18.7
Mark Sugarbush								
Cnt.	2119	2444	2464	1479	1.0	1.0	28.9	21.0
4 Mg/ha	1727	1714	2906	1470	0.9	1.0	20.0	23.8
8 Mg/ha	2075	2506	1842	1888	1.0	1.0	26.0	28.0
Mineral Layer								
Brookland Farm								
Cnt.	405	421	8623	5421	0.07	0.15	7.9	10.5
4 Mg/ha	469	279	3485	3550	0.1	0.07	20.0*	18.0*
8 Mg/ha	392	105	5596	2969	0.2	0.15	11.7	20.5
Wilf Sugarbush								
Cnt.	773	463	9522	6930	0.15	0.26	10.9^{a}	23.6^{b}
4 Mg/ha	385	687	7358	4495	0.1	0.13	7.9^{a}	18.5^{b}
8 Mg/ha	505	454	9632^{a}	4728^{b}	0.2	0.24	17.0	28.6
Mark Sugarbush								
Cnt.	537	408	8521^{a}	4204^{b}	0.1	0.2	9.0^{a}	19.7^{b}
4 Mg/ha	306	349	7911^{a}	4187^{b}	0.09	0.2	6.6^{a}	21.0^{b}
8 Mg/ha	365	480	6595^{a}	4147^{b}	0.08	0.2	10.5^{a}	23.5^{b}

	Fe (mg.kg $^{-1}$)		B (mg.kg $^{-1}$)		Cu (mg.kg $^{-1}$)	
	Pre Ash-Application	*Post Ash Application*	*Pre Ash-Application*	*Post Ash Application*	*Pre Ash-Application*	*Post Ash Application*
Litter Layer						
Brookland Farm						
Cnt.	508	445	12.17	13.0	2.5^{a}	7.6^{b}
4 Mg/ha	271^{a}	1416^{b}*	12.6^{a}	59.0^{b}*	2.0^{a}	54.0^{b}*
8 Mg/ha	350^{a}	1399^{b}*	10.8^{a}	95.5^{b}**	3.0^{a}	107^{b}**
Wilf Sugarbush						
Cnt.	263	237	20.5^{a}	12.0^{b}	4.0	6.7
4 Mg/ha	419^{a}	738^{b}*	16.0^{a}	75.8^{b}*	2.5^{a}	87.8^{b}*
8 Mg/ha	357^{a}	1079^{b}*	18.0^{a}	117^{b}**	2.8	138*
Mark Sugarbush						
Cnt.	252	404	18.0	13.0	1.7^{a}	6.0^{b}
4 Mg/ha	270^{a}	1084^{b}*	22.0^{a}	69.5^{b}*	2.5^{a}	82.0^{b}*
8 Mg/ha	213^{a}	1361^{b}*	21.0^{a}	86.0^{b}*	1.0^{a}	86.0^{b}*
FH Layer						
Brookland Farm						
Cnt.	6164	3683	BDL	0.7	1.9^{a}	7.5^{b}
4 Mg/ha	3714	3382	0.2^{a}	6.0^{b}*	6.0^{a}	10.6^{b}
8 Mg/ha	4475^{a}	1971^{b}	BDL^{a}	21.8^{b}**	5.0^{a}	18.7^{b}*
Wilf Sugarbush						
Cnt.	3767	3809	0.2^{a}	2.0^{b}	4.8^{a}	8.0^{b}
4 Mg/ha	4676	2824	0.3^{a}	10.6^{b}*	3.8^{a}	15.5^{b}*
8 Mg/ha	3224	2983	0.3^{a}	19.0^{b}*	4.8^{a}	16.0^{b}*
Mark Sugarbush						
Cnt.	3546	2861	1.0	3.0	7.0^{a}	8.8^{b}
4 Mg/ha	3287	2692	BDL^{a}	13.0^{b}*	4.7^{a}	13.0^{b}
8 Mg/ha	3582	3286	BDL^{a}	15.0^{b}*	6.0^{a}	14.0^{b}*
Mineral Layer						
Brookland Farm						
Cnt.	10456	8421	0.4	0.4	1.5	2.5
4 Mg/ha	7222	7589	0.9	0.4	1.5^{a}	5.9^{b}
8 Mg/ha	7833	5419	1.6	0.2	2.0	2.6
Wilf Sugarbush						
Cnt.	13335	8916	0.1	BDL	1.0	1.8
4 Mg/ha	10992	9023	0.4	BDL	1.7	1.0
8 Mg/ha	11910^{a}	8037^{b}	0.8	0.3	1.0	2.0
Mark Sugarbush						
Cnt.	12338^{a}	8943^{b}	BDL	0.3	0.08	5.0*
4 Mg/ha	11162^{a}	7981^{b}	BDL	BDL	0.2	0.5**
8 Mg/ha	11014^{a}	7960^{b}	BDL	BDL	BDL^{a}	2.0^{b}*

	Ni (mg.kg $^{-1}$)		Zn (mg.kg $^{-1}$)	
	Pre Ash-Application	*Post Ash Application*	*Pre Ash-Application*	*Post Ash Application*
Litter Layer				
Brookland Farm				
Cnt.	1.1	1.0	52.0	58.0
4 Mg/ha	0.8^{a}	5.7^{b}*	66.7^{a}	202^{b}*
8 Mg/ha	0.9^{a}	8.0^{b}*	52.0^{a}	319^{b}**
Wilf Sugarbush				
Cnt.	1.0	0.9	47.0	46.0
4 Mg/ha	0.9^{a}	6.0^{b}*	45.0^{a}	268^{b}*
8 Mg/ha	1.0^{a}	8.8^{b}**	50.0^{a}	394^{b}**
Mark Sugarbush				
Cnt.	0.6^{a}	1.0^{b}	51.0	53.0
4 Mg/ha	0.7^{a}	5.8^{b}*	52.6^{a}	240^{b}*
8 Mg/ha	0.7^{a}	7.5^{b}*	48.8^{a}	287^{b}*
FH Layer				
Brookland Farm				
Cnt.	4.5	3.7	44.1	56.7
4 Mg/ha	5.6	4.0	57.5	63.7
8 Mg/ha	5.7	4.0	60.8^{a}	83.9^{b}
Wilf Sugarbush				
Cnt.	4.8	3.0	39.6	44.0
4 Mg/ha	4.0	3.0	43.8^{a}	61.0^{b}*
8 Mg/ha	4.6	4.0	41.6^{a}	75.0^{b}*
Mark Sugarbush				
Cnt.	5.0	4.0	88.5	61.0
4 Mg/ha	4.8	4.0	59.4	73.5
8 Mg/ha	5.0	4.9	60.0^{a}	95.0^{b}
Mineral Layer				
Brookland Farm				
Cnt.	2.9	2.6	25.6	24.0
4 Mg/ha	2.0		19.0	22.0
8 Mg/ha	2.6	2.7	25.8	22.0
Wilf Sugarbush				
Cnt.	3.8	3.8	24.6	24.0
4 Mg/ha	3.5	2.7	22.9	18.5
8 Mg/ha	4.8	4.0	26.0	22.5
Mark Sugarbush				
Cnt.	2.8	4.0	31.07	27.7
4 Mg/ha	3.9	3.0	26.0	27.0
8 Mg/ha	3.5	3.0	23.9	30.0

3.4.2 Sugar maple foliage

Changes in sugar maple mature and sapling macro and micronutrients

There were small treatment effects on sugar maple foliar Ca and Mg concentrations at all three sties 10 months after ash application (Figures 3.9 – 3.11). Foliar Ca and Mg concentrations in mature trees tended to be higher in the 8 Mg ha^{-1} treatment at Wilf's and Marks's sugar bush but the only significant treatment response was observed at Mark's sugar bush were foliar Mg in mature trees receiving 8 Mg ha^{-1} was about 50% higher than the control (Figure 3.10).

In contrast to Ca and Mg, foliar K concentrations were higher in the ash treatment plots at all study sties compared with control plots 10 months after ash application (Figure 3.11). For example, at Brookland farms foliar K concentrations on average increased by 57% (4 Mg ha^{-1}) to 67% (8 Mg ha^{-1}) in mature and approximately by 72% (4 & 8 Mg ha^{-1}) in sapling foliage in treatment plots than control plots. Similar increases in foliar K occurred at Wilf's and Mark's sugarbush. No treatment effects were observed in foliar P concentrations (Figure 3.12).

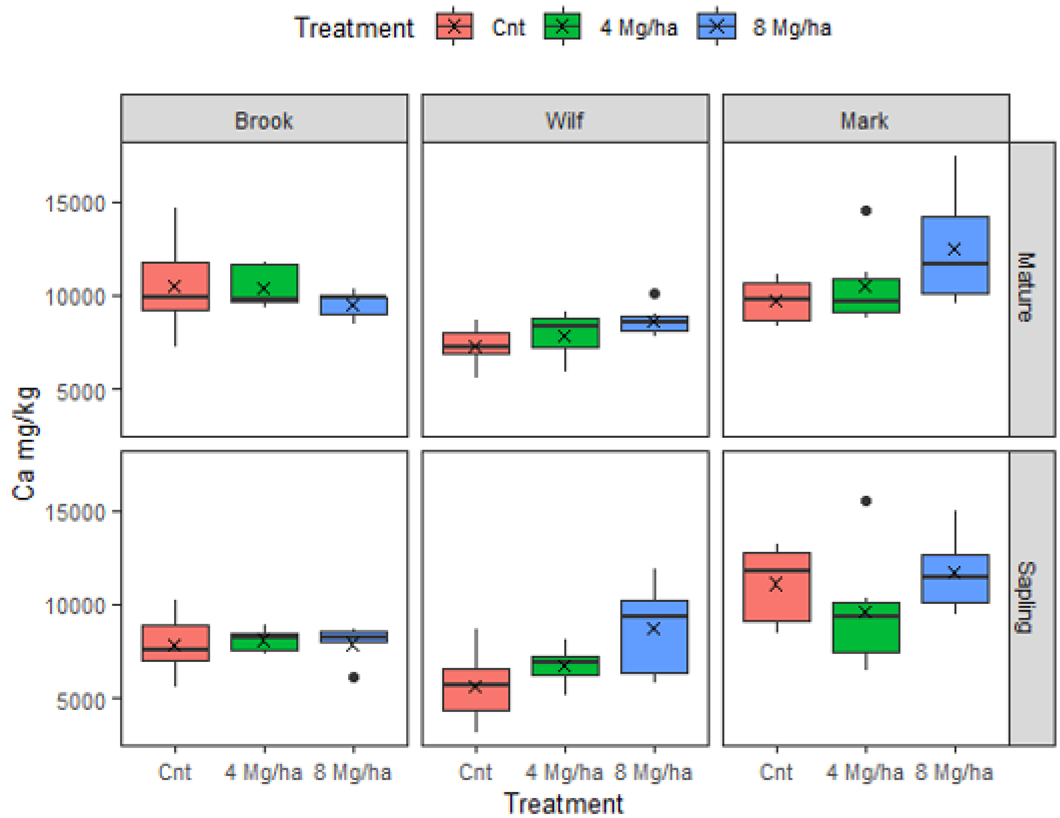


Figure 3.9 Foliar Ca concentrations in mature and sapling foliage 10 months after non-industrial wood ash application at three study sites in Muskoka, Ontario. Significant differences to control indicated by an asterisk (*). Significant differences between dosage amounts (4 and 8 Mg ha^{-1}) indicated by double asterisk (**). Significant differences were determined using the Kruskal Wallis test, with a post hoc pairwise Wilcox test. P value significant at 0.05.

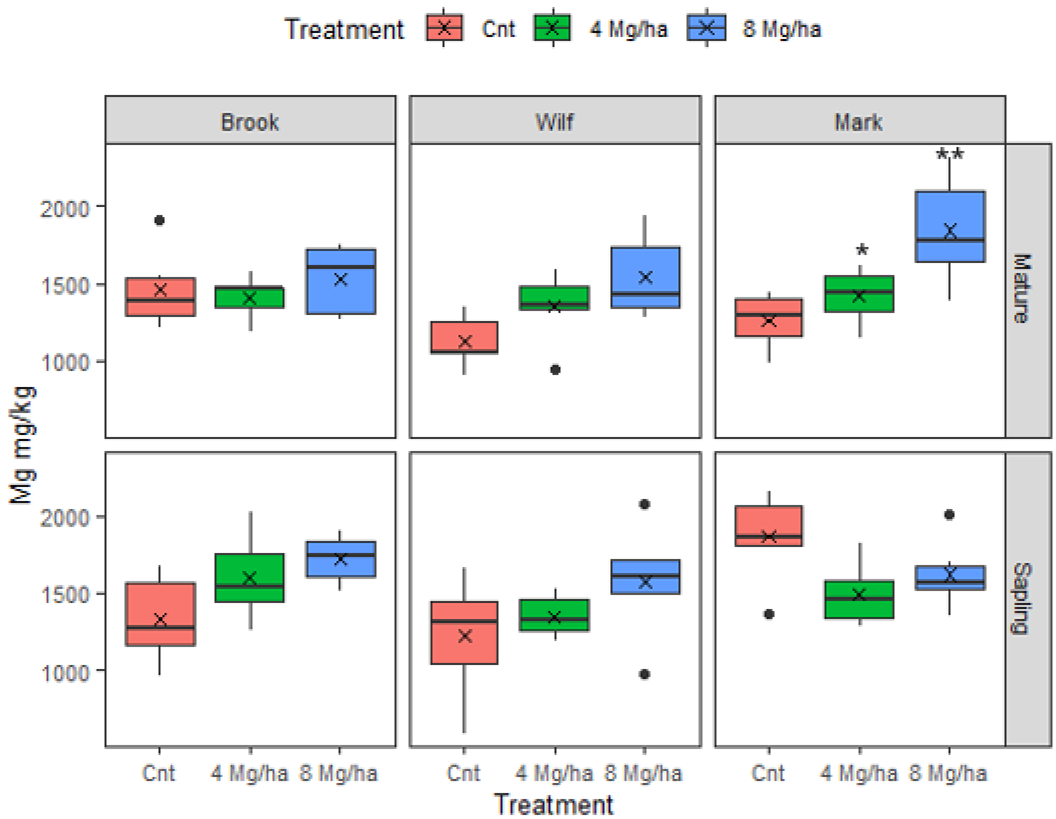


Figure 3.10 Foliar Mg concentrations for mature and sapling sugar maple foliage 10 months after non-industrial wood ash application at three study sites in Muskoka, Ontario. Significant differences to control indicated by an asterisk (*). Significant differences between dosage amounts (4 and 8 Mg ha^{-1}) indicated by double asterisk (**). Significant differences were determined using the Kruskal Wallis test, with a post hoc pairwise Wilcox test. P value significant at 0.05.

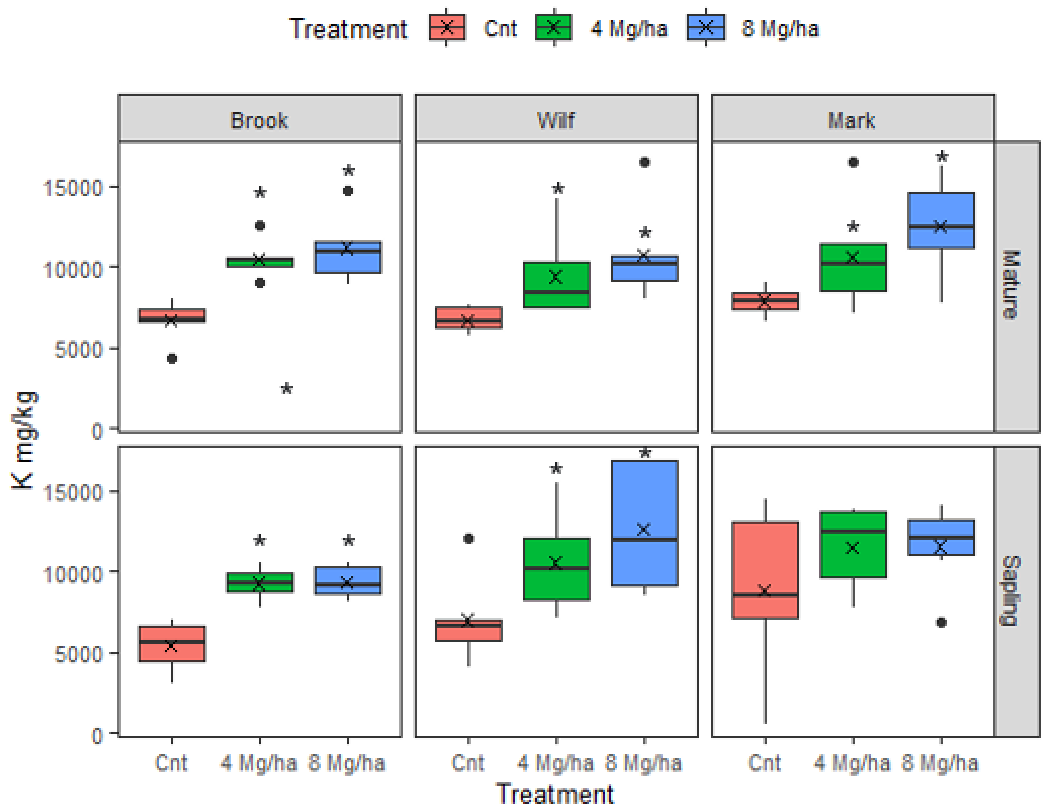


Figure 3.11 Foliar K concentrations in mature and sapling sugar maple foliage 10 months after non-industrial wood ash application at three study sites in Muskoka, Ontario. Significant differences to control indicated by an asterisk (*). Significant differences between dosage amounts (4 and 8 Mg ha^{-1}) indicated by double asterisk (**). Significant differences were determined using the Kruskal Wallis test, with a post hoc pairwise Wilcox test. P value significant at 0.05.

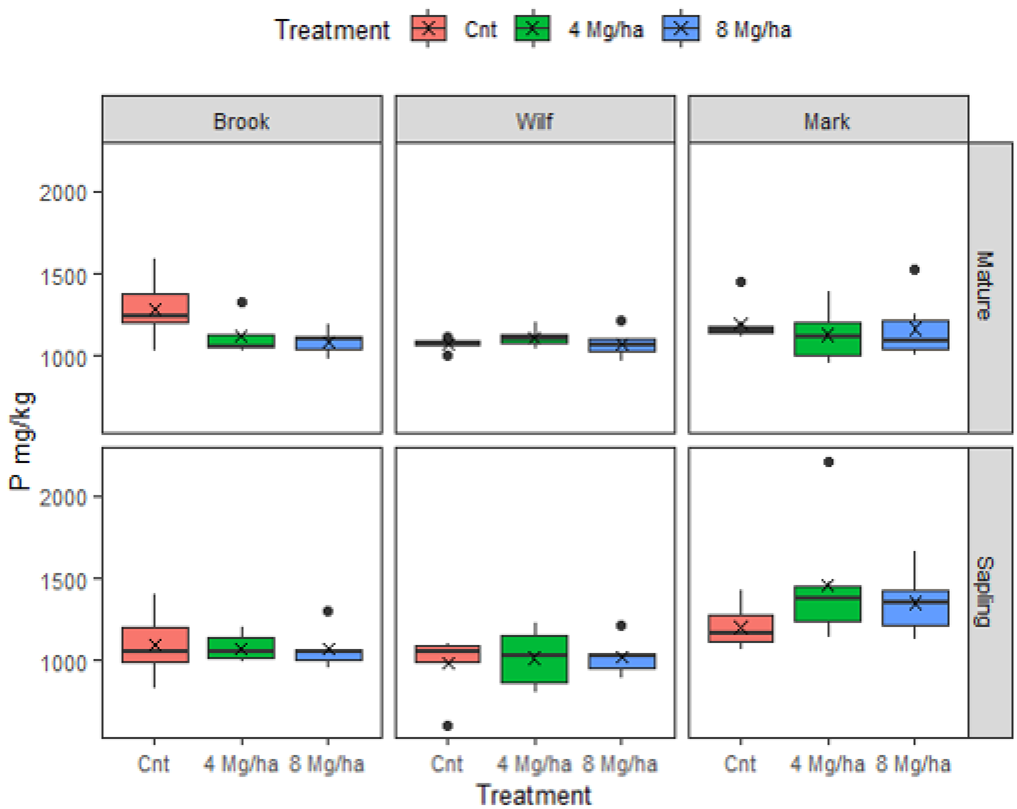


Figure 3.12 Foliar P concentrations in mature and sapling sugar maple foliage 10 months after non-industrial wood ash application at three study sites in Muskoka, Ontario. Significant differences to control indicated by an asterisk (*). Significant differences between dosage amounts (4 and 8 Mg ha^{-1}) indicated by double asterisk (**). Significant differences were determined using the Kruskal Wallis test, with a post hoc pairwise Wilcox test. P value significant at 0.05.

Ten months after ash application, concentrations of a few metals were higher in sugar maple foliage in ash treated plots compared with control plots, but responses were not consistent among sites or between mature and sapling foliage (Table 3.5 – 3.6). For example, B and Cu concentrations in sugar maple saplings exhibited a significant response (increase) to treatment at Brookland Farm's, while only Zn exhibited a significant response (increase) at Wilf's and there were no treatment effects for any metals at Mark's sugar bush (Table 3.5). In mature trees, there were no significant responses to treatment at Brookland Farms, while Cd and Zn increased significantly at Wilf's and Mark's sugar bushes (Table 3.6). When significant responses were observed, concentrations only increased by 10 – 30% and never exceeded the range of foliar nutrient concentrations for healthy sugar maples as reported in the literature (Kolb and McCormick, 1993).

Table 3.5 Mean (SE) sapling sugar maple foliar (n=52) metal concentrations measured, 10 months after non-industrial wood ash application at three study sites in Muskoka, Ontario. Significant differences to control indicated by an asterisk (*). Significant differences were determined using the Kruskal Wallis test, with a post hoc pairwise Wilcox test. P value significant at 0.05. Previously reported foliar nutrient concentrations for healthy sugar maple are also shown.

Sapling Foliage	Treatment dosage			*Reported foliar concentrations*[†]
Study Sites	Cnt.	4 Mg/ha	8 Mg/ha	
Brookland Farms				
Mn mg/kg	1241 (272)	1209 (154)	985 (91.0)	*632 - 1630*
Al mg/kg	19.6 (1)	20.6 (1.6)	19.3 (1.0)	*32 - 60*
Cd mg/kg	0.3 (0.1)	0.3 (0.03)	0.3 (0.03)	
Zn mg/kg	26.9 (2)	29.0 (2.0)	29.0 (1.8)	*29 - 71*
Pb mg/kg	0.48 (0.05)	0.5 (0.13)	0.5 (0.07)	
Ni mg/kg	0.9 (0.13)	1.04 (0.26)	0.8 (0.15)	
Fe mg/kg	50.4 (2.3)	52.0 (2.6)	48.8 (1.2)	*59 -130*
Cu mg/kg	0.5 (0.2)	2.0 (0.9) *	2.0 (0.3) *	*3 - 9*
B mg/kg	34.3 (2.0)	42.6 (2.39) *	49.0 (3.5) *	
Wilf's Sugarbush				
Mn mg/kg	1096 (191)	1612 (305)	1480 (322)	*632 - 1630*
Al mg/kg	13.5 (2.7)	13.0 (3.0)	11.0 (2.0)	*32 - 60*
Cd mg/kg	0.2 (0.1)	0.3 (0.1)	0.3 (0.1)	
Zn mg/kg	22.0 (1.4)	26.8 (1.0) *	27.8 (1.0) *	*29 - 71*
Pb mg/kg	0.5 (0.2)	0.7 (0.2)	0.6 (0.2)	
Ni mg/kg	0.7 (0.2)	0.7 (0.2)	0.6 (0.2)	
Fe mg/kg	39.0 (3.8)	43.0 (1.8)	41.0 (3.6)	*59 -130*
Cu mg/kg	1.0 (0.7)	0.2 (0.14)	0.5 (0.4)	*3 - 9*
B mg/kg	32.0 (2.5)	42.0 (2.8) *	36.0 (4.5)	
Mark's Sugarbush				
Mn mg/kg	907 (156)	1180 (176)	955 (130)	*632 - 1630*
Al mg/kg	32.8 (5.8)	30.0 (7.9)	23.0 (3.8)	*32 - 60*
Cd mg/kg	0.4 (0.2)	0.6 (0.2)	0.5 (0.1)	
Zn mg/kg	29.0 (1.1)	38.0 (2.0) *	32.0 (3.5)	*29 - 71*
Pb mg/kg	BDL	BDL	BDL	
Ni mg/kg	0.7 (0.2)	1.0 (0.6)	0.8 (0.3)	
Fe mg/kg	72.0 (10.1)	57.0 (5.38)	71.0 (6.6)	*59 -130*
Cu mg/kg	BDL	1.0 (0.5)	0.1 (0.2)	*3 - 9*
B mg/kg	38.0 (2.1)	5.0 (4.2)	42.0 (1.7)	

Kolb and McCormick 1993[†] BDL -Below detection limit

Table 3.6 Mean (SE) mature sugar maple foliar (n=51) metal concentrations measured, 10 months after non-industrial wood ash application at three study sites in Muskoka, Ontario. Significant differences to control indicated by an asterisk (*). Significant differences were determined using the Kruskal Wallis test, with a post hoc pairwise Wilcox test. P value significant at 0.05. Previously reported foliar nutrient concentrations for sugar maple are also shown.

Mature Foliage	Treatment dosage			*Reported foliar concentrations*†
Study Sites	Cnt.	4 Mg/ha	8 Mg/ha	
Brookland Farms				
Mn mg/kg	1542 (168)	2424 (365)	1329 (105)	*632 - 1630*
Al mg/kg	22.0 (1.0)	26.5 (2.9)	21.0 (0.8)	*32 - 60*
Cd mg/kg	0.3 (0.03)	0.5 (0.05)	0.3 (0.05)	
Zn mg/kg	33.0 (1.7)	37.7 (3.0)	35.0 (2.0)	*29 - 71*
Pb mg/kg	0.8 (0.1)	0.8 (0.1)	0.6 (0.1)	
Ni mg/kg	1.0 (0.24)	0.9 (0.03)	1.1 (0.15)	
Fe mg/kg	52.0 (2.5)	62.0 (3.8)	57.5 (2.9)	*59 -130*
Cu mg/kg	3.6 (0.7)	1.9 (0.3)	1.0 (0.2)	*3 - 9*
B mg/kg	42.8 (4.4)	60.0 (3.3)	51.0 (3.0)	
Wilf's Sugarbush				
Mn mg/kg	1397 (206)	1845 (344.5)	2149 (679)	*632 - 1630*
Al mg/kg	19.0 (2.0)	19.0 (1.31)	21.0 (1.0)	*32 - 60*
Cd mg/kg	0.3 (0.06)	0.4 (0.04)	0.5 (0.07) *	
Zn mg/kg	26.0 (26.5)	31.8 (1.17) *	36.7 (3.0) *	*29 - 71*
Pb mg/kg	0.6 (0.13)	0.5 (0.08)	0.6 (0.09)	
Ni mg/kg	1.0 (0.2)	1.0 (0.2)	0.8 (0.2)	
Fe mg/kg	44.0 (3.0)	55.0 (2.4)	51.0 (4.7)	*59 -130*
Cu mg/kg	1.8 (0.6)	1.9 (0.5)	3.9 (0.8)	*3 - 9*
B mg/kg	37.0 (3.9)	43.0 (2.6)	51.0 (3.19)	
Mark's Sugarbush				
Mn mg/kg	1128 (139)	1416 (130)	1493 (219)	*632 - 1630*
Al mg/kg	21.0 (2.0)	17.0 (1.0)	17.0 (2.0)	*32 - 60*
Cd mg/kg	0.2 (0.02)	0.3 (0.04) *	0.5 (0.05) *	
Zn mg/kg	30.0 (2.0)	35.0 (2.0)	40.0 (2.0) *	*29 - 71*
Pb mg/kg	0.5 (0.03)	0.6 (0.06)	0.8 (0.1)	
Ni mg/kg	1.0 (0.2)	1.5 (0.2)	1.0 (0.3)	
Fe mg/kg	56.0 (3.2)	49.7 (2.9)	81.0 (28.0)	*59 -130*
Cu mg/kg	1.0 (0.4)	1.0 (0.5)	1.0 (0.4)	*3 - 9*
B mg/kg	43.7 (4.0)	47.0 (3.15)	57.0 (3.0)	

Kolb and McCormick 1993†

Foliage Diagnosis and Recommendation Integrated System (DRIS)

At all three sites DRIS indices generally indicated adequate (-20<0>20) foliar nutrition levels for mature trees however K deficiencies were observed in sugar maple saplings in control plots at Brookland Farms and Mark sugarbush (Table 3.7 – 3.8). Ash application resulted in decreases in DRIS values of mature sugar maple for Ca, Mg, P and N with a large increase in the K DRIS value because of the large increase in foliar K relative to other nutrients. However, treatment effects were only significant for K at Brookland and P at Wilf's and Mark's sugar bushes (Table 3.7 – 3.8). Foliar DRIS values remained negative for Ca and P at all sites except for sugar maple saplings in the control plots at Mark's sugar bush (Table 3.8). Foliar nutrient ratios were generally close to DRIS norms, and nutrient concentrations fell within previously established foliar concentrations for healthy sugar maples (Table 3.7 – 3.8).

Table 3.7 Mean (n=51) nutrient concentrations, ratio and DRIS values in mature sugar maples sampled 10 months after non-industrial wood ash application at three study sites in Muskoka, Ontario. Significant differences to control indicated by an asterisk (*). Significant differences were determined using the Kruskal Wallis test, with a post hoc pairwise Wilcox test. P value significant at 0.05. Previously reported foliar nutrient concentrations for healthy sugar maple and DRIS norms for mature sugar maple are also shown.

Mature Foliage	Brookland Farm			Wilf Sugarbush			Mark's Sugarbush			*Reported foliar concentrations*
	Cnt.	4 Mg/ha	8 Mg/ha	Cnt.	4 Mg/ha	8 Mg/ha	Cnt.	4 Mg/ha	8 Mg/ha	
Concentrations										
(%)										
Ca	**1.05**	**1.04**	**0.95**	**0.73**	**0.79**	**0.86**	**0.97**	**1.05**	**1.25**	*0.5-2.19***
Mg	0.10	0.14	0.15	0.11	0.14	0.15	0.13	0.14	**0.18***	*0.11-0.4***
K	0.67	**1.05***	**1.12***	0.67	0.94	**1.07***	0.79	1.06	**1.25***	*0.55-1.04***
P	0.13	0.11	0.11	0.11	0.11	0.11	0.12	0.11	0.12	*0.08-0.18***
N	2.18	2.20	2.18	2.08	2.11	2.16	2.09	2.12	2.24	*1.6-2.23***
Ratios										*DRIS norms*
Ca:Mg	7.21	7.44	6.33	6.58	5.86	5.69	7.80	7.40	6.73	*8.12*†
Ca:K	1.69	**0.99***	**0.89***	1.10	0.88	0.84	1.25	1.04	1.05	*1.28*†
Mg:K	0.23	**0.14***	**0.14***	0.17	0.15	0.15	0.16	0.14	0.16	*0.14*†
P:Ca	0.13	**0.11**	0.12	0.15	**0.14**	0.13	0.13	**0.11**	0.10	*0.17*†
P:Mg	0.91	0.80	0.72	0.97	0.84	0.72	0.96	0.80	**0.66***	*0.83*†
P:K	0.20	**0.11***	**0.10***	0.16	**0.13***	**0.11***	0.15	0.12	0.10	*0.18*†
DRIS indices										
Ca	-0.97	-1.93	-4.91	-7.35	-8.29	-7.12	-1.67	-2.16	-1.70	
Mg	6.48	1.91	4.74	1.29	3.85	6.03	0.48	2.23	6.50	
K	-13.82	**3.73***	**4.19***	-5.68	1.22	3.10	-3.38	2.28	3.27	
P	-7.31	-13.22	-12.70	-6.94	-9.53	**-12.09***	-7.75	-11.35	**-13.78***	
N	15.62	9.50	8.68	18.7	12.75	10.08	12.3	9.01	5.71	

Kolb and McCormick 1993**, Lozano and Huynh 1989†

Table 3.8 Mean (n=52) nutrient concentrations, ratio and DRIS values in sapling sugar maples 10 months after non-industrial wood ash application at three study sites in Muskoka, Ontario. Significant differences to control indicated by an asterisk (*). Significant differences were determined using the Kruskal Wallis test, with a post hoc pairwise Wilcox test. P value significant at 0.05. Previously reported foliar nutrient concentrations for healthy sugar maple and DRIS norms for mature sugar maple are also shown.

Sapling Foliage	Brookland Farm			Wilf Sugarbush			Mark's Sugarbush			*Reported foliar concentrations*
	Cnt.	4 Mg/ha	8 Mg/ha	Cnt.	4 Mg/ha	8 Mg/ha	Cnt.	4 Mg/ha	8 Mg/ha	
Concentrations										
(%)										
Ca	0.78	0.8	0.7	0.5	0.7	0.8	1.1	0.9	1.0	*0.5-2.19***
Mg	0.13	0.16	0.17	0.1	0.1	0.3	0.1	0.1	0.1	*0.11-0.4***
K	0.54	**0.93***	**0.94***	0.7	**1.0***	**1.3***	0.8	1.1	1.15	*0.55-1.04***
P	0.11	0.11	0.11	0.09	0.1	0.10	0.1	0.1	0.14	*0.08-0.18***
N	2.08	2.08	2.08	2.0	2.0	1.9	2.0	1.8	2.0	*1.6-2.23***
Ratios										*DRIS norms*
Ca:Mg	5.	**5.0***	**4.6***	4.7	4.9	5.6	6.0	6.0	7.0	*8.12*†
Ca:K	1.5	**0.9***	**0.8***	0.8	0.6	0.7	3.0	0.8	1.0	*1.28*†
Mg:K	0.3	0.2	0.2	0.1	0.1	0.1	0.6	0.1	0.1	*0.14*†
P:Ca	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	*0.17*†
P:Mg	0.8	0.7	0.6	0.8	0.7	0.6	0.6	**0.9***	0.8	*0.83*†
P:K	0.2	**0.1***	**0.1***	0.2	0.1	0.1	0.5	0.1	0.1	*0.18*†
DRIS indices										
Ca	-5.9	-8.1	-9.5	-16	-11.7	-7.0	4.0	-6.0	-2.0	
Mg	9.0	9.5	10	4.5	5.3	5.7	33.0	**3.06***	**2.6***	
K	-18.0	**1.1***	**0.29***	-5.8	**4.9***	**7.5***	-75	5.0	1.8	
P	-6.8	**-13.0***	**-11.6***	-7	-10.9	-12.9	0.1	-6.5	-10.0	
N	21.8	**10.5***	**9.9***	25.5	12.5	7.0	37	7.4	7.7	

Kolb and McCormick 1993**, Lozano and Huynh 1989†

3.4.3 Treatment Effects on Tree Growth

Mean basal area of surviving trees increased similarly (between 6 and 15%) at all three sites between 2019 and 2021. No significant differences were observed in percent change in BA between treatment plots and control plots (Table 3.9).

Table 3.9 Mean basal area (m^2 ha^{-1}) pre ash application (2019) and % change in BA two years post application is shown for three study sites in Muskoka, Ontario. Only trees which survived from the period 2019 to 2021 are included.

	2019			2021			
Site	Basal area			Basal area			% Change in BA
Brookland Farms	Mean	SD	*Cv*	Mean	SD	*Cv*	2019 - 2021
Cnt.	23.9	6.5	0.3	25.9	6.4	0.2	10.86
4 Mg/ha	26.9	8.4	0.3	28.3	8.5	0.3	6.30
8 Mg/ha	22.9	7.3	0.3	24.8	7.6	0.3	9.60
Wilf Sugarbush							
Cnt.	34.0	6.7	0.2	36.5	6.5	0.2	10.30
4 Mg/ha	23.7	5.4	0.2	25.6	5.6	0.2	9.30
8 Mg/ha	27.9	9.0	0.3	30.4	9.8	0.3	11.21
Mark's Sugarbush							
Cnt.	20.6	8.2	0.4	22.5	8.9	0.4	11.60
4 Mg/ha	33.3	1.4	0.0	35.9	1.3	0.0	10.79
8 Mg/ha	17.6	2.0	0.1	18.8	2.0	0.1	15.13

3.4.4 Understory Vegetation Diversity (Richness and Abundance) – Treatment Affects

At Mark's sugar bush there was a significant increase in species diversity in treatment plots compared with control plots one year post application, however Mark's also was the least diverse of the three sites; there was no effect of treatment at the other two sites (Figure 3.13) and no difference in species diversity was observed 2 years after application at all three sites. Slight increases in species richness were generally observed in treatment plots compared with control plots, however the difference was only significant at Brookland farms in the 8 Mg ha^{-1} plots, two years after application (Figure 3.12).

Additionally, an Anosim test revealed no significant changes in species abundance between treatment and control plots at all three sites post application (2020 significance value 0.97 R = - 0.2922; 2021 significance value 0.552 R = -0.0699). Results of the Simper test indicated that sugar maple and trout lily (*Erythronium americanum*) were the most influential species in the differences between treatment and control plots one year after application, meanwhile sugar maple and spinulose wood fern (*Dryopteris carthusiana*) were the most influential species two years after application.

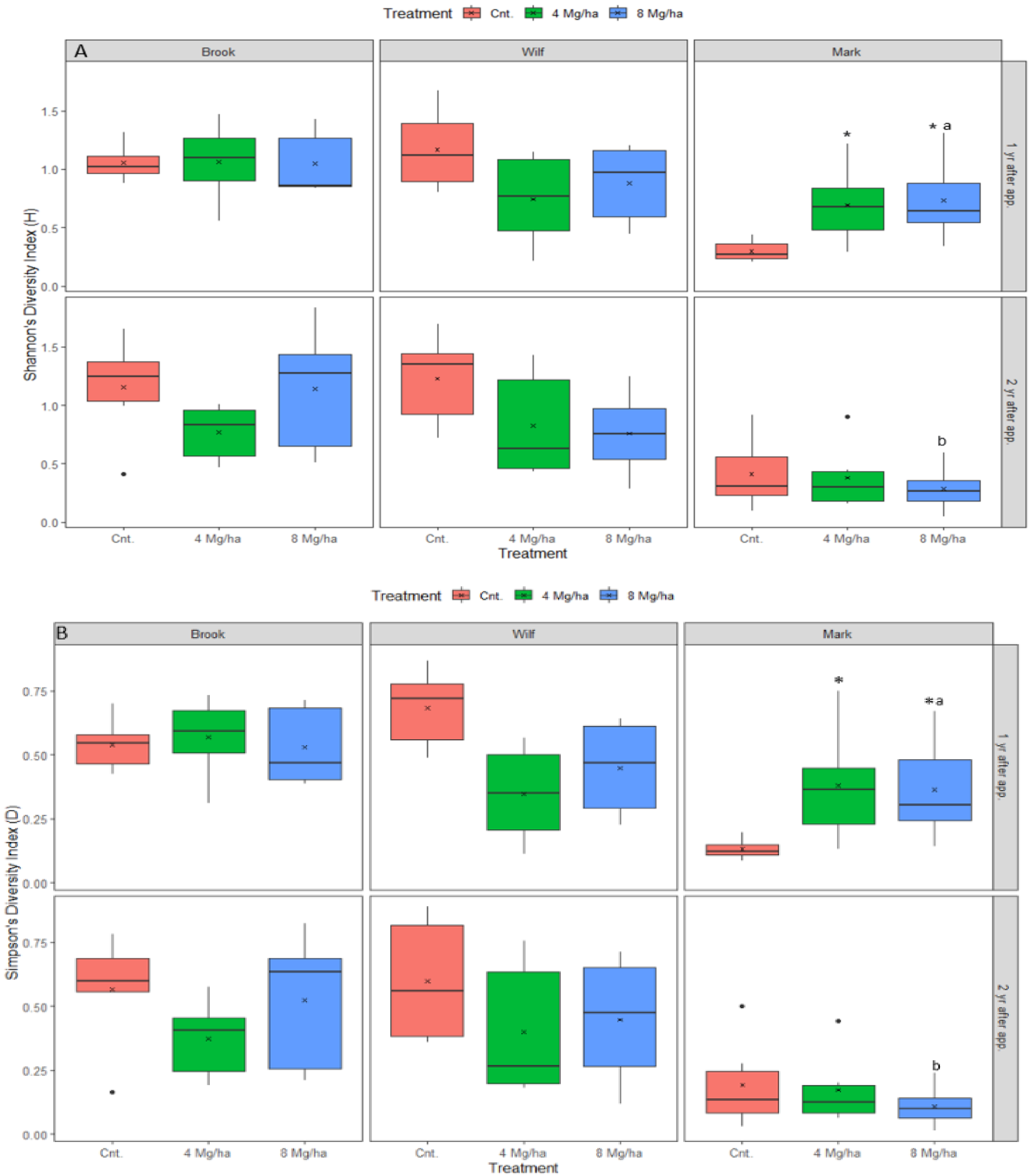


Figure 3.13 A.) Shannon's Diversity index (H), B.) Simpson's Diversity index (D) for understory vegetation, 1 and 2 years after non-industrial wood ash application at three study sites in Muskoka, Ontario. Higher H indicates greater diversity in taxa richness and evenness. Higher D indicates greater diversity where more weight is given to abundance of species. Significant differences to control indicated by an asterisk (*). Significant differences over time indicated by differing letters. Significant differences were determined using the Kruskal Wallis test, with a post hoc pairwise Wilcox test. P value significant at 0.05.

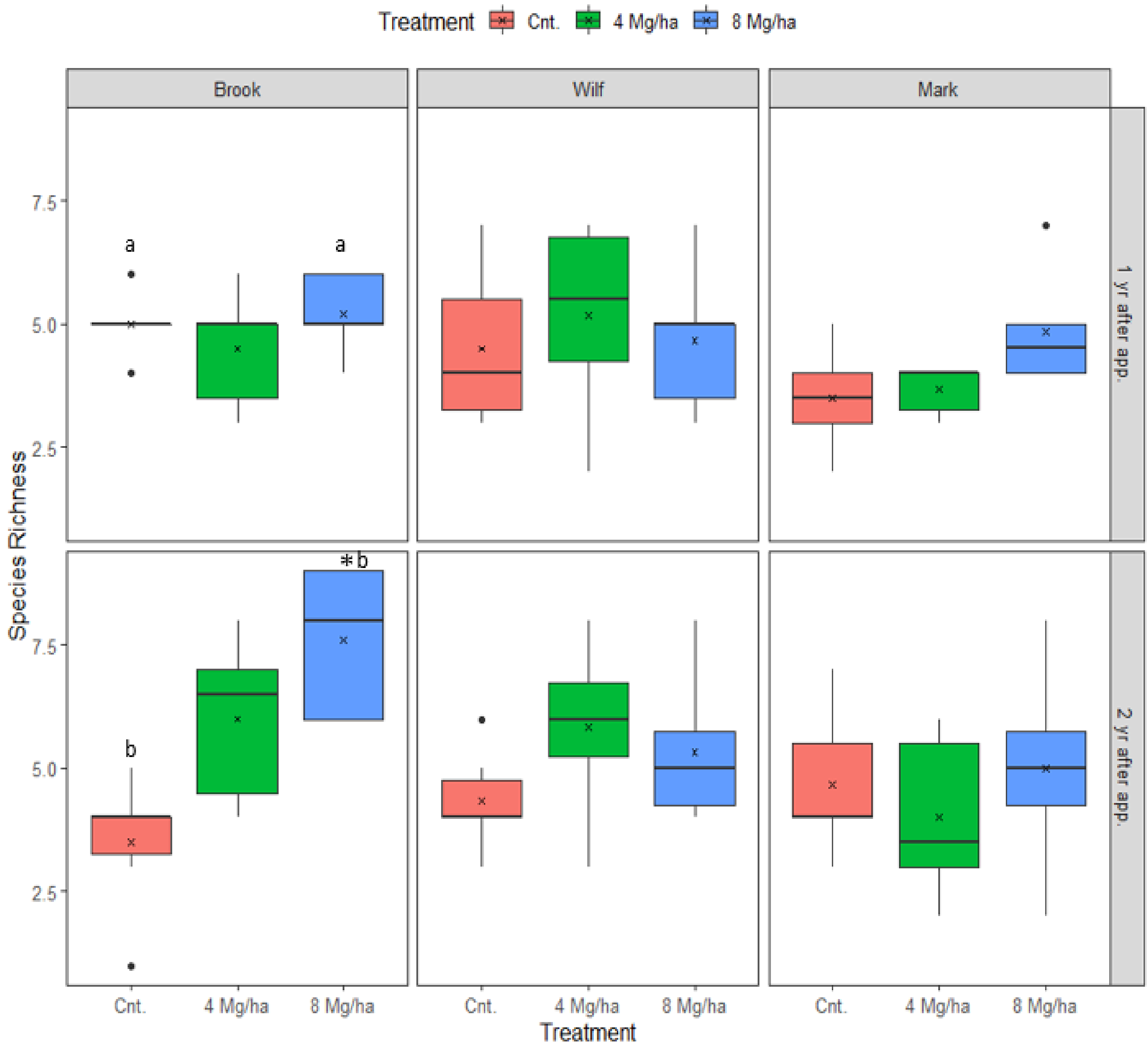


Figure 3.14 Species richness per quadrat, 1 and 2 years after non-industrial wood ash application at three study sites in Muskoka, Ontario. Significant differences to control indicated by an asterisk (*). Significant differences over time indicated by differing letters. Significant differences were determined using the Kruskal Wallis test, with a post hoc pairwise Wilcox test. P value significant at 0.05.

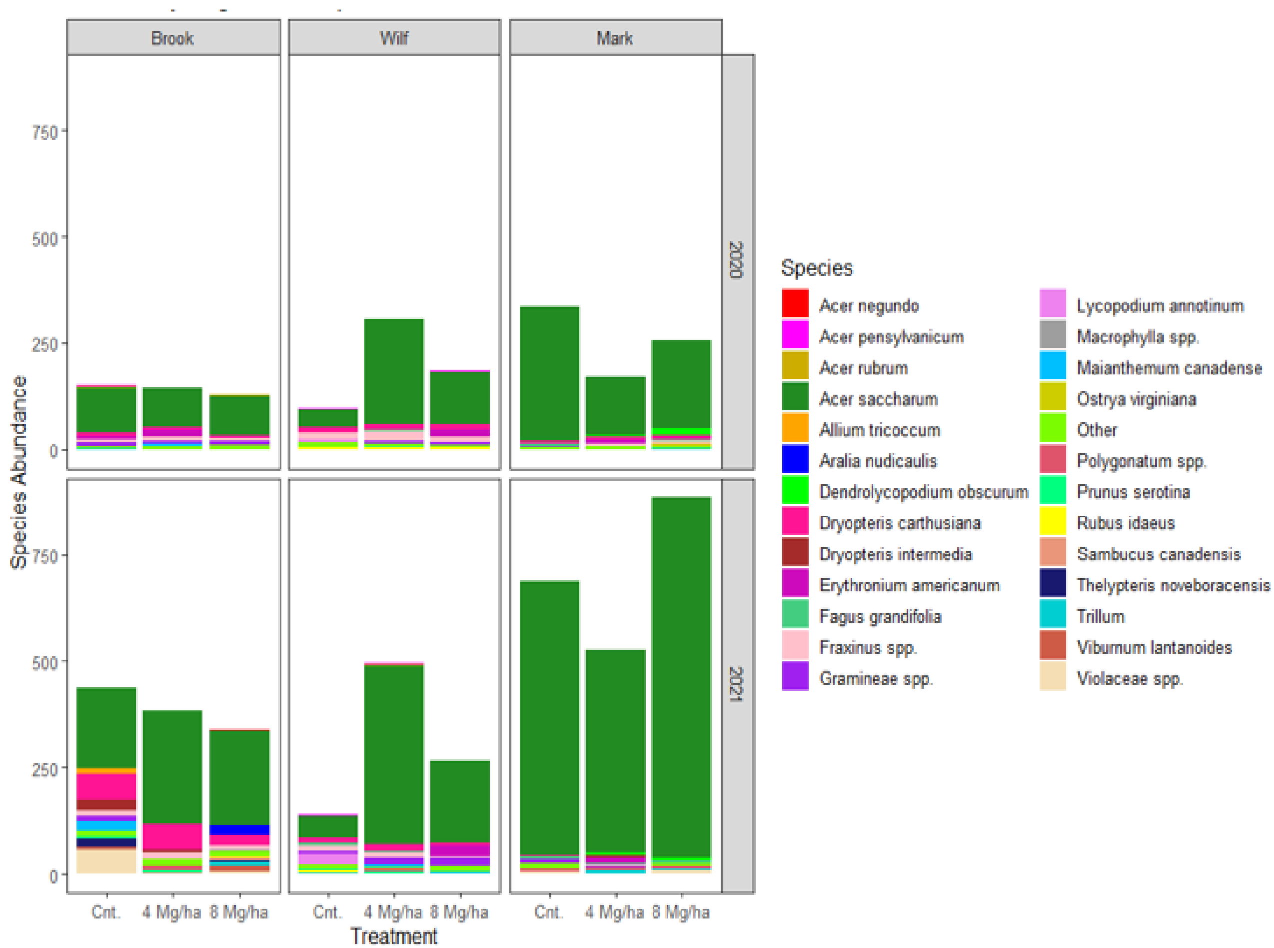


Figure 3.15 Species abundance 1 and 2 years after non-industrial wood ash application at three study sites in Muskoka, Ontario. Species making up less than 2 individuals per plot are listed under others, these include *Ribbs spp., Quercus spp., Cornus canadensis, Solidago spp., Abies balsamea, Duranta erecta, Viburnum dentatum, Actaea racemosa, and Cornus florida.*

3.5 Discussion

This study evaluated the short-term response of forest soils, sugar maple growth and nutrition and understory composition to NIWA additions. Ten months after application there were increases in soil pH and soil exchangeable base cation concentrations in all treatment plots compared with control plots in the soil organic horizons, but there were few responses in mineral soil with the notable exception of K that increased in ash treated plots at all three sites. Soil metals were generally low and significant increases in concentration occurred in the litter and FH horizons for most metals. DRIS analysis indicated that K was the most limiting nutrient at all sites and foliage K concentrations increased significantly at all study sites. There were minimal responses in foliar Ca, Mg, P and N to ash treatment and there were small increases in some metals, but these did not occur at all sites. In 2020 there were small changes to ground vegetation diversity and richness, but the understory response varied among sites. Sugar maple growth was unaffected by treatment two years post application, however due to the loss of several sample trees, these results may not be an accurate representation of growth post ash application.

3.5.1 Effects of NIWA on soil chemistry

Prior to ash application soils were acidic at all three study sites (< 5.0 pH units). Ten months after NIWA application soil pH increased significantly at all sites, by approximately 2.0 pH units, in the litter and FH horizons. Ash induced increases in soil pH have been well documented. For example, Saarsalmi et al. (2001) reported an increase of 0.6 – 1.0 pH units in the humus layer after ash application of 3 Mg ha^{-1}, to a Scots pine stand located in northern Finland. Similarly, Levula et al., (2000) reported pH increase of 1.0, 2.0 and 3.0 in the humus layer after wood ash application of 1 ,2.5 and 5 Mg ha^{-1} respectively, to a Scots pine (*Pinus sylvestris*) forest located in central Finland. Even though large increases in pH in the soil organic horizon were observed ten months after ash application there were few significant changes in mineral soil pH. Only one of the sites (Mark's) exhibited a significant increase in mineral soil pH in 8 Mg ha^{-1} ash treated plots. This is consistent with previous studies that show, where treatment responses to ash application in mineral soil are often not observed for several years (Brais et al., 2015; Domes et al., 2018; Saarsalmi et al., 2006). The lack of pH response to ash application in mineral soils can primarily be explained by the slow vertical movement of soluble components of the ash downward in the soil profile (Reid & Watmough, 2014; Van Der Heijden et al., 2013).

The alkalinity of wood ash varies depending on the carbonate, bicarbonate, and hydroxide content of ash (Etitgni & Campbell, 1991), and NIWA used in this study has a pH value and Ca content that is generally higher than industrial wood ash (Chapter 2). The strong neutralizing and buffering capacity of ash is due to the hydroxyl ions that form because of the dissolution of hydroxides, oxides, and carbonates such as CaO, MgO, NaOH and $CaCO_3$, which neutralize the protons in soil solution and those bound on cation exchange sites in the soil (Saarsalmi et al., 2006; Ulery et al., 1993). However, the response of soils to ash application can vary depending upon the original soil pH, the thickness of the humus layer and cation exchange capacity of the soil (Saarsalmi et al., 2006). Differences in these variables between sites could explain why significant changes in the mineral horizon were only observed at Mark's sugarbush and not Brookland farms or Wilf's sugar bush.

Exchangeable base cation (Ca, Mg) concentrations also significantly increased in the litter and FH horizons in all treatment plots at the three sites compared with the controls post application. As with pH, responses in mineral soil Ca and Mg to ash application were small and were only significant for Mg in the 8 Mg ha^{-1} treatment plots. This is consistent with previous findings (Domes et al., 2018; Kahl et al., 1996). For example, in one study using industrial bottom ash treatment of 5 Mg ha^{-1} in a spruce forest in British

Columbia a significant increase in exchangeable base cations was observed in the LFH horizons of ash treated sites compared with control after one growing season, however no treatment effects were observed in the mineral soil (Domes et al., 2018). Kahl et al. (1996) reported increases in exchangeable base cations one month after an ash application of 20 Mg ha^{-1} in the organic soil horizon, however the increases were only significant for Ca and K, and after 25 months significant differences were reported for Ca and Mg while K levels returned to pre-treatment values.

In this study K levels in soil exhibited a different behavior to Ca and Mg. In contrast to Ca and Mg, there was no increase in K concentration in the litter layer measured ten months after ash application, but there were increases in the FH layer and the most significant response was measured in the mineral horizons in treatment plots. The difference in behavior of the base cations can be attributed to the solubility of K in the ash compared with Ca and Mg. The dissolution of wood ash is complicated as each cation dissolves at different rates, however K is the most soluble nutrient in wood ash followed by Ca and Mg (Meiwes, 1995). The soluble potassium hydroxide and potassium carbonate react rapidly with acids, while less soluble calcium hydroxide and calcium carbonate react more slowly (Campbell, 1990); therefore, extractable K concentrations increase rapidly after ash treatments (Meiwes, 1995). For example, a gram of granulated wood ash dissolved in 40 ml of water resulted in 24% of total K, 2% of total Ca, and 0% of total Mg being released in five hours (Meiwes, 1995). Another study found that approximately 60% of K leached with distilled water while <0.1 % leachate occurred in Mg (Etitgni & Campbell, 1991). Additionally, NIWA mixtures used in this study generally had higher K concentrations compared with previously reported industrial wood ash K concentrations (Chapter 2). Potassium is also a monovalent cation that generally has a weak bond to soil particles (Farahani et al., 2018) and thus is readily exchanged with other cations, and levels can be affected by the concentrations of divalent cations (Ca, Mg) (Mouhamad et al., 2016), which explains the increases recorded further down the soil profile, in the mineral layer rather than the litter.

A major concern over the usage of wood ash as a soil amendment is the presence of trace metals within ash and their subsequent accumulation in forest soils (Etitgni & Campbell, 1991; Hannam et al., 2018; Narodoslawsky & Obernberger, 1996). Detrimental effects on plant health caused by elevated soil concentrations of metals such as Mn, Pb, Cd, Zn, and Cu are well documented in literature (Fernando et al., 2016; Schaberg et al., 2006; Watmough, 2010). Ten months after ash application C, N and % OM were lower in the litter horizon at the treated sites compared with the control, which can be attributed to the layer of residual ash still visible during post application sampling. While concentrations of all metals measured in this study increased significantly in the litter horizon of treatment plots relative to control or pre-treatment plots. Elevated metal concentrations were mainly restricted to the litter horizon and there were few significant increases in metal concentrations in the FH and mineral horizons of treatment plots. However, concentrations of several metals in the litter horizon of the treated plots in this study were much larger than previously reported concentrations of metals found in forest floors of healthy sugar maple stands. For example, Watmough, (2010) reported concentrations of Cd, Zn, Cu, Pb and Mn for sites with healthy sugar maple stands to be <

0.4, 45, 9, 10, 600 mg kg^{-1} respectively, meanwhile sites with higher concentrations of these metals in the forest floor, > 0.8, 60, 12, 20, 800 mg kg^{-1} respectively, exhibited moderate decline symptoms. However, these increases are consistent with other studies, and metal solubility and bioavailability may be restricted.

For example, Ludwig et al., (2002) found similar increases in heavy metal content in the organic layer but differences were not observed further down the soil profile. Additionally, Hansen et al., (2018) found significantly higher concentrations of heavy metals such as Cd and Zn in the O-horizon after an ash application of dosage rates varying from 3 to 6 Mg ha^{-1} in a Norway spruce stand located in Denmark. Nevertheless, the solubility and bioavailability of metals in ash, generally depend upon multiple factors such as pH and organic matter (Martinez & Motto, 2000; Vance, 1996) and metal availability can be altered by changes in soil pH brought on by the ash addition (Vance, 1996). For example, the solubility of Pb, Zn, and Cu increases as soil pH decrease, with a pH threshold of 5.2, 6.2 and 5.5 respectively, below which point metal mobility, bioavailability and toxicity in soil are enhanced (Martinez & Motto 2000). These limitations to solubility and mobility could explain why large increases in metal concentrations did not occur in the mineral horizon and were mainly restricted to the litter layer, as the pH of the litter horizon was around 7.0 in ash treated plots. Additionally, NIWA applied in this study generally had lower concentrations of trace metals compared with previously reported literature metal concentrations of industrial bottom and fly ash (Chapter 2). Furthermore, the increases in metal concentrations in the O-horizon may be proportionally to increasing ash dosage rate

(Hansen et al., 2018), and therefore impact can be reduced with an application of lower doses.

Only Cu and B concentrations in deeper soil horizons exhibited significant treatment effects and these were most pronounced at the higher ash dose (8 Mg ha^{-1}). This could be attributed to the initial chemical composition of the NIWA applied to the study sites (mean concentrations > 110 mg kg^{-1}) and the higher dosage rate. For example, Saarsalmi et al., (2006) found in their study on the effects of wood ash on soil chemistry in varying doses (1, 2.5, 5 Mg ha^{-1}) that the highest dosage rate significantly increased the total concentrations of several metals including Cu. Additionally, Cu was the only metal whose concentrations were above the land application (unrestricted CM1) guidelines as described in Chapter 2. However, solubility is affected by decreasing soil pH, generally below 5.5 after which Cu's biological availability and metal mobility increases (Cuske et al., 2013; Martinez & Motto, 2000), and since pH values increased after ash application it is likely that these concentrations should not pose a risk, as studies have shown ash induced soil pH increases can last for decades after initial application (Saarsalmi et al., 2001; Saarsalmi et al., 2006). The increases in soil B concentration are consistent with previously reported findings (Saarsalmi et al., 2006) and its availability also depends largely on soil factors such as pH, texture and organic matter (Goldberg, 1997). Boron is most available in soils within the pH range of 5.0 to 7.0, with availability dropping as pH rises, with the highest concentrations found in the organic horizons which explains why significant increases are reported after ash application (Wright, 1986). Boron is an important micronutrient for healthy plant development aiding in cell wall and membrane structure and functionality (Brdar-Jokanović, 2020). However, it has been reported to become phytotoxic in excess amounts although the threshold for toxicity varies depending on the species and within species genomes (Brdar-Jokanović, 2020; Ghanati et al., 2001). Although, several studies have reported elevated levels of B after ash applications, toxicity in plants from B were not reported (Saarsalmi et al., 2006, Moilanen et al., 2002).

3.5.2 Effects of NIWA on Sugar Maple Foliage Chemistry

Foliar base cation concentrations were generally lower in the control plots compared with treatment plots, but they were typically within previously reported healthy ranges for sugar maple trees (Kolb and McCormick, 1993). Ten months after ash application foliar K concentrations in both saplings and mature trees increased substantially while Ca, Mg and P exhibited only small changes in response to ash treatment, and these did not occur at all sites. DRIS indices indicated K to be the most limiting nutrient prior to ash application and a significant treatment response for K indices occurred in treatment plots for mature and sapling foliage reflecting the increases in K relative to other nutrients. Similar increases in foliar needle K concentrations have been reported in other ash application studies (Ludwig et al., 2002, Moilanen et al., 2013). However, not all studies have shown large increases in foliar K following the application of wood ash. For example, Arseneau et al. (2021) reported continued deficiencies in K in sugar maple (seedlings and mature trees) in 75% of sampled individuals post wood ash application. The nutrient status of foliage following ash application is likely explained by the characteristics of the ash and the dose applied (Arvidsson & Lundkvist, 2002). The high concentrations of K in NIWA used in this study and the high K solubility in soil could be the reason why significant increases were observed for foliar K within the short period of time between sampling events.

Phosphorus concentrations in the NIWA applied to the study sites were generally towards the higher end (> 7 g kg^{-1}) of the previously reported industrial wood ash values in existing literature (0.1 – 11.9 bottom ash / 3.2 – 10.6 g kg^{-1} fly ash), nevertheless negative DRIS values for P were recorded in the control and treatment plots post ash application indicating that slight P deficiencies existed prior to ash application and that they persisted posted application, which is in contrast to K where strongly negative DRIS values became positive. Phosphorus availability is strongly related to soil pH (Ara et al., 2018) and P availability to plants is highest in soils with pH 6.5 - 7, and as pH falls, P deficiency increases (Penn & Camberato, 2019). Wood ash has the potential to improve P availability through mechanisms such as increases in soil pH as P fixation is weakest at neutral pH values (Johan et al., 2021). In a study looking at the effects of wood ash application over 50 years, plots treated with 16 Mg ha^{-1} birch wood ash showed increases in foliar P and K concentrations above deficiency levels while control plots suffered from continued deficiencies (Moilanen et al., 2002). Although ash induced increases occurred in soil pH in the litter and FH horizons post ash application, mineral horizons did not undergo large changes in pH and soils remained acidic (pH < 5.0) in the treatment plots which can explain why P deficiencies continued post ash application.

Before treatment, DRIS indices indicated that all sites had slight deficiencies in Ca, except for saplings at Mark's sugar bush. There were small increases in foliar Ca concentrations in mature and sapling foliage at two out of the three study sites, with the treatment response noted to be more prominent in the 8 Mg ha^{-1} treatment plots; however, these increases were not significant and DRIS index values were negative for control and treatment plots. In some cases, DRIS values for Ca fell because of the larger increases in foliar K. Previous studies have shown that the response of Ca in foliage to ash application varies tremendously (Arseneau et al., 2021, Domes et al., 2018, Ludwig et al., 2002). For example, studies have reported significant increases in foliar Ca concentrations in sugar maple seedlings after ash application (Deighton & Watmough, 2020), and significant increases were also seen in spruce after just one growing season (Domes et al., 2018). Meanwhile, Ludwig et al. (2002) reported no significant changes in foliar Ca one to two years after ash application, while another study reported decreases in Ca deficiencies in foliage 3 years after ash application (Arseneau et al., 2021). Treatment dosage and time since treatment are the strongest drivers of foliar Ca concentrations (Reid & Watmough, 2014). Transport of Ca in the xylem to foliage is slow as compared with other nutrients such as N, due to successive cation exchanges along the xylem vessel (Augusto et al., 2011), and foliar Ca concentrations have been found to increase with time (Augusto et al., 2008). Additionally, in a systematic meta-analysis on the effects of lime and wood ash, it was concluded that hardwoods treated with lime at high dosage rates resulted in the largest mean foliar Ca increases (Reid & Watmough, 2014). Furthermore, Ca along with Mg and Fe are the more moderately soluble elements in ash while K, B and Na are the most soluble and P in the most insoluble element present (Augusto et al., 2008). It can be inferred that the full effects of the ash treatment on foliar Ca have not yet been realized due the element's general behavior in the xylem, solubility in ash and the dosage applied and continued monitoring may provide better insight.

NIWA contains trace metals which have the potential to bioaccumulate within plants causing detrimental effects (Deighton & Watmough, 2020; Rodriguez et al., 2019). Ten months after ash application concentrations of a few metals increased slightly in tree foliage of treatment plots compared with controls, however the concentrations never exceeded the range of previously reported foliar nutrient levels for healthy sugar maple and responses differed by site. Metals that exhibited the greatest increases were B, Cu, Cd and Zn, but increases were < 30% at all sites. Foliar B deficiency in sugar maple has been reported below < 23 mg kg^{-1} (Bernier & Brazeau, 1988a), however phytotoxicity levels in plants are species and genotype within the species dependent (Brdar-Jokanović, 2020). Foliar Zn concentrations for sapling and mature foliage were generally below or towards the lower end of previously reported foliar nutrient concentrations for healthy sugar maple in the control plots and saw significant increases in the treatment plots. However, there may be a small range between Zn concentrations promoting healthy growth in sugar maples and Zn levels causing distress. For example, Watmough (2010) reported foliar Zn concentrations in healthy sugar maple foliage at > 25 mg kg^{-1} while sugar maples displaying signs of distress had foliar Zn concentrations > 30 mg kg^{-1}. Foliar Cu concentrations generally increased or remained the same in the treatment plots as compared to control. However, they were generally much lower than levels after which moderate decline symptoms in mature sugar maple have been reported (Watmough, 2010). In this study, trace metal concentrations after ash application do not seem to pose a threat to healthy growth however due to increases in Zn and B levels continued monitoring for phytotoxicity symptoms should be considered.

3.5.3 Effects of NIWA on Sugar Maple Growth

No significant treatment response in tree growth was recorded two years after application. This is similar to some existing short-term studies on wood ash that often show limited growth response to ash application (Mandre et al., 2006; Saarsalmi et al., 2006). For example, Saarsalmi et al., (2006) found positive increases of about 7 to 8% in volume growth in the first and second year of a five-year study in the ash treated plots however the increases were not significant. Similarly, Mandre et al., (2006) found that diameter and height growth of Scots pine increased slightly three years after response to ash application, but the response was not significant. In contrast, other long-term studies have found significant increases in annual BAI in ash treated plots compared with control plots (Moilanen et al.,2002), and in one study, significant increases in annual BAI of mature sugar maples were observed just three years after ash application (Arseneau et al.,2021). The lack of significant growth response in treatment plots may be attributed to the limited passage of time between sampling periods. In a meta-analysis evaluating the effects of wood ash on forest ecosystems, number of years since treatment was one of the most important variables in detecting and assessing growth effects (Reid & Watmough 2014). Additionally, the same meta-analysis study found tree growth response to wood ash treatments to be highly variable with negative growth effects reported 8% of the time, positive growth responses reported 31%, while 61% of the time there were no treatment effects reported (Reid & Watmough 2014), which could explain why significant increases were not observed in our study however did occur in other short-term studies. Additionally, major summer storms in year one and two after ash application, resulted in losses of several trees included in the study, therefore only the surviving trees were included.

Site fertility may have an impact on tree growth response to ash application, with larger increases occurring on more fertile sites (Augusto et al., 2008; Jacobson, 2003). All three sites used in this study were situated on acidic soils with thin organic horizons. Calcium is usually the most important nutrient limiting the growth of sugar maples on acidic soils (St.Clair et al., 2008; Vadeboncoeur, 2010). Negative DRIS values suggest slight deficiency in Ca at all three sites which persisted after treatment. As previously noted, dissolution of wood ash in soil and the rate at which nutrients become plant available are highly variable, and Ca has been observed to only be moderately soluble (Meiwes, 1995). Therefore, although positive growth increases have been observed in this study, they are not yet significant since total Ca may not have yet become bioavailable for mature sugar maples to utilize.

3.5.4 Effects of NIWA on Understory Vegetation

In this study, no significant changes in understory vegetation diversity were observed among treatments one and two years after application, except for Mark's sugar bush where significant increases in diversity were recorded one year after ash application but this was not evident two years after application. There is some variability in existing literature regarding treatment effects of wood ash application on understory plant communities, where response have varied from severe visible damage after initial application (Jacobson & Gustafsson, 2001) to no negative response (Arvidsson et al., 2002). The contrasting response of the plant community at Mark's sugarbush and the other two sites cannot easily be explained by differences in soil quality as soil chemistry in ash treated plots at all sites was generally quite similar. It is possible that the difference in ash chemistry applied at Mark's site as previous work as shown that plant response to ash can vary depending on ash characteristics. The chemical composition of ash applied at Mark's sugarbush varied slightly from the other two sites. Ash pH and Cu concentrations in the ash applied to Mark's sugarbush were significantly lower than in the ash applied to Brookland Farms and Wilf's sugar bush.

There were slight changes in species composition observed at all three sites however these changes were not significant. However, large increases in abundance for sugar maples were observed at all three sites. Wood ash treatments have been shown to significantly increase sugar maple seedling foliar, stem and root nutrient concentrations (Ca, Mg, and K), and increase root to shoot ratio (Deighton & Watmough, 2020). Juice et al. (2006) reported significant increases in the density of sugar maple seedlings after the addition of 0.85 Mg Ca/ha in the form of wollastonite ($CaSiO_3$). Additionally, positive responses in sugar maple canopy vigor, branch dieback and annual basal area increment growth has also been reported following Ca (in the form of wollastonite) additions (Huggett et al., 2007). Furthermore, sugar maple seedling survival has been shown to increase in areas treated with Ca additions, however other factors such as initial soil characteristic, application amounts, and leaf litter cycling have been demonstrated to have an effect on sugar maple seed regeneration (Cleavitt et al., 2011), which could explain why in this study increases in sugar maple seedlings were recorded in both control and treatment plots.

3.6 Conclusion

In this study the short-term effects of nonindustrial wood ash (NIWA) application (0, 4 and 8 Mg ha^{-1}) were evaluated on three sugar bush stands in Muskoka, south central Ontario. Ten months after ash application soil pH increased significantly at treatment plots in the litter and FH horizons while no changes were generally observed in the mineral horizons at all study sites. Significant increases in exchangeable Ca, and Mg were similarly observed at all treatment plots in the litter and FH horizons while mineral layer concentrations of Ca and Mg did not respond to treatment. There was an exception in K concentrations which increased significantly in the mineral soil horizons. This is most likely due to the solubility of K in ash, as existing literature suggests K is the most soluble element present in ash (Meiwes, 1995). Most metals were significantly higher in the litter horizon at all treatment plots; however, these increases were restricted to the upper horizons for most metal except for of Cu and B. This is similar to the findings from other ash studies, and it is unlikely that phytotoxicity will occur due to factors such as increased pH restricting solubility and bioavailability. However, the sites should be monitored further to observe if pH levels plateau with time and or metal concentrations and solubility increases. DRIS indices indicated K to be the most limiting nutrient at all study sites and while foliar nutrients remained generally consistent with pre ash application levels, foliar K increased significantly in mature and sapling foliage. No significant changes occurred in foliage metal concentrations at all three sites. Minimal changes were observed for ground vegetation diversity one year and two years after NIWA application, which is consistent with most existing studies (Jacobson and Gustafsson, 2001, Arvidsson et al., 2002); however slight changes in composition were observed at all three study sites, with an increase in sugar maple sapling abundance at all plots. Additionally, no significant differences in tree growth between control and treatment plots were noted 2 years after application.

4. General Conclusion

The objective of this thesis was to understand the chemical variability of non-industrial wood ash (NIWA), and its short-term effects on soil properties, sugar maple foliar chemistry, tree growth, and understory vegetation community composition at three sugar bushes in Muskoka. The chemical analysis of NIWA samples obtained from the wood stoves of Muskoka, Ontario residents and small businesses, indicated that NIWA generally has high concentrations of macro nutrients like Ca and K and low concentrations of metals. Base cation concentrations were generally higher in NIWA compared with previously reported values for industrially sourced wood ash. Ash mixtures that were amalgamated in the field were relatively homogenous in their chemical composition and metal concentrations were generally below NASM regulation guidelines, with only Cu and Zn exceeding CM1 guidelines; however, Cu and Zn concentrations were always below restricted metals land application limits (CM2). Additionally, tested samples were generally within the land application guidelines of other Canadian provinces and some European countries where wood ash can be used as a soil amendment.

Positive effects on soil properties and foliar nutrients were also recorded after application of NIWA to forest soils at the three sites. Ten months after NIWA application at rates of 0, 4, and 8 Mg ha^{-1}, soil pH and exchangeable base cations increased significantly in the litter and FH horizons at all treatment plots compared with control plots, however few treatment effects were recorded for the surface (0 – 10 cm) mineral horizon, with only K increasing in mineral soil at all three study sites. Elevated concentrations of most metals (Al, B, Cd, Cu, Fe, Mn, Ni, Pb, Zn) were recorded in soil at all treatment plots, however these effects were generally restricted to the litter horizon, except for Cu and B that increased in surface mineral soil. DRIS analysis conducted on the sugar maple foliage indicated that prior to ash application K was the most limiting nutrient at all three study sites, and significant increases in K foliar concentrations were observed ten months after NIWA application in sapling and mature trees at all treatment plots. In contrast, increases in foliar Ca and Mg concentrations were small and variable amongst the study sites. Additionally, there was no significant effect of NIWA treatment on sugar maple tree growth measured two years after ash application. Small changes in understory composition were noted, but these varied both among sites and by time after ash application.

Overall, this study shows that NIWA homogenized in field has a relatively consistent chemical composition with high concentrations of important macro-nutrients, and low metal levels that fall within the NASM guidelines. Additionally, NIWA application leads to significant changes in soil chemistry, although these changes are restricted primarily to the soil organic horizon in the short term (< 1 year). These results indicate that homogenized NIWA can be a safe source of important base cations to nutrient poor forest stands, with minimal adverse effects from metal toxicity.

Recommendations

This study focused on characterizing the chemical composition of NIWA and understanding the short-term effects of NIWA, on forest ecosystems. As these effects were mostly restricted to the upper organic soil horizons and highly mobile elements like K, longer-term changes in ecosystem response should be evaluated. In this study only foliar K increased significantly, however a longer sampling period may provide more insight into the impact of NIWA on all base cations and other nutrients such as P. Additionally, slight changes were recorded in understory vegetation composition, however these changes were variable but may have a more meaningful impact with the passage of time. Impacts of NIWA on non-vascular plants, microbial communities, other forest fauna, along with important forest functions such as microbial respiration, and changes in mineralization rates, were not evaluated in this current study and remain important knowledge gaps and should be looked at in the future. Finally, this study was restricted to forests dominated by sugar maple on thin, nutrient poor soils, and other tree species or forest situated on different geology may respond differently to ash application, as differing tree species can have different nutrient requirements and soil weathering rates and baseline nutrient status may also vary. Therefore, it is recommended that impacts of NIWA application be studied on differing forest types consisting of various bedrock geology.

Finally, NIWA samples in this study were primarily sourced from one region (Muskoka), and the tree species burned by residents, along with other factors such as burn temperature, and boiler used, likely has a significant impact on the chemical composition of wood ash (Azan, et al., 2019, Deighton & Watmough, 2020) and likely contributes to the chemical variability observed in this study. If there is a significant change in any of these factors, it could potentially impact the chemical composition of NIWA. It is therefore recommended that a wider study is conducted to study the differences, if any, in the chemical composition of NIWA sourced from various regions.

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Appendix

A.) Sample Wood Ash Questionnaire sent to the residents of Muskoka, Ontario, in January of 2021.

Trent University
Environmental and Life Sciences
Muskoka Wood-ash Project
January/2021
Wood Ash Questionnaire

1.) Please indicate the type of wood burned. Hardwood or softwood? Please provide tree species if possible. Yellow Birch, Sugar Maple etc.

2.) What type of furnace was used?

3.) What parts of the tree were burned? Bark, trunk, branches, etc.

B.) DRIS Sample Equation:

Step 1.) Use % foliar nutrients to obtain foliar ratio for each nutrient:

Example P:

Foliar Nutrients	Nutrient %	Foliar Ratio	
P	0.14		
Ca	0.923	P:Ca	0.151679
Mg	0.167	P:Mg	0.838323
K	0.612	P:K	0.228758
N	2.121	P:N	0.066007

Step 2.) Using appropriate DRIS norms and CV, use either equation 2 or 3 to determine f(A/B), f (A/C), f (A/D), f (A/E),

Where, f (A/B) is P/Ca, f (A/C) is P/Mg, f (A/D) is P/K, f (A/E) is P/N

Example:

Eq 2.) To Calculate F (A/D) where, when foliar ratio is greater than or equal to the DRIS norm for that nutrient (A/B =/> a/b),

$$6.338105 = \left(\frac{(0.228758)}{(0.1842)} - 1\right) * \frac{1000}{38.1}$$

Eq 3.) To Calculate F (A/B) where, when foliar ratio is less than the DRIS norm for that nutrient A/B < a/b,

$$-2.85022 = \left(1 - \frac{(0.1683)}{(0.151697)}\right) * \frac{1000}{38.4}$$

Where, DRIS norm and CV were as follows,

Nutrient	DRIS Norm	Norm CV
Ca	0.1683	38.4
K	0.1842	38.1

DRIS Sample Equation continued:

Step 3.) Use values obtained from following step two to complete equation 1

Example:

Eq 1.) $(\text{P index}) - 7.11833 = [-2.85022 + -16.7552 + 6.338105 + -15.206] / 4$

Where,

A/B=	-2.85022
A/C=	-16.7552
A/D=	6.338105
A/E=	-15.206

C.) Non-industrial Unamalgamated Ash Nutrient, Metal, pH and CNS Raw Data:

- Unamalgamated Ash Nutrients and Metals

ID	P mg/kg	Mg mg/kg	K mg/kg	Ca mg/kg	Zn mg/kg	Pb mg/kg	Ni mg/kg	Fe mg/kg	Cu mg/kg	Cd mg/kg	B mg/kg	As mg/kg	Al mg/kg	Mn mg/kg
2001	14182.0	23832.0	153393.0	333654.0	442.0	7.0	7.0	647.0	146.0	1.0	308.0	1.0	2137.0	6004.0
2003	9712.0	31858.0	107089.0	367805.0	1472.0	17.0	6.0	1465.0	120.0	4.0	229.0	0.0	2827.0	7202.0
2004	10350.0	37068.0	135364.0	329884.0	2107.0	29.0	15.0	1801.0	124.0	6.0	344.0	0.0	3292.0	5602.0
2005	6235.0	30393.0	125892.0	324141.0	286.0	5.0	8.0	652.0	90.0	2.0	208.0	3.0	5579.0	4684.0
2006	7262.0	20567.0	108565.0	270488.0	860.0	1885.0	6.0	2360.0	131.0	3.0	177.0	0.0	10596.0	4308.0
2007	8079.0	23769.0	98830.0	282555.0	437.0	229.0	10.0	3984.0	205.0	2.0	239.0	0.0	7030.0	2771.0
2008	9933.0	29536.0	157103.0	320822.0	748.0	11.0	12.0	1249.0	510.0	4.0	250.0	0.0	7060.0	5832.0
2009	8106.0	27100.0	119320.0	343077.0	748.0	16.0	9.0	1440.0	2329.0	4.0	298.0	3.0	7310.0	6500.0
2010	8722.0	28053.0	120792.0	313474.0	513.0	12.0	25.0	1058.0	140.0	4.0	230.0	2.0	1736.0	3684.0
2011	8364.0	27874.0	160771.0	256840.0	477.0	8.0	7.0	2571.0	304.0	7.0	297.0	0.0	13063.0	5627.0
2012	6923.0	20976.0	75787.0	316184.0	368.0	10.0	4.0	1821.0	101.0	4.0	190.0	0.0	7333.0	7686.0
2013	7962.0	19555.0	97240.0	298430.0	376.0	6.0	3.0	1307.0	126.0	1.0	213.0	0.0	13178.0	1116.0
2014	4883.0	13883.0	66770.0	192101.0	685.0	11.0	5.0	4453.0	328.0	6.0	131.0	2.0	1204.0	3861.0
2015	7358.0	22450.0	92527.0	332623.0	714.0	18.0	4.0	2078.0	129.0	1.0	211.0	0.0	10055.0	1423.0
2016	6213.0	18361.0	103938.0	339313.0	208.0	6.0	11.0	834.0	63.0	2.0	188.0	3.0	592.0	2326.0
2018	9478.0	23935.0	54067.0	353223.0	628.0	134.0	16.0	1443.0	139.0	2.0	230.0	0.0	9807.0	5031.0
2019	9439.0	17041.0	90201.0	257308.0	1898.0	20.0	105.0	1186.0	149.0	2.0	229.0	22.0	6617.0	3740.0
2021	7107.0	23871.0	122484.0	316475.0	191.0	3.0	19.0	1222.0	95.0	1.0	202.0	0.0	3158.0	4759.0
2025	10079.0	21433.0	70268.0	388029.0	183.0	4.0	3.0	746.0	104.0	1.0	193.0	4.0	773.0	1203.0
2026	7318.0	19177.0	101066.0	349250.0	504.0	9.0	6.0	2592.0	179.0	2.0	233.0	0.0	5955.0	4525.0
2027	8279.0	22318.0	125881.0	404734.0	348.0	7.0	4.0	735.0	98.0	1.0	207.0	0.0	2889.0	7192.0
2028	7237.0	18719.0	98132.0	336102.0	576.0	11.0	5.0	1419.0	173.0	2.0	222.0	0.0	3902.0	4120.0
2030	15619.0	59568.0	281057.0	589964.0	563.0	20.0	8.0	1104.0	139.0	3.0	391.0	2.0	2513.0	6335.0
2032	7012.0	19253.0	109975.0	363565.0	302.0	10.0	6.0	650.0	102.0	2.0	292.0	7.0	1500.0	3629.0
2033	4762.0	10067.0	45121.0	396665.0	189.0	2.0	6.0	759.0	60.0	1.0	117.0	3.0	1174.0	2598.0
2034	7844.0	28469.0	123579.0	339618.0	1004.0	23.0	4.0	428.0	95.0	7.0	299.0	4.0	489.0	6039.0
2035	8562.0	28159.0	167625.0	383974.0	624.0	4.0	15.0	790.0	116.0	1.0	211.0	1.0	1811.0	2382.0
2038	7815.0	17046.0	106062.0	367131.0	335.0	3.0	7.0	739.0	83.0	1.0	185.0	3.0	1128.0	3962.0
2042	14532.0	50098.0	200744.0	625421.0	468.0	34.0	9.0	806.0	103.0	4.0	193.0	0.0	3609.0	1642.0
2043	8306.0	27365.0	123638.0	205726.0	415.0	6.0	48.0	4160.0	194.0	2.0	223.0	45.0	9000.0	5117.0
2046	9317.0	17350.0	112316.0	303309.0	196.0	9.0	4.0	1477.0	372.0	5.0	218.0	335.0	4340.0	2196.0
2047	10578.0	24980.0	57415.0	347610.0	355.0	8.0	11.0	24399.0	117.0	3.0	210.0	1.0	2330.0	6964.0
2048	6703.0	18477.0	69343.0	225381.0	437.0	118.0	7.0	7682.0	85.0	11.0	214.0	2.0	1501.0	5051.0
2050	5580.0	29848.0	97050.0	282215.0	326.0	7.0	22.0	1554.0	97.0	3.0	217.0	0.0	9173.0	5007.0

Unamalgamated Ash Nutrients and Metals Continued:

ID	P mg/kg	Mg mg/kg	K mg/kg	Ca mg/kg	Zn mg/kg	Pb mg/kg	Ni mg/kg	Fe mg/kg	Cu mg/kg	Cd mg/kg	B mg/kg	As mg/kg	Al mg/kg	Mn mg/kg
2051	6314.0	23688.0	87569.0	317660.0	375.0	227.0	4.0	6867.0	65.0	3.0	133.0	2.0	3533.0	1509.0
2052	7190.0	18105.0	155434.0	262507.0	502.0	5.0	7.0	1420.0	123.0	2.0	284.0	0.0	5376.0	4730.0
2053	8358.0	20887.0	143771.0	298372.0	415.0	4.0	9.0	1334.0	102.0	1.0	319.0	1.0	2442.0	4991.0
2058	8210.0	22527.0	91484.0	318300.0	168.0	4.0	2.0	1883.0	96.0	1.0	217.0	0.0	3606.0	2246.0
2120	6187.0	27898.0	95623.0	255256.0	982.0	65.0	19.0	2849.0	144.0	2.0	190.0	0.0	15799.0	3213.0
2121	16839.0	47205.0	265871.0	514945.0	471.0	11.0	9.0	2372.0	108.0	6.0	225.0	1.0	3627.0	4746.0
2122	8099.0	21511.0	108864.0	220135.0	224.0	5.0	4.0	3051.0	110.0	1.0	179.0	0.0	4485.0	3067.0
2123	8751.0	22531.0	120262.0	253109.0	859.0	7.0	14.0	3475.0	99.0	3.0	233.0	0.0	4055.0	5901.0
2127	8139.0	24341.0	80081.0	272725.0	846.0	11.0	10.0	3104.0	157.0	13.0	384.0	0.0	13689.0	4385.0
2128	9277.0	31022.0	96847.0	301808.0	429.0	9.0	18.0	2065.0	116.0	5.0	230.0	0.0	3844.0	7557.0
2129	16089.0	34628.0	126458.0	376924.0	669.0	7.0	29.0	1255.0	158.0	2.0	302.0	2.0	2477.0	5770.0
2130	7817.0	30306.0	182736.0	316443.0	1337.0	19.0	6.0	630.0	100.0	5.0	298.0	2.0	1928.0	6241.0
2131	9762.0	28962.0	128717.0	346851.0	262.0	4.0	10.0	9659.0	110.0	4.0	197.0	0.0	4233.0	3573.0
2133	21987.0	45161.0	247555.0	546333.0	709.0	7.0	10.0	2110.0	107.0	2.0	317.0	0.0	2831.0	6211.0
2134	5026.0	17649.0	102327.0	240615.0	412.0	6.0	7.0	1684.0	61.0	2.0	173.0	0.0	3985.0	7086.0
2135	6063.0	12324.0	36632.0	141612.0	1023.0	613.0	7.0	6910.0	372.0	2.0	131.0	121.0	10447.0	1537.0
2136	6935.0	14355.0	105763.0	258761.0	328.0	5.0	7.0	1753.0	91.0	2.0	181.0	0.0	4492.0	6846.0
2137	9718.0	27663.0	164894.0	269658.0	423.0	9.0	10.0	1912.0	102.0	3.0	210.0	3.0	1997.0	5093.0
2138	8466.0	25532.0	160612.0	253929.0	380.0	6.0	11.0	1563.0	89.0	2.0	190.0	0.0	3597.0	5307.0
2139	7287.0	24069.0	155677.0	220365.0	314.0	7.0	9.0	1031.0	81.0	2.0	190.0	3.0	1170.0	5401.0
2141	6561.0	27913.0	119938.0	357696.0	239.0	5.0	5.0	1316.0	161.0	2.0	222.0	126.0	6355.0	4109.0
2142	9296.0	24199.0	127485.0	313356.0	421.0	8.0	6.0	678.0	92.0	1.0	224.0	1.0	2136.0	7327.0
2143	7943.0	24432.0	120269.0	299450.0	385.0	9.0	7.0	1208.0	85.0	3.0	303.0	2.0	1607.0	6256.0
2145	9589.0	31359.0	126305.0	324050.0	252.0	9.0	15.0	417.0	112.0	3.0	230.0	3.0	739.0	4673.0
2146	7278.0	22945.0	119910.0	290319.0	375.0	10.0	10.0	2146.0	269.0	4.0	214.0	109.0	7969.0	6040.0
2147	7211.0	24500.0	103029.0	338955.0	416.0	16.0	9.0	850.0	82.0	15.0	285.0	3.0	1056.0	4595.0
2148	9759.0	35232.0	76912.0	413884.0	190.0	11.0	6.0	633.0	94.0	3.0	223.0	2.0	1857.0	3485.0
2149	8155.0	24923.0	144710.0	279379.0	401.0	10.0	11.0	1301.0	94.0	4.0	200.0	0.0	4712.0	7153.0
2150	14098.0	36273.0	115264.0	410262.0	39.0	69.0	8.0	8617.0	146.0	0.0	159.0	0.0	10335.0	5156.0
2151	4695.0	23080.0	66319.0	277334.0	163.0	8.0	9.0	2204.0	120.0	1.0	148.0	1.0	6763.0	6857.0
2152	11270.0	29642.0	161659.0	314619.0	701.0	10.0	7.0	592.0	143.0	4.0	392.0	1.0	2851.0	4996.0
2154	8572.0	26403.0	113795.0	323350.0	759.0	6.0	4.0	699.0	87.0	7.0	215.0	3.0	1109.0	6621.0
5002	9563.0	28900.0	127874.0	280008.0	550.0	10.0	6.0	831.0	116.0	4.0	302.0	3.0	718.0	3712.0
5003	9274.0	28068.0	121615.0	271375.0	505.0	9.0	6.0	478.0	94.0	3.0	316.0	3.0	674.0	3905.0
5004	11454.0	37665.0	179766.0	333632.0	358.0	7.0	18.0	1267.0	118.0	1.0	325.0	2.0	1633.0	5503.0
5010	13774.0	28056.0	159588.0	327542.0	569.0	7.0	12.0	1668.0	132.0	2.0	321.0	2.0	2875.0	7545.0

Unamalgamated Ash Nutrients and Metals Continued:

ID	P mg/kg	Mg mg/kg	K mg/kg	Ca mg/kg	Zn mg/kg	Pb mg/kg	Ni mg/kg	Fe mg/kg	Cu mg/kg	Cd mg/kg	B mg/kg	As mg/kg	Al mg/kg	Mn mg/kg
5011	17815.0	26815.0	191513.0	271357.0	722.0	5.0	11.0	1650.0	151.0	2.0	420.0	2.0	2581.0	5628.0
5012	9051.0	23209.0	102360.0	365458.0	653.0	9.0	9.0	3212.0	329.0	4.0	235.0	1.0	2402.0	6438.0
5022	6449.0	25048.0	111313.0	308196.0	400.0	151.0	13.0	2331.0	138.0	3.0	210.0	2.0	2477.0	5440.0
5023	6148.0	21526.0	91521.0	284268.0	402.0	11.0	6.0	709.0	84.0	3.0	159.0	1.0	1956.0	2623.0
5039	7405.0	23192.0	128746.0	315626.0	359.0	6.0	5.0	1202.0	215.0	2.0	194.0	0.0	4179.0	5608.0
5041	7293.0	23360.0	126472.0	327085.0	356.0	5.0	5.0	1133.0	96.0	2.0	192.0	0.0	5529.0	5382.0
5059	8756.0	27231.0	93274.0	283711.0	123.0	0.0	4.0	1411.0	153.0	1.0	316.0	0.0	8266.0	2996.0
5060	6070.0	19499.0	61663.0	307648.0	236.0	4.0	4.0	1757.0	115.0	1.0	195.0	0.0	7316.0	3015.0
5072	9594.0	23981.0	102275.0	411708.0	144.0	3.0	4.0	724.0	57.0	1.0	192.0	2.0	1799.0	2649.0
5076	5674.0	26740.0	115508.0	224986.0	303.0	5.0	14.0	3097.0	157.0	2.0	541.0	0.0	3420.0	2902.0
5081	9575.0	31958.0	132134.0	399903.0	381.0	8.0	18.0	869.0	101.0	2.0	225.0	2.0	1367.0	6368.0
5082	7720.0	25180.0	108049.0	316828.0	345.0	8.0	16.0	967.0	95.0	2.0	221.0	2.0	1435.0	6291.0
5083	16081.0	51286.0	270492.0	676963.0	395.0	7.0	18.0	1013.0	100.0	2.0	226.0	2.0	1412.0	6087.0
5084	6881.0	22461.0	102941.0	310826.0	258.0	6.0	13.0	984.0	64.0	2.0	205.0	2.0	1652.0	7034.0
5085	7023.0	23240.0	103987.0	332883.0	284.0	7.0	10.0	1011.0	82.0	2.0	200.0	1.0	2016.0	4711.0
5090	3609.0	10027.0	49486.0	143337.0	305.0	7.0	8.0	501.0	41.0	1.0	101.0	4.0	375.0	3994.0
5092	8967.0	29034.0	136390.0	338013.0	419.0	9.0	10.0	6282.0	111.0	4.0	247.0	0.0	8947.0	5822.0
5100	7995.0	20389.0	129511.0	336150.0	260.0	7.0	11.0	863.0	193.0	2.0	348.0	3.0	2227.0	5952.0
5105	7519.0	23387.0	95527.0	343175.0	410.0	27.0	6.0	1105.0	108.0	6.0	226.0	6.0	1789.0	5800.0
5106	6109.0	20654.0	86021.0	258952.0	2060.0	464.0	5.0	849.0	89.0	4.0	173.0	0.0	7930.0	7634.0
5132	9491.0	20664.0	77297.0	327325.0	710.0	12.0	6.0	1375.0	113.0	2.0	242.0	0.0	2588.0	7402.0
5137	5342.0	19656.0	84558.0	234233.0	453.0	12.0	10.0	4893.0	68.0	2.0	161.0	0.0	5111.0	6055.0
5155	5612.0	18660.0	116573.0	311524.0	175.0	5.0	4.0	490.0	1504.0	1.0	208.0	1.0	2507.0	3315.0
5156	10057.0	31624.0	95149.0	358345.0	114.0	2.0	13.0	987.0	97.0	1.0	230.0	0.0	5875.0	5293.0
5157	8920.0	25294.0	87230.0	330162.0	154.0	3.0	10.0	825.0	68.0	3.0	210.0	1.0	2649.0	6177.0
5158	11744.0	32458.0	95870.0	434122.0	93.0	2.0	12.0	907.0	94.0	1.0	230.0	0.0	3129.0	2966.0
5160	23409.0	37593.0	178191.0	282989.0	425.0	0.0	1.0	948.0	158.0	0.0	432.0	3.0	1572.0	968.0
5175	28016.0	55918.0	237882.0	413665.0	599.0	0.0	1.0	1417.0	168.0	0.0	425.0	2.0	2459.0	1146.0
5176	11589.0	24349.0	106693.0	301100.0	442.0	6.0	6.0	1206.0	88.0	1.0	223.0	1.0	1929.0	5465.0
5178	7367.0	22663.0	112787.0	335534.0	577.0	11.0	10.0	786.0	91.0	7.0	228.0	0.0	5534.0	6984.0
5179	7165.0	21409.0	126455.0	315629.0	459.0	10.0	11.0	545.0	81.0	4.0	211.0	0.0	3029.0	6271.0
5194	7001.0	31728.0	115655.0	312975.0	532.0	8.0	29.0	966.0	126.0	1.0	170.0	0.0	6448.0	3379.0
0001un	8216.0	26749.0	115106.0	313160.0	472.0	11.0	8.0	4421.0	91.0	5.0	237.0	0.0	6867.0	6562.0
0005f	7045.0	19173.0	88227.0	298016.0	348.0	11.0	19.0	1259.0	131.0	3.0	216.0	0.0	2553.0	7030.0
0006f	10647.0	32184.0	144753.0	317187.0	586.0	11.0	7.0	787.0	105.0	5.0	322.0	4.0	809.0	3123.0
0007F	12879.0	23663.0	123399.0	321653.0	493.0	9.0	5.0	1495.0	160.0	1.0	323.0	0.0	3723.0	5644.0
unlab	7025.0	21325.0	117413.0	276219.0	840.0	16.0	8.0	1704.0	199.0	8.0	216.0	50.0	5463.0	5756.0

- *Unamalgamated Ash Nitrogen, Carbon, Sulphur, pH*

Ash Type	pH	N %	C %	S %
Raw Ash 1	13.34	0.06	8.98	0
Raw Ash 2	12.96	0.09	8.66	0
Raw Ash 3	13.44	0.04	8.42	0
Raw Ash 4	13.49	0.05	8.66	0
Raw Ash 5	10.59	0.06	7.37	0.06
Raw Ash 6	10.50	0.07	8.60	0
Raw Ash 7	12.98	0.05	8.52	0
Raw Ash 8	10.78	0.04	9.26	0
Raw Ash 9	10.66	0.04	4.71	0.01
Raw Ash 10	13.96	0.07	9.64	0
Raw Ash 11	11.96	0.06	10.27	0
Raw Ash 12	13.17	0.04	8.92	0
Raw Ash 13	10.80	0.03	8.93	0
Raw Ash 14	13.47	0.03	8.81	0
Raw Ash 15	12.45	0.06	10.72	0
Raw Ash 16	10.45	0.03	9.68	0
Raw Ash 17	13.29	0.03	10.34	0
Raw Ash 18	11.28	0.2	10.57	0
Raw Ash 19	13.20	0.06	9.43	0
Raw Ash 20	12.96	0.03	9.95	0
Raw Ash 21	13.07	0.04	8.65	0
Raw Ash 22	13.55	0.08	9.29	0
Raw Ash 23	12.71	0.04	4.67	0.07
Raw Ash 24	12.72	0.02	8.13	0
Raw Ash 25	12.68	0.02	9.40	0
Raw Ash 26	13.49	0.09	10.48	0
Raw Ash 27	11.20	0.04	9.10	0
Raw Ash 28	12.72	0.05	9.52	0
Raw Ash 29	13.10	0.07	9.14	0
Raw Ash 30	12.77	0.01	8.39	0
Raw Ash 31	12.97	0.06	10.19	0
Raw Ash 32	13.10	0.12	10.99	0
Raw Ash 33	10.75	0.06	8.66	0
Raw Ash 34	10.70	0.05	8.91	0
Raw Ash 35	10.88	0.04	8.31	0
Raw Ash 36	13.16	0.06	8.55	0
Raw Ash 37	12.62	0.07	7.12	0.17
Raw Ash 38	10.44	0.05	8.65	0
Raw Ash 39	13.78	0.05	9.09	0
Raw Ash 40	10.47	0.05	8.67	0
Raw Ash 41	13.37	0.05	7.81	0
Raw Ash 42	12.92	0.05	9.02	0

Unamalgamated Ash Nitrogen, Carbon, Sulphur, pH continued:

Ash Type	pH	N %	C %	S %
Raw Ash 43	10.45	0.12	10.4	0
Raw Ash 44	13.20	0.04	7.65	0
Raw Ash 45	13.01	0.04	6.60	0
Raw Ash 46	13.62	0.16	10.72	0
Raw Ash 47	12.26	0.03	9.65	0
Raw Ash 48	13.38	0.07	8.38	0
Raw Ash 49	13.22	0.05	8.40	0
Raw Ash 50	13.57	0.07	8.49	0.02
Raw Ash 51	13.23	0.04	7.14	0
Raw Ash 52	13.53	0.06	7.84	0
Raw Ash 53	13.34	0.04	7.88	0
Raw Ash 54	13.34	0.09	8.19	0
Raw Ash 55	10.83	0.06	6.95	0.05
Raw Ash 56	13.04	0.07	8.40	0
Raw Ash 57	10.16	0.07	8.85	0
Raw Ash 58	13.14	0.03	7.29	0
Raw Ash 59	12.87	0.02	6.59	0
Raw Ash 60	13.35	0.13	14.10	0
Raw Ash 61	12.89	0.09	10.23	0
Raw Ash 62	12.44	0.07	10.08	0
Raw Ash 63	12.96	0.04	7.41	0
Raw Ash 64	13.54	0.07	9.96	0
Raw Ash 65	13.81	0.04	7.07	0
Raw Ash 66	13.38	0.04	8.30	0
Raw Ash 67	13.34	0.09	9.76	0
Raw Ash 68	12.95	0.05	8.30	0
Raw Ash 69	13.21	0.19	9.51	0
Raw Ash 70	13.34	0.05	8.01	0
Raw Ash 71	12.81	0.04	8.83	0
Raw Ash 72	11.70	0.03	7.83	0
Raw Ash 73	12.45	0.03	7.67	0.01
Raw Ash 74	10.92	0.06	9.46	0.01
Raw Ash 75	13.29	0.08	9.27	0
Raw Ash 76	12.59	0.06	8.64	0
Raw Ash 77	11.73	0.1	10.03	0
Raw Ash 78	12.99	0.06	8.76	0
Raw Ash 79	13.41	0.09	10.23	0
Raw Ash 80	12.84	0.14	11.24	0
Raw Ash 81	13.31	0.09	8.95	0
Raw Ash 82	13.76	0.07	7.32	0
Raw Ash 83	12.69	0.08	8.28	0
Raw Ash 84	12.96	0.06	8.10	0
Raw Ash 85	10.23	0.08	8.57	0

Unamalgamated Ash Nitrogen, Carbon, Sulphur, pH continued:

Ash Type	pH	N %	C %	S %
Raw Ash 86	12.42	0.06	7.64	0
Raw Ash 87	13.46	0.03	9.17	0
Raw Ash 88	10.24	0.06	9.01	0
Raw Ash 89	12.27	0.05	8.60	0
Raw Ash 90	10.77	0.05	8.80	0
Raw Ash 91	13.15	0.07	10.6	0
Raw Ash 92	13.04	0.06	8.50	0
Raw Ash 93	13.13	0.04	9.57	0
Raw Ash 94	13.17	0.08	7.13	0.02
Raw Ash 95	13.22	0.03	9.58	0
Raw Ash 96	12.84	0.05	8.36	0.01
Raw Ash 97	13.20	0.05	8.07	0
Raw Ash 98	13.32	0.06	8.86	0
Raw Ash 99	13.26	0.05	7.92	0
Raw Ash 100	11.45	0.06	8.57	0
Raw Ash 101	13.08	0.1	9.26	0
Raw Ash 102	13.12	0.05	9.75	0
Raw Ash 103	13.01	0.12	11	0
Raw Ash 104	12.94	0.09	9.5	0
Raw Ash 105	13.02	0.07	9.42	0
Raw Ash 106	13.41	0.06	9.64	0
Raw Ash 107	13.78	0.12	8.40	0

D.) Non-industrial Wood Charcoal pH, Nutrient, Metal and CNS Raw Data:

- *Wood Charcoal pH, CNS, Nutrients*

Wood Charcoal	pH	N %	C %	S %	P mg/kg	Mg mg/kg	K mg/kg	Ca mg/kg
1	9.50	0.17	15.65	0	7372.5	23322.8	130516.6	304401.6
2	9.78	0.15	17.13	0	7374.0	20353.4	141338.5	261699.2
3	9.96	0.08	12.28	0	8207.4	20984.6	134876.3	285802.0
4	10.39	0.09	11.99	0	7867.9	20727.4	124106.9	249338.2
5	10.41	0.07	13.23	0	9307.4	19102.6	128881.6	216759.2
6	11.01	0.20	20.90	0	6449.6	18935.5	157212.9	198368.0
7	11.29	0.13	13.10	0	20324.6	40589.5	236680.1	249735.8
8	11.80	0.30	32.14	0.01	5440.4	16458.3	100441.4	173537.7
9	12.06	0.20	23.24	0	6376.6	18756.9	114380.4	219503.4
10	12.69	0.27	26.28	0.01	4627.4	14380.7	79048.3	161164.6

- *Wood Charcoal Metals*

Wood Charcoal	Zn mg/kg	Pb mg/kg	Ni mg/kg	Mn mg/kg	Fe mg/kg	Cu mg/kg	Cd mg/kg	B mg/kg	As mg/kg	AL mg/kg
1	235.12	4.86	13.86	5748.48	2239.73	115.54	1.33	238.82	-2.80	2617.63
2	337.42	9.80	7.83	6174.55	1233.45	100.40	2.59	202.92	-1.31	1623.71
3	374.68	7.10	8.81	6310.33	1335.12	150.61	1.71	221.51	-6.77	5341.26
4	489.13	7.46	8.19	5330.15	1663.49	146.21	2.43	194.88	-1.36	2808.84
5	680.31	9.48	6.88	5999.57	1336.80	119.39	1.92	225.41	-2.31	2382.45
6	391.94	8.06	8.59	5903.85	1173.96	127.46	2.28	158.26	-0.89	2111.05
7	422.78	-0.23	1.64	1063.98	1706.99	205.67	0.10	405.38	-3.49	3352.42
8	265.32	8.69	5.29	5629.43	1062.10	96.77	2.13	174.73	-1.30	1837.55
9	451.85	6.83	8.91	5769.62	1785.04	98.69	1.95	192.09	-3.01	2468.70
10	439.15	9.89	14.78	5730.87	586.48	111.88	2.27	146.01	-1.78	1623.73

E.) Non-industrial Amalgamated Wood Ash pH, Nutrient, Metal and CNS Raw data:

- Amalgamated Ash Nutrients, pH and CNS:

Ash	P g/kg	Mg g/kg	K g/kg	Ca g/kg	pH	N %	C %	S %
Mixture A	6.9766	20.4417	89.9751	270.4525	13.45	0.144	13.192	0
Mixture A	8.9662	22.0404	91.2473	298.2140	13.46	0.081	8.117	0
Mixture A	8.3281	22.1081	107.2449	305.4195	13.57	0.145	18.073	0
Mixture A	8.5638	22.7185	104.2484	305.9194	13.55	0.074	8.856	0
Mixture A	8.4702	23.5863	105.4567	306.0721	13.44	0.604	17.204	0
Mixture A	8.3405	24.0914	108.9494	316.2060	13.6	0.068	10.412	0
Mixture A	9.8647	24.3175	117.0427	313.3187	13.37	0.625	15.140	0.038
Mixture A	7.9479	26.5076	116.0623	298.5065	13.36	0.055	7.726	0
Mixture A	9.9333	27.4942	123.2931	320.3374	13.56	0.073	10.083	0
Mixture A	11.2214	28.5067	131.7722	324.3332	13.66	0.066	7.552	0
Mixture B	4.8875	13.0031	52.4929	153.7972	13.43	0.074	8.379	0
Mixture B	7.5184	20.9829	109.6563	242.5902	12.95	0.067	9.441	0
Mixture B	7.9650	21.2127	119.3002	288.2133	13.54	0.070	8.620	0
Mixture B	8.2812	21.9540	118.0573	251.7868	12.88	0.063	9.440	0
Mixture B	7.8323	21.9680	117.4919	288.3536	13.38	0.063	10.414	0
Mixture B	8.4780	23.4760	122.9357	291.5909	13.45	0.069	8.242	0
Mixture B	7.6932	23.7740	118.8823	309.8058	13.45	0.094	9.237	0
Mixture B	9.1986	24.1711	118.3667	290.7929	13.4	0.066	7.868	0
Mixture B	8.8663	24.8619	119.2463	322.6793	13.46	0.075	8.174	0
Mixture B	8.8443	25.3751	130.1128	295.5684	13.29	0.057	8.372	0
Mixture C	5.5694	14.5669	62.9304	196.8381	11.36	0.068	10.245	0
Mixture C	7.3653	19.2167	85.5589	249.5218	12.03	0.074	10.587	0
Mixture C	6.4480	19.7450	88.4129	261.1200	12.43	0.056	7.967	0
Mixture C	8.4280	22.3640	108.7022	292.1618	12.35	0.077	9.797	0
Mixture C	7.6659	22.8319	116.4110	297.3566	12.37	0.079	9.701	0
Mixture C	8.5105	23.1774	107.0889	325.1853	12.26	0.087	8.042	0
Mixture C	8.8422	24.6924	127.4605	319.4574	11.43	0.059	8.321	0
Mixture C	8.7995	25.5840	120.2066	327.4891	11.23	0.081	8.823	0
Mixture C	7.5525	26.6847	101.2829	328.0077	11.21	0.062	8.688	0
Mixture C	9.4025	26.7461	124.9278	348.4278	11.09	0.077	8.842	0

- *Amalgamated Ash Metals:*

Ash	Pb mg/kg	Zn mg/kg	Ni mg/kg	Fe mg/kg	Cu mg/kg	Cd mg/kg	B mg/kg	As mg/kg	Al mg/kg	Mn mg/kg
Mixture A	23.106	480.436	8.878	3728.978	88.617	2.772	200.066	0	3908.914	6590.11
Mixture A	20.489	435.376	7.381	1685.213	110.281	2.154	213.294	7.471	3068.885	5629.905
Mixture A	22.688	561.469	9.875	3087.961	96.112	2.633	219.074	0.000	4446.564	6452.87
Mixture A	23.426	656.190	14.813	2730.334	200.065	2.971	220.310	15.518	6093.674	6910.049
Mixture A	22.133	510.777	9.667	2483.676	114.407	2.676	213.229	0	4083.580	6985.775
Mixture A	71.708	441.807	11.167	1758.747	115.472	3.018	236.249	0	3326.216	7105.252
Mixture A	20.325	745.709	9.017	5511.559	205.001	2.765	228.992	0	2371.939	6234.014
Mixture A	19.497	562.021	17.315	1969.530	156.036	3.367	223.441	13.352	4965.360	4861.99
Mixture A	11.842	438.309	9.587	2863.051	151.759	3.214	239.761	2.581	4332.179	6002.584
Mixture A	7.812	403.618	7.405	2113.327	170.330	2.152	361.414	0.379	4162.472	6294.289
Mixture B	6.412	291.647	4.097	778.954	45.599	1.366	130.287	0	1319.970	4199.116
Mixture B	15.045	575.116	8.942	1219.056	123.378	3.121	234.036	0	2251.532	7299.500
Mixture B	18.533	428.934	9.974	925.059	141.969	2.216	215.911	0.282	2442.784	7261.251
Mixture B	14.085	593.470	8.821	1322.814	131.361	2.641	235.728	0	2567.878	6793.521
Mixture B	8.635	419.667	8.853	984.525	127.031	2.127	224.647	0.488	3324.737	6391.911
Mixture B	13.557	470.416	11.055	1179.804	394.365	2.376	239.417	23.250	2884.644	7607.441
Mixture B	17.418	549.113	11.045	2151.584	123.967	3.420	225.822	7.139	4398.824	7157.150
Mixture B	9.497	860.774	8.231	1045.700	121.240	2.876	299.201	0	2853.115	7917.713
Mixture B	13.590	433.889	7.952	1231.295	132.887	2.125	291.718	0	4704.253	6842.971
Mixture B	10.882	537.688	9.958	2389.293	199.296	3.223	296.243	0	3698.563	6901.654
Mixture C	52.670	350.197	5.960	3247.189	113.072	1.908	141.916	17.529	5551.568	3880.166
Mixture C	17.387	484.855	5.244	1433.245	91.711	2.060	190.510	1.397	2944.152	5646.793
Mixture C	220.517	361.722	8.769	2154.727	96.040	2.722	193.847	5.939	3423.702	7515.944
Mixture C	9.005	389.294	6.556	1461.702	105.390	2.498	223.352	0	3466.938	6014.588
Mixture C	79.349	499.149	9.775	1852.564	104.884	2.990	215.773	0	3390.234	5254.418
Mixture C	23.347	482.367	7.977	1387.419	102.935	2.780	239.526	0	2973.991	6980.964
Mixture C	17.334	522.723	8.309	1715.424	146.114	2.528	231.317	0.351	6821.825	7752.749
Mixture C	18.531	465.185	9.565	2607.109	99.344	3.219	230.977	2.954	4011.281	6871.904
Mixture C	12.627	390.547	8.524	1667.957	98.799	2.765	226.881	9.335	3543.379	5930.881
Mixture C	34.397	449.922	8.701	1201.008	102.859	2.847	237.425	0.045	3203.699	7451.198

F.) Soil Baseline Raw Data (3 study sites):

- *Baseline Soil pH at the 3 study sites:*

Soil	Site	Treatment	pH	Soil	Site	Treatment	pH	Soil	Site	Treatment	pH
Litter	Brook	8	4.72	Fh	Brook	8	3.93	Mineral	Brook	8	4.96
Litter	Brook	8	4.63	Fh	Brook	8	3.85	Mineral	Brook	8	3.53
Litter	Brook	8	4.86	Fh	Brook	8	3.97	Mineral	Brook	8	3.45
Litter	Brook	8	4.58	Fh	Brook	8	3.89	Mineral	Brook	8	4.02
Litter	Brook	8	4.47	Fh	Brook	8	3.92	Mineral	Brook	8	3.91
Litter	Brook	4	4.62	Fh	Brook	4	3.44	Mineral	Brook	4	3.65
Litter	Brook	4	5.09	Fh	Brook	4	4.12	Mineral	Brook	4	3.54
Litter	Brook	4	4.32	Fh	Brook	4	3.55	Mineral	Brook	4	3.8
Litter	Brook	4	4.46	Fh	Brook	4	3.78	Mineral	Brook	4	3.33
Litter	Brook	4	4.9	Fh	Brook	4	3.96	Mineral	Brook	4	3.73
Litter	Brook	4	4.61	Fh	Brook	4	4.13	Mineral	Brook	4	3.61
Litter	Brook	Cnt	4.55	Fh	Brook	Cnt	3.84	Mineral	Brook	Cnt	4.05
Litter	Brook	Cnt	4.62	Fh	Brook	Cnt	4.02	Mineral	Brook	Cnt	3.62
Litter	Brook	Cnt	4.8	Fh	Brook	Cnt	3.81	Mineral	Brook	Cnt	3.91
Litter	Brook	Cnt	4.71	Fh	Brook	Cnt	4.28	Mineral	Brook	Cnt	3.77
Litter	Brook	Cnt	5.07	Fh	Brook	Cnt	4.19	Mineral	Brook	Cnt	4.16
Litter	Brook	Cnt	4.32	Fh	Brook	Cnt	3.82	Mineral	Brook	Cnt	4
Litter	Wilf	8	4.46	Fh	Wilf	8	3.57	Mineral	Wilf	8	3.72
Litter	Wilf	8	4.25	Fh	Wilf	8	4.16	Mineral	Wilf	8	3.95
Litter	Wilf	8	4.1	Fh	Wilf	8	3.32	Mineral	Wilf	8	3.64
Litter	Wilf	8	4.12	Fh	Wilf	8	3.41	Mineral	Wilf	8	3.88
Litter	Wilf	8	4.3	Fh	Wilf	8	3.57	Mineral	Wilf	8	3.67
Litter	Wilf	8	4.16	Fh	Wilf	8	3.5	Mineral	Wilf	8	3.91
Litter	Wilf	4	4.13	Fh	Wilf	4	3.79	Mineral	Wilf	4	3.89
Litter	Wilf	4	4.46	Fh	Wilf	4	3.52	Mineral	Wilf	4	3.9
Litter	Wilf	4	4.42	Fh	Wilf	4	3.71	Mineral	Wilf	4	4
Litter	Wilf	4	4.31	Fh	Wilf	4	3.54	Mineral	Wilf	4	4.01
Litter	Wilf	4	4.28	Fh	Wilf	4	3.64	Mineral	Wilf	4	4.01
Litter	Wilf	4	4.39	Fh	Wilf	4	3.3	Mineral	Wilf	4	3.39
Litter	Wilf	Cnt	4.45	Fh	Wilf	Cnt	3.81	Mineral	Wilf	Cnt	4.08
Litter	Wilf	Cnt	4.12	Fh	Wilf	Cnt	3.79	Mineral	Wilf	Cnt	4.16
Litter	Wilf	Cnt	4.49	Fh	Wilf	Cnt	3.55	Mineral	Wilf	Cnt	3.84
Litter	Wilf	Cnt	3.93	Fh	Wilf	Cnt	3.5	Mineral	Wilf	Cnt	4.15
Litter	Wilf	Cnt	4.16	Fh	Wilf	Cnt	3.91	Mineral	Wilf	Cnt	3.76
Litter	Wilf	Cnt	4.27	Fh	Wilf	Cnt	3.56	Mineral	Wilf	Cnt	3.79
Litter	Mark	8	4.58	Fh	Mark	4	3.76	Mineral	Mark	8	3.97
Litter	Mark	8	4.38	Fh	Mark	4	3.86	Mineral	Mark	8	3.91
Litter	Mark	8	4.68	Fh	Mark	4	4.11	Mineral	Mark	8	3.59

Baseline Soil pH at the 3 study sites continued:

Soil	Site	Treatment	pH	Soil	Site	Treatment	pH	Soil	Site	Treatment	pH
Litter	Mark	8	4.69	Fh	Mark	4	4.3	Mineral	Mark	8	3.75
Litter	Mark	8	4.79	Fh	Mark	4	4.01	Mineral	Mark	8	3.95
Litter	Mark	8	4.69	Fh	Mark	4	4.44	Mineral	Mark	8	3.96
Litter	Mark	4	4.31	Fh	Mark	8	4	Mineral	Mark	4	4.12
Litter	Mark	4	4.81	Fh	Mark	8	3.96	Mineral	Mark	4	3.79
Litter	Mark	4	4.39	Fh	Mark	8	4.01	Mineral	Mark	4	4.03
Litter	Mark	4	4.8	Fh	Mark	8	4.37	Mineral	Mark	4	3.69
Litter	Mark	4	4.67	Fh	Mark	8	4.45	Mineral	Mark	4	3.98
Litter	Mark	4	4.7	Fh	Mark	8	4.03	Mineral	Mark	4	3.8
Litter	Mark	Cnt	4.34	Fh	Mark	Cnt	4.55	Mineral	Mark	Cnt	4.43
Litter	Mark	Cnt	4.64	Fh	Mark	Cnt	4.63	Mineral	Mark	Cnt	4.09
Litter	Mark	Cnt	4.8	Fh	Mark	Cnt	4.15	Mineral	Mark	Cnt	3.92
Litter	Mark	Cnt	4.72	Fh	Mark	Cnt	4.48	Mineral	Mark	Cnt	4.24
Litter	Mark	Cnt	4.64	Fh	Mark	Cnt	3.87	Mineral	Mark	Cnt	3.84
Litter	Mark	Cnt	4.8	Fh	Mark	Cnt	4.19	Mineral	Mark	Cnt	4.28

- *Baseline Soil CN, and OM at the 3 study sites:*

Treatment	Site	Soil	OM %	N %	C %
4 Mg/ha	Brook	Mineral	9.873016	0.546	9.534
4 Mg/ha	Brook	Mineral	9.552571	0.491	7.892
4 Mg/ha	Brook	Mineral	8.834951	0.387	5.853
4 Mg/ha	Brook	Mineral	8.184295	0.335	4.676
4 Mg/ha	Brook	Mineral	9.566372	0.532	7.189
4 Mg/ha	Brook	Mineral	8.861537	0.445	5.221
4 Mg/ha	Wilf	Mineral	10.15845	0.328	4.662
4 Mg/ha	Wilf	Mineral	9.393214	0.367	5.184
4 Mg/ha	Wilf	Mineral	9.393121	0.304	4.626
4 Mg/ha	Wilf	Mineral	10.8213	0.373	5.162
4 Mg/ha	Wilf	Mineral	9.697801	0.33	4.591
4 Mg/ha	Wilf	Mineral	4.79467	0.177	2.439
4 Mg/ha	Mark	Mineral	7.069503	0.256	3.186
4 Mg/ha	Mark	Mineral	7.934019	0.302	3.736
4 Mg/ha	Mark	Mineral	7.242439	0.267	3.361
4 Mg/ha	Mark	Mineral	8.039262	0.331	4.036
4 Mg/ha	Mark	Mineral	8.235925	0.316	4.27
4 Mg/ha	Mark	Mineral	7.792105	0.306	3.521
4 Mg/ha	Brook	FH	33.28041	1.128	18.412
4 Mg/ha	Brook	FH	73.33051	2.104	36.229
4 Mg/ha	Brook	FH	40.03265	1.65	28.523
4 Mg/ha	Brook	FH	64.97655	2.053	36.329
4 Mg/ha	Brook	FH	65.36558	2.197	37.604
4 Mg/ha	Brook	FH	48.82565	1.82	30.608
4 Mg/ha	Wilf	FH	87.2831	2.245	44.768
4 Mg/ha	Wilf	FH	70.26464	2.042	35.732
4 Mg/ha	Wilf	FH	26.23229	0.902	13.659
4 Mg/ha	Wilf	FH	59.09697	1.969	37.428
4 Mg/ha	Wilf	FH	27.1338	1.339	24.941
4 Mg/ha	Wilf	FH	25.44473	1.095	19.936
4 Mg/ha	Mark	FH	65.98572	2.08	33.312
4 Mg/ha	Mark	FH	67.25103	1.917	33.742
4 Mg/ha	Mark	FH	39.29358	2.306	41.904
4 Mg/ha	Mark	FH	42.65331	1.865	32.44
4 Mg/ha	Mark	FH	32.15639	1.484	23.64
4 Mg/ha	Mark	FH	77.70976	2.322	41.883
4 Mg/ha	Brook	Litter	88.56109	2.062	44.35
4 Mg/ha	Brook	Litter	90.15286	2.195	45.592
4 Mg/ha	Brook	Litter	91.01236	2.044	45.259
4 Mg/ha	Brook	Litter	91.84769	2.14	46.311
4 Mg/ha	Brook	Litter	90.58551	2.213	44.886
4 Mg/ha	Brook	Litter	89.94121	2.001	46.91
4 Mg/ha	Wilf	Litter	92.47513	1.84	46.76

Baseline Soil CN, and OM at the 3 study sites continued:

Treatment	Site	Soil	OM %	N %	C %
4 Mg/ha	Wilf	Litter	91.87807	2.085	46.041
4 Mg/ha	Wilf	Litter	88.74011	1.998	45.791
4 Mg/ha	Wilf	Litter	90.49845	2.085	46.618
4 Mg/ha	Wilf	Litter	91.27417	2.079	46.516
4 Mg/ha	Wilf	Litter	82.34888	2.046	42.404
4 Mg/ha	Mark	Litter	91.18204	2.165	45.532
4 Mg/ha	Mark	Litter	90.72155	2.077	45.729
4 Mg/ha	Mark	Litter	89.43772	2.09	45.127
4 Mg/ha	Mark	Litter	86.57351	2.06	45.915
4 Mg/ha	Mark	Litter	88.75944	2.002	44.557
4 Mg/ha	Mark	Litter	89.99805	2.058	45.518
8 Mg/ha	Brook	Mineral	9.58836	0.454	6.464
8 Mg/ha	Brook	Mineral	8.241236	0.413	5.847
8 Mg/ha	Brook	Mineral	9.698745	0.595	8.908
8 Mg/ha	Brook	Mineral	7.911988	0.316	3.914
8 Mg/ha	Brook	Mineral	7.839746	0.366	6.26
8 Mg/ha	Wilf	Mineral	12.14666	0.427	6.932
8 Mg/ha	Wilf	Mineral	12.59107	0.469	6.676
8 Mg/ha	Wilf	Mineral	10.45631	0.306	5.072
8 Mg/ha	Wilf	Mineral	10.50354	0.296	4.283
8 Mg/ha	Wilf	Mineral	10.73454	0.36	5.216
8 Mg/ha	Wilf	Mineral	10.48769	0.428	6.18
8 Mg/ha	Mark	Mineral	7.192506	0.249	3.11
8 Mg/ha	Mark	Mineral	8.231313	0.332	4.159
8 Mg/ha	Mark	Mineral	8.607093	0.335	4.097
8 Mg/ha	Mark	Mineral	8.171608	0.34	4.096
8 Mg/ha	Mark	Mineral	7.704458	0.295	3.631
8 Mg/ha	Mark	Mineral	9.922447	0.396	4.701
8 Mg/ha	Brook	FH	30.43478	1.348	20.927
8 Mg/ha	Brook	FH	43.20357	1.432	23.08
8 Mg/ha	Brook	FH	61.22709	1.833	32.878
8 Mg/ha	Brook	FH	38.6195	1.405	21.661
8 Mg/ha	Brook	FH	32.5023	1.759	32.508
8 Mg/ha	Wilf	FH	52.15169	1.513	24.782
8 Mg/ha	Wilf	FH	78.43569	2.166	38.355
8 Mg/ha	Wilf	FH	62.4943	1.846	35.558
8 Mg/ha	Wilf	FH	49.75591	1.737	35.267
8 Mg/ha	Wilf	FH	67.21512	2.046	40.367
8 Mg/ha	Wilf	FH	56.06683	2.001	33.483
8 Mg/ha	Mark	FH	46.07558	2.27	39.307
8 Mg/ha	Mark	FH	32.90314	0.902	10.942
8 Mg/ha	Mark	FH	72.51545	2.147	38.214
8 Mg/ha	Mark	FH	56.80687	1.945	31.603

Baseline Soil CN, and OM at the 3 study sites continued:

Treatment	Site	Soil	OM %	N %	C %
8 Mg/ha	Mark	FH	73.66579	2.322	35.344
8 Mg/ha	Mark	FH	45.97814	1.647	27.003
8 Mg/ha	Brook	Litter	87.89667	2.222	44.419
8 Mg/ha	Brook	Litter	89.28271	2.214	44.362
8 Mg/ha	Brook	Litter	90.1106	2.152	45.303
8 Mg/ha	Brook	Litter	89.99901	2.142	44.873
8 Mg/ha	Brook	Litter	86.18163	1.915	43.169
8 Mg/ha	Wilf	Litter	90.90032	2.111	46.277
8 Mg/ha	Wilf	Litter	91.68117	1.971	46.21
8 Mg/ha	Wilf	Litter	91.45582	1.825	46.162
8 Mg/ha	Wilf	Litter	91.42335	1.908	46.517
8 Mg/ha	Wilf	Litter	91.78737	1.909	46.553
8 Mg/ha	Wilf	Litter	90.64278	2.201	45.725
8 Mg/ha	Mark	Litter	90.67742	1.953	45.668
8 Mg/ha	Mark	Litter	91.76725	1.985	46.931
8 Mg/ha	Mark	Litter	90.22333	2.041	45.43
8 Mg/ha	Mark	Litter	89.42867	2.096	44.714
8 Mg/ha	Mark	Litter	90.07983	2.134	45.344
8 Mg/ha	Mark	Litter	89.99459	2.051	45.059
Cnt.	Brook	Mineral	9.190372	0.263	3.706
Cnt.	Brook	Mineral	6.813726	0.292	3.588
Cnt.	Brook	Mineral	8.188108	0.306	3.555
Cnt.	Brook	Mineral	6.706064	0.346	4.759
Cnt.	Brook	Mineral	10.10315	0.37	5.12
Cnt.	Brook	Mineral	6.298775	0.213	3.06
Cnt.	Wilf	Mineral	12.75135	0.473	6.064
Cnt.	Wilf	Mineral	16.66893	0.65	9.811
Cnt.	Wilf	Mineral	10.48792	0.334	5.022
Cnt.	Wilf	Mineral	8.746472	0.254	4.213
Cnt.	Wilf	Mineral	8.112036	0.311	4.181
Cnt.	Wilf	Mineral	10.33118	0.402	6.047
Cnt.	Mark	Mineral	8.162901	0.336	3.954
Cnt.	Mark	Mineral	8.113095	0.311	3.867
Cnt.	Mark	Mineral	8.33713	0.331	4.422
Cnt.	Mark	Mineral	9.421757	0.326	4.303
Cnt.	Mark	Mineral	10.76675	0.385	5.492
Cnt.	Mark	Mineral	10.10051	0.399	5.914
Cnt.	Brook	FH	18.60192	0.805	12.536
Cnt.	Brook	FH	68.36885	2.192	40.141
Cnt.	Brook	FH	38.67222	1.523	24.829
Cnt.	Brook	FH	25.15456	1.5	24.54
Cnt.	Brook	FH	40.99334	1.657	26.658
Cnt.	Brook	FH	29.12405	1.137	18.329

Baseline Soil CN, and OM at the 3 study sites continued:

Treatment	Site	Soil	OM %	N %	C %
Cnt.	Wilf	FH	82.60075	2.243	43.468
Cnt.	Wilf	FH	69.29195	2.028	34.771
Cnt.	Wilf	FH	31.35194	1.085	20.303
Cnt.	Wilf	FH	54.59008	1.624	30.625
Cnt.	Wilf	FH	55.67188	1.819	33.219
Cnt.	Wilf	FH	46.69904	2.068	40.734
Cnt.	Mark	FH	79.11609	2.257	39.361
Cnt.	Mark	FH	42.79488	1.671	28.183
Cnt.	Mark	FH	76.93135	2.112	42.277
Cnt.	Mark	FH	41.98118	1.843	28.695
Cnt.	Mark	FH	52.27869	2.055	38.01
Cnt.	Mark	FH	68.72942	2.251	41.533
Cnt.	Brook	Litter	85.06154	2.046	45.544
Cnt.	Brook	Litter	90.51288	2.134	45.025
Cnt.	Brook	Litter	90.02216	2.362	45.33
Cnt.	Brook	Litter	90.34425	2.052	46.794
Cnt.	Brook	Litter	84.48963	2.105	43.429
Cnt.	Brook	Litter	85.16489	1.742	43.585
Cnt.	Wilf	Litter	91.19879	1.989	45.804
Cnt.	Wilf	Litter	91.98688	2.032	45.284
Cnt.	Wilf	Litter	90.73099	1.883	41.188
Cnt.	Wilf	Litter	90.97267	1.881	46.048
Cnt.	Wilf	Litter	91.8231	1.937	46.333
Cnt.	Wilf	Litter	89.5577	2.147	46.163
Cnt.	Mark	Litter	90.88161	2.051	45.405
Cnt.	Mark	Litter	88.59876	2.008	44.725
Cnt.	Mark	Litter	89.56152	1.958	45.543
Cnt.	Mark	Litter	88.20297	2.12	45.412
Cnt.	Mark	Litter	89.37828	2.093	44.984
Cnt.	Mark	Litter	89.54518	1.979	44.823

- *Baseline Soil Nutrients at the 3 study sites:*

Site	Soil	Treatment	K mg/g	Site	Soil	Treatment	Mg mg/g	Site	Soil	Treatment	Ca mg/g
Brook	Litter	Cnt	0.368	Brook	Litter	Cnt	0.184	Brook	Litter	Cnt	1.933
Brook	Litter	Cnt	0.636	Brook	Litter	Cnt	0.328	Brook	Litter	Cnt	2.497
Brook	Litter	Cnt	0.606	Brook	Litter	Cnt	0.326	Brook	Litter	Cnt	2.981
Brook	Litter	Cnt	0.784	Brook	Litter	Cnt	0.460	Brook	Litter	Cnt	3.699
Brook	Litter	Cnt	0.807	Brook	Litter	Cnt	0.694	Brook	Litter	Cnt	5.021
Brook	Litter	Cnt	0.482	Brook	Litter	Cnt	0.235	Brook	Litter	Cnt	2.376
Wilf	Litter	Cnt	0.833	Wilf	Litter	Cnt	0.338	Wilf	Litter	Cnt	3.305
Wilf	Litter	Cnt	0.686	Wilf	Litter	Cnt	0.357	Wilf	Litter	Cnt	2.699
Wilf	Litter	Cnt	0.759	Wilf	Litter	Cnt	0.340	Wilf	Litter	Cnt	2.785
Wilf	Litter	Cnt	0.677	Wilf	Litter	Cnt	0.388	Wilf	Litter	Cnt	2.577
Wilf	Litter	Cnt	0.715	Wilf	Litter	Cnt	0.404	Wilf	Litter	Cnt	2.756
Wilf	Litter	Cnt	0.649	Wilf	Litter	Cnt	0.310	Wilf	Litter	Cnt	2.759
Mark	Litter	Cnt	1.010	Mark	Litter	Cnt	0.500	Mark	Litter	Cnt	3.836
Mark	Litter	Cnt	0.897	Mark	Litter	Cnt	0.432	Mark	Litter	Cnt	4.817
Mark	Litter	Cnt	0.766	Mark	Litter	Cnt	0.350	Mark	Litter	Cnt	6.045
Mark	Litter	Cnt	0.632	Mark	Litter	Cnt	0.370	Mark	Litter	Cnt	5.129
Mark	Litter	Cnt	0.712	Mark	Litter	Cnt	0.329	Mark	Litter	Cnt	4.059
Mark	Litter	Cnt	0.792	Mark	Litter	Cnt	0.396	Mark	Litter	Cnt	4.027
Brook	Fh	Cnt	0.055	Brook	Fh	Cnt	0.028	Brook	Fh	Cnt	0.499
Brook	Fh	Cnt	0.335	Brook	Fh	Cnt	0.209	Brook	Fh	Cnt	2.017
Brook	Fh	Cnt	0.148	Brook	Fh	Cnt	0.097	Brook	Fh	Cnt	1.212
Brook	Fh	Cnt	0.105	Brook	Fh	Cnt	0.133	Brook	Fh	Cnt	1.322
Brook	Fh	Cnt	0.277	Brook	Fh	Cnt	0.290	Brook	Fh	Cnt	2.723
Brook	Fh	Cnt	0.105	Brook	Fh	Cnt	0.062	Brook	Fh	Cnt	0.995
Wilf	Fh	Cnt	0.055	Wilf	Fh	Cnt	0.268	Wilf	Fh	Cnt	1.552
Wilf	Fh	Cnt	0.213	Wilf	Fh	Cnt	0.106	Wilf	Fh	Cnt	0.671
Wilf	Fh	Cnt	0.566	Wilf	Fh	Cnt	1.110	Wilf	Fh	Cnt	0.757
Wilf	Fh	Cnt	0.190	Wilf	Fh	Cnt	0.252	Wilf	Fh	Cnt	1.273
Wilf	Fh	Cnt	0.267	Wilf	Fh	Cnt	0.489	Wilf	Fh	Cnt	3.537
Wilf	Fh	Cnt	0.174	Wilf	Fh	Cnt	0.118	Wilf	Fh	Cnt	1.214
Mark	Fh	Cnt	0.998	Mark	Fh	Cnt	0.662	Mark	Fh	Cnt	13.358
Mark	Fh	Cnt	0.507	Mark	Fh	Cnt	0.362	Mark	Fh	Cnt	7.394
Mark	Fh	Cnt	0.617	Mark	Fh	Cnt	0.409	Mark	Fh	Cnt	4.982
Mark	Fh	Cnt	0.435	Mark	Fh	Cnt	0.348	Mark	Fh	Cnt	6.090
Mark	Fh	Cnt	0.902	Mark	Fh	Cnt	0.629	Mark	Fh	Cnt	7.123
Mark	Fh	Cnt	0.164	Mark	Fh	Cnt	0.790	Mark	Fh	Cnt	10.280
Brook	Mineral	Cnt	0.046	Brook	Mineral	Cnt	0.023	Brook	Mineral	Cnt	0.179
Brook	Mineral	Cnt	0.053	Brook	Mineral	Cnt	0.033	Brook	Mineral	Cnt	0.282
Brook	Mineral	Cnt	0.067	Brook	Mineral	Cnt	0.030	Brook	Mineral	Cnt	0.229
Brook	Mineral	Cnt	0.045	Brook	Mineral	Cnt	0.030	Brook	Mineral	Cnt	0.263
Brook	Mineral	Cnt	0.066	Brook	Mineral	Cnt	0.047	Brook	Mineral	Cnt	0.362
Brook	Mineral	Cnt	0.038	Brook	Mineral	Cnt	0.021	Brook	Mineral	Cnt	0.139
Wilf	Mineral	Cnt	0.122	Wilf	Mineral	Cnt	0.044	Wilf	Mineral	Cnt	0.278

Baseline Soil Nutrients at the 3 study sites continued:

Site	Soil	Treatment	K mg/g	Site	Soil	Treatment	Mg mg/g	Site	Soil	Treatment	Ca mg/g
Wilf	Mineral	Cnt	0.098	Wilf	Mineral	Cnt	0.033	Wilf	Mineral	Cnt	0.103
Wilf	Mineral	Cnt	0.061	Wilf	Mineral	Cnt	0.023	Wilf	Mineral	Cnt	0.144
Wilf	Mineral	Cnt	0.034	Wilf	Mineral	Cnt	0.020	Wilf	Mineral	Cnt	0.110
Wilf	Mineral	Cnt	0.055	Wilf	Mineral	Cnt	0.027	Wilf	Mineral	Cnt	0.156
Wilf	Mineral	Cnt	0.078	Wilf	Mineral	Cnt	0.030	Wilf	Mineral	Cnt	0.134
Mark	Mineral	Cnt	0.003	Mark	Mineral	Cnt	0.006	Mark	Mineral	Cnt	0.524
Mark	Mineral	Cnt	0.024	Mark	Mineral	Cnt	0.017	Mark	Mineral	Cnt	0.144
Mark	Mineral	Cnt	0.014	Mark	Mineral	Cnt	0.013	Mark	Mineral	Cnt	0.098
Mark	Mineral	Cnt	0.008	Mark	Mineral	Cnt	0.009	Mark	Mineral	Cnt	0.403
Mark	Mineral	Cnt	0.009	Mark	Mineral	Cnt	0.010	Mark	Mineral	Cnt	0.147
Mark	Mineral	Cnt	0.004	Mark	Mineral	Cnt	0.007	Mark	Mineral	Cnt	0.191
Brook	Litter	8	0.850	Brook	Litter	8	0.496	Brook	Litter	8	4.228
Brook	Litter	8	1.081	Brook	Litter	8	0.563	Brook	Litter	8	4.830
Brook	Litter	8	0.781	Brook	Litter	8	0.403	Brook	Litter	8	2.588
Brook	Litter	8	0.582	Brook	Litter	8	0.338	Brook	Litter	8	2.514
Brook	Litter	8	0.530	Brook	Litter	8	0.325	Brook	Litter	8	3.589
Wilf	Litter	8	0.882	Wilf	Litter	8	0.448	Wilf	Litter	8	3.449
Wilf	Litter	8	0.859	Wilf	Litter	8	0.448	Wilf	Litter	8	2.947
Wilf	Litter	8	1.255	Wilf	Litter	8	0.649	Wilf	Litter	8	3.181
Wilf	Litter	8	1.289	Wilf	Litter	8	0.352	Wilf	Litter	8	4.993
Wilf	Litter	8	0.811	Wilf	Litter	8	0.329	Wilf	Litter	8	3.074
Wilf	Litter	8	0.609	Wilf	Litter	8	0.346	Wilf	Litter	8	2.554
Mark	Litter	8	0.629	Mark	Litter	8	0.276	Mark	Litter	8	6.956
Mark	Litter	8	0.861	Mark	Litter	8	0.425	Mark	Litter	8	4.354
Mark	Litter	8	1.065	Mark	Litter	8	0.557	Mark	Litter	8	3.683
Mark	Litter	8	1.326	Mark	Litter	8	0.706	Mark	Litter	8	4.765
Mark	Litter	8	0.858	Mark	Litter	8	0.354	Mark	Litter	8	5.636
Mark	Litter	8	0.865	Mark	Litter	8	0.451	Mark	Litter	8	4.984
Brook	Fh	8	0.095	Brook	Fh	8	0.080	Brook	Fh	8	2.054
Brook	Fh	8	0.197	Brook	Fh	8	0.145	Brook	Fh	8	2.943
Brook	Fh	8	0.406	Brook	Fh	8	0.261	Brook	Fh	8	1.057
Brook	Fh	8	0.232	Brook	Fh	8	0.126	Brook	Fh	8	1.698
Brook	Fh	8	0.194	Brook	Fh	8	0.158	Brook	Fh	8	1.251
Wilf	Fh	8	0.158	Wilf	Fh	8	0.230	Wilf	Fh	8	0.886
Wilf	Fh	8	0.159	Wilf	Fh	8	0.147	Wilf	Fh	8	1.629
Wilf	Fh	8	0.287	Wilf	Fh	8	0.418	Wilf	Fh	8	1.242
Wilf	Fh	8	0.227	Wilf	Fh	8	0.339	Wilf	Fh	8	2.158
Wilf	Fh	8	0.239	Wilf	Fh	8	0.520	Wilf	Fh	8	1.620
Wilf	Fh	8	0.233	Wilf	Fh	8	0.658	Wilf	Fh	8	0.902
Mark	Fh	8	0.596	Mark	Fh	8	0.446	Mark	Fh	8	6.016
Mark	Fh	8	0.406	Mark	Fh	8	0.295	Mark	Fh	8	4.465
Mark	Fh	8	0.662	Mark	Fh	8	0.504	Mark	Fh	8	6.732
Mark	Fh	8	0.731	Mark	Fh	8	0.469	Mark	Fh	8	7.247

Baseline Soil Nutrients at the 3 study sites continued:

Site	Soil	Treatment	K mg/g	Site	Soil	Treatment	Mg mg/g	Site	Soil	Treatment	Ca mg/g
Mark	Fh	8	0.889	Mark	Fh	8	0.646	Mark	Fh	8	9.248
Mark	Fh	8	0.999	Mark	Fh	8	0.642	Mark	Fh	8	9.378
Brook	Mineral	8	0.076	Brook	Mineral	8	0.088	Brook	Mineral	8	2.830
Brook	Mineral	8	0.067	Brook	Mineral	8	0.039	Brook	Mineral	8	0.316
Brook	Mineral	8	0.066	Brook	Mineral	8	0.044	Brook	Mineral	8	0.248
Brook	Mineral	8	0.048	Brook	Mineral	8	0.030	Brook	Mineral	8	0.225
Brook	Mineral	8	0.046	Brook	Mineral	8	0.027	Brook	Mineral	8	0.231
Wilf	Mineral	8	0.064	Wilf	Mineral	8	0.023	Wilf	Mineral	8	0.115
Wilf	Mineral	8	0.071	Wilf	Mineral	8	0.034	Wilf	Mineral	8	0.264
Wilf	Mineral	8	0.045	Wilf	Mineral	8	0.030	Wilf	Mineral	8	0.184
Wilf	Mineral	8	0.049	Wilf	Mineral	8	0.028	Wilf	Mineral	8	0.147
Wilf	Mineral	8	0.055	Wilf	Mineral	8	0.036	Wilf	Mineral	8	0.180
Wilf	Mineral	8	0.096	Wilf	Mineral	8	0.036	Wilf	Mineral	8	0.228
Mark	Mineral	8	0.000	Mark	Mineral	8	0.004	Mark	Mineral	8	0.124
Mark	Mineral	8	0.002	Mark	Mineral	8	0.004	Mark	Mineral	8	0.104
Mark	Mineral	8	0.025	Mark	Mineral	8	0.016	Mark	Mineral	8	0.100
Mark	Mineral	8	0.009	Mark	Mineral	8	0.009	Mark	Mineral	8	0.061
Mark	Mineral	8	0.005	Mark	Mineral	8	0.006	Mark	Mineral	8	0.054
Mark	Mineral	8	0.007	Mark	Mineral	8	0.006	Mark	Mineral	8	0.125
Brook	Litter	4	0.882	Brook	Litter	4	0.463	Brook	Litter	4	3.890
Brook	Litter	4	1.182	Brook	Litter	4	0.759	Brook	Litter	4	5.253
Brook	Litter	4	0.741	Brook	Litter	4	0.414	Brook	Litter	4	3.474
Brook	Litter	4	0.543	Brook	Litter	4	0.328	Brook	Litter	4	2.437
Brook	Litter	4	0.884	Brook	Litter	4	0.465	Brook	Litter	4	3.808
Brook	Litter	4	0.703	Brook	Litter	4	0.500	Brook	Litter	4	3.402
Wilf	Litter	4	0.645	Wilf	Litter	4	0.327	Wilf	Litter	4	4.074
Wilf	Litter	4	1.178	Wilf	Litter	4	0.451	Wilf	Litter	4	4.321
Wilf	Litter	4	0.883	Wilf	Litter	4	0.545	Wilf	Litter	4	2.454
Wilf	Litter	4	0.601	Wilf	Litter	4	0.271	Wilf	Litter	4	3.590
Wilf	Litter	4	0.878	Wilf	Litter	4	0.392	Wilf	Litter	4	3.680
Wilf	Litter	4	0.893	Wilf	Litter	4	0.409	Wilf	Litter	4	2.987
Mark	Litter	4	1.396	Mark	Litter	4	0.476	Mark	Litter	4	4.445
Mark	Litter	4	0.680	Mark	Litter	4	0.311	Mark	Litter	4	4.960
Mark	Litter	4	0.906	Mark	Litter	4	0.393	Mark	Litter	4	7.030
Mark	Litter	4	1.223	Mark	Litter	4	0.717	Mark	Litter	4	4.966
Mark	Litter	4	0.874	Mark	Litter	4	0.475	Mark	Litter	4	3.733
Mark	Litter	4	0.784	Mark	Litter	4	0.384	Mark	Litter	4	4.623
Brook	Fh	4	0.382	Brook	Fh	4	0.317	Brook	Fh	4	1.030
Brook	Fh	4	0.319	Brook	Fh	4	0.253	Brook	Fh	4	3.318
Brook	Fh	4	0.123	Brook	Fh	4	0.078	Brook	Fh	4	0.565
Brook	Fh	4	0.501	Brook	Fh	4	0.303	Brook	Fh	4	2.146
Brook	Fh	4	0.057	Brook	Fh	4	0.047	Brook	Fh	4	3.476
Brook	Fh	4	0.348	Brook	Fh	4	0.230	Brook	Fh	4	2.800

Baseline Soil Nutrients at the 3 study sites continued:

Site	Soil	Treatment	K mg/g	Site	Soil	Treatment	Mg mg/g	Site	Soil	Treatment	Ca mg/g
Wilf	Fh	4	0.089	Wilf	Fh	4	0.189	Wilf	Fh	4	2.157
Wilf	Fh	4	0.446	Wilf	Fh	4	0.300	Wilf	Fh	4	0.322
Wilf	Fh	4	0.013	Wilf	Fh	4	0.139	Wilf	Fh	4	0.571
Wilf	Fh	4	0.056	Wilf	Fh	4	0.266	Wilf	Fh	4	0.783
Wilf	Fh	4	0.106	Wilf	Fh	4	0.481	Wilf	Fh	4	0.770
Wilf	Fh	4	0.224	Wilf	Fh	4	0.318	Wilf	Fh	4	1.322
Mark	Fh	4	0.728	Mark	Fh	4	0.441	Mark	Fh	4	6.179
Mark	Fh	4	0.902	Mark	Fh	4	0.608	Mark	Fh	4	7.548
Mark	Fh	4	0.446	Mark	Fh	4	0.341	Mark	Fh	4	5.115
Mark	Fh	4	0.694	Mark	Fh	4	0.440	Mark	Fh	4	6.437
Mark	Fh	4	0.276	Mark	Fh	4	0.193	Mark	Fh	4	2.786
Mark	Fh	4	1.112	Mark	Fh	4	0.778	Mark	Fh	4	9.654
Brook	Mineral	4	0.081	Brook	Mineral	4	0.035	Brook	Mineral	4	0.326
Brook	Mineral	4	0.082	Brook	Mineral	4	0.051	Brook	Mineral	4	0.463
Brook	Mineral	4	0.063	Brook	Mineral	4	0.028	Brook	Mineral	4	0.195
Brook	Mineral	4	0.072	Brook	Mineral	4	0.038	Brook	Mineral	4	0.269
Brook	Mineral	4	0.086	Brook	Mineral	4	0.052	Brook	Mineral	4	0.452
Brook	Mineral	4	0.078	Brook	Mineral	4	0.054	Brook	Mineral	4	0.439
Wilf	Mineral	4	0.069	Wilf	Mineral	4	0.025	Wilf	Mineral	4	0.160
Wilf	Mineral	4	0.068	Wilf	Mineral	4	0.023	Wilf	Mineral	4	0.127
Wilf	Mineral	4	0.049	Wilf	Mineral	4	0.023	Wilf	Mineral	4	0.105
Wilf	Mineral	4	0.063	Wilf	Mineral	4	0.024	Wilf	Mineral	4	0.226
Wilf	Mineral	4	0.041	Wilf	Mineral	4	0.014	Wilf	Mineral	4	0.073
Wilf	Mineral	4	0.047	Wilf	Mineral	4	0.019	Wilf	Mineral	4	0.072
Mark	Mineral	4	0.001	Mark	Mineral	4	0.004	Mark	Mineral	4	0.048
Mark	Mineral	4	0.007	Mark	Mineral	4	0.007	Mark	Mineral	4	0.163
Mark	Mineral	4	0.013	Mark	Mineral	4	0.009	Mark	Mineral	4	0.300
Mark	Mineral	4	0.008	Mark	Mineral	4	0.008	Mark	Mineral	4	0.081
Mark	Mineral	4	0.009	Mark	Mineral	4	0.010	Mark	Mineral	4	0.077
Mark	Mineral	4	0.004	Mark	Mineral	4	0.007	Mark	Mineral	4	0.146

- *Baseline Soil Metals at the 3 study sites:*

Soil	Treatment	Site	Zn mg/kg	Ni mg/kg	Fe mg/kg	Cu mg/kg	B mg/kg	As mg/kg
Litter	Cnt	Brook	59.633	0.742	164.505	1.305	15.721	0.000
Litter	Cnt	Brook	53.598	0.974	1066.905	3.000	11.947	0.000
Litter	Cnt	Brook	58.460	1.012	244.011	2.095	11.481	0.000
Litter	Cnt	Brook	40.923	1.031	373.374	2.158	8.915	0.000
Litter	Cnt	Brook	52.411	1.033	341.582	3.892	13.367	0.000
Litter	Cnt	Brook	49.425	1.940	862.782	3.036	11.645	0.000
Mineral	Cnt	Brook	13.922	1.950	6711.153	0.000	0.000	0.000
Mineral	Cnt	Brook	16.845	1.954	7597.701	0.000	0.000	0.000
Mineral	Cnt	Brook	21.649	2.223	11155.484	0.631	0.000	0.000
Mineral	Cnt	Brook	24.076	2.393	15149.746	8.368	2.232	0.000
Mineral	Cnt	Brook	29.232	2.875	7357.987	0.000	0.000	0.000
Mineral	Cnt	Brook	48.109	6.470	14765.212	0.000	0.000	0.000
Fh	Cnt	Brook	28.742	3.361	11599.561	2.322	0.000	0.000
Fh	Cnt	Brook	33.291	3.617	3276.681	1.681	0.000	0.000
Fh	Cnt	Brook	36.124	3.938	5945.788	1.233	0.000	0.000
Fh	Cnt	Brook	48.904	4.284	5663.129	0.000	0.000	0.000
Fh	Cnt	Brook	62.631	4.792	2067.211	5.733	0.000	0.000
Fh	Cnt	Brook	54.922	6.784	8435.018	1.310	0.000	0.000
Fh	80 Kg	Brook	60.860	6.944	4608.733	4.546	0.000	0.000
Fh	80 Kg	Brook	77.530	8.120	6593.916	7.299	0.000	0.000
Fh	80 Kg	Brook	45.718	3.782	2946.344	8.410	0.000	0.000
Fh	80 Kg	Brook	77.113	4.438	2118.373	4.005	0.000	0.000
Fh	80 Kg	Brook	42.782	5.161	6110.164	2.691	0.000	0.000
Litter	80 Kg	Brook	53.274	1.195	495.556	3.601	10.297	0.000
Litter	80 Kg	Brook	44.970	0.832	415.064	4.343	10.575	0.000
Litter	80 Kg	Brook	45.200	0.925	265.434	2.620	10.564	0.000
Litter	80 Kg	Brook	62.354	1.074	278.703	3.298	11.523	0.000
Litter	80 Kg	Brook	56.140	0.497	297.036	1.304	11.217	0.000
Mineral	80 Kg	Brook	20.834	2.798	10863.795	0.000	0.000	0.000
Mineral	80 Kg	Brook	54.129	4.118	7947.936	4.209	3.190	0.000
Mineral	80 Kg	Brook	16.731	1.753	7039.242	2.406	1.893	0.000
Mineral	80 Kg	Brook	12.786	1.710	5482.474	2.642	2.950	0.000
Mineral	80 Kg	Brook	24.915	2.829	7833.926	1.714	0.000	0.000
Fh	40 Kg	Brook	58.077	3.646	2172.007	8.237	1.171	0.000
Fh	40 Kg	Brook	116.980	6.898	8267.544	3.916	0.000	0.000
Fh	40 Kg	Brook	40.774	7.202	4994.218	7.013	0.000	0.000
Fh	40 Kg	Brook	67.103	4.893	1816.417	8.375	0.000	0.000
Fh	40 Kg	Brook	23.660	4.366	3536.657	0.775	0.000	0.000
Fh	40 Kg	Brook	38.476	6.422	1498.456	9.166	0.000	0.000

Baseline Soil Metals at the 3 study sites continued:

Soil	Treatment	Site	Zn mg/kg	Ni mg/kg	Fe mg/kg	Cu mg/kg	B mg/kg	As mg/kg
Litter	40 Kg	Brook	46.355	0.431	217.249	1.826	14.285	0.000
Litter	40 Kg	Brook	185.599	1.086	274.501	2.528	13.650	0.000
Litter	40 Kg	Brook	39.196	0.697	375.399	1.715	11.969	0.000
Litter	40 Kg	Brook	50.557	0.741	238.714	3.381	15.274	0.000
Litter	40 Kg	Brook	38.681	1.105	309.089	2.001	9.227	0.000
Litter	40 Kg	Brook	40.112	0.795	213.935	3.537	11.614	0.000
Mineral	40 Kg	Brook	27.409	2.138	10547.218	0.739	0.000	0.000
Mineral	40 Kg	Brook	28.677	2.961	8264.504	1.110	0.000	0.000
Mineral	40 Kg	Brook	17.247	2.502	7220.092	4.135	3.018	0.000
Mineral	40 Kg	Brook	15.633	1.776	6695.310	1.203	1.382	0.000
Mineral	40 Kg	Brook	14.266	1.756	6717.956	0.953	0.216	0.000
Mineral	40 Kg	Brook	11.750	1.755	3892.652	0.957	0.802	0.000
Fh	Cnt	Mark	61.881	4.400	2475.370	5.306	2.070	0.000
Fh	Cnt	Mark	102.069	7.821	6130.844	6.173	0.748	0.000
Fh	Cnt	Mark	58.769	6.171	3810.067	6.975	1.693	0.000
Fh	Cnt	Mark	65.330	6.105	2555.268	1.084	21.684	0.000
Fh	Cnt	Mark	160.944	3.030	1958.893	4.841	0.000	0.000
Fh	Cnt	Mark	82.062	4.745	4346.068	7.437	0.000	0.000
Litter	Cnt	Mark	44.158	0.387	171.155	0.647	18.069	0.000
Litter	Cnt	Mark	58.322	0.755	255.331	1.052	16.576	0.000
Litter	Cnt	Mark	46.819	0.565	257.307	0.676	15.771	0.000
Litter	Cnt	Mark	45.832	0.708	262.619	0.000	0.000	0.000
Litter	Cnt	Mark	59.658	0.432	172.428	6.078	20.492	0.000
Litter	Cnt	Mark	51.930	0.977	395.374	1.066	17.520	0.000
Mineral	Cnt	Mark	22.040	3.040	13161.216	0.000	0.000	0.000
Mineral	Cnt	Mark	29.873	5.677	9024.817	0.000	0.000	0.000
Mineral	Cnt	Mark	26.313	3.219	12610.448	1.084	21.684	0.000
Mineral	Cnt	Mark	25.940	2.910	10162.552	12.509	2.467	0.000
Mineral	Cnt	Mark	45.480	4.060	12652.530	0.402	0.000	0.000
Mineral	Cnt	Mark	36.793	5.595	14241.606	0.000	0.000	0.000
Fh	80 Kg	Mark	64.466	5.124	4428.842	6.183	0.000	0.000
Fh	80 Kg	Mark	64.772	5.344	5592.029	9.105	0.000	0.000
Fh	80 Kg	Mark	39.825	4.409	1533.859	3.645	0.000	0.000
Fh	80 Kg	Mark	60.560	6.036	3473.461	7.095	0.000	0.000
Fh	80 Kg	Mark	76.440	5.683	1914.350	8.400	0.000	0.000
Fh	80 Kg	Mark	54.120	4.203	4549.998	4.267	0.000	0.000
Litter	80 Kg	Mark	48.591	0.578	249.383	1.215	18.531	0.000
Litter	80 Kg	Mark	48.081	0.565	183.699	0.073	19.041	0.000
Litter	80 Kg	Mark	45.148	0.485	218.103	0.000	17.554	0.000

Baseline Soil Metals at the 3 study sites continued:

Soil	Treatment	Site	Zn mg/kg	Ni mg/kg	Fe mg/kg	Cu mg/kg	B mg/kg	As mg/kg
Litter	80 Kg	Mark	51.168	0.527	184.379	3.398	29.309	0.000
Litter	80 Kg	Mark	53.857	1.354	249.448	1.820	19.723	0.000
Litter	80 Kg	Mark	46.320	0.486	193.207	0.756	22.139	0.000
Mineral	80 Kg	Mark	22.991	2.870	14810.639	0.000	0.000	0.000
Mineral	80 Kg	Mark	27.507	4.318	10154.284	0.000	0.000	0.000
Mineral	80 Kg	Mark	23.840	3.536	9588.629	0.000	0.000	0.000
Mineral	80 Kg	Mark	21.385	3.831	8847.125	0.000	0.000	0.000
Mineral	80 Kg	Mark	25.941	3.711	10903.635	0.000	0.000	0.000
Mineral	80 Kg	Mark	22.116	3.028	11779.727	0.000	0.000	0.000
Fh	40 Kg	Mark	106.961	7.773	3030.191	6.613	0.000	0.000
Fh	40 Kg	Mark	37.685	4.888	2479.555	1.073	0.000	0.000
Fh	40 Kg	Mark	61.930	3.370	3289.629	4.618	0.036	0.000
Fh	40 Kg	Mark	54.668	4.751	2129.394	8.581	0.000	0.000
Fh	40 Kg	Mark	56.336	3.536	4319.232	4.927	0.000	0.000
Fh	40 Kg	Mark	38.608	4.544	4475.226	2.967	0.000	0.000
Litter	40 Kg	Mark	73.247	1.217	193.877	6.253	36.745	0.000
Litter	40 Kg	Mark	44.412	0.353	398.997	1.095	19.928	0.000
Litter	40 Kg	Mark	51.037	0.494	211.044	0.960	20.453	0.000
Litter	40 Kg	Mark	46.947	0.530	297.511	0.750	18.027	0.000
Litter	40 Kg	Mark	51.864	1.073	245.863	6.713	20.464	0.000
Litter	40 Kg	Mark	48.304	0.385	276.780	0.000	16.694	0.000
Mineral	40 Kg	Mark	29.867	3.993	11168.705	0.000	0.000	0.000
Mineral	40 Kg	Mark	29.262	5.521	12696.888	0.000	0.000	0.000
Mineral	40 Kg	Mark	24.817	3.372	10735.790	0.000	0.000	0.000
Mineral	40 Kg	Mark	22.263	3.340	8192.387	0.000	0.000	0.000
Mineral	40 Kg	Mark	30.154	4.369	12226.097	1.273	0.000	0.000
Mineral	40 Kg	Mark	20.258	2.740	11956.626	0.000	0.000	0.000
Litter	Cnt	Wilf	44.010	0.682	209.708	3.170	22.637	0.000
Litter	Cnt	Wilf	41.084	0.786	327.390	4.022	31.208	0.000
Litter	Cnt	Wilf	39.475	0.907	429.101	5.400	19.965	0.000
Litter	Cnt	Wilf	55.808	0.942	365.138	12.912	18.569	0.000
Litter	Cnt	Wilf	54.693	1.169	202.713	1.590	15.885	0.000
Litter	Cnt	Wilf	48.344	1.705	227.336	1.150	12.902	0.000
Mineral	Cnt	Wilf	26.532	2.759	15436.929	0.259	0.681	0.000
Mineral	Cnt	Wilf	15.671	3.458	8508.582	0.000	0.000	0.000
Mineral	Cnt	Wilf	22.409	3.693	12993.221	0.000	0.000	0.000
Mineral	Cnt	Wilf	28.915	3.880	10305.693	3.122	0.000	0.000
Mineral	Cnt	Wilf	26.098	4.092	14417.429	0.000	0.000	0.000
Mineral	Cnt	Wilf	28.439	5.233	10434.949	3.370	0.000	0.000

Baseline Soil Metals at the 3 study sites continued:

Soil	Treatment	Site	Zn mg/kg	Ni mg/kg	Fe mg/kg	Cu mg/kg	B mg/kg	As mg/kg
Fh	Cnt	Wilf	29.717	3.883	3966.073	4.081	0.000	0.000
Fh	Cnt	Wilf	25.693	3.935	8632.175	1.820	0.453	0.000
Fh	Cnt	Wilf	36.909	4.805	2455.405	3.315	0.000	0.000
Fh	Cnt	Wilf	46.552	5.251	4577.484	7.440	0.000	0.000
Fh	Cnt	Wilf	57.033	6.395	1941.275	5.983	0.563	0.000
Fh	Cnt	Wilf	41.553	10.571	2694.510	2.521	0.000	0.000
Fh	80 Kg	Wilf	39.767	5.482	5112.952	2.010	0.000	0.000
Fh	80 Kg	Wilf	43.506	3.897	1871.304	3.899	1.402	0.000
Fh	80 Kg	Wilf	36.628	4.752	2433.608	5.544	0.000	0.000
Fh	80 Kg	Wilf	41.057	4.390	2301.666	7.666	0.000	0.000
Fh	80 Kg	Wilf	45.786	6.235	3583.389	7.558	0.000	0.000
Fh	80 Kg	Wilf	42.557	4.252	2380.861	5.999	0.364	0.000
Litter	80 Kg	Wilf	54.314	1.353	315.101	2.795	12.608	0.000
Litter	80 Kg	Wilf	48.725	0.392	218.872	0.215	14.836	0.000
Litter	80 Kg	Wilf	50.694	0.564	340.316	1.923	23.388	0.000
Litter	80 Kg	Wilf	52.731	0.574	248.069	3.075	22.015	0.000
Litter	80 Kg	Wilf	47.285	1.359	580.405	6.180	25.214	0.000
Litter	80 Kg	Wilf	48.965	2.109	260.338	0.607	12.510	0.000
Mineral	80 Kg	Wilf	20.225	3.008	10183.522	0.000	0.000	0.000
Mineral	80 Kg	Wilf	18.613	3.006	12834.265	0.000	0.000	0.000
Mineral	80 Kg	Wilf	29.233	5.008	13560.859	0.282	0.000	0.000
Mineral	80 Kg	Wilf	34.192	5.901	16427.293	0.000	0.000	0.000
Mineral	80 Kg	Wilf	25.468	3.997	15295.010	3.822	0.000	0.000
Mineral	80 Kg	Wilf	29.231	7.960	11082.422	4.448	5.040	0.000
Fh	40 Kg	Wilf	23.489	2.804	1643.619	1.323	0.000	0.000
Fh	40 Kg	Wilf	69.800	6.325	844.241	9.292	1.515	0.000
Fh	40 Kg	Wilf	49.772	4.571	1958.283	5.307	0.000	0.000
Fh	40 Kg	Wilf	34.497	4.598	8712.138	0.528	0.000	0.000
Fh	40 Kg	Wilf	41.677	4.009	4040.040	3.487	0.000	0.000
Fh	40 Kg	Wilf	43.527	5.596	10860.672	3.136	0.000	0.000
Litter	40 Kg	Wilf	51.296	0.990	576.679	2.326	15.467	0.000
Litter	40 Kg	Wilf	40.263	0.718	142.461	1.457	19.133	0.000
Litter	40 Kg	Wilf	49.690	0.953	179.401	2.320	18.420	0.000
Litter	40 Kg	Wilf	42.542	1.118	802.387	3.751	12.483	0.000
Litter	40 Kg	Wilf	44.289	0.818	415.380	1.485	15.090	0.000
Litter	40 Kg	Wilf	44.592	0.757	399.742	3.538	15.834	0.000
Mineral	40 Kg	Wilf	5.424	2.118	3050.518	0.000	0.000	0.000
Mineral	40 Kg	Wilf	22.312	4.066	13306.329	0.000	0.000	0.000
Mineral	40 Kg	Wilf	16.088	2.733	11631.159	0.000	0.000	0.000

Baseline Soil Metals at the 3 study sites continued:

Soil	Treatment	Site	Zn mg/kg	Ni mg/kg	Fe mg/kg	Cu mg/kg	B mg/kg	As mg/kg
Mineral	40 Kg	Wilf	19.574	3.426	11290.577	7.233	16.659	0.000
Mineral	40 Kg	Wilf	31.854	3.519	12396.141	0.000	1.798	0.000
Mineral	40 Kg	Wilf	42.605	5.446	14281.886	3.368	0.103	0.000

Baseline Soil Metals at the 3 study sites continued:

Soil	Site	Treatment	Mn mg/kg	Cd mg/kg	Al mg/kg	Pb mg/kg
Fh	Brook	Cnt	828.950	0.110	7282.390	10.425
Fh	Brook	Cnt	1579.970	0.920	1432.430	20.958
Fh	Brook	Cnt	1595.910	0.470	3700.100	36.850
Fh	Brook	Cnt	1547.510	0.580	3529.930	23.460
Fh	Brook	Cnt	1409.250	0.710	5612.910	42.120
Fh	Brook	Cnt	886.010	0.520	1836.210	22.376
Litter	Brook	Cnt	2087.260	0.820	800.210	1.547
Litter	Brook	Cnt	2188.640	0.950	195.980	0.912
Litter	Brook	Cnt	3662.700	0.990	306.450	1.395
Litter	Brook	Cnt	1504.170	0.770	201.790	1.028
Litter	Brook	Cnt	1611.230	0.660	851.890	2.792
Litter	Brook	Cnt	1692.360	0.660	305.350	3.391
Mineral	Brook	Cnt	367.820	0.000	14587.220	3.356
Mineral	Brook	Cnt	174.440	0.090	3213.090	17.548
Mineral	Brook	Cnt	799.060	0.020	7269.970	7.877
Mineral	Brook	Cnt	505.580	0.240	4398.670	14.626
Mineral	Brook	Cnt	446.290	0.050	16367.970	2.508
Mineral	Brook	Cnt	141.880	0.060	5906.900	1.660
Fh	Mark	Cnt	2667.590	2.250	1445.120	45.641
Fh	Mark	Cnt	1180.340	0.580	2973.700	11.837
Fh	Mark	Cnt	2692.560	1.150	1253.740	26.796
Fh	Mark	Cnt	3425.620	1.560	4460.410	44.653
Fh	Mark	Cnt	1216.550	0.680	2868.780	24.003
Fh	Mark	Cnt	1531.730	0.900	1783.050	20.930
Litter	Mark	Cnt	1433.960	0.760	139.060	0.574
Litter	Mark	Cnt	2213.040	0.900	260.510	2.233
Litter	Mark	Cnt	2353.910	0.840	133.720	0.351
Litter	Mark	Cnt	2133.260	0.820	206.120	0.726
Litter	Mark	Cnt	1817.150	0.600	206.700	0.561
Litter	Mark	Cnt	1750.880	0.620	194.940	0.530
Mineral	Mark	Cnt	881.560	0.200	8001.400	15.892
Mineral	Mark	Cnt	321.090	0.060	10639.950	2.006
Mineral	Mark	Cnt	374.760	0.070	8125.930	7.275
Mineral	Mark	Cnt	828.830	0.180	8827.890	8.942
Mineral	Mark	Cnt	280.390	0.090	7014.670	11.233
Fh	Wilf	Cnt	1400.410	0.860	6665.660	12.334
Fh	Wilf	Cnt	339.000	0.640	7141.780	21.710
Fh	Wilf	Cnt	904.110	0.490	3922.050	22.284
Fh	Wilf	Cnt	392.980	0.490	1549.200	23.316

Baseline Soil Metals at the 3 study sites continued:

Soil	Site	Treatment	Mn mg/kg	Cd mg/kg	Al mg/kg	Pb mg/kg
Fh	Wilf	Cnt	1416.870	0.700	3083.620	18.285
Fh	Wilf	Cnt	702.440	0.400	1617.950	19.319
Litter	Wilf	Cnt	2026.330	0.830	351.870	0.846
Litter	Wilf	Cnt	1342.840	0.460	1281.840	1.337
Litter	Wilf	Cnt	3123.410	0.930	281.110	2.523
Litter	Wilf	Cnt	1027.950	0.660	241.610	1.430
Litter	Wilf	Cnt	1900.050	0.690	169.470	0.563
Litter	Wilf	Cnt	2008.330	0.630	322.810	1.189
Mineral	Wilf	Cnt	1850.880	0.420	7381.890	23.667
Mineral	Wilf	Cnt	433.750	0.340	14302.100	10.867
Mineral	Wilf	Cnt	941.100	0.000	10274.400	3.564
Mineral	Wilf	Cnt	95.530	0.010	10736.010	5.298
Mineral	Wilf	Cnt	1261.790	0.050	7622.280	11.893
Mineral	Wilf	Cnt	57.040	0.080	6820.240	10.418
Fh	Brook	8	2639.020	0.860	4488.380	43.577
Fh	Brook	8	1633.410	0.630	1540.140	31.339
Fh	Brook	8	1361.890	0.890	1104.930	22.140
Fh	Brook	8	956.410	0.410	6016.990	15.775
Fh	Brook	8	1137.010	0.980	3836.320	36.633
Litter	Brook	8	2590.280	0.640	360.600	2.397
Litter	Brook	8	2607.660	0.740	222.970	1.542
Litter	Brook	8	2297.540	0.840	246.010	1.574
Litter	Brook	8	2189.850	0.880	213.460	1.313
Litter	Brook	8	1682.930	0.900	375.020	4.930
Mineral	Brook	8	1062.640	0.500	6224.860	11.374
Mineral	Brook	8	221.240	0.060	3413.890	13.015
Mineral	Brook	8	52.020	0.070	3428.630	21.172
Mineral	Brook	8	353.630	0.160	6917.200	6.586
Mineral	Brook	8	271.000	0.030	7995.990	6.456
Fh	Mark	8	1426.840	0.940	1931.040	35.478
Fh	Mark	8	2677.430	2.300	2489.060	23.150
Fh	Mark	8	2353.980	1.270	1123.150	36.898
Fh	Mark	8	1966.980	0.520	1887.220	20.359
Fh	Mark	8	1137.730	0.430	1446.630	27.917
Fh	Mark	8	2889.310	1.180	2179.780	14.799
Litter	Mark	8	1604.470	0.710	160.830	0.685
Litter	Mark	8	2319.420	0.790	209.820	1.578
Litter	Mark	8	1918.160	0.610	139.930	0.005
Litter	Mark	8	2202.460	0.870	211.950	0.527

Baseline Soil Metals at the 3 study sites continued:

Soil	Site	Treatment	Mn mg/kg	Cd mg/kg	Al mg/kg	Pb mg/kg
Litter	Mark	8	2006.510	0.750	134.370	0.727
Litter	Mark	8	2004.710	0.750	169.630	0.300
Mineral	Mark	8	135.440	0.040	6590.740	2.826
Mineral	Mark	8	398.400	0.120	6890.520	4.309
Mineral	Mark	8	99.270	0.150	4429.540	30.806
Mineral	Mark	8	291.970	0.000	7067.390	9.765
Mineral	Mark	8	480.240	0.100	8174.520	2.912
Mineral	Mark	8	785.510	0.120	6417.590	12.443
Fh	Wilf	8	668.810	0.530	5851.480	29.263
Fh	Wilf	8	1986.650	0.980	6953.280	13.042
Fh	Wilf	8	440.230	0.760	1143.520	18.468
Fh	Wilf	8	628.920	0.680	1427.930	25.631
Fh	Wilf	8	869.070	0.610	1345.820	21.797
Litter	Wilf	8	1794.460	0.690	488.750	1.209
Litter	Wilf	8	1863.290	0.770	3535.780	2.386
Litter	Wilf	8	1064.270	0.730	184.220	0.830
Litter	Wilf	8	1533.090	0.800	247.970	1.138
Litter	Wilf	8	1772.490	0.880	225.090	1.100
Litter	Wilf	8	4162.290	0.870	719.850	4.704
Mineral	Wilf	8	214.160	0.170	9139.820	15.856
Mineral	Wilf	8	925.940	0.770	10098.010	29.558
Mineral	Wilf	8	55.610	0.040	8904.040	4.880
Mineral	Wilf	8	145.500	0.080	11801.610	11.912
Mineral	Wilf	8	388.980	0.120	10864.130	12.992
Mineral	Wilf	8	1302.380	0.080	6988.720	27.728
Fh	Brook	4	678.220	0.510	2485.820	43.449
Fh	Brook	4	1913.020	0.900	1031.640	19.286
Fh	Brook	4	567.020	0.260	1910.070	26.265
Fh	Brook	4	1154.790	0.440	1032.950	14.331
Fh	Brook	4	3657.590	1.060	1091.650	25.493
Fh	Brook	4	2695.520	1.490	4610.640	46.842
Litter	Brook	4	2186.660	0.730	246.780	1.762
Litter	Brook	4	2492.530	0.790	208.110	0.903
Litter	Brook	4	2010.700	0.620	252.930	1.677
Litter	Brook	4	1713.220	0.580	195.280	1.098
Litter	Brook	4	3563.370	0.860	172.890	0.949
Litter	Brook	4	2585.350	1.800	225.430	1.513
Mineral	Brook	4	217.100	0.120	4326.270	16.903
Mineral	Brook	4	386.240	0.100	2531.970	20.729

Baseline Soil Metals at the 3 study sites continued:

Soil	Site	Treatment	Mn mg/kg	Cd mg/kg	Al mg/kg	Pb mg/kg
Mineral	Brook	4	115.660	0.040	4351.780	8.261
Mineral	Brook	4	50.050	0.110	1739.470	23.078
Mineral	Brook	4	1664.180	0.120	4739.750	23.826
Mineral	Brook	4	383.000	0.220	3224.760	29.393
Fh	Mark	4	1094.250	1.030	2656.890	25.927
Fh	Mark	4	1569.410	0.960	1478.910	23.382
Fh	Mark	4	1136.210	0.580	5750.790	11.477
Fh	Mark	4	2350.240	1.160	3287.340	19.679
Fh	Mark	4	1590.120	0.960	3245.650	19.918
Fh	Mark	4	2625.750	1.230	1020.830	21.525
Litter	Mark	4	1505.340	0.790	210.170	1.382
Litter	Mark	4	1683.080	0.720	232.780	2.328
Litter	Mark	4	2261.880	0.880	179.170	1.262
Litter	Mark	4	1871.150	0.640	185.890	0.186
Litter	Mark	4	1731.770	0.730	249.100	1.821
Litter	Mark	4	1921.970	0.750	174.660	0.497
Mineral	Mark	4	232.070	0.060	10731.480	1.328
Mineral	Mark	4	134.990	0.120	5746.440	5.856
Mineral	Mark	4	197.160	0.150	7464.020	8.876
Mineral	Mark	4	345.290	0.040	6823.770	8.193
Mineral	Mark	4	507.390	0.050	10355.150	5.779
Mineral	Mark	4	422.120	0.120	6348.590	9.648
Fh	Wilf	4	679.080	0.760	945.890	10.773
Fh	Wilf	4	848.690	0.570	2208.140	14.431
Fh	Wilf	4	828.140	0.330	5246.570	25.580
Fh	Wilf	4	1265.000	0.640	2113.970	15.916
Fh	Wilf	4	1498.420	0.260	6623.980	25.189
Fh	Wilf	4	2352.500	0.920	318.700	18.404
Litter	Wilf	4	1435.390	0.530	113.060	0.548
Litter	Wilf	4	1485.160	0.550	213.820	0.623
Litter	Wilf	4	2446.420	0.700	493.670	2.619
Litter	Wilf	4	2208.080	0.750	303.330	1.058
Litter	Wilf	4	3009.510	0.810	324.510	2.523
Litter	Wilf	4	2352.500	0.920	318.700	3.246
Mineral	Wilf	4	473.800	0.230	6771.420	6.491
Mineral	Wilf	4	186.790	0.070	7635.940	9.997
Mineral	Wilf	4	468.320	0.070	7749.080	4.167
Mineral	Wilf	4	502.290	0.250	9660.410	7.944
Mineral	Wilf	4	671.130	0.150	11024.010	4.953
Mineral	Wilf	4	10.400	0.100	1312.940	13.977

G.) Soil Post Ash Application Raw Data (3 Study Sites):

Post Application Soil Carbon, Nitrogen and OM:

Treatment	Site	Soil	OM %	N %	C %
Cnt.	Brook	Mineral	8.492244	0.314	3.835
Cnt.	Brook	Mineral	7.190288	0.32	4.054
Cnt.	Brook	Mineral	9.310457	0.449	5.236
Cnt.	Brook	Mineral	8.491594	0.347	3.642
Cnt.	Brook	Mineral	11.41482	0.428	5.227
Cnt.	Brook	Mineral	5.373627	0.225	2.647
Cnt.	Wilf	Mineral	14.82114	0.483	6.171
Cnt.	Wilf	Mineral	24.17003	0.775	11.204
Cnt.	Wilf	Mineral	11.02122	0.685	11.453
Cnt.	Wilf	Mineral	12.57878	0.49	9.355
Cnt.	Wilf	Mineral	13.71873	0.481	6.952
Cnt.	Wilf	Mineral	14.71803	0.461	7.535
Cnt.	Mark	Mineral	10.54836	0.404	5.455
Cnt.	Mark	Mineral	10.65369	0.632	8.361
Cnt.	Mark	Mineral	7.462565	0.321	3.612
Cnt.	Mark	Mineral	9.40378	0.496	6.53
Cnt.	Mark	Mineral	10.71155	0.439	6.908
Cnt.	Mark	Mineral	8.540398	0.33	4.462
Cnt.	Brook	FH	43.02593	1.004	13.767
Cnt.	Brook	FH	62.52686	1.956	38.215
Cnt.	Brook	FH	39.45104	1.66	27.992
Cnt.	Brook	FH	30.3978	1.673	29.866
Cnt.	Brook	FH	50.3226	1.808	27.76
Cnt.	Brook	FH	32.44361	1.767	37.373
Cnt.	Wilf	FH	50.80285	2.125	38.067
Cnt.	Wilf	FH	69.9697	2.3	43.477
Cnt.	Wilf	FH	67.69992	2.327	42.969
Cnt.	Wilf	FH	64.66699	1.88	36.58
Cnt.	Wilf	FH	48.62832	2.017	35.389
Cnt.	Wilf	FH	56.36585	2.194	43.264
Cnt.	Mark	FH	75.16757	2.273	41.418
Cnt.	Mark	FH	71.33476	2.286	41.439
Cnt.	Mark	FH	55.79308	2.081	40.646
Cnt.	Mark	FH	62.71101	2.047	36.871
Cnt.	Mark	FH	47.17021	2.04	39.079
Cnt.	Mark	FH	41.8679	1.957	35.731
Cnt.	Brook	Litter	91.02047	1.877	45.546
Cnt.	Brook	Litter	87.89351	2.084	46.056
Cnt.	Brook	Litter	90.59419	1.966	46.714
Cnt.	Brook	Litter	87.43065	2.178	45.895
Cnt.	Brook	Litter	87.44227	1.967	45.49
Cnt.	Brook	Litter	83.33333	1.658	45.917
Cnt.	Wilf	Litter	92.00797	2.112	47.035

Post Application Soil Carbon, Nitrogen and OM Continued:

Treatment	Site	Soil	OM %	N %	C %
Cnt.	Wilf	Litter	91.8026	1.95	46.93
Cnt.	Wilf	Litter	91.35485	2.155	47.332
Cnt.	Wilf	Litter	92.5463	1.841	47.67
Cnt.	Wilf	Litter	92.2002	1.695	47.415
Cnt.	Wilf	Litter	92.10566	2.219	47.98
Cnt.	Mark	Litter	90.4475	2.104	46.944
Cnt.	Mark	Litter	90.17087	1.937	46.623
Cnt.	Mark	Litter	89.52713	2.269	45.776
Cnt.	Mark	Litter	88.86875	1.992	45.875
Cnt.	Mark	Litter	84.29739	1.909	45.01
Cnt.	Mark	Litter	87.61753	2.186	45.716
4 Mg/ha	Brook	Mineral	9.019552	0.336	3.925
4 Mg/ha	Brook	Mineral	11.72377	0.443	7.051
4 Mg/ha	Brook	Mineral	8.73345	0.356	5.516
4 Mg/ha	Brook	Mineral	8.2172	0.396	5.727
4 Mg/ha	Brook	Mineral	9.919819	0.509	6.708
4 Mg/ha	Brook	Mineral	9.148245	0.403	5.11
4 Mg/ha	Wilf	Mineral	7.718976	0.328	4.62
4 Mg/ha	Wilf	Mineral	9.221337	0.355	4.952
4 Mg/ha	Wilf	Mineral	7.953525	0.494	7.949
4 Mg/ha	Wilf	Mineral	15.48259	0.715	11.596
4 Mg/ha	Wilf	Mineral	10.76656	0.439	5.451
4 Mg/ha	Wilf	Mineral	11.07354	0.406	6.539
4 Mg/ha	Mark	Mineral	11.70838	0.539	8.266
4 Mg/ha	Mark	Mineral	11.30817	0.887	13.923
4 Mg/ha	Mark	Mineral	9.701702	0.638	10.257
4 Mg/ha	Mark	Mineral	9.089058	0.362	5.132
4 Mg/ha	Mark	Mineral	9.159337	0.469	6.384
4 Mg/ha	Mark	Mineral	8.204866	0.39	5.356
4 Mg/ha	Brook	FH	37.68101	1.749	34.322
4 Mg/ha	Brook	FH	44.37202	1.853	34.635
4 Mg/ha	Brook	FH	60.40976	2.066	40.467
4 Mg/ha	Brook	FH	48.30114	1.772	31.766
4 Mg/ha	Brook	FH	34.77814	1.427	23.046
4 Mg/ha	Brook	FH	63.51672	2.081	35.67
4 Mg/ha	Wilf	FH	65.49104	1.947	38.166
4 Mg/ha	Wilf	FH	59.42419	1.893	32.72
4 Mg/ha	Wilf	FH	58.31196	1.942	36.937
4 Mg/ha	Wilf	FH	59.94601	1.955	37.759
4 Mg/ha	Wilf	FH	47.64527	2.11	40.568
4 Mg/ha	Wilf	FH	68.55723	2.009	43.323
4 Mg/ha	Mark	FH	62.07274	1.853	35.913
4 Mg/ha	Mark	FH	50.05317	2.046	41.187
4 Mg/ha	Mark	FH	75.93381	2.025	40.654
4 Mg/ha	Mark	FH	38.2687	1.771	35.62

Post Application Soil Carbon, Nitrogen and OM Continued:

Treatment	Site	Soil	OM %	N %	C %
4 Mg/ha	Mark	FH	37.40977	1.269	19.68
4 Mg/ha	Mark	FH	49.95459	2.098	38.89
4 Mg/ha	Brook	Litter	61.48567	1.555	36.617
4 Mg/ha	Brook	Litter	64.13888	1.809	39.006
4 Mg/ha	Brook	Litter	66.37485	1.776	40.13
4 Mg/ha	Brook	Litter	50.41339	1.584	37.408
4 Mg/ha	Brook	Litter	63.26801	1.834	42.083
4 Mg/ha	Brook	Litter	78.25109	1.819	41.688
4 Mg/ha	Wilf	Litter	58.29217	1.332	36.38
4 Mg/ha	Wilf	Litter	73.27573	1.76	40.991
4 Mg/ha	Wilf	Litter	63.96904	1.688	40.229
4 Mg/ha	Wilf	Litter	73.35031	1.715	44.046
4 Mg/ha	Wilf	Litter	61.34432	1.532	36.66
4 Mg/ha	Wilf	Litter	71.05142	1.722	42.909
4 Mg/ha	Mark	Litter	73.15409	1.674	42.485
4 Mg/ha	Mark	Litter	55.90021	1.574	40.064
4 Mg/ha	Mark	Litter	72.39925	1.788	44.279
4 Mg/ha	Mark	Litter	44.71419	1.142	29.286
4 Mg/ha	Mark	Litter	66.75174	1.658	37.828
4 Mg/ha	Mark	Litter	63.15684	1.7	40.58
8 Mg/ha	Brook	Mineral	11.07186	0.422	5.13
8 Mg/ha	Brook	Mineral	6.226895	0.258	3.169
8 Mg/ha	Brook	Mineral	8.071677	0.403	6.352
8 Mg/ha	Brook	Mineral	8.768612	0.282	3.606
8 Mg/ha	Brook	Mineral	8.836117	0.423	6.884
8 Mg/ha	Wilf	Mineral	9.993264	0.446	7.425
8 Mg/ha	Wilf	Mineral	12.55612	0.552	7.543
8 Mg/ha	Wilf	Mineral	12.29331	0.59	11.501
8 Mg/ha	Wilf	Mineral	12.85471	0.923	20.135
8 Mg/ha	Wilf	Mineral	12.37863	0.344	5.155
8 Mg/ha	Wilf	Mineral	10.87702	0.403	5.225
8 Mg/ha	Mark	Mineral	9.159147	0.376	4.478
8 Mg/ha	Mark	Mineral	12.26329	0.646	10.591
8 Mg/ha	Mark	Mineral	9.569836	0.571	7.984
8 Mg/ha	Mark	Mineral	7.815602	0.348	4.162
8 Mg/ha	Mark	Mineral	8.44253	0.712	10.721
8 Mg/ha	Mark	Mineral	9.156295	0.477	7.429
8 Mg/ha	Brook	FH	61.27848	2.022	37.049
8 Mg/ha	Brook	FH	34.37446	1.856	33.165
8 Mg/ha	Brook	FH	55.71026	1.962	38.248
8 Mg/ha	Brook	FH	56.94215	1.889	36.004
8 Mg/ha	Brook	FH	42.37493	1.745	31.065
8 Mg/ha	Wilf	FH	48.39896	1.834	34.623
8 Mg/ha	Wilf	FH	57.95761	2.213	38.77
8 Mg/ha	Wilf	FH	78.53558	2.161	45.095

Post Application Soil Carbon, Nitrogen and OM Continued:

Treatment	Site	Soil	OM %	N %	C %
8 Mg/ha	Wilf	FH	69.77845	2.039	40.634
8 Mg/ha	Wilf	FH	55.63905	1.693	33.856
8 Mg/ha	Wilf	FH	48.11538	1.736	35.335
8 Mg/ha	Mark	FH	39.9814	1.561	26.865
8 Mg/ha	Mark	FH	53.70978	1.71	31.026
8 Mg/ha	Mark	FH	60.5039	1.771	33.475
8 Mg/ha	Mark	FH	37.17488	1.809	29.9
8 Mg/ha	Mark	FH	52.67122	2.169	38.707
8 Mg/ha	Mark	FH	61.80096	1.848	37.967
8 Mg/ha	Brook	Litter	56.17788	1.426	35.026
8 Mg/ha	Brook	Litter	42.43428	1.285	27.684
8 Mg/ha	Brook	Litter	38.87471	1.449	34.879
8 Mg/ha	Brook	Litter	44.47922	1.499	38.507
8 Mg/ha	Brook	Litter	57.196	1.377	37.881
8 Mg/ha	Wilf	Litter	44.33763	1.186	31.462
8 Mg/ha	Wilf	Litter	42.12606	1.071	29.81
8 Mg/ha	Wilf	Litter	39.29759	1.155	34.366
8 Mg/ha	Wilf	Litter	60.01833	1.477	38.403
8 Mg/ha	Wilf	Litter	40.5277	1.122	32.986
8 Mg/ha	Wilf	Litter	53.40764	1.418	36.227
8 Mg/ha	Mark	Litter	55.56176	1.665	40.455
8 Mg/ha	Mark	Litter	45.98401	1.207	31.44
8 Mg/ha	Mark	Litter	59.77323	1.572	38.488
8 Mg/ha	Mark	Litter	67.88012	1.542	35.329
8 Mg/ha	Mark	Litter	59.38994	1.458	34.455
8 Mg/ha	Mark	Litter	38.8638	0.835	24.118

Post Application Soil pH:

Soil	Site	Treatment	pH	Soil	Site	Treatment	pH	Soil	Site	Treatment	pH
Litter	Brook	8	7	Fh	Brook	8	5.5	Mineral	Brook	8	4.18
Litter	Brook	8	7.09	Fh	Brook	8	6.6	Mineral	Brook	8	4.57
Litter	Brook	8	7.43	Fh	Brook	8	5.89	Mineral	Brook	8	4.16
Litter	Brook	8	7.3	Fh	Brook	8	5.83	Mineral	Brook	8	3.97
Litter	Brook	8	7	Fh	Brook	8	5.62	Mineral	Brook	8	4.26
Litter	Brook	4	6.62	Fh	Brook	4	5.6	Mineral	Brook	4	4
Litter	Brook	4	6.64	Fh	Brook	4	5.65	Mineral	Brook	4	4.31
Litter	Brook	4	6.68	Fh	Brook	4	4.25	Mineral	Brook	4	3.7
Litter	Brook	4	6.93	Fh	Brook	4	5.44	Mineral	Brook	4	3.78
Litter	Brook	4	6.79	Fh	Brook	4	5.06	Mineral	Brook	4	4.44
Litter	Brook	4	6.2	Fh	Brook	4	5.28	Mineral	Brook	4	4.31
Litter	Brook	Cnt	4.57	Fh	Brook	Cnt	3.53	Mineral	Brook	Cnt	4
Litter	Brook	Cnt	4.52	Fh	Brook	Cnt	3.92	Mineral	Brook	Cnt	4.16
Litter	Brook	Cnt	4.82	Fh	Brook	Cnt	3.82	Mineral	Brook	Cnt	4.13
Litter	Brook	Cnt	5.04	Fh	Brook	Cnt	4.42	Mineral	Brook	Cnt	4.35
Litter	Brook	Cnt	5.19	Fh	Brook	Cnt	4.37	Mineral	Brook	Cnt	4.27
Litter	Brook	Cnt	4.37	Fh	Brook	Cnt	3.7	Mineral	Brook	Cnt	3.9
Litter	Wilf	8	7.2	Fh	Wilf	8	5.66	Mineral	Wilf	8	4.05
Litter	Wilf	8	7.58	Fh	Wilf	8	6.15	Mineral	Wilf	8	4.73
Litter	Wilf	8	7.25	Fh	Wilf	8	5.65	Mineral	Wilf	8	3.68
Litter	Wilf	8	7.22	Fh	Wilf	8	6.01	Mineral	Wilf	8	4.17
Litter	Wilf	8	7.25	Fh	Wilf	8	5.78	Mineral	Wilf	8	3.43
Litter	Wilf	8	7.36	Fh	Wilf	8	6.62	Mineral	Wilf	8	4.5
Litter	Wilf	4	6.79	Fh	Wilf	4	5.13	Mineral	Wilf	4	4.01
Litter	Wilf	4	6.53	Fh	Wilf	4	5.3	Mineral	Wilf	4	4.28
Litter	Wilf	4	7.1	Fh	Wilf	4	5.61	Mineral	Wilf	4	4.44
Litter	Wilf	4	6.9	Fh	Wilf	4	5.42	Mineral	Wilf	4	3.99
Litter	Wilf	4	6.79	Fh	Wilf	4	5.74	Mineral	Wilf	4	3.98
Litter	Wilf	4	6.68	Fh	Wilf	4	4.85	Mineral	Wilf	4	3.39
Litter	Wilf	Cnt	4.98	Fh	Wilf	Cnt	3.74	Mineral	Wilf	Cnt	4.31
Litter	Wilf	Cnt	4.39	Fh	Wilf	Cnt	3.52	Mineral	Wilf	Cnt	4.14
Litter	Wilf	Cnt	4.91	Fh	Wilf	Cnt	3.92	Mineral	Wilf	Cnt	3.56
Litter	Wilf	Cnt	4.65	Fh	Wilf	Cnt	3.66	Mineral	Wilf	Cnt	3.3
Litter	Wilf	Cnt	4.52	Fh	Wilf	Cnt	3.95	Mineral	Wilf	Cnt	3.97
Litter	Wilf	Cnt	5.08	Fh	Wilf	Cnt	3.95	Mineral	Wilf	Cnt	3.98
Litter	Mark	8	7.08	Fh	Mark	4	5.16	Mineral	Mark	8	4.39
Litter	Mark	8	7.11	Fh	Mark	4	5.81	Mineral	Mark	8	4.44
Litter	Mark	8	6.87	Fh	Mark	4	5.42	Mineral	Mark	8	4.04
Litter	Mark	8	6.48	Fh	Mark	4	6.67	Mineral	Mark	8	4.2
Litter	Mark	8	6.84	Fh	Mark	4	5.89	Mineral	Mark	8	4.13

Post Application Soil pH Continued:

Soil	Site	Treatment	pH	Soil	Site	Treatment	pH	Soil	Site	Treatment	pH
Litter	Mark	8	7.2	Fh	Mark	4	6.11	Mineral	Mark	8	3.98
Litter	Mark	4	6.36	Fh	Mark	8	6.19	Mineral	Mark	4	4.09
Litter	Mark	4	7.05	Fh	Mark	8	6.33	Mineral	Mark	4	3.54
Litter	Mark	4	6.57	Fh	Mark	8	6.08	Mineral	Mark	4	3.95
Litter	Mark	4	6.52	Fh	Mark	8	6.05	Mineral	Mark	4	4.24
Litter	Mark	4	6.65	Fh	Mark	8	6.33	Mineral	Mark	4	3.79
Litter	Mark	4	6.74	Fh	Mark	8	6.47	Mineral	Mark	4	4.23
Litter	Mark	Cnt	4.66	Fh	Mark	Cnt	4.8	Mineral	Mark	Cnt	3.68
Litter	Mark	Cnt	5.01	Fh	Mark	Cnt	4.6	Mineral	Mark	Cnt	3.98
Litter	Mark	Cnt	4.66	Fh	Mark	Cnt	4.09	Mineral	Mark	Cnt	3.6
Litter	Mark	Cnt	4.81	Fh	Mark	Cnt	4.79	Mineral	Mark	Cnt	4.06
Litter	Mark	Cnt	4.4	Fh	Mark	Cnt	4.32	Mineral	Mark	Cnt	3.38
Litter	Mark	Cnt	4.5	Fh	Mark	Cnt	4.1	Mineral	Mark	Cnt	3.56

Post Application Soil Nutrients:

Site	Soil	Treatment	K mg/g	Site	Soil	Treatment	Mg mg/g	Site	Soil	Treatment	Ca mg/g
Brook	Fh	Cnt	0.906	Brook	Litter	Cnt	0.687	Brook	Litter	Cnt	8.390
Brook	Fh	Cnt	0.460	Brook	Litter	Cnt	1.182	Brook	Litter	Cnt	8.984
Brook	Fh	Cnt	0.393	Brook	Litter	Cnt	0.852	Brook	Litter	Cnt	8.490
Brook	Fh	Cnt	0.674	Brook	Litter	Cnt	1.154	Brook	Litter	Cnt	9.960
Brook	Fh	Cnt	0.355	Brook	Litter	Cnt	1.311	Brook	Litter	Cnt	8.615
Brook	Fh	Cnt	0.533	Brook	Litter	Cnt	0.754	Brook	Litter	Cnt	7.860
Brook	Litter	Cnt	1.258	Wilf	Litter	Cnt	0.631	Brook	Litter	40 Kg	22.936
Brook	Litter	Cnt	1.640	Wilf	Litter	Cnt	0.597	Brook	Litter	40 Kg	18.725
Brook	Litter	Cnt	1.484	Wilf	Litter	Cnt	0.722	Brook	Litter	40 Kg	20.020
Brook	Litter	Cnt	1.315	Wilf	Litter	Cnt	0.884	Brook	Litter	40 Kg	15.491
Brook	Litter	Cnt	1.428	Wilf	Litter	Cnt	0.794	Brook	Litter	40 Kg	16.936
Brook	Litter	Cnt	1.548	Wilf	Litter	Cnt	0.875	Brook	Litter	40 Kg	16.168
Brook	Mineral	Cnt	0.039	Mark	Litter	Cnt	1.085	Brook	Litter	80 Kg	14.400
Brook	Mineral	Cnt	0.064	Mark	Litter	Cnt	1.024	Brook	Litter	80 Kg	17.641
Brook	Mineral	Cnt	0.038	Mark	Litter	Cnt	0.987	Brook	Litter	80 Kg	14.200
Brook	Mineral	Cnt	0.066	Mark	Litter	Cnt	0.769	Brook	Litter	80 Kg	16.767
Brook	Mineral	Cnt	0.036	Mark	Litter	Cnt	0.881	Brook	Litter	80 Kg	16.987
Brook	Mineral	Cnt	0.073	Mark	Litter	Cnt	0.986	Wilf	Litter	Cnt	5.939
Mark	Fh	Cnt	0.492	Brook	Fh	Cnt	0.301	Wilf	Litter	Cnt	4.768
Mark	Fh	Cnt	0.863	Brook	Fh	Cnt	0.620	Wilf	Litter	Cnt	6.373
Mark	Fh	Cnt	0.538	Brook	Fh	Cnt	0.280	Wilf	Litter	Cnt	6.954
Mark	Fh	Cnt	0.571	Brook	Fh	Cnt	0.399	Wilf	Litter	Cnt	6.087
Mark	Fh	Cnt	1.013	Brook	Fh	Cnt	0.953	Wilf	Litter	Cnt	8.550
Mark	Fh	Cnt	0.984	Brook	Fh	Cnt	0.218	Wilf	Litter	40 Kg	14.910
Mark	Litter	Cnt	1.943	Wilf	Fh	Cnt	0.207	Wilf	Litter	40 Kg	15.363
Mark	Litter	Cnt	1.300	Wilf	Fh	Cnt	0.373	Wilf	Litter	40 Kg	14.111
Mark	Litter	Cnt	1.337	Wilf	Fh	Cnt	0.484	Wilf	Litter	40 Kg	13.558
Mark	Litter	Cnt	1.253	Wilf	Fh	Cnt	0.476	Wilf	Litter	40 Kg	14.666
Mark	Litter	Cnt	1.810	Wilf	Fh	Cnt	0.299	Wilf	Litter	40 Kg	15.045
Mark	Litter	Cnt	1.605	Wilf	Fh	Cnt	0.309	Wilf	Litter	80 Kg	12.750
Mark	Mineral	Cnt	0.074	Mark	Fh	Cnt	0.664	Wilf	Litter	80 Kg	13.229
Mark	Mineral	Cnt	0.067	Mark	Fh	Cnt	0.746	Wilf	Litter	80 Kg	17.210
Mark	Mineral	Cnt	0.069	Mark	Fh	Cnt	0.310	Wilf	Litter	80 Kg	18.529
Mark	Mineral	Cnt	0.059	Mark	Fh	Cnt	0.552	Wilf	Litter	80 Kg	15.563
Mark	Mineral	Cnt	0.106	Mark	Fh	Cnt	0.336	Wilf	Litter	80 Kg	14.305
Mark	Mineral	Cnt	0.078	Mark	Fh	Cnt	0.469	Mark	Litter	Cnt	12.427
Wilf	Fh	Cnt	0.862	Brook	Mineral	Cnt	0.021	Mark	Litter	Cnt	13.283
Wilf	Fh	Cnt	0.571	Brook	Mineral	Cnt	0.023	Mark	Litter	Cnt	12.092

Post Application Soil Nutrients Continued:

Site	Soil	Treatment	K mg/g	Site	Soil	Treatment	Mg mg/g	Site	Soil	Treatment	Ca mg/g
Wilf	Fh	Cnt	0.477	Brook	Mineral	Cnt	0.032	Mark	Litter	Cnt	11.485
Wilf	Fh	Cnt	0.524	Brook	Mineral	Cnt	0.047	Mark	Litter	Cnt	9.839
Wilf	Fh	Cnt	0.413	Brook	Mineral	Cnt	0.016	Mark	Litter	Cnt	10.426
Wilf	Fh	Cnt	0.543	Brook	Mineral	Cnt	0.019	Mark	Litter	40 Kg	17.028
Wilf	Litter	Cnt	1.171	Wilf	Mineral	Cnt	0.055	Mark	Litter	40 Kg	21.316
Wilf	Litter	Cnt	1.370	Wilf	Mineral	Cnt	0.048	Mark	Litter	40 Kg	19.002
Wilf	Litter	Cnt	1.257	Wilf	Mineral	Cnt	0.039	Mark	Litter	40 Kg	18.341
Wilf	Litter	Cnt	1.469	Wilf	Mineral	Cnt	0.059	Mark	Litter	40 Kg	22.134
Wilf	Litter	Cnt	1.133	Wilf	Mineral	Cnt	0.038	Mark	Litter	40 Kg	18.447
Wilf	Litter	Cnt	1.076	Wilf	Mineral	Cnt	0.061	Mark	Litter	80 Kg	19.507
Wilf	Mineral	Cnt	0.094	Mark	Mineral	Cnt	0.027	Mark	Litter	80 Kg	17.097
Wilf	Mineral	Cnt	0.072	Mark	Mineral	Cnt	0.043	Mark	Litter	80 Kg	16.156
Wilf	Mineral	Cnt	0.105	Mark	Mineral	Cnt	0.040	Mark	Litter	80 Kg	22.589
Wilf	Mineral	Cnt	0.147	Mark	Mineral	Cnt	0.035	Mark	Litter	80 Kg	18.101
Wilf	Mineral	Cnt	0.110	Mark	Mineral	Cnt	0.040	Mark	Litter	80 Kg	24.509
Wilf	Mineral	Cnt	0.125	Mark	Mineral	Cnt	0.037	Brook	Fh	Cnt	2.965
Brook	Fh	80 Kg	1.088	Brook	Litter	80 Kg	1.866	Brook	Fh	Cnt	3.782
Brook	Fh	80 Kg	0.615	Brook	Litter	80 Kg	2.863	Brook	Fh	Cnt	6.369
Brook	Fh	80 Kg	0.941	Brook	Litter	80 Kg	1.977	Brook	Fh	Cnt	3.733
Brook	Fh	80 Kg	1.197	Brook	Litter	80 Kg	3.249	Brook	Fh	Cnt	3.948
Brook	Fh	80 Kg	0.725	Brook	Litter	80 Kg	2.066	Brook	Fh	Cnt	7.499
Brook	Litter	80 Kg	1.158	Wilf	Litter	80 Kg	1.481	Brook	Fh	40 Kg	8.921
Mark	Fh	80 Kg	0.777	Wilf	Litter	80 Kg	1.462	Brook	Fh	40 Kg	8.944
Mark	Fh	80 Kg	0.815	Wilf	Litter	80 Kg	2.072	Brook	Fh	40 Kg	6.429
Mark	Fh	80 Kg	1.161	Wilf	Litter	80 Kg	2.094	Brook	Fh	40 Kg	9.463
Mark	Fh	80 Kg	1.101	Wilf	Litter	80 Kg	1.780	Brook	Fh	40 Kg	7.294
Mark	Fh	80 Kg	0.941	Wilf	Litter	80 Kg	2.273	Brook	Fh	40 Kg	10.254
Mark	Fh	80 Kg	0.930	Mark	Litter	80 Kg	2.630	Brook	Fh	80 Kg	11.171
Wilf	Fh	80 Kg	1.273	Mark	Litter	80 Kg	2.440	Brook	Fh	80 Kg	6.564
Wilf	Fh	80 Kg	0.551	Mark	Litter	80 Kg	1.794	Brook	Fh	80 Kg	11.529
Wilf	Fh	80 Kg	1.548	Mark	Litter	80 Kg	2.175	Brook	Fh	80 Kg	12.192
Wilf	Fh	80 Kg	1.523	Mark	Litter	80 Kg	2.505	Brook	Fh	80 Kg	9.075
Wilf	Fh	80 Kg	1.017	Mark	Litter	80 Kg	2.910	Wilf	Fh	Cnt	2.955
Wilf	Fh	80 Kg	1.484	Brook	Fh	80 Kg	0.940	Wilf	Fh	Cnt	3.554
Brook	Litter	80 Kg	1.516	Brook	Fh	80 Kg	0.448	Wilf	Fh	Cnt	4.952
Brook	Litter	80 Kg	1.467	Brook	Fh	80 Kg	1.436	Wilf	Fh	Cnt	4.750
Brook	Litter	80 Kg	1.575	Brook	Fh	80 Kg	1.915	Wilf	Fh	Cnt	2.814
Brook	Litter	80 Kg	1.196	Brook	Fh	80 Kg	0.807	Wilf	Fh	Cnt	3.051

Post Application Soil Nutrients Continued:

Site	Soil	Treatment	K mg/g	Site	Soil	Treatment	Mg mg/g	Site	Soil	Treatment	Ca mg/g
Mark	Litter	80 Kg	1.353	Wilf	Fh	80 Kg	2.339	Wilf	Fh	40 Kg	11.118
Mark	Litter	80 Kg	1.150	Wilf	Fh	80 Kg	1.238	Wilf	Fh	40 Kg	10.092
Mark	Litter	80 Kg	1.183	Wilf	Fh	80 Kg	3.382	Wilf	Fh	40 Kg	10.723
Mark	Litter	80 Kg	1.449	Wilf	Fh	80 Kg	2.674	Wilf	Fh	40 Kg	7.640
Mark	Litter	80 Kg	1.229	Wilf	Fh	80 Kg	1.650	Wilf	Fh	40 Kg	11.334
Mark	Litter	80 Kg	1.510	Wilf	Fh	80 Kg	2.698	Wilf	Fh	40 Kg	7.930
Wilf	Litter	80 Kg	0.998	Mark	Fh	80 Kg	1.022	Wilf	Fh	80 Kg	14.257
Wilf	Litter	80 Kg	1.007	Mark	Fh	80 Kg	0.482	Wilf	Fh	80 Kg	9.760
Wilf	Litter	80 Kg	1.384	Mark	Fh	80 Kg	1.652	Wilf	Fh	80 Kg	14.754
Wilf	Litter	80 Kg	1.707	Mark	Fh	80 Kg	0.767	Wilf	Fh	80 Kg	16.856
Wilf	Litter	80 Kg	1.125	Mark	Fh	80 Kg	1.325	Wilf	Fh	80 Kg	10.457
Wilf	Litter	80 Kg	1.128	Mark	Fh	80 Kg	1.861	Wilf	Fh	80 Kg	14.705
Brook	Mineral	80 Kg	0.210	Brook	Mineral	80 Kg	0.087	Mark	Fh	Cnt	9.764
Brook	Mineral	80 Kg	0.324	Brook	Mineral	80 Kg	0.048	Mark	Fh	Cnt	11.805
Brook	Mineral	80 Kg	0.242	Brook	Mineral	80 Kg	0.088	Mark	Fh	Cnt	4.029
Brook	Mineral	80 Kg	0.350	Brook	Mineral	80 Kg	0.103	Mark	Fh	Cnt	8.445
Mark	Mineral	80 Kg	0.225	Brook	Mineral	80 Kg	0.068	Mark	Fh	Cnt	4.443
Mark	Mineral	80 Kg	0.449	Wilf	Mineral	80 Kg	0.051	Mark	Fh	Cnt	5.943
Mark	Mineral	80 Kg	0.274	Wilf	Mineral	80 Kg	0.186	Mark	Fh	40 Kg	11.491
Mark	Mineral	80 Kg	0.512	Wilf	Mineral	80 Kg	0.196	Mark	Fh	40 Kg	10.386
Mark	Mineral	80 Kg	0.221	Wilf	Mineral	80 Kg	0.162	Mark	Fh	40 Kg	11.354
Mark	Mineral	80 Kg	0.227	Wilf	Mineral	80 Kg	0.071	Mark	Fh	40 Kg	10.109
Wilf	Mineral	80 Kg	0.296	Wilf	Mineral	80 Kg	0.147	Mark	Fh	40 Kg	5.970
Wilf	Mineral	80 Kg	0.331	Mark	Mineral	80 Kg	0.049	Mark	Fh	40 Kg	9.245
Wilf	Mineral	80 Kg	0.650	Mark	Mineral	80 Kg	0.068	Mark	Fh	80 Kg	9.702
Wilf	Mineral	80 Kg	0.549	Mark	Mineral	80 Kg	0.122	Mark	Fh	80 Kg	8.396
Wilf	Mineral	80 Kg	0.332	Mark	Mineral	80 Kg	0.070	Mark	Fh	80 Kg	15.659
Wilf	Mineral	80 Kg	0.680	Mark	Mineral	80 Kg	0.081	Mark	Fh	80 Kg	10.332
Brook	Mineral	80 Kg	0.223	Mark	Mineral	80 Kg	0.036	Mark	Fh	80 Kg	13.221
Brook	Fh	40 Kg	0.440	Brook	Litter	40 Kg	2.202	Mark	Fh	80 Kg	13.545
Brook	Fh	40 Kg	0.702	Brook	Litter	40 Kg	2.072	Brook	Min	Cnt	0.180
Brook	Fh	40 Kg	0.941	Brook	Litter	40 Kg	2.249	Brook	Min	Cnt	0.160
Brook	Fh	40 Kg	0.802	Brook	Litter	40 Kg	1.719	Brook	Min	Cnt	0.140
Brook	Fh	40 Kg	0.595	Brook	Litter	40 Kg	1.686	Brook	Min	Cnt	0.250
Brook	Fh	40 Kg	1.019	Brook	Litter	40 Kg	1.624	Brook	Min	Cnt	0.290
Brook	Litter	40 Kg	3.914	Wilf	Litter	40 Kg	1.431	Brook	Min	Cnt	0.120
Mark	Fh	40 Kg	1.025	Wilf	Litter	40 Kg	1.377	Brook	Min	40 Kg	0.190
Mark	Fh	40 Kg	0.741	Wilf	Litter	40 Kg	1.158	Brook	Min	40 Kg	0.370
Mark	Fh	40 Kg	1.193	Wilf	Litter	40 Kg	1.238	Brook	Min	40 Kg	0.170

Post Application Soil Nutrients Continued:

Site	Soil	Treatment	K mg/g	Site	Soil	Treatment	Mg mg/g	Site	Soil	Treatment	Ca mg/g
Mark	Fh	40 Kg	0.508	Wilf	Litter	40 Kg	1.260	Brook	Min	40 Kg	0.320
Mark	Fh	40 Kg	0.692	Wilf	Litter	40 Kg	1.472	Brook	Min	40 Kg	0.670
Mark	Fh	40 Kg	0.757	Mark	Litter	40 Kg	1.452	Brook	Min	40 Kg	0.390
Wilf	Fh	40 Kg	1.139	Mark	Litter	40 Kg	2.587	Brook	Min	80 Kg	0.393
Wilf	Fh	40 Kg	0.794	Mark	Litter	40 Kg	1.803	Brook	Min	80 Kg	0.462
Wilf	Fh	40 Kg	0.934	Mark	Litter	40 Kg	2.636	Brook	Min	80 Kg	0.402
Wilf	Fh	40 Kg	2.042	Mark	Litter	40 Kg	1.984	Brook	Min	80 Kg	0.410
Wilf	Fh	40 Kg	0.863	Mark	Litter	40 Kg	1.939	Brook	Min	80 Kg	0.515
Wilf	Fh	40 Kg	1.051	Brook	Fh	40 Kg	0.638	Wilf	Min	Cnt	0.196
Brook	Litter	40 Kg	1.561	Brook	Fh	40 Kg	0.945	Wilf	Min	Cnt	0.245
Brook	Litter	40 Kg	1.736	Brook	Fh	40 Kg	0.431	Wilf	Min	Cnt	0.214
Brook	Litter	40 Kg	1.293	Brook	Fh	40 Kg	0.923	Wilf	Min	Cnt	0.440
Brook	Litter	40 Kg	1.366	Brook	Fh	40 Kg	0.721	Wilf	Min	Cnt	0.201
Brook	Litter	40 Kg	1.542	Brook	Fh	40 Kg	1.030	Wilf	Min	Cnt	0.462
Brook	Mineral	40 Kg	0.117	Wilf	Fh	40 Kg	1.560	Wilf	Min	40 Kg	0.164
Mark	Litter	40 Kg	1.297	Wilf	Fh	40 Kg	1.058	Wilf	Min	40 Kg	0.207
Mark	Litter	40 Kg	1.803	Wilf	Fh	40 Kg	1.357	Wilf	Min	40 Kg	0.205
Mark	Litter	40 Kg	1.509	Wilf	Fh	40 Kg	1.808	Wilf	Min	40 Kg	0.194
Mark	Litter	40 Kg	1.733	Wilf	Fh	40 Kg	1.320	Wilf	Min	40 Kg	0.579
Mark	Litter	40 Kg	1.288	Wilf	Fh	40 Kg	1.155	Wilf	Min	40 Kg	0.474
Mark	Litter	40 Kg	1.189	Mark	Fh	40 Kg	1.037	Wilf	Min	80 Kg	0.189
Wilf	Litter	40 Kg	1.164	Mark	Fh	40 Kg	1.016	Wilf	Min	80 Kg	0.503
Wilf	Litter	40 Kg	1.237	Mark	Fh	40 Kg	0.896	Wilf	Min	80 Kg	0.606
Wilf	Litter	40 Kg	1.296	Mark	Fh	40 Kg	0.888	Wilf	Min	80 Kg	1.632
Wilf	Litter	40 Kg	1.127	Mark	Fh	40 Kg	0.853	Wilf	Min	80 Kg	0.205
Wilf	Litter	40 Kg	1.314	Mark	Fh	40 Kg	0.888	Wilf	Min	80 Kg	0.530
Wilf	Litter	40 Kg	1.210	Brook	Mineral	40 Kg	0.060	Mark	Min	Cnt	0.567
Mark	Mineral	40 Kg	0.183	Brook	Mineral	40 Kg	0.092	Mark	Min	Cnt	0.504
Mark	Mineral	40 Kg	0.274	Brook	Mineral	40 Kg	0.068	Mark	Min	Cnt	0.691
Mark	Mineral	40 Kg	0.123	Brook	Mineral	40 Kg	0.036	Mark	Min	Cnt	0.316
Mark	Mineral	40 Kg	0.147	Brook	Mineral	40 Kg	0.040	Mark	Min	Cnt	0.460
Mark	Mineral	40 Kg	0.168	Brook	Mineral	40 Kg	0.012	Mark	Min	Cnt	0.889
Mark	Mineral	40 Kg	0.252	Wilf	Mineral	40 Kg	0.035	Mark	Min	40 Kg	0.534
Brook	Mineral	40 Kg	0.147	Wilf	Mineral	40 Kg	0.040	Mark	Min	40 Kg	0.760
Brook	Mineral	40 Kg	0.163	Wilf	Mineral	40 Kg	0.043	Mark	Min	40 Kg	0.484
Brook	Mineral	40 Kg	0.084	Wilf	Mineral	40 Kg	0.055	Mark	Min	40 Kg	0.965
Wilf	Mineral	40 Kg	0.151	Wilf	Mineral	40 Kg	0.137	Mark	Min	40 Kg	0.502
Wilf	Mineral	40 Kg	0.191	Wilf	Mineral	40 Kg	0.104	Mark	Min	40 Kg	0.381
Wilf	Mineral	40 Kg	0.218	Mark	Mineral	40 Kg	0.057	Mark	Min	80 Kg	0.753

Post Application Soil Nutrients Continued:

Site	Soil	Treatment	K mg/g	Site	Soil	Treatment	Mg mg/g	Site	Soil	Treatment	Ca mg/g
Wilf	Mineral	40 Kg	0.364	Mark	Mineral	40 Kg	0.048	Mark	Min	80 Kg	0.692
Wilf	Mineral	40 Kg	0.269	Mark	Mineral	40 Kg	0.026	Mark	Min	80 Kg	0.831
Wilf	Mineral	40 Kg	0.567	Mark	Mineral	40 Kg	0.102	Mark	Min	80 Kg	0.392
Brook	Mineral	40 Kg	0.279	Mark	Mineral	40 Kg	0.070	Mark	Min	80 Kg	0.847
Brook	Mineral	40 Kg	0.119	Mark	Mineral	40 Kg	0.064	Mark	Min	80 Kg	0.418

Post Application Soil Metals:

Soil	Treatment	Site	Zn mg/kg	Ni mg/kg	Fe mg/kg	Cu mg/kg	B mg/kg	As mg/kg
Fh	Cnt	Brook	19.743	1.976	2620.563	1.276	0.000	0.000
Fh	Cnt	Brook	86.922	3.166	2851.026	8.504	2.163	0.000
Fh	Cnt	Brook	55.343	4.136	4392.265	6.184	0.805	0.000
Fh	Cnt	Brook	52.920	4.159	4551.074	7.638	0.000	0.000
Fh	Cnt	Brook	53.112	4.242	3738.470	5.488	0.000	0.000
Fh	Cnt	Brook	72.491	4.544	3945.733	16.438	1.691	0.000
Litter	Cnt	Brook	42.890	0.482	311.678	3.930	10.425	0.000
Litter	Cnt	Brook	78.507	0.763	363.711	8.358	14.853	0.143
Litter	Cnt	Brook	46.690	0.971	453.509	6.670	13.878	0.171
Litter	Cnt	Brook	68.569	1.149	304.336	13.664	16.713	0.008
Litter	Cnt	Brook	57.318	1.307	859.328	6.272	11.250	0.000
Litter	Cnt	Brook	56.090	1.480	381.076	6.821	13.661	0.000
Mineral	Cnt	Brook	9.993	1.094	3964.979	0.000	0.000	0.000
Mineral	Cnt	Brook	20.010	2.120	6878.671	2.119	0.000	0.000
Mineral	Cnt	Brook	23.545	2.291	11224.310	3.312	2.355	0.000
Mineral	Cnt	Brook	20.854	2.395	9721.879	3.659	0.000	0.000
Mineral	Cnt	Brook	35.719	3.207	7189.157	1.317	0.000	0.000
Mineral	Cnt	Brook	35.258	4.713	11550.644	5.142	0.000	0.000
Fh	8	Brook	77.546	3.716	1875.201	21.518	22.541	0.000
Fh	8	Brook	98.362	3.865	1586.734	19.182	24.699	0.666
Fh	8	Brook	88.034	4.181	1238.026	16.998	27.075	0.584
Fh	8	Brook	83.141	4.220	3506.850	12.197	11.292	0.000
Fh	8	Brook	72.730	5.112	1650.722	23.753	23.549	1.604
Litter	8	Brook	245.083	5.516	1064.679	69.391	80.669	0.000
Litter	8	Brook	306.521	6.423	1563.433	103.106	86.270	0.000
Litter	8	Brook	302.975	7.623	1580.771	95.811	99.515	0.000
Litter	8	Brook	342.721	9.746	1067.377	160.375	97.410	0.000
Litter	8	Brook	399.943	11.774	1722.840	106.484	113.915	1.438
Mineral	8	Brook	15.111	1.238	4000.356	0.000	0.000	0.000
Mineral	8	Brook	19.815	2.592	5839.167	1.634	0.000	0.000
Mineral	8	Brook	23.154	2.630	8334.485	0.190	0.000	0.000
Mineral	8	Brook	28.272	3.005	4148.085	3.191	0.633	0.000
Mineral	8	Brook	24.703	4.229	4774.147	8.439	0.182	0.000
Fh	4	Brook	45.027	3.246	3612.582	7.822	3.063	3.068
Fh	4	Brook	64.544	3.706	2841.447	14.614	9.424	2.744
Fh	4	Brook	56.169	3.918	5681.801	9.596	4.266	0.000
Fh	4	Brook	114.131	4.029	2357.065	10.876	7.879	1.508

Post Application Soil Metals Continued:

Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
Fh	4	Brook	59.911	4.071	4389.085	12.030	7.251	0.000
Fh	4	Brook	42.809	5.574	1414.729	8.899	5.888	1.657
Litter	4	Brook	149.856	3.881	1123.638	47.307	50.446	0.274
Litter	4	Brook	163.208	3.953	902.763	41.884	54.224	0.621
Litter	4	Brook	199.744	5.362	2581.717	56.606	53.002	1.753
Litter	4	Brook	219.344	5.639	1472.334	73.350	70.568	0.085
Litter	4	Brook	249.148	9.848	1335.273	64.533	80.373	2.018
Litter	4	Brook	235.588	20.658	1086.141	42.231	46.955	2.479
Mineral	4	Brook	16.095	1.840	9085.596	12.235	0.170	0.000
Mineral	4	Brook	17.045	1.859	4888.516	4.381	1.259	0.000
Mineral	4	Brook	25.601	2.005	7649.949	3.352	0.000	0.000
Mineral	4	Brook	25.491	2.190	10909.485	2.465	0.000	0.000
Mineral	4	Brook	21.307	2.558	4593.470	4.918	0.576	0.000
Mineral	4	Brook	26.557	2.736	8408.667	8.099	0.320	0.000
Fh	Cnt	Mark	60.397	3.293	1963.371	9.913	6.280	0.000
Fh	Cnt	Mark	82.386	3.426	1946.977	9.529	5.148	0.000
Fh	Cnt	Mark	54.969	4.133	3880.015	8.173	1.141	0.000
Fh	Cnt	Mark	59.372	4.216	2912.204	8.080	2.615	0.000
Fh	Cnt	Mark	58.002	4.518	2470.055	8.112	1.799	0.000
Fh	Cnt	Mark	54.721	4.666	3995.469	9.369	2.737	0.000
Litter	Cnt	Mark	42.086	0.747	144.513	5.064	16.252	0.183
Litter	Cnt	Mark	54.785	0.857	227.423	6.622	14.670	0.197
Litter	Cnt	Mark	49.260	1.232	476.465	4.310	10.476	0.000
Litter	Cnt	Mark	54.335	1.289	1015.764	6.925	11.656	0.000
Litter	Cnt	Mark	56.368	1.323	359.903	7.497	13.503	0.000
Litter	Cnt	Mark	62.008	2.921	203.519	6.688	16.816	0.243
Mineral	Cnt	Mark	14.107	1.392	6722.012	4.583	2.184	0.000
Mineral	Cnt	Mark	25.578	2.582	8528.981	3.627	0.000	0.000
Mineral	Cnt	Mark	30.875	2.636	11275.869	9.991	0.000	0.000
Mineral	Cnt	Mark	22.517	2.764	9177.940	1.238	0.000	1.477
Mineral	Cnt	Mark	35.183	3.669	9875.410	6.734	0.000	2.554
Mineral	Cnt	Mark	38.350	4.096	8081.457	4.117	0.000	0.000
Fh	8	Mark	154.903	5.301	3771.333	11.989	11.848	0.000
Fh	8	Mark	77.503	4.678	3300.348	12.602	11.632	0.000
Fh	8	Mark	78.765	4.111	1434.931	14.032	26.101	0.000
Fh	8	Mark	57.722	4.189	2969.882	11.796	13.629	4.717
Fh	8	Mark	122.319	6.684	4478.110	18.184	14.584	0.000
Fh	8	Mark	79.227	4.198	3764.583	17.565	18.178	0.000
Litter	8	Mark	184.987	4.333	630.283	44.696	62.927	0.000
Litter	8	Mark	233.138	6.236	1449.656	72.859	75.937	0.000
Litter	8	Mark	379.028	11.367	1626.210	89.714	121.000	0.381

Post Application Soil Metals Continued:

Soil	Treatment	Site	Zn mg/kg	Ni mg/kg	Fe mg/kg	Cu mg/kg	B mg/kg	As mg/kg
Litter	8	Mark	342.664	7.055	1079.439	75.622	86.183	0.789
Litter	8	Mark	352.492	10.022	1510.643	120.669	97.730	1.462
Litter	8	Mark	233.958	6.018	1872.569	113.776	76.971	0.000
Mineral	8	Mark	16.868	1.862	9190.296	0.000	0.000	0.000
Mineral	8	Mark	35.823	4.362	6258.105	8.095	3.815	0.000
Mineral	8	Mark	18.443	2.409	6820.007	2.049	2.116	0.000
Mineral	8	Mark	25.207	4.002	8051.659	0.720	0.000	0.000
Mineral	8	Mark	55.155	4.674	9865.422	2.734	0.000	0.000
Mineral	8	Mark	29.711	3.135	7577.280	0.000	0.000	0.000
Fh	4	Mark	61.837	2.385	684.217	12.589	14.912	0.000
Fh	4	Mark	48.270	3.324	3875.195	8.041	5.008	0.000
Fh	4	Mark	53.927	3.419	2133.594	14.036	12.328	0.000
Fh	4	Mark	79.561	4.065	3243.920	18.129	20.895	0.000
Fh	4	Mark	99.112	5.307	3945.999	14.355	12.412	0.000
Fh	4	Mark	98.817	5.718	2273.855	12.776	12.999	0.000
Litter	4	Mark	201.383	4.614	1018.162	56.181	52.342	2.578
Litter	4	Mark	195.785	5.138	763.223	139.246	54.752	2.107
Litter	4	Mark	215.998	5.654	782.716	58.833	74.325	3.259
Litter	4	Mark	270.557	5.740	1857.603	70.472	71.312	0.878
Litter	4	Mark	263.656	6.344	964.515	74.630	78.630	3.417
Litter	4	Mark	294.553	7.192	1122.108	94.273	85.711	3.764
Mineral	4	Mark	16.808	1.747	8199.999	0.000	0.000	0.000
Mineral	4	Mark	16.967	1.965	7450.188	0.000	0.000	0.000
Mineral	4	Mark	29.934	3.184	7035.260	0.284	0.000	0.000
Mineral	4	Mark	32.828	3.551	9100.168	0.000	0.000	0.000
Mineral	4	Mark	33.319	3.665	10848.547	0.000	0.000	0.000
Mineral	4	Mark	32.543	4.174	5255.246	3.101	0.000	0.000
Fh	Cnt	Wilf	46.494	1.934	936.311	7.176	3.122	0.122
Fh	Cnt	Wilf	35.686	2.892	4379.238	8.100	2.376	0.000
Fh	Cnt	Wilf	41.155	2.970	2496.605	9.103	5.349	0.000
Fh	Cnt	Wilf	45.879	3.971	7129.416	6.367	0.800	0.000
Fh	Cnt	Wilf	43.034	3.978	2362.456	11.304	1.750	0.000
Fh	Cnt	Wilf	52.441	4.528	5553.896	6.959	0.000	0.000
Litter	Cnt	Wilf	38.899	0.470	185.515	3.517	11.430	0.120
Litter	Cnt	Wilf	43.416	0.717	248.730	4.793	12.979	0.139
Litter	Cnt	Wilf	43.231	0.865	293.257	6.640	12.372	0.460
Litter	Cnt	Wilf	41.107	0.897	198.225	10.755	13.203	0.000
Litter	Cnt	Wilf	57.347	1.017	218.528	6.922	13.984	0.000
Litter	Cnt	Wilf	54.433	1.182	283.457	7.893	10.965	0.000
Mineral	Cnt	Wilf	18.779	2.098	8091.947	1.306	0.000	0.000
Mineral	Cnt	Wilf	16.730	2.400	6761.834	0.000	0.000	0.000

Post Application Soil Metals Continued:

Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
Mineral	Cnt	Wilf	20.669	3.517	7365.933	0.227	0.000	0.000
Mineral	Cnt	Wilf	27.714	3.811	10429.255	0.822	0.000	0.000
Mineral	Cnt	Wilf	28.687	5.229	8640.140	4.417	0.000	0.000
Mineral	Cnt	Wilf	33.978	5.871	12212.110	4.101	0.000	0.000
Fh	8	Wilf	67.493	2.672	1044.220	15.116	25.341	1.485
Fh	8	Wilf	85.409	3.841	1357.303	22.112	25.645	3.874
Fh	8	Wilf	59.108	4.354	5556.303	11.850	10.427	6.106
Fh	8	Wilf	59.606	4.609	3727.010	14.270	14.090	2.045
Fh	8	Wilf	103.874	5.340	3231.454	21.520	21.343	0.000
Litter	8	Wilf	272.750	6.309	597.457	64.696	81.860	0.000
Litter	8	Wilf	332.553	8.651	1030.571	158.311	113.642	0.000
Litter	8	Wilf	417.428	8.664	1059.814	109.072	116.078	0.000
Litter	8	Wilf	377.986	9.442	1320.947	128.502	117.498	0.000
Litter	8	Wilf	447.048	9.656	1107.444	218.248	132.117	4.080
Litter	8	Wilf	521.268	10.102	1360.761	151.968	143.267	0.000
Mineral	8	Wilf	19.254	2.707	4754.338	1.166	0.000	0.000
Mineral	8	Wilf	15.463	2.732	6468.587	0.910	1.451	0.000
Mineral	8	Wilf	21.644	3.317	3112.600	3.674	0.447	0.000
Mineral	8	Wilf	21.728	3.653	10038.008	0.360	0.000	0.000
Mineral	8	Wilf	23.758	4.527	9050.648	1.072	0.000	0.000
Mineral	8	Wilf	33.289	7.716	14801.988	5.395	0.000	0.000
Fh	4	Wilf	50.037	2.419	1166.507	17.830	13.239	0.000
Fh	4	Wilf	48.216	3.192	2581.591	10.707	9.870	0.919
Fh	4	Wilf	73.664	3.358	1769.255	17.022	16.381	1.529
Fh	4	Wilf	64.160	3.401	3159.387	19.381	7.493	2.565
Fh	4	Wilf	76.601	4.135	2304.652	15.855	11.589	1.283
Fh	4	Wilf	55.202	4.175	5965.573	12.369	5.327	0.000
Litter	4	Wilf	192.276	4.404	711.620	52.493	55.499	1.184
Litter	4	Wilf	233.183	4.693	626.064	82.082	65.817	1.507
Litter	4	Wilf	286.139	5.602	769.561	71.337	77.570	0.277
Litter	4	Wilf	347.182	6.224	911.544	82.031	94.748	0.483
Litter	4	Wilf	285.168	6.755	670.895	170.872	94.315	4.795
Litter	4	Wilf	264.960	9.243	742.640	68.431	67.309	0.783
Mineral	4	Wilf	14.295	1.580	8931.388	0.000	0.000	0.000
Mineral	4	Wilf	14.260	2.556	4700.735	0.791	0.000	0.000
Mineral	4	Wilf	13.298	2.590	6158.129	0.000	0.000	0.000
Mineral	4	Wilf	19.432	2.661	9584.917	0.388	0.000	0.000
Mineral	4	Wilf	22.080	3.049	11283.346	2.817	0.000	0.000
Mineral	4	Wilf	28.145	4.109	13483.722	3.384	0.000	0.000

Post Application Soil Metals Continued:

Soil	Site	Treatment	Mn mg/kg	Cd mg/kg	Al mg/kg	Pb mg/kg
Fh	Brook	Cnt	2353.350	0.780	3189.760	40.019
Fh	Brook	Cnt	2227.840	1.230	2550.270	30.264
Fh	Brook	Cnt	1604.660	0.920	3626.080	27.787
Fh	Brook	Cnt	978.780	0.760	2385.380	26.353
Fh	Brook	Cnt	1561.640	1.670	1746.050	24.978
Fh	Brook	Cnt	556.810	0.360	1637.490	14.716
Litter	Brook	Cnt	1949.330	0.840	526.240	4.393
Litter	Brook	Cnt	2733.410	1.010	259.100	3.751
Litter	Brook	Cnt	3473.360	0.990	478.190	3.320
Litter	Brook	Cnt	2184.720	1.100	219.820	3.122
Litter	Brook	Cnt	1375.760	0.650	236.550	2.405
Litter	Brook	Cnt	1344.750	0.610	387.830	2.173
Mineral	Brook	Cnt	567.070	0.270	9479.880	15.255
Mineral	Brook	Cnt	796.760	0.050	6342.040	11.747
Mineral	Brook	Cnt	748.800	0.280	5197.950	11.059
Mineral	Brook	Cnt	176.740	0.090	4096.180	10.333
Mineral	Brook	Cnt	162.690	0.100	4768.400	8.630
Mineral	Brook	Cnt	79.630	0.080	2644.380	6.177
Fh	Mark	Cnt	1513.350	0.920	2129.010	31.090
Fh	Mark	Cnt	1475.630	0.980	1353.170	28.605
Fh	Mark	Cnt	2434.560	0.980	1770.480	22.555
Fh	Mark	Cnt	3734.950	1.310	1554.460	22.270
Fh	Mark	Cnt	2782.500	1.200	1084.840	13.628
Fh	Mark	Cnt	2727.250	1.790	984.550	8.481
Litter	Mark	Cnt	2317.360	0.990	166.600	1.091
Litter	Mark	Cnt	2167.720	0.840	725.800	0.984
Litter	Mark	Cnt	1814.040	0.790	112.340	2.681
Litter	Mark	Cnt	2874.990	1.160	253.210	1.369
Litter	Mark	Cnt	1693.570	0.680	303.990	3.494
Litter	Mark	Cnt	1468.470	0.890	162.260	2.369
Mineral	Mark	Cnt	761.000	0.320	4522.070	28.732
Mineral	Mark	Cnt	435.340	0.110	4602.920	21.131
Mineral	Mark	Cnt	198.340	0.130	3248.070	21.125
Mineral	Mark	Cnt	495.840	0.210	7052.230	19.098
Mineral	Mark	Cnt	495.940	0.180	3439.500	19.013
Mineral	Mark	Cnt	65.810	0.080	2359.550	9.511
Fh	Wilf	Cnt	479.240	0.640	3056.380	24.383
Fh	Wilf	Cnt	1058.160	0.820	5672.960	23.698
Fh	Wilf	Cnt	1510.910	0.880	1563.920	21.609
Fh	Wilf	Cnt	815.620	0.570	4083.350	21.400

Post Application Soil Metals Continued:

Soil	Site	Treatment	Mn mg/kg	Cd mg/kg	Al mg/kg	Pb mg/kg
Fh	Wilf	Cnt	689.600	0.670	1493.410	13.518
Fh	Wilf	Cnt	512.190	0.570	591.550	9.290
Litter	Wilf	Cnt	1668.220	0.910	350.590	1.543
Litter	Wilf	Cnt	1988.090	0.780	197.240	1.062
Litter	Wilf	Cnt	965.310	0.500	135.290	2.761
Litter	Wilf	Cnt	1814.010	0.670	167.560	0.505
Litter	Wilf	Cnt	1836.480	0.590	158.030	0.897
Litter	Wilf	Cnt	2709.180	0.800	186.850	3.141
Mineral	Wilf	Cnt	586.160	0.430	9530.960	28.984
Mineral	Wilf	Cnt	645.980	0.190	6497.540	24.069
Mineral	Wilf	Cnt	461.980	0.140	3557.020	23.713
Mineral	Wilf	Cnt	943.070	0.320	12088.170	23.247
Mineral	Wilf	Cnt	78.750	0.250	5106.140	21.952
Mineral	Wilf	Cnt	65.450	0.230	4800.190	19.640
Fh	Brook	8	1211.850	1.390	2518.030	28.443
Fh	Brook	8	1485.280	0.920	1210.780	21.815
Fh	Brook	8	2273.090	0.820	1249.290	19.903
Fh	Brook	8	1584.620	0.980	1059.520	14.840
Fh	Brook	8	1942.430	0.920	794.770	11.723
Litter	Brook	8	5355.020	2.150	2175.710	
Litter	Brook	8	5367.200	2.140	2936.930	21.107
Litter	Brook	8	4550.410	1.670	2000.910	19.466
Litter	Brook	8	5381.490	2.340	2875.800	18.839
Litter	Brook	8	4150.440	2.990	1839.490	12.761
Mineral	Brook	8	108.010	0.230	1852.340	39.111
Mineral	Brook	8	86.770	0.140	2153.690	22.916
Mineral	Brook	8	87.080	0.150	3521.850	19.562
Mineral	Brook	8	133.350	0.110	5121.400	12.678
Mineral	Brook	8	110.580	0.120	2199.490	8.232
Fh	Mark	8	2269.240	0.900	2076.600	51.628
Fh	Mark	8	3696.840	1.810	2332.500	40.427
Fh	Mark	8	2308.180	1.000	1989.940	27.133
Fh	Mark	8	2343.430	0.900	1828.640	21.188
Fh	Mark	8	1261.710	0.760	2152.010	16.774
Fh	Mark	8	3161.470	1.090	948.860	11.784
Litter	Mark	8	5712.750	2.180	2846.540	71.846
Litter	Mark	8	4230.930	1.460	2074.740	23.189
Litter	Mark	8	5888.060	2.460	2586.070	15.279
Litter	Mark	8	4339.150	1.730	1628.200	15.198
Litter	Mark	8	3826.130	1.440	1111.270	14.476

Post Application Soil Metals Continued:

Soil	Site	Treatment	Mn mg/kg	Cd mg/kg	Al mg/kg	Pb mg/kg
Litter	Mark	8	4219.460	1.790	1685.760	10.958
Mineral	Mark	8	379.280	0.340	2717.260	31.932
Mineral	Mark	8	1081.160	0.610	4899.650	29.033
Mineral	Mark	8	185.640	0.160	5195.990	24.037
Mineral	Mark	8	497.210	0.320	4538.180	21.885
Mineral	Mark	8	507.870	0.060	3422.680	20.028
Mineral	Mark	8	231.550	0.000	4114.020	14.021
Fh	Wilf	8	1361.230	0.630	3734.630	28.355
Fh	Wilf	8	1967.080	1.120	2685.330	21.758
Fh	Wilf	8	1037.200	0.610	1860.120	19.346
Fh	Wilf	8	1601.460	0.890	866.350	16.724
Fh	Wilf	8	880.370	0.630	781.090	7.237
Litter	Wilf	8	6669.910	2.490	2555.170	14.721
Litter	Wilf	8	6898.260	2.670	2517.360	14.280
Litter	Wilf	8	4237.400	1.630	1147.780	13.753
Litter	Wilf	8	5976.920	2.130	1883.550	10.795
Litter	Wilf	8	6054.940	2.330	1992.620	9.042
Litter	Wilf	8	5457.570	2.230	2299.560	8.822
Mineral	Wilf	8	109.100	0.370	1480.020	49.248
Mineral	Wilf	8	43.710	0.220	2004.230	43.814
Mineral	Wilf	8	1516.250	0.250	7417.920	24.877
Mineral	Wilf	8	432.960	0.150	7363.730	20.048
Mineral	Wilf	8	58.330	0.190	3544.480	18.036
Mineral	Wilf	8	566.040	0.260	6560.190	15.382
Fh	Brook	4	1781.080	0.560	1327.290	43.056
Fh	Brook	4	1352.890	0.740	2343.480	34.760
Fh	Brook	4	1879.160	0.520	2850.050	31.876
Fh	Brook	4	2315.330	1.640	1271.730	26.248
Fh	Brook	4	892.830	0.480	1562.860	22.791
Fh	Brook	4	893.100	0.460	806.510	14.473
Litter	Brook	4	4007.440	1.240	1200.070	42.901
Litter	Brook	4	4710.390	1.550	2010.610	30.083
Litter	Brook	4	4762.980	1.340	1511.280	21.388
Litter	Brook	4	4401.170	1.420	2126.630	18.802
Litter	Brook	4	4004.620	1.820	1264.280	6.829
Litter	Brook	4	3599.090	1.150	1115.990	5.515
Mineral	Brook	4	65.050	0.260	2217.840	33.158
Mineral	Brook	4	50.040	0.050	1894.910	18.768
Mineral	Brook	4	303.550	0.030	5160.050	16.575
Mineral	Brook	4	846.940	0.070	3637.110	15.705
Mineral	Brook	4	273.960	0.030	4377.540	14.097

Post Application Soil Metals Continued:

Soil	Site	Treatment	Mn mg/kg	Cd mg/kg	Al mg/kg	Pb mg/kg
Mineral	Brook	4	139.910	0.000	4016.570	11.810
Fh	Mark	4	2594.050	1.410	2513.290	36.542
Fh	Mark	4	1404.430	0.760	1737.790	32.121
Fh	Mark	4	1287.770	0.890	1053.630	24.033
Fh	Mark	4	2639.560	0.890	1669.640	23.104
Fh	Mark	4	1112.100	1.160	1409.380	19.345
Fh	Mark	4	1248.650	1.170	441.840	7.880
Litter	Mark	4	4658.930	1.600	1585.110	10.447
Litter	Mark	4	5065.060	1.940	2273.980	16.594
Litter	Mark	4	3650.750	1.330	1380.820	44.648
Litter	Mark	4	3677.220	1.340	1393.730	15.145
Litter	Mark	4	4603.630	1.610	2113.920	24.403
Litter	Mark	4	4453.590	1.670	1981.070	54.531
Mineral	Mark	4	191.960	0.400	2459.140	36.391
Mineral	Mark	4	249.770	0.210	5711.780	23.475
Mineral	Mark	4	331.880	0.250	3556.600	23.144
Mineral	Mark	4	652.580	0.190	5829.100	16.239
Mineral	Mark	4	329.020	0.020	3170.670	15.964
Mineral	Mark	4	342.150	0.040	4396.550	11.666
Fh	Wilf	4	2436.420	0.640	2829.390	27.637
Fh	Wilf	4	2141.680	0.570	1556.210	25.723
Fh	Wilf	4	1413.960	0.650	1081.470	16.312
Fh	Wilf	4	1182.390	0.910	632.440	12.594
Fh	Wilf	4	1360.310	0.640	1310.170	12.144
Fh	Wilf	4	1193.590	0.710	899.090	8.974
Litter	Wilf	4	4503.760	1.310	1233.240	7.310
Litter	Wilf	4	5779.390	1.640	1575.750	
Litter	Wilf	4	4981.910	1.650	1491.620	6.635
Litter	Wilf	4	4759.800	1.640	1053.720	5.604
Litter	Wilf	4	4083.520	1.350	1140.880	6.097
Litter	Wilf	4	4855.450	1.630	1443.690	4.976
Mineral	Wilf	4	2322.490	0.120	6920.030	28.528
Mineral	Wilf	4	452.200	0.150	5292.360	25.498
Mineral	Wilf	4	77.490	0.240	1509.120	24.071
Mineral	Wilf	4	235.990	0.190	3903.250	11.980
Mineral	Wilf	4	177.360	0.100	3307.870	10.524
Mineral	Wilf	4	861.460	0.020	6039.250	10.342

H.) Foliage Post Ash Application Raw Data:

- Post Application Sapling Foliage Metals:

Foliage type	Site	Treatment	Al mg/kg	B mg/kg	Cd mg/kg	Cu mg/kg	Fe mg/kg	Mn mg/kg	Pb mg/kg	Zn mg/kg	Ni mg/kg
Sapling	Brook	Cnt	20.350	36.187	0.450	0.985	61.922	1113.720	0.462	34.810	1.077
Sapling	Brook	Cnt	16.180	28.884	0.340	0.000	48.963	1433.380	0.503	28.760	1.039
Sapling	Brook	Cnt	20.450	30.570	0.500	0.157	48.698	2488.530	0.488	21.510	0.957
Sapling	Brook	Cnt	20.760	33.757	0.300	0.889	47.495	744.880	0.688	30.310	1.135
Sapling	Brook	Cnt	17.070	34.887	0.260	0.853	48.009	703.100	0.507	23.910	0.273
Sapling	Brook	Cnt	22.820	41.647	0.220	0.379	47.219	962.620	0.277	22.450	1.105
Sapling	Brook	4	27.400	38.835	0.450	0.000	48.669	1243.260	0.348	29.440	0.609
Sapling	Brook	4	19.270	46.360	0.380	1.123	48.079	830.470	1.028	29.270	2.295
Sapling	Brook	4	21.010	35.200	0.390	6.116	63.338	1466.730	0.608	26.780	0.865
Sapling	Brook	4	21.080	45.861	0.250	2.093	50.926	938.700	0.079	24.830	0.636
Sapling	Brook	4	18.890	50.671	0.380	1.283	46.696	1838.430	0.424	25.180	0.909
Sapling	Brook	4	16.080	39.092	0.470	1.337	56.349	937.120	0.583	40.860	0.940
Sapling	Brook	8	22.500	38.054	0.370	1.540	47.999	1013.250	0.303	34.060	1.101
Sapling	Brook	8	20.580	51.100	0.390	2.885	50.933	784.450	0.394	24.040	1.314
Sapling	Brook	8	16.160	44.870	0.430	2.597	47.197	1120.010	0.740	27.930	0.664
Sapling	Brook	8	21.090	56.168	0.300	2.481	45.758	1234.830	0.543	27.960	0.603
Sapling	Brook	8	16.180	55.796	0.290	1.753	52.533	775.350	0.553	32.430	0.525
Sapling	Wilf	Cnt	7.948	34.775	0.130	0.000	41.080	634.342	0.095	16.530	0.462
Sapling	Wilf	Cnt	21.311	33.323	0.180	0.585	39.228	1733.934	0.801	21.840	1.064
Sapling	Wilf	Cnt	18.563	36.314	0.170	1.460	47.246	1254.535	0.926	22.950	0.929
Sapling	Wilf	Cnt	15.619	36.671	0.020	3.834	33.137	554.013	0.000	19.910	0.000
Sapling	Wilf	Cnt	14.062	20.213	0.160	0.000	24.967	937.347	0.425	26.170	1.057
Sapling	Wilf	Cnt	3.694	34.388	0.400	3.015	50.193	1465.223	0.650	24.900	0.998
Sapling	Wilf	4	10.930	55.040	0.280	0.544	42.215	996.640	0.000	27.750	0.000
Sapling	Wilf	4	7.880	40.336	0.190	0.790	41.051	704.620	0.700	22.920	0.726
Sapling	Wilf	4	29.410	34.920	0.320	0.066	36.584	1340.290	0.990	29.210	0.775
Sapling	Wilf	4	14.450	40.122	0.310	0.007	49.361	1744.990	0.850	27.330	1.754
Sapling	Wilf	4	12.010	44.049	0.680	0.036	45.678	2685.770	0.890	26.370	1.018
Sapling	Wilf	4	8.350	40.499	0.490	0.000	43.354	2200.850	0.980	27.470	0.505
Sapling	Wilf	8	8.980	20.832	0.213	0.000	31.463	1110.330	0.786	28.120	0.696
Sapling	Wilf	8	11.870	47.225	0.385	0.150	43.317	1576.400	1.067	29.300	0.706
Sapling	Wilf	8	6.200	42.650	0.295	1.883	53.607	546.170	0.000	23.350	0.000
Sapling	Wilf	8	14.580	34.470	0.385	0.849	39.866	1683.110	0.573	31.285	1.026
Sapling	Wilf	8	15.250	39.342	0.520	0.000	38.113	2487.100	0.651	27.262	0.953
Sapling	Mark	Cnt	44.695	43.187	1.350	0.000	54.419	810.057	0.000	31.440	0.669
Sapling	Mark	Cnt	24.104	41.352	0.106	0.000	94.461	429.248	0.000	30.448	0.874
Sapling	Mark	Cnt	17.307	36.173	0.343	0.000	58.343	1190.935	0.000	33.211	0.881
Sapling	Mark	Cnt	42.049	32.309	0.372	0.000	111.696	1484.636	0.000	28.847	0.819
Sapling	Mark	Cnt	49.187	43.665	0.197	0.061	61.005	896.832	0.000	23.480	0.105
Sapling	Mark	Cnt	19.371	32.816	0.179	0.000	53.576	634.393	0.000	27.929	1.405
Sapling	Mark	4	22.592	62.991	0.512	1.292	39.741	1186.210	0.000	35.508	3.827
Sapling	Mark	4	65.979	44.618	0.774	0.000	63.204	556.846	0.000	31.455	0.000
Sapling	Mark	4	40.011	61.499	1.400	2.692	70.708	997.947	0.000	38.242	0.394
Sapling	Mark	4	13.515	42.882	0.416	0.000	57.922	1044.646	0.000	40.413	0.281
Sapling	Mark	4	21.365	40.015	0.323	0.000	68.577	1811.599	0.000	36.457	1.130
Sapling	Mark	4	20.995	58.264	0.494	2.041	42.586	1482.993	0.000	47.565	1.000

- Post Application Sapling Foliage Metals Continued:

Foliage type	Site	Treatment	Al mg/kg	B mg/kg	Cd mg/kg	Cu mg/kg	Fe mg/kg	Mn mg/kg	Pb mg/kg	Zn mg/kg	Ni mg/kg
Sapling	Mark	8	33.144	43.058	0.538	0.000	78.501	756.386	0.000	23.007	1.704
Sapling	Mark	8	16.480	40.189	0.941	0.000	54.732	402.630	0.000	22.227	1.191
Sapling	Mark	8	16.644	39.152	0.348	0.000	78.985	1224.406	0.000	40.690	1.329
Sapling	Mark	8	18.488	51.006	0.350	0.890	97.657	1183.167	0.000	37.628	0.000
Sapling	Mark	8	32.293	41.811	0.402	0.000	59.418	1131.342	0.000	41.697	0.000

- Post Application Mature Foliage Metals:

Foliage type	Site	Treatment	Al mg/kg	B mg/kg	Cd mg/kg	Cu mg/kg	Fe mg/kg	Mn mg/kg	Ni Mg/kg	Pb mg/kg	Zn mg/kg
Mature	Brook	Cnt	20.350	39.419	0.400	3.911	62.014	1667.070	0.916	0.922	37.430
Mature	Brook	Cnt	23.380	26.352	0.330	1.411	53.058	2103.570	1.591	0.472	30.410
Mature	Brook	Cnt	23.920	42.412	0.370	6.082	44.012	1913.210	1.353	0.594	30.010
Mature	Brook	Cnt	26.650	41.747	0.260	1.995	48.853	1202.990	1.670	0.958	35.370
Mature	Brook	Cnt	18.090	46.949	0.370	4.102	51.058	1142.230	2.484	1.126	38.270
Mature	Brook	Cnt	23.910	59.872	0.250	4.117	54.827	1225.580	0.905	0.933	28.210
Mature	Brook	4	25.350	57.951	0.590	1.186	61.876	3528.520	0.848	0.715	40.320
Mature	Brook	4	22.130	62.133	0.320	2.326	74.446	1616.040	1.003	0.734	28.370
Mature	Brook	4	21.650	49.977	0.590	1.400	65.273	2487.680	1.017	1.067	45.460
Mature	Brook	4	26.030	70.435	0.480	2.361	52.308	1644.940	0.895	0.976	34.510
Mature	Brook	4	37.600	60.400	0.600	2.491	56.180	2843.340	0.901	0.716	40.240
Mature	Brook	8	23.020	42.809	0.260	1.438	59.276	1308.600	0.913	0.425	36.800
Mature	Brook	8	21.640	48.790	0.310	0.911	62.709	1644.670	1.256	0.704	30.250
Mature	Brook	8	22.050	56.738	0.230	1.304	46.645	1435.550	0.602	0.457	31.340
Mature	Brook	8	19.380	59.373	0.420	1.358	56.621	1010.230	1.393	0.756	34.590
Mature	Brook	8		49.685	0.500	2.147	62.285	1249.530	1.353	0.640	42.460
Mature	Wilf	Cnt	15.330	49.160	0.270	0.789	59.383	873.770	1.561	0.452	30.200
Mature	Wilf	Cnt	14.580	46.166	0.300	0.000	64.836	1218.620	1.887	0.658	24.860
Mature	Wilf	Cnt	20.360	34.436	0.340	1.657	62.441	1578.920	2.770	0.628	37.400
Mature	Wilf	Cnt	30.010	29.655	0.290	0.000	56.364	1443.820	2.015	0.600	29.210
Mature	Wilf	Cnt	25.700	49.239	0.220	1.837	44.637	932.740	2.139	0.607	28.830
Mature	Wilf	4	20.970	53.548	0.230	2.206	48.665	725.540	1.379	0.603	32.090
Mature	Wilf	4	15.670	50.991	0.400	1.353	39.989	1327.100	2.250	0.715	36.310
Mature	Wilf	4	17.200	35.324	0.350	0.000	61.722	1113.450	1.825	0.606	32.450
Mature	Wilf	4	19.620	48.976	0.240	3.908	49.490	1371.110	1.146	0.730	31.180
Mature	Wilf	4	17.770	41.150	0.540	1.239	51.088	1846.660	0.949	0.481	30.850
Mature	Wilf	4	17.060	56.360	0.370	2.044	46.971	1084.400	1.900	0.552	39.580
Mature	Wilf	8	15.720	51.439	0.370	0.351	49.255	1753.420	1.391	0.852	41.530
Mature	Wilf	8	26.200	62.639	0.320	0.777	52.514	703.450	2.268	0.983	45.340
Mature	Wilf	8	14.580	48.032	0.490	-0.013	41.880	2007.450	1.503	0.534	35.840
Mature	Wilf	8	13.780	61.035	0.490	0.736	221.286	1088.470	3.354	1.274	41.040
Mature	Wilf	8	20.210	48.677	0.650	0.388	69.935	2001.400	1.450	0.647	46.880
Mature	Wilf	8	13.910	59.769	0.370	2.483	53.655	1346.220	1.254	0.411	44.600
Mature	Mark	Cnt	19.340	62.778	0.400	1.648	47.103	1811.100	1.703	1.052	32.280
Mature	Mark	Cnt	19.860	25.480	0.340	0.122	40.149	1815.700	1.120	0.937	27.400
Mature	Mark	Cnt	21.380	34.219	0.160	1.061	41.430	1209.070	0.956	0.399	26.130
Mature	Mark	Cnt	25.670	47.812	0.480	2.407	43.182	1876.330	0.726	0.380	23.530
Mature	Mark	Cnt	13.320	43.282	0.210	1.916	56.259	761.780	1.752	0.876	25.580
Mature	Mark	Cnt	18.310	34.577	0.350	3.689	43.229	1325.470	1.624	0.357	29.620
Mature	Mark	4	14.130	39.352	0.410	0.961	56.554	1584.520	0.854	0.349	29.400
Mature	Mark	4	19.380	48.546	0.360	2.154	58.391	994.400	1.315	0.679	29.180
Mature	Mark	4	18.600	36.328	0.440	1.103	45.476	1649.630	1.585	0.637	34.700
Mature	Mark	4	23.840	50.548	0.380	2.529	62.184	1789.720	1.497	0.645	31.310
Mature	Mark	4	20.880	38.135	0.600	4.111	51.592	3475.040	1.348	0.312	36.050
Mature	Mark	4	23.450	48.199	0.300	0.557	57.418	1577.040	0.308	0.297	30.510
Mature	Mark	8	18.920	60.433	0.580	3.254	45.803	2262.270	0.666	0.836	31.350
Mature	Mark	8	22.010	41.613	0.360	2.697	48.969	1148.600	1.018	0.407	31.820

Post Application Mature Foliage Metals Continued:

Foliage type	Site	Treatment	Al mg/kg	B mg/kg	Cd mg/kg	Cu mg/kg	Fe mg/kg	Mn mg/kg	Ni Mg/kg	Pb mg/kg	Zn mg/kg
Mature	Mark	8	22.360	53.838	0.490	3.059	53.589	1000.390	0.542	0.430	31.420
Mature	Mark	8	17.640	59.774	0.500	2.694	74.359	1100.980	0.198	0.592	36.630
Mature	Mark	8	23.580	44.792	0.750	7.499	46.276	2011.560	1.304	0.940	48.560
Mature	Mark	8		48.407	0.760	4.454	42.570	5372.880	1.206	0.537	40.820

Post Application Sapling Foliage Nutrients:

Foliage Type	Site	Treatment	Ca mg/kg	K mg/kg	Mg mg/kg	P mg/kg
Sapling	Brook	Cnt	7132.6	7026.12	1181.49	1230.16
Sapling	Brook	Cnt	9229.98	6118.23	1667.4	1404.47
Sapling	Brook	Cnt	7032.31	4319.65	1162.41	1106.64
Sapling	Brook	Cnt	7974.38	6732.7	1359.73	1005.25
Sapling	Brook	Cnt	10197.37	5074.48	1625.82	991.87
Sapling	Brook	Cnt	5569.6	3127.75	953.85	827.93
Sapling	Brook	4	7364.25	10506.74	1430.69	1205.7
Sapling	Brook	4	8235.31	10059.04	1808.88	1028.79
Sapling	Brook	4	8164.7	9141.5	1475.7	994.57
Sapling	Brook	4	7365.14	8687.56	1258.18	1071.07
Sapling	Brook	4	8573.2	7809.67	1600.05	1006.74
Sapling	Brook	4	8940.33	9511.97	2014.87	1162.31
Sapling	Brook	8	8717.74	10299.9	1605.67	1009.84
Sapling	Brook	8	6079.46	8193.88	1831.28	1309.4
Sapling	Brook	8	7954.69	10555.91	1506.83	1058.66
Sapling	Brook	8	8232.35	8652.49	1894.37	1066.61
Sapling	Brook	8	8537.45	9177.1	1734.12	950.4
Sapling	Wilf	Cnt	3198.06	4105.42	591.17	615.337
Sapling	Wilf	Cnt	3954.01	6344.22	1459.26	1097.03
Sapling	Wilf	Cnt	5588.7	5613.4	981.37	1081.338
Sapling	Wilf	Cnt	5701.4	7032.39	1204.82	975.791
Sapling	Wilf	Cnt	6785.2	6941.38	1402.61	1102.38
Sapling	Wilf	Cnt	8658.6	12068.23	1664.32	1026.13
Sapling	Wilf	4	6116.21	7828.89	1250.97	812.89
Sapling	Wilf	4	5128.31	7123.12	1184.95	831.21
Sapling	Wilf	4	6567.07	12595.34	1344.68	969.81
Sapling	Wilf	4	7156.29	10736.67	1294.5	1102.79
Sapling	Wilf	4	7277.23	9553.34	1487.41	1165.54
Sapling	Wilf	4	8111.63	15446.46	1519.67	1227.06
Sapling	Wilf	8	5844.112	8503.508	1492.017	958.76
Sapling	Wilf	8	10211.95	16949.44	1716.134	1038.1
Sapling	Wilf	8	6394.952	9150.275	976.5	895.76
Sapling	Wilf	8	9340.369	16881.73	2068.492	1026.38
Sapling	Wilf	8	11908.78	11914.22	1601.346	1215.97
Sapling	Mark	Cnt	8851.911	41.6736	1241.5496	1012.153
Sapling	Mark	Cnt	7398.359	7992.473	1165.5016	1106.172
Sapling	Mark	Cnt	9910.855	8575.981	1582.6249	1223.82
Sapling	Mark	Cnt	13812.76	6589.629	1616.8696	1021.279
Sapling	Mark	Cnt	7889.679	6935.048	1356.0168	920.129
Sapling	Mark	Cnt	12144.81	6772.14	1877.0707	1033.604
Sapling	Mark	4	10808.85	105.5731	1499.7607	1127.757
Sapling	Mark	4	10710.76	92.12478	1669.0158	1071.473
Sapling	Mark	4	10573.25	70.35403	1316.5979	1273.433
Sapling	Mark	4	15089.88	16218.92	2438.6693	2207.461

Post Application Sapling Foliage Nutrients Continued:

Foliage Type	Site	Treatment	Ca mg/kg	K mg/kg	Mg mg/kg	P mg/kg
Sapling	Mark	4	16124.12	13898.84	1948.2263	1341.368
Sapling	Mark	4	12180.58	13639.15	1903.0761	1104.158
Sapling	Mark	8	6751.377	170.5335	1746.7048	1081.891
Sapling	Mark	8	4800.12	50.28165	1141.0011	1221.339
Sapling	Mark	8	11601.7	8945.301	1979.301	1212.512
Sapling	Mark	8	9793.623	10038.89	1352.7953	1214.181
Sapling	Mark	8	10513.49	12214.98	1684.2487	1556.439
Sapling	Mark	8	9659.296	13634.39	2055.1675	1158.765

Post Application Mature Foliage Nutrients:

Foliage Type	Site	Treatment	Ca mg/kg	K mg/kg	Mg mg/kg	P mg/kg
Mature	Brook	Cnt	10254.83	8031.25	1321.12	1268.09
Mature	Brook	Cnt	7234.68	7440.08	1212.75	1202.63
Mature	Brook	Cnt	9405.55	6932.5	1289.15	1418.08
Mature	Brook	Cnt	9108.33	6645.34	1553.06	1026.82
Mature	Brook	Cnt	12178.28	6586.39	1913.4	1207.68
Mature	Brook	Cnt	14626.49	4383.92	1459.04	1589.25
Mature	Mark	Cnt	10733.26	9076.64	1443.66	1121.71
Mature	Mark	Cnt	8997.35	8364.46	981.42	1155.64
Mature	Mark	Cnt	8575.07	8210.73	1181.04	1156.12
Mature	Mark	Cnt	11112.65	7556.19	1399.2	1128.53
Mature	Mark	Cnt	8343.73	7323.55	1409.55	1444.98
Mature	Mark	Cnt	10432.11	6669.83	1146.7	1179.42
Mature	Wilf	Cnt	7950.11	7573.61	1353.45	1068.131
Mature	Wilf	Cnt	6877.71	7478.57	1049.71	1009.952
Mature	Wilf	Cnt	7270.27	6561.54	1255.14	1064.501
Mature	Wilf	Cnt	5517.07	6208.76	1050.45	1085.653
Mature	Wilf	Cnt	8614.01	5669.39	911.86	1118.792
Mature	Brook	8	9035.27	14743.61	1272.8	1188.75
Mature	Brook	8	8478.03	11595.85	1753.5	1046.71
Mature	Brook	8	10325.89	10972.14	1718.47	1118.27
Mature	Brook	8	9895.22	9593.97	1601.18	1106.45
Mature	Brook	8	9886.22	8922.43	1313.07	977.01
Mature	Mark	8	15017.7	16226.82	2198.51	1003.91
Mature	Mark	8	9522.62	14856.94	1385.95	1524.08
Mature	Mark	8	11639.89	13627.96	1828.22	1017.76
Mature	Mark	8	11597.71	11243.7	1608.55	1257.14
Mature	Mark	8	17435.82	11105.58	2320.6	1102.82
Mature	Mark	8	9663.58	7724.67	1726.27	1092.15
Mature	Wilf	8	8954.7	16457.15	1390.51	1027.66
Mature	Wilf	8	10047.18	10746.84	1827.75	1101.86
Mature	Wilf	8	8677.08	10251.15	1474.13	962.88
Mature	Wilf	8	8354.85	10149.05	1944.15	1090.67
Mature	Wilf	8	8042.2	8763.86	1338.29	1055.1
Mature	Wilf	8	7731.44	7980.87	1284.07	1218.11
Mature	Brook	4	11667.09	12574.36	1347.06	1324.16
Mature	Brook	4	11725.66	10585.85	1464.12	1050.12
Mature	Brook	4	9601.84	10392.83	1463.23	1058.86
Mature	Brook	4	9322.64	10006.26	1191.55	1028.26
Mature	Brook	4	9716.77	8996.37	1581.19	1129.7
Mature	Mark	4	9208.95	16450.69	1620.44	986.16
Mature	Mark	4	11220.13	11412.69	1373.46	1173.09
Mature	Mark	4	14509.61	11409.51	1568.63	1389.05
Mature	Mark	4	10013.36	8817.99	1508.32	1210.22
Mature	Mark	4	9006.89	8487.75	1141.19	1060.71

Post Application Mature Foliage Nutrients Continued:

Foliage Type	Site	Treatment	Ca mg/kg	K mg/kg	Mg mg/kg	P mg/kg
Mature	Mark	4	8796.46	7117.67	1297.64	958.95
Mature	Wilf	4	8763.9	14176.59	1592.55	1037.53
Mature	Wilf	4	6933.84	10705.17	1517.9	1133.39
Mature	Wilf	4	9088.61	9035.64	1333.83	1125.21
Mature	Wilf	4	8608.37	7643.5	1396.25	1203.23
Mature	Wilf	4	7955.78	7482.41	1334.58	1081.56
Mature	Wilf	4	5845.94	7330.31	947.25	1073.61

Post Application Foliage CNS:

Site	Treatment	Foliage Type	CNS type	CNS %	Site	Treatment	Foliage Type	CNS type	CNS %
Wilf	Cnt	Sapling	N mg/kg	2.076	Brook	Cnt	Mature	N mg/kg	2.58
Wilf	Cnt	Sapling	N mg/kg	2.46	Brook	Cnt	Mature	N mg/kg	2.365
Wilf	Cnt	Sapling	N mg/kg	2.126	Brook	Cnt	Mature	N mg/kg	2.184
Wilf	Cnt	Sapling	N mg/kg	2.247	Brook	Cnt	Mature	N mg/kg	2.056
Wilf	Cnt	Sapling	N mg/kg	2.118	Brook	Cnt	Mature	N mg/kg	1.931
Wilf	Cnt	Sapling	N mg/kg	1.775	Brook	Cnt	Mature	N mg/kg	1.984
Brook	Cnt	Sapling	N mg/kg	2.183	Wilf	Cnt	Mature	N mg/kg	2.177
Brook	Cnt	Sapling	N mg/kg	2.121	Wilf	Cnt	Mature	N mg/kg	2.023
Brook	Cnt	Sapling	N mg/kg	2.208	Wilf	Cnt	Mature	N mg/kg	1.827
Brook	Cnt	Sapling	N mg/kg	1.913	Wilf	Cnt	Mature	N mg/kg	2.247
Brook	Cnt	Sapling	N mg/kg	1.99	Wilf	Cnt	Mature	N mg/kg	2.117
Brook	Cnt	Sapling	N mg/kg	2.069	Wilf	Cnt	Mature	N mg/kg	1.965
Mark	Cnt	Sapling	N mg/kg	2.173	Mark	Cnt	Mature	N mg/kg	2.061
Mark	Cnt	Sapling	N mg/kg	2.289	Mark	Cnt	Mature	N mg/kg	2.255
Mark	Cnt	Sapling	N mg/kg	2.179	Mark	Cnt	Mature	N mg/kg	2.396
Mark	Cnt	Sapling	N mg/kg	2.039	Mark	Cnt	Mature	N mg/kg	2.28
Mark	Cnt	Sapling	N mg/kg	2.259	Mark	Cnt	Mature	N mg/kg	2.17
Wilf	Cnt	Sapling	C mg/kg	46.024	Mark	Cnt	Mature	N mg/kg	2.479
Wilf	Cnt	Sapling	C mg/kg	45.673	Brook	Cnt	Mature	C mg/kg	45.198
Wilf	Cnt	Sapling	C mg/kg	45.624	Brook	Cnt	Mature	C mg/kg	44.93
Wilf	Cnt	Sapling	C mg/kg	45.174	Brook	Cnt	Mature	C mg/kg	44.824
Wilf	Cnt	Sapling	C mg/kg	45.62	Brook	Cnt	Mature	C mg/kg	44.876
Wilf	Cnt	Sapling	C mg/kg	45.689	Brook	Cnt	Mature	C mg/kg	43.357
Brook	Cnt	Sapling	C mg/kg	45.794	Brook	Cnt	Mature	C mg/kg	44.889
Brook	Cnt	Sapling	C mg/kg	45.478	Wilf	Cnt	Mature	C mg/kg	45.417
Brook	Cnt	Sapling	C mg/kg	45.646	Wilf	Cnt	Mature	C mg/kg	45.569
Brook	Cnt	Sapling	C mg/kg	45.094	Wilf	Cnt	Mature	C mg/kg	45.519
Brook	Cnt	Sapling	C mg/kg	44.758	Wilf	Cnt	Mature	C mg/kg	45.088
Brook	Cnt	Sapling	C mg/kg	45.322	Wilf	Cnt	Mature	C mg/kg	45.102
Mark	Cnt	Sapling	C mg/kg	45.232	Wilf	Cnt	Mature	C mg/kg	45.81
Mark	Cnt	Sapling	C mg/kg	45.032	Mark	Cnt	Mature	C mg/kg	45.266
Mark	Cnt	Sapling	C mg/kg	43.762	Mark	Cnt	Mature	C mg/kg	45.281
Mark	Cnt	Sapling	C mg/kg	44.848	Mark	Cnt	Mature	C mg/kg	44.745
Mark	Cnt	Sapling	C mg/kg	44.258	Mark	Cnt	Mature	C mg/kg	44.487
Wilf	Cnt	Sapling	S mg/kg	0.143	Mark	Cnt	Mature	C mg/kg	45.002
Wilf	Cnt	Sapling	S mg/kg	0.242	Mark	Cnt	Mature	C mg/kg	44.609
Wilf	Cnt	Sapling	S mg/kg	0.1	Brook	Cnt	Mature	S mg/kg	0.146
Wilf	Cnt	Sapling	S mg/kg	0.115	Brook	Cnt	Mature	S mg/kg	0.121
Wilf	Cnt	Sapling	S mg/kg	0.089	Brook	Cnt	Mature	S mg/kg	0.222
Wilf	Cnt	Sapling	S mg/kg	0.085	Brook	Cnt	Mature	S mg/kg	0.136
Brook	Cnt	Sapling	S mg/kg	0.131	Brook	Cnt	Mature	S mg/kg	0.143
Brook	Cnt	Sapling	S mg/kg	0.066	Brook	Cnt	Mature	S mg/kg	0.087
Brook	Cnt	Sapling	S mg/kg	0.094	Wilf	Cnt	Mature	S mg/kg	0.139
Brook	Cnt	Sapling	S mg/kg	0.069	Wilf	Cnt	Mature	S mg/kg	0.155

Post Application Foliage CNS Continued:

Site	Treatment	Foliage Type	CNS type	CNS %	Site	Treatment	Foliage Type	CNS type	CNS %
Brook	Cnt	Sapling	S mg/kg	0.083	Wilf	Cnt	Mature	S mg/kg	0.085
Brook	Cnt	Sapling	S mg/kg	0.077	Wilf	Cnt	Mature	S mg/kg	0.129
Mark	Cnt	Sapling	S mg/kg	0.119	Wilf	Cnt	Mature	S mg/kg	0.12
Mark	Cnt	Sapling	S mg/kg	0.146	Wilf	Cnt	Mature	S mg/kg	0.091
Mark	Cnt	Sapling	S mg/kg	0.098	Mark	Cnt	Mature	S mg/kg	0.138
Mark	Cnt	Sapling	S mg/kg	0.258	Mark	Cnt	Mature	S mg/kg	0.148
Mark	Cnt	Sapling	S mg/kg	0.251	Mark	Cnt	Mature	S mg/kg	0.124
Wilf	8	Sapling	N mg/kg	2.134	Mark	Cnt	Mature	S mg/kg	0.129
Wilf	8	Sapling	N mg/kg	2.084	Mark	Cnt	Mature	S mg/kg	0.12
Wilf	8	Sapling	N mg/kg	1.865	Mark	Cnt	Mature	S mg/kg	0.126
Wilf	8	Sapling	N mg/kg	2.066	Brook	8	Mature	N mg/kg	2.42
Wilf	8	Sapling	N mg/kg	1.755	Brook	8	Mature	N mg/kg	1.996
Brook	8	Sapling	N mg/kg	2.152	Brook	8	Mature	N mg/kg	2.19
Brook	8	Sapling	N mg/kg	2.019	Brook	8	Mature	N mg/kg	2.147
Brook	8	Sapling	N mg/kg	2.156	Brook	8	Mature	N mg/kg	2.12
Brook	8	Sapling	N mg/kg	2.173	Wilf	8	Mature	N mg/kg	2.201
Brook	8	Sapling	N mg/kg	1.944	Wilf	8	Mature	N mg/kg	2.139
Mark	8	Sapling	N mg/kg	2.157	Wilf	8	Mature	N mg/kg	2.128
Mark	8	Sapling	N mg/kg	2.524	Wilf	8	Mature	N mg/kg	2.097
Mark	8	Sapling	N mg/kg	2.428	Wilf	8	Mature	N mg/kg	2.18
Mark	8	Sapling	N mg/kg	2.233	Wilf	8	Mature	N mg/kg	2.223
Mark	8	Sapling	N mg/kg	2.553	Mark	8	Mature	N mg/kg	2.177
Mark	8	Sapling	N mg/kg	2.155	Mark	8	Mature	N mg/kg	2.444
Wilf	8	Sapling	C mg/kg	45.215	Mark	8	Mature	N mg/kg	2.274
Wilf	8	Sapling	C mg/kg	44.041	Mark	8	Mature	N mg/kg	2.107
Wilf	8	Sapling	C mg/kg	45.513	Mark	8	Mature	N mg/kg	2.144
Wilf	8	Sapling	C mg/kg	43.474	Mark	8	Mature	N mg/kg	2.203
Wilf	8	Sapling	C mg/kg	44.373	Brook	8	Mature	C mg/kg	44.816
Brook	8	Sapling	C mg/kg	44.156	Brook	8	Mature	C mg/kg	44.365
Brook	8	Sapling	C mg/kg	44.886	Brook	8	Mature	C mg/kg	44.193
Brook	8	Sapling	C mg/kg	44.633	Brook	8	Mature	C mg/kg	44.441
Brook	8	Sapling	C mg/kg	44.222	Brook	8	Mature	C mg/kg	43.669
Brook	8	Sapling	C mg/kg	44.15	Wilf	8	Mature	C mg/kg	44.5
Mark	8	Sapling	C mg/kg	43.958	Wilf	8	Mature	C mg/kg	44.383
Mark	8	Sapling	C mg/kg	44.699	Wilf	8	Mature	C mg/kg	44.157
Mark	8	Sapling	C mg/kg	43.965	Wilf	8	Mature	C mg/kg	44.574
Mark	8	Sapling	C mg/kg	44.396	Wilf	8	Mature	C mg/kg	44.403
Mark	8	Sapling	C mg/kg	44.283	Wilf	8	Mature	C mg/kg	44.096
Mark	8	Sapling	C mg/kg	44.016	Mark	8	Mature	C mg/kg	43.509
Wilf	8	Sapling	S mg/kg	0.111	Mark	8	Mature	C mg/kg	44.458
Wilf	8	Sapling	S mg/kg	0.119	Mark	8	Mature	C mg/kg	43.366
Wilf	8	Sapling	S mg/kg	0.075	Mark	8	Mature	C mg/kg	43.157
Wilf	8	Sapling	S mg/kg	0.103	Mark	8	Mature	C mg/kg	43.939
Wilf	8	Sapling	S mg/kg	0.206	Mark	8	Mature	C mg/kg	43.327

Post Application Foliage CNS Continued:

Site	Treatment	Foliage Type	CNS type	CNS %	Site	Treatment	Foliage Type	CNS type	CNS %
Brook	8	Sapling	S mg/kg	0.112	Brook	8	Mature	S mg/kg	0.109
Brook	8	Sapling	S mg/kg	0.085	Brook	8	Mature	S mg/kg	0.109
Brook	8	Sapling	S mg/kg	0.172	Brook	8	Mature	S mg/kg	0.11
Brook	8	Sapling	S mg/kg	0.097	Brook	8	Mature	S mg/kg	0.132
Brook	8	Sapling	S mg/kg	0.087	Brook	8	Mature	S mg/kg	0.116
Mark	8	Sapling	S mg/kg	0.162	Wilf	8	Mature	S mg/kg	0.122
Mark	8	Sapling	S mg/kg	0.134	Wilf	8	Mature	S mg/kg	0.106
Mark	8	Sapling	S mg/kg	0.132	Wilf	8	Mature	S mg/kg	0.133
Mark	8	Sapling	S mg/kg	0.186	Wilf	8	Mature	S mg/kg	0.123
Mark	8	Sapling	S mg/kg	0.176	Wilf	8	Mature	S mg/kg	0.101
Mark	8	Sapling	S mg/kg	0.123	Wilf	8	Mature	S mg/kg	0.163
Wilf	4	Sapling	N mg/kg	2.004	Mark	8	Mature	S mg/kg	0.131
Wilf	4	Sapling	N mg/kg	2.067	Mark	8	Mature	S mg/kg	0.292
Wilf	4	Sapling	N mg/kg	1.864	Mark	8	Mature	S mg/kg	0.134
Wilf	4	Sapling	N mg/kg	2.394	Mark	8	Mature	S mg/kg	0.105
Wilf	4	Sapling	N mg/kg	2.203	Mark	8	Mature	S mg/kg	0.109
Wilf	4	Sapling	N mg/kg	1.744	Mark	8	Mature	S mg/kg	0.145
Brook	4	Sapling	N mg/kg	2.156	Brook	4	Mature	N mg/kg	2.38
Brook	4	Sapling	N mg/kg	2.087	Brook	4	Mature	N mg/kg	2.216
Brook	4	Sapling	N mg/kg	2.057	Brook	4	Mature	N mg/kg	2.04
Brook	4	Sapling	N mg/kg	2.227	Brook	4	Mature	N mg/kg	2.149
Brook	4	Sapling	N mg/kg	1.931	Brook	4	Mature	N mg/kg	2.215
Brook	4	Sapling	N mg/kg	2.027	Wilf	4	Mature	N mg/kg	2.095
Mark	4	Sapling	N mg/kg	2.181	Wilf	4	Mature	N mg/kg	2.311
Mark	4	Sapling	N mg/kg	2.242	Wilf	4	Mature	N mg/kg	2.085
Mark	4	Sapling	N mg/kg	2.255	Wilf	4	Mature	N mg/kg	2.21
Mark	4	Sapling	N mg/kg	1.847	Wilf	4	Mature	N mg/kg	2.048
Mark	4	Sapling	N mg/kg	2.358	Wilf	4	Mature	N mg/kg	1.919
Mark	4	Sapling	N mg/kg	2.36	Mark	4	Mature	N mg/kg	2.148
Wilf	4	Sapling	C mg/kg	45.271	Mark	4	Mature	N mg/kg	2.352
Wilf	4	Sapling	C mg/kg	46.095	Mark	4	Mature	N mg/kg	2.237
Wilf	4	Sapling	C mg/kg	44.347	Mark	4	Mature	N mg/kg	2.03
Wilf	4	Sapling	C mg/kg	44.623	Mark	4	Mature	N mg/kg	1.992
Wilf	4	Sapling	C mg/kg	44.367	Mark	4	Mature	N mg/kg	2.11
Wilf	4	Sapling	C mg/kg	44.247	Brook	4	Mature	C mg/kg	44.084
Brook	4	Sapling	C mg/kg	44.869	Brook	4	Mature	C mg/kg	44.384
Brook	4	Sapling	C mg/kg	44.691	Brook	4	Mature	C mg/kg	43.566
Brook	4	Sapling	C mg/kg	44.328	Brook	4	Mature	C mg/kg	44.295
Brook	4	Sapling	C mg/kg	44.725	Brook	4	Mature	C mg/kg	44.573
Brook	4	Sapling	C mg/kg	45.3	Wilf	4	Mature	C mg/kg	45.351
Brook	4	Sapling	C mg/kg	44.496	Wilf	4	Mature	C mg/kg	44.619
Mark	4	Sapling	C mg/kg	43.821	Wilf	4	Mature	C mg/kg	44.083
Mark	4	Sapling	C mg/kg	44.168	Wilf	4	Mature	C mg/kg	45.092
Mark	4	Sapling	C mg/kg	43.693	Wilf	4	Mature	C mg/kg	44.649

Post Application Foliage CNS Continued:

Site	Treatment	Foliage Type	CNS type	CNS %	Site	Treatment	Foliage Type	CNS type	CNS %
Mark	4	Sapling	C mg/kg	42.565	Wilf	4	Mature	C mg/kg	44.533
Mark	4	Sapling	C mg/kg	44.699	Mark	4	Mature	C mg/kg	43.614
Mark	4	Sapling	C mg/kg	44.521	Mark	4	Mature	C mg/kg	45.384
Wilf	4	Sapling	S mg/kg	0.119	Mark	4	Mature	C mg/kg	44.501
Wilf	4	Sapling	S mg/kg	0.109	Mark	4	Mature	C mg/kg	43.877
Wilf	4	Sapling	S mg/kg	0.102	Mark	4	Mature	C mg/kg	43.504
Wilf	4	Sapling	S mg/kg	0.121	Mark	4	Mature	C mg/kg	45.228
Wilf	4	Sapling	S mg/kg	0.094	Brook	4	Mature	S mg/kg	0.143
Wilf	4	Sapling	S mg/kg	0.179	Brook	4	Mature	S mg/kg	0.127
Brook	4	Sapling	S mg/kg	0.121	Brook	4	Mature	S mg/kg	0.109
Brook	4	Sapling	S mg/kg	0.085	Brook	4	Mature	S mg/kg	0.16
Brook	4	Sapling	S mg/kg	0.108	Brook	4	Mature	S mg/kg	0.234
Brook	4	Sapling	S mg/kg	0.099	Wilf	4	Mature	S mg/kg	0.122
Brook	4	Sapling	S mg/kg	0.084	Wilf	4	Mature	S mg/kg	0.27
Brook	4	Sapling	S mg/kg	0.091	Wilf	4	Mature	S mg/kg	0.092
Mark	4	Sapling	S mg/kg	0.104	Wilf	4	Mature	S mg/kg	0.117
Mark	4	Sapling	S mg/kg	0.143	Wilf	4	Mature	S mg/kg	0.09
Mark	4	Sapling	S mg/kg	0.136	Wilf	4	Mature	S mg/kg	0.098
Mark	4	Sapling	S mg/kg	0.115	Mark	4	Mature	S mg/kg	0.158
Mark	4	Sapling	S mg/kg	0.224	Mark	4	Mature	S mg/kg	0.168
Mark	4	Sapling	S mg/kg	0.128	Mark	4	Mature	S mg/kg	0.121
Mark	4	Mature	S mg/kg	0.11					
Mark	4	Mature	S mg/kg	0.097					
Mark	4	Mature	S mg/kg	0.095					

I.) DBH Raw Data (Surviving trees only):

Site	Treatment	Plot Num.	DBH 2021	DBH 2020	DBH 2019	Species
Brook	Cnt.	1	14.4	14.5	13.4	Sugar Maple
Brook	Cnt.	1	18.7	18.5	16.5	Sugar Maple
Brook	Cnt.	1	15.2	15	13.4	Sugar Maple
Brook	Cnt.	1	21	20.5	18.7	Sugar Maple
Brook	Cnt.	1	25.9	25.5	25.3	Sugar Maple
Brook	Cnt.	1	16.6	16.5	15.1	Sugar Maple
Brook	Cnt.	1	31	31	30.6	Sugar Maple
Brook	Cnt.	1	11.9	11	11	Sugar Maple
Brook	4	2	21.2	20.5	20.2	Sugar Maple
Brook	4	2	20.4	20	19.7	Sugar Maple
Brook	4	2	16	16	16.1	Sugar Maple
Brook	4	2	43.8	43	42.9	Sugar Maple
Brook	4	2	17.5	17	17.2	Sugar Maple
Brook	8	3	51.6	50.5	50.5	Sugar Maple
Brook	8	3	24.4	24.5	23.6	Sugar Maple
Brook	8	3	23.8	24	23.2	Sugar Maple
Brook	8	3	21.4	20.5	20.4	Sugar Maple
Brook	8	3	24.8	24	22.5	Sugar Maple
Brook	8	4	17.2	16.5	16.7	Sugar Maple
Brook	8	4	28.3	28	27.8	Sugar Maple
Brook	8	4	20.2	20	19.6	Sugar Maple
Brook	8	4	17.4	17	16.8	Sugar Maple
Brook	8	4	20.4	20	20	Sugar Maple
Brook	4	5	28.2	27.5	27.6	Sugar Maple
Brook	4	5	30.7	30.1	30.1	Sugar Maple
Brook	4	5	12.2	11.5	11.7	Sugar Maple
Brook	4	5	28.5	27.6	27.1	Sugar Maple
Brook	4	5	28	27	26.9	Sugar Maple
Brook	4	5	13.5	13.5	13.3	Iron wood
Brook	4	5	32.1	32	31.4	Basswood
Brook	4	5	22.1	22	21.5	Sugar Maple
Brook	8	6	25.2	25	24.4	Sugar Maple

DBH Data Continued:

Site	Treatment	Plot Num.	DBH 2021	DBH 2020	DBH 2019	Species
Brook	8	6	17.2	17	16.5	Sugar Maple
Brook	8	6	15.4	15	14.1	Sugar Maple
Brook	8	6	41.5	41	40.3	Yellow Birch
Brook	8	6	12.4	11.5	11.7	Sugar Maple
Brook	8	6	22	20	19.3	Sugar Maple
Brook	4	7	12.9	12.5	12.2	Sugar Maple
Brook	4	7	21.4	21.5	21.6	Sugar Maple
Brook	4	7	17.4	17	17.4	Sugar Maple
Brook	4	7	22.2	21.5	21.6	Sugar Maple
Brook	4	7	34.5	34.5	34.2	White Ash
Brook	4	8	13.4	13	12.1	Sugar Maple
Brook	4	8	38.3	37	37.2	White Ash
Brook	4	8	21.2	21	20.1	Sugar Maple
Brook	4	8	16.3	16	15	Sugar Maple
Brook	4	8	32.9	32.5	31.9	Sugar Maple
Brook	8	9	27.2	26.5	26.3	Sugar Maple
Brook	8	9	13.9	13	13	Sugar Maple
Brook	8	9	22.1	22	21.5	Sugar Maple
Brook	8	9	16.6	15	14.5	Sugar Maple
Brook	8	9	14.1	13.5	13.3	Sugar Maple
Brook	8	9	16.4	16	15.9	Sugar Maple
Brook	Cnt.	10	36.8	35	34.1	Sugar Maple
Brook	Cnt.	10	32.2	30	31.7	Sugar Maple
Brook	Cnt.	10	22.5	22	22	Sugar Maple
Brook	Cnt.	10	16.8	16	16.1	Sugar Maple
Brook	Cnt.	10	17.7	16.5	16.5	Sugar Maple
Brook	Cnt.	10	13.1	13	12.9	Sugar Maple
Brook	4	11	25	24	24.4	Sugar Maple
Brook	4	11	23.9	23.5	23.4	Sugar Maple
Brook	4	11	20.1	20	19.4	Sugar Maple
Brook	4	11	17.5	17	16.4	Sugar Maple
Brook	4	11	14.3	14	13.7	Sugar Maple
Brook	Cnt.	12	19.1	20	19.4	Sugar Maple

DBH Data Continued:

Site	Treatment	Plot Num.	DBH 2021	DBH 2020	DBH 2019	Species
Brook	Cnt.	12	11.4	11	10.6	Sugar Maple
Brook	Cnt.	12	15.2	15	14.2	Sugar Maple
Brook	Cnt.	12	28	28	27.4	Sugar Maple
Brook	Cnt.	12	23.7	22	21.5	Sugar Maple
Brook	Cnt.	12	16.5	15	15	Sugar Maple
Brook	Cnt.	14	18.7	19	18.9	Sugar Maple
Brook	Cnt.	14	12.7	12	12.2	Sugar Maple
Brook	Cnt.	14	11.6	11.5	11.2	Sugar Maple
Brook	Cnt.	14	33.6	33.5	33.2	Sugar Maple
Brook	Cnt.	14	11.6	11.5	11.5	Sugar Maple
Brook	Cnt.	14	21.5	21	20.9	Sugar Maple
Brook	4	15	28.8	28	28	Sugar Maple
Brook	4	15	14.9	15	14.6	Sugar Maple
Brook	4	15	13.8	13.5	13.8	Sugar Maple
Brook	4	15	49.5	49	48.6	Yellow Birch
Brook	4	15	17.5	17.5	17.7	Sugar Maple
Brook	4	15	30.8	30.5	29.9	Sugar Maple
Brook	Cnt.	16	23.2	22.5	22	Sugar Maple
Brook	Cnt.	16	33	32.5	32.5	Sugar Maple
Brook	Cnt.	16	30.3	30	29.7	Basswood
Brook	Cnt.	16	25.6	25.5	25.4	Sugar Maple
Brook	Cnt.	16	26.6	26	26	Sugar Maple
Brook	Cnt.	16	24.4	24	23.9	Sugar Maple
Brook	Cnt.	16	20	19.5	18.9	Sugar Maple
Brook	8	17	22.2	21.5	21.4	Sugar Maple
Brook	8	17	32	31	30.5	Sugar Maple
Brook	8	17	16	17	16.2	Sugar Maple
Brook	8	17	17	17	16.4	Sugar Maple
Brook	8	17	30.5	29.5	29.2	Sugar Maple
Brook	Cnt.	18	14.9	14	13.3	Sugar Maple
Brook	Cnt.	18	13.9	12	12	Sugar Maple
Brook	Cnt.	18	17	16.5	15.7	Sugar Maple
Brook	Cnt.	18	43.3	43	41.8	Sugar Maple

DBH Data Continued:

Site	Treatment	Plot Num.	DBH 2021	DBH 2020	DBH 2019	Species
Brook	Cnt.	18	12.8	12.5	12.5	Sugar Maple
Brook	Cnt.	18	21.5	20.5	20.5	Sugar Maple
Wilf	8	1	25.6	25	24.5	Sugar Maple
Wilf	8	1	21.9	21	21.2	Sugar Maple
Wilf	8	1	27.5	27	27.8	Sugar Maple
Wilf	8	1	17.5	17	16.6	Sugar Maple
Wilf	8	1	35.8	35	34.1	Black Cherry
Wilf	4	2	23	22	22.1	Sugar Maple
Wilf	4	2	21.8	21.4	21.2	Sugar Maple
Wilf	4	2	16.5	16.5	16	Sugar Maple
Wilf	4	2	22.2	22	20.3	Sugar Maple
Wilf	4	2	35.8	35.3	35.1	Sugar Maple
Wilf	4	3	37.9	37.8	37.6	Sugar Maple
Wilf	4	3	10.5	10.5	10.1	Sugar Maple
Wilf	4	3	26.8	26	25.9	Sugar Maple
Wilf	4	3	15.5	15.4	15.2	Sugar Maple
Wilf	4	3	18.9	18.5	18	Sugar Maple
Wilf	4	3	13.7	13.5	12.4	Sugar Maple
Wilf	4	3	27.8	27.6	27.5	Sugar Maple
Wilf	4	3	16.7	16	15.7	Sugar Maple
Wilf	Cnt.	4	15.4	15	15.1	Sugar Maple
Wilf	Cnt.	4	23.3	23	22.5	Sugar Maple
Wilf	Cnt.	4	31.3	30.5	30.5	Sugar Maple
Wilf	Cnt.	4	26.5	26	25.8	Sugar Maple
Wilf	Cnt.	4	21.9	22	22	Sugar Maple
Wilf	Cnt.	4	28	28	27.4	Sugar Maple
Wilf	Cnt.	4	38.4	38	37.1	Sugar Maple
Wilf	Cnt.	5	28.9	29	28.3	Sugar Maple
Wilf	Cnt.	5	24.5	24	24.3	Sugar Maple
Wilf	Cnt.	5	20.4	20	20	Sugar Maple
Wilf	Cnt.	5	29.1	29	28.6	Sugar Maple
Wilf	Cnt.	5	34.3	33	33	Sugar Maple

DBH Data Continued:

Site	Treatment	Plot Num.	DBH 2021	DBH 2020	DBH 2019	Species
Wilf	Cnt.	5	27.6	28	27.5	Sugar Maple
Wilf	Cnt.	5	27.5	27	26.4	Sugar Maple
Wilf	4	6	25.8	25	24.4	Sugar Maple
Wilf	4	6	14.6	14	14.6	Sugar Maple
Wilf	4	6	23.3	21.5	21.8	Sugar Maple
Wilf	4	6	22.1	22	20.6	Sugar Maple
Wilf	4	6	30.5	29.5	28.4	Sugar Maple
Wilf	8	7	12.8	12	10.9	Sugar Maple
Wilf	8	7	36.9	36	35	Sugar Maple
Wilf	8	7	29.7	29.5	29.4	Sugar Maple
Wilf	8	7	30.4	30	29.8	Sugar Maple
Wilf	8	7	14.9	14.5	14	Sugar Maple
Wilf	4	8	30.7	29.5	28.3	Sugar Maple
Wilf	4	8	36.2	35.5	35.5	Sugar Maple
Wilf	4	8	23.4	23	22.6	Sugar Maple
Wilf	4	8	39.2	39	37.7	Sugar Maple
Wilf	4	9	32.5	32	31.5	Sugar Maple
Wilf	4	9	36.8	36.5	36.4	Sugar Maple
Wilf	4	9	22.2	22	21.5	Sugar Maple
Wilf	Cnt.	10	25.4	24.7	24.1	Sugar Maple
Wilf	Cnt.	10	24.9	24	22.9	Sugar Maple
Wilf	Cnt.	10	34.7	34	33.5	Sugar Maple
Wilf	Cnt.	10	29.3	29	28.6	Sugar Maple
Wilf	8	11	23.5	22.5	22	Sugar Maple
Wilf	8	11	41.8	41	40.4	Sugar Maple
Wilf	8	11	11.9	12	11.6	Sugar Maple
Wilf	8	11	16.5	16.5	15.1	Yellow Birch
Wilf	8	11	39.5	38.5	37.4	Sugar Maple
Wilf	8	11	39.3	38.4	37.7	Sugar Maple
Wilf	8	11	29	28	28.2	Sugar Maple
Wilf	Cnt.	12	33.5	30.5	30.4	Sugar Maple
Wilf	Cnt.	12	14.9	13.5	12.4	Sugar Maple
Wilf	Cnt.	12	24.3	24	23.1	Sugar Maple

DBH Data Continued:

Site	Treatment	Plot Num.	DBH 2021	DBH 2020	DBH 2019	Species
Wilf	Cnt.	12	19.6	19.5	18.9	Sugar Maple
Wilf	Cnt.	12	39	39.5	37.7	Sugar Maple
Wilf	8	13	37.2	36.5	35.6	Sugar Maple
Wilf	8	13	13	12.5	11.7	Yellow Birch
Wilf	8	13	17	17	16	Beech
Wilf	8	13	19.3	17	17.2	Sugar Maple
Wilf	8	13	31.5	30.5	29.3	Sugar Maple
Wilf	Cnt.	14	17.8	17	15.7	Sugar Maple
Wilf	Cnt.	14	47.9	47.6	47.5	Sugar Maple
Wilf	Cnt.	14	19.7	19.5	18.6	Sugar Maple
Wilf	Cnt.	14	47.6	46.8	46.4	Sugar Maple
Wilf	Cnt.	14	17.4	17	16.4	Sugar Maple
Wilf	8	15	25	24	23	Sugar Maple
Wilf	8	15	15.5	15	14.5	Iron Wood
Wilf	8	15	38.3	37.5	36.9	Sugar Maple
Wilf	8	15	25.7	25.5	24.9	Sugar Maple
Wilf	Cnt.	16	44.2	43.5	43.2	Sugar Maple
Wilf	Cnt.	16	11	11	10.3	beech
Wilf	Cnt.	16	30.5	29.5	27.9	Sugar Maple
Wilf	Cnt.	16	10.9	10.5	10	Sugar Maple
Wilf	Cnt.	16	13.5	13	13.3	Sugar Maple
Wilf	Cnt.	16	15.3	15	13.7	Sugar Maple
Wilf	Cnt.	16	18.5	18.5	17.5	Sugar Maple
Wilf	Cnt.	16	26.5	26	26	Sugar Maple
Wilf	4	17	39.2	38.5	38	Sugar Maple
Wilf	4	17	12.8	13	12.1	Sugar Maple
Wilf	4	17	12.6	12	11.2	Yellow Birch
Wilf	4	17	13.5	13.5	12.8	Sugar Maple
Wilf	4	17	17.3	17	16.6	Sugar Maple
Wilf	8	18	35.7	35	35.9	Sugar Maple
Wilf	8	18	16.1	15	15.3	Sugar Maple
Wilf	8	18	25.1	25	23.7	Sugar Maple
Wilf	8	18	34.5	34.5	33.3	Sugar Maple

DBH Data Continued:

Site	Treatment	Plot Num.	DBH 2021	DBH 2020	DBH 2019	Species
Mark	4	1	27.7	27	25.9	Sugar Maple
Mark	4	1	19.9	18.5	17.3	Sugar Maple
Mark	4	1	14.5	14	13.6	Sugar Maple
Mark	4	1	31.2	30.5	29.5	Sugar Maple
Mark	8	2	14.3	14	13.3	Sugar Maple
Mark	8	2	20.8	20.5	20	Sugar Maple
Mark	8	2	12.2	11.5	10.9	Sugar Maple
Mark	8	2	14.8	14	13.1	Sugar Maple
Mark	4	3	21.5	21	20.3	Sugar Maple
Mark	4	3	26.5	25.9	25.6	Sugar Maple
Mark	4	3	28.5	28	27.5	Sugar Maple
Mark	4	3	25	24.5	23.3	Sugar Maple
Mark	4	3	42.8	42.5	41.8	Sugar Maple
Mark	4	3	34.9	34.5	33.7	Sugar Maple
Mark	Cnt.	4	44.8	44.5	44.7	Sugar Maple
Mark	Cnt.	4	17	16.5	15.1	Sugar Maple
Mark	Cnt.	4	43.6	42.5	41.6	Sugar Maple
Mark	Cnt.	4	11.7	11.5	10.1	Sugar Maple
Mark	Cnt.	4	15.7	15.5	14.3	Sugar Maple
Mark	4	5	48.2	47.6	47	Sugar Maple
Mark	4	5	32.7	32	31.4	Sugar Maple
Mark	4	5	23.4	23	22.8	Sugar Maple
Mark	4	5	38.5	38	37.2	Sugar Maple
Mark	4	5	13.7	13.5	13.5	Sugar Maple
Mark	4	5	63.9	63.1	62.3	Sugar Maple
Mark	8	6	12.5	12	10.9	Sugar Maple
Mark	8	6	16.5	15.5	14.9	Sugar Maple
Mark	8	6	18.3	17.5	16.7	Sugar Maple
Mark	8	6	14.7	14	13.1	Sugar Maple
Mark	8	6	14.9	14.2	13.2	Sugar Maple
Mark	Cnt.	7	16.7	16.5	16.5	Sugar Maple
Mark	Cnt.	7	13.6	13	12	Sugar Maple
Mark	Cnt.	7	19.9	19.5	18.6	Sugar Maple
Mark	Cnt.	7	29.8	29.5	28.8	Sugar Maple
Mark	Cnt.	7	21	20.5	20.3	Sugar Maple
Mark	Cnt.	7	46.2	45	43.8	Sugar Maple
Mark	8	8	16.9	16.5	15.6	Sugar Maple
Mark	8	8	12.5	12.5	11.5	basswood
Mark	8	8	22.8	21.8	21.2	Sugar Maple
Mark	8	8	10.7	10	10	Sugar Maple
Mark	8	8	16.5	16.5	16.3	Sugar Maple

DBH Data Continued:

Site	Treatment	Plot Num.	DBH 2021	DBH 2020	DBH 2019	Species
Mark	8	8	14.3	14	12.9	Sugar Maple
Mark	4	9	46.2	46	46.2	Sugar Maple
Mark	4	9	29.6	28.5	28.5	Sugar Maple
Mark	4	9	13.2	13	12.5	Sugar Maple
Mark	4	9	15.5	15	14.6	Sugar Maple
Mark	4	9	16.5	15.4	15.4	Sugar Maple
Mark	4	9	20.3	20	19.8	Sugar Maple
Mark	4	9	24.5	23.5	23.2	Sugar Maple
Mark	4	10	13.2	13	12.7	Sugar Maple
Mark	4	10	12.2	12	12.1	Sugar Maple
Mark	4	10	24.2	23	22.1	Sugar Maple
Mark	4	10	28.6	28	26.7	Sugar Maple
Mark	4	10	23.5	23	23.2	Sugar Maple
Mark	4	10	14.2	14	13.3	Sugar Maple
Mark	8	11	22.9	22	21.1	Sugar Maple
Mark	8	11	13.9	13.5	12.7	Sugar Maple
Mark	8	11	19.2	18.5	19	Sugar Maple
Mark	8	11	14.7	14.5	13.1	Sugar Maple
Mark	8	11	20.5	20	17.9	Sugar Maple
Mark	8	11	32.5	32.5	35.8	Sugar Maple
Mark	8	12	18.9	18	18.5	Sugar Maple
Mark	8	12	51.3	51	51	Sugar Maple
Mark	8	12	12.6	12.5	12.8	Sugar Maple
Mark	8	12	53.1	53	52.3	Sugar Maple
Mark	4	13	22.3	21.2	20.4	Sugar Maple
Mark	4	13	13.5	13	12.4	Sugar Maple
Mark	4	13	25.4	25	24.5	Sugar Maple
Mark	4	13	17	16.5	15.9	Sugar Maple
Mark	4	13	12.6	12.5	12.4	Sugar Maple
Mark	4	13	21.2	21	19.7	Sugar Maple
Mark	4	13	18.5	18.5	17.6	Sugar Maple
Mark	Cnt.	14	19.3	19	18	Sugar Maple
Mark	Cnt.	14	13.5	13.5	13.7	Sugar Maple
Mark	Cnt.	14	20.5	20	19.2	Sugar Maple
Mark	Cnt.	14	14.7	14.5	14.1	Sugar Maple
Mark	Cnt.	14	20	19.5	19.4	Sugar Maple
Mark	Cnt.	14	12	11.5	11.3	Sugar Maple
Mark	8	15	12.3	12	11.7	Sugar Maple
Mark	8	15	13.9	13.5	12.3	Sugar Maple
Mark	8	15	17.8	17	16.3	Sugar Maple
Mark	8	15	12.5	12	11.3	Sugar Maple
Mark	8	15	13.4	13	13.6	Sugar Maple
Mark	8	15	23.7	23	22.9	Sugar Maple
Mark	8	15	18.5	18	16.2	Sugar Maple

DBH Data Continued:

Site	Treatment	Plot Num.	DBH 2021	DBH 2020	DBH 2019	Species
Mark	Cnt.	16	20	20	19.3	Sugar Maple
Mark	Cnt.	16	15.8	15	14.1	Sugar Maple
Mark	Cnt.	16	13.5	12	12.1	Sugar Maple
Mark	Cnt.	16	18.7	17.5	17.3	Sugar Maple
Mark	Cnt.	16	20.2	19	19	Sugar Maple
Mark	Cnt.	16	25.2	24	23	Sugar Maple
Mark	Cnt.	17	32.2	31	30.6	Sugar Maple
Mark	Cnt.	17	17.5	17.5	16.5	Sugar Maple
Mark	Cnt.	17	19	19	18.5	Sugar Maple
Mark	Cnt.	17	11.8	11	11.2	Sugar Maple
Mark	Cnt.	17	16	15.5	15.3	Sugar Maple
Mark	Cnt.	17	13.5	13.5	13.2	Sugar Maple
Mark	Cnt.	18	26.9	26.5	26	Beech
Mark	Cnt.	18	11.4	11	11.5	Sugar Maple
Mark	Cnt.	18	22.5	22	22.8	Sugar Maple
Mark	Cnt.	18	10.9	10.8	10	Sugar Maple
Mark	Cnt.	18	13	13	13.1	Sugar Maple
Mark	Cnt.	18	19.7	19	19.4	Sugar Maple