Utilization of Wood Ash as a Potential Remediation for Hardwood Forests: Baseline Soil Chemistry

Trent Community Research Project Completed by Anieca Lloyd

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1.0 Introduction

1.1. Acid Deposition of Sugar Maple Forests in the Canadian Shield

Air pollution abatement in Canada has generally been successful in decreasing deposition of targeted compounds (Venkatesh et al. 2000; Miller and Watmough, 2009). Southern Ontario still receives the highest level of air pollution in Canada despite a 50% reduction in sulphur dioxide (SO₂) emissions (Miller and Watmough, 2009; Bal et al. 2014). In addition, critical-load estimates for acidity suggest that half of the forested area in Ontario are at risk from sulphur (S) and nitrogen (N) deposition (Schaberg et al. 2017; Hutchinson et al. 1999; Hutchinson et al. 1998). Atmospheric deposition of strong acids can leach essential nutrients from canopy leaves and affect trees health by altering soil nutrient pools (Miller and Watmough, 2009). Leaching losses of calcium (Ca), magnesium (Mg), and potassium (K) are major concerns in eastern North America, where acid deposition is high and has been correlated with sugar maple (Acer saccharum) decline (Miller and Watmough, 2009; Bal et al. 2014). Several studies have suggested acid deposition has led to decreases in soil exchangeable Ca that also contributes to poor sugar maple health (Bal et al. 2014). An increased deposition of sulfate (SO₄) is correlated with increased soil base cation leaching and decreased acid neutralizing capacities of local stream water (Bal et al. 2014; Schaberg et al. 2017). The reduction in available soil base cations is caused by the exchange of H+ ions into the soil solution, which releases cations and facilitates leaching to surface waters (Bal et al. 2014). Calcium in plants is essential for structural integrity and stress response (Schaberg et al. 2017). Acid rain affects a plant’s stress response making them more vulnerable to damage following exposure to stresses (Schaberg et al. 2017). These stresses threaten sugar maples social, cultural, economic, and ecological values.
1.2. Sugar Maple Value and Vulnerability to Calcium Loss

Sugar Maple is a keystone species in eastern Canada and north eastern United States with its lumber and maple syrup widely used, while its iconic bright orange and red leaves are a major tourist attraction in the fall (Horsley et al. 2002; Ballard, 2000). Due to its economic and social importance, the sustained health of the sugar maple is important in both managed and unmanaged forests (Horsley et al. 2002; Brown et al. 2015; Turner, 2019). Ecologically, sugar maples provide nutrient-rich litter to forest soils, promote N mineralization and reduces leaching of nitrate into groundwater (Juice et al. 2006). Economically, they provide raw materials for hardwood furniture and flooring as well as the maple syrup industry (Juice et al. 2006; Murphy et al. 2009). Production of maple sugar products is based on sap flow which is caused by positive internal pressure (Skinner et al. 2010; Horsley, 2002). There is a well established and predictable relationship between sap flow and altering-freezing and thawing temperatures (Skinner et al. 2010). Due to this physical relationship between temperature and internal pressure, sap is influenced by climate warming in addition to site-specific soil moisture, tree health, and snow cover (Skinner et al. 2010). When mature trees established themselves, it was under different growing conditions and when acidic conditions are introduced it speeds the loss of soil base cations including Ca, Mg, and K (Brown et al. 2015; Schaberg, 2017). Not only is Ca more vulnerable to leaching loss and soil depletion, Ca deficiencies are particularly damaging to trees because Ca-dependent physiology is crucial to maintaining tree heath (Schaberg, 2017; Watmough et al. 2019). Although legislation has greatly reduced acidic atmospheric deposition in North America, soils are still experiencing long-term acidification and base cation depletion, which in turn affects forest productivity (Bal et al. 2015; Schaberg et al. 2006).
Calcium provides two basic functions; 1) to enhance structural integrity of cells walls and membranes and 2) as a single agent that helps cells regulate carbon metabolism and stress response (Schaberg, 2017). In cell wall formation, Ca plays a role in physiological mechanisms of cold tolerance, oxidation and stress response factors associated with sugar maple vigour and health (Bal et al. 2015). Deficiencies of Ca impair cellular stress response systems predisposing trees to be more vulnerable to damage after exposure to environmental stresses that would have otherwise not been consequential (Schaberg, 2017). Recruitment, crown vigor and foliar nutrition of sugar maples tend to be lower on base cation poor soil relative to base cation rich soils (Bishop et al. 2015). Calcium poor soils predisposes trees to dieback due to diminished health from environmental stresses such as soil acidification and lumber harvesting causing a nutrient imbalance and leaf loss (Hallett et al., 2006; Bal et al. 2015). However, mitigative approaches are being explored to reduce leaching of essential base cations.

1.3. Mitigative Efforts for Calcium Decline

The decline in Ca concentration in the Canadian Shield forest soils and lakes in eastern North America (Azan et al. 2019) has resulted in studies to investigate whether Ca rich non-industrial wood ash application may be used to address the situation (Bieser and Thomas, 2019). The application of wood ash in Canadian forests is potentially a sustainable way to manage the waste product that has historically been landfilled (Hannam et al. 2018; Basiliko and Jones, 2019). Application of wood ash to forests can mimic some of the effects of wildfire, to replace nutrients removed during harvesting, counteracting the negative effects of acid deposition, and improve tree growth (Hannam et al. 2018; Reid and Watmough, 2014). Currently, the provincial and territorial processes for obtaining regulatory approval are challenging, but benefits have been found with biodiversity, water quality and the productivity of Canadian forests which have
shown policy makers the benefits of wood ash application (Hannam et al. 2018). The benefits of wood ash are dependent on soil type, soil pH, and the dosage (Qin et al. 2017; Bieser and Thomas, 2019). Reid and Watmough (2014) determined that base saturation and tree growth were the most responsive properties to wood ash in a long-term study. The analysis indicated that the addition of Ca is not universally beneficial, indicating that sites with nutrient poor acidic soils are expected to have the best response to the application (Reid and Watmough, 2014).

As it is recognized that the potential beneficial response of forests to wood ash additions is highly dependent on prior soil conditions, the objective of this report is to describe baseline soil chemistry at three sugar bush sites in Muskoka prior to the application of residential wood ash. These data will be compared with data collected as part of a regional survey (McDonough, 2011) and values published in the literature. This study focuses on Ca, Mg and K as well as soil pH and soil organic matter.

2.0. Site Description and Sampling Methods

2.1. Muskoka

The Region of Muskoka in Ontario is bounded by Georgian Bay to the west, Haliburton to the east and Simcoe to the south (Figure 1) (Ifeesey, 2018). The region was named for Chippewa Chief Mesquas Ukee who negotiated the land claim for the territory in the mid-1800s (Ifeesey, 2018). The land is situated on the lower tip of the Canadian Shield, which is the world’s largest area of pre-Cambrian rock (Ifeesey, 2018). This landscape is marked by rock formations, which carved the lakes and rivers in prehistoric times by retreating glaciers (Marsh and Dale, 2009). Muskoka contains a total of nineteen watersheds (1,600 lakes) all beginning in Algonquin Park and flowing westward into Georgian Bay (Marsh and Dale, 2009). This geological
formation is approximately 4.5 billion years old and is the core of the North American continent (Ifeesey, 2018). After a land settlement in 1860 the region was available for lumber production, white settlement, and sight seeing (Ifeesey, 2018; Marsh and Dale, 2009). Sight seeing and guided tours started to become popular in the late 1860s with tourists exploring the pristine landscape comprising of watersheds and mixed forests (Ifeesey, 2018).

The District Municipality of Muskoka occupies an area of 6,475 km² in Southern Ontario which includes the towns of Bracebridge, Gravenhurst and Huntsville, Wahta Mohawk and Moose Deer Point First Nations, as well as the townships of Georgian Bay, Lake of Bays and Muskoka Lakes (Marsh and Dale, 2009). Today, Muskoka is part of one of the larger cottage communities in Ontario, with most of Muskoka Islands and waterfront properties being privately owned (Marsh and Dale, 2009). The region of Muskoka is transitional between conifer forests in the north and deciduous forests in the south (Marsh and Dale, 2009). Soft wood species including white pine (Pinus strobus), red pine (Pinus resinosa), eastern hemlock (Tsuga canadensis), and white spruce (Picea glauca), which were harvested in the lumber boom in the late 19th century, have since regrown (March and Dale, 2009). Hard-wood species include beech (Fagus Americana), red oak (Quercus rubra), yellow birch (Betula alleghaniensis), and sugar maple (March and Dale, 2009).
Calcium depletion of soils in Muskoka can be attributed to decades of atmospheric acid deposition and forest harvesting (Azan et al., 2019; Reid and Watmough, 2014). This decline causes reduced growth, health and vigour, decreased regeneration and reduced foliage health in sugar maple trees (Azan et al., 2019). To address this issue, the ASHMuskoka project, an initiative of the Friends of Muskoka Watershed seeks to remediate Ca depleted soils in Muskoka through applied research, the development of residential wood ash recycling programme, and educational awareness of the issue (ASHMuskoka, 2020).

2.2. Site Description

The ASHMuskoka project is being initiated at three sugar maple bushes (Figure 3): Marks Muskoka Maple (lat. 45.282712, long -79.148108), Creasor Family Sugar Bush (lat.
45.219953, long -79.446722) and Brooklands Farm (lat. 45.08197, long -79.46246). Each of these privately-owned sugar bushes are within 35 kilometers of each other, are used for tapping sugar maple trees, and were chosen because of the enthusiastic support of the property owners and to get a range of forest characteristics that typify sugar bushes. Of the area sampled Mark’s Muskoka Maple site had 98% sugar maple trees along with beech and balsam fir (Abies balsamea). Brooklands Farm had 94% sugar maple trees along with beech, basswood (Tilia Americana), yellow birch and white ash. Creasor Family Sugar Bush had 92% sugar maple along with black cherry (Prunus serotina), white ash, yellow birch, beech and ironwood (Ostrya virginiana).

2.3. Field Sampling

To characterize soil conditions at the three sites prior to wood ash application 20 plots were established at each of the sample sites each measuring 10 meters by 10 meters. Plots were randomly selected but required sugar maple saplings and at least two mature sugar maple trees within the defined boundaries. This was to collect and assess the foliage of mature trees and saplings from a compiled representation of each plot [not included in this study]. Sampling occurred in late August and early September 2019 with an average daily high of 20 degrees Celsius.

2.3.1 Sugar Maple DBH

All trees with a diameter at breast height (DBH) greater than 10cm in each plot were measured and recorded at each of the three Muskoka sites.
2.32 Soil Samples

Soil samples were collected from each corner and the centre of each plot (Figure 2). Soil samples were collected from litter material, fermentation-humus (FH) layer, and mineral soil (0-15cm) [totaling 15 samples per plot]. Litter material was collected by removing the leaf litter from the top layer of the soil by hand and placing into a labeled paper bag. The FH layer was also collected by removing by hand and placed into a labeled paper bag. Upper mineral soil was collected using a soil auger, by placing it in the same place where the FH and litter material were collected and turning the handle until the auger was well below the soil surface. Soil samples for each horizon within each plot were bulked to obtain a composite sample, resulting in 20 samples per horizon per site and 180 samples in total.

Figure 2: Outline of a sampling plot (10 x 10 meters). Each red square indicates an approximate sampling point.

2.4. Laboratory Analysis

Soils were analyzed for pH, loss of ignition (LOI), and exchangeable base cations as described below. Additional analyses were also conducted [e.g. metals], but these are not part of this study.
2.41. Soil pH

Soil pH was measured for the three-soil horizons for all 20 plots at each of the three Muskoka sites. A calcium chloride (CaCl₂) slurry at a ratio of 1:5 was used [5g soil:25 mL CaCl₂], samples were shaken for one hour, set to rest for one hour and then the pH was measured. The pH values were averaged to obtain site averages per soil horizon.

2.42. Loss of Ignition

Approximately 5 g of soil was weighed for LOI for each soil sample collected. Each sample was oven dried at 100 degrees Celsius for 24 hours, weighed for dry weight then placed in the oven to bake at 400 degrees Celsius for 8 hours for the ash weight. To determine the percent of organic matter in each soil sample measured (in grams) was completed using the following equation: \[ \frac{(\text{dry-ash})}{\text{dry}} \times 100\%. \]

2.43. Exchangeable Base Cations

This procedure required a Buchner funnel with rubber seal, two side arms flasks, two filter papers and a vacuum hose. Soil samples were oven dried at 120 degrees Celcius, passed through a 2 mm sieve, organic soils were weighed to 1 g (litter and FH) and mineral soil was weighed to 5g. Each soil sample was placed into 50 ml conical tubes. Using a graduated cylinder, 25 ml of 1 M ammonium chloride (NH₄Cl) is transferred into the conical tubes containing the samples. The filtration system was setup to the vacuum spigot and the filter was placed in the funnel ensuring the entire surface was covered. The moisture trap was connected, and the vacuum pump was turned on. With the vacuum on, the soil is poured into the funnel. While the solution is draining, an additional 25-mL of NH₄Cl is added to the Buchner funnel. The NH₄Cl is left to drain completely into the flask. Once the soil is drained, the 50 ml solution
is poured into the corresponding labelled falcon tube. Base cations Ca, Mg, K and Na are then analyzed by ICP-OES.

2.5 ArcGIS Maps

Regional mineral soil (A horizon) data compilations from seventy sugar maple locations across southern Ontario (McDonough, 2011) were used along with data from the three Muskoka sites to generate regional maps. Data was sorted in Excel to be imported into ArcGIS so that it could be converted into a point file with base cation concentrations and site coordinates (latitude and longitude). The interpolation tool IDW on ArcGIS was used with the point file to obtain raster maps (Figure 4, 5, and 6) of the chemical gradients and a regional map of the area (Figure 3).

3.0 Results

3.1. Basal Area and Stem Density

Table 1: Stem density and basal area for all sampled trees at each of the three sugar bush sites in Muskoka.

<table>
<thead>
<tr>
<th>Site</th>
<th>Stem Density Mean (stem/ha)</th>
<th>Stem Density SD (stem/ha)</th>
<th>Basal Area Mean (m²/ha)</th>
<th>Basal Area SD (m²/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brooklands Farm</td>
<td>635</td>
<td>167</td>
<td>26</td>
<td>8</td>
</tr>
<tr>
<td>Creasor Family Sugar Bush</td>
<td>555</td>
<td>158</td>
<td>33</td>
<td>10</td>
</tr>
<tr>
<td>Mark’s Muskoka Maple</td>
<td>695</td>
<td>194</td>
<td>28</td>
<td>17</td>
</tr>
</tbody>
</table>

In general stem density and basal area were similar at the 3 sites (Table 1). Marks Muskoka Maple site had the highest average stem density (Table 1) for all the trees sampled with
695 stems/ha (SD 194 stem/ha). Creasor Family Sugar Bush had the lowest stem density (Table 1) with the average of 555 stems/ha (SD 158 stems/ha).

Creasor Family Sugar Bush site had the highest basal area average with 33 \( m^2/ha \) (SD 10 \( m^2/ha \)), while Brookland’s Farm had the lowest basal area average with 26 \( m^2/ha \) (SD 8 \( m^2/ha \)).

All sites were dominated by sugar maple and in general sugar maple density and basal area were similar at the three sites (Table 2).

Table 2: Stem density and basal area of sugar maple trees sampled at each of the three sugar maple sites in Muskoka.

<table>
<thead>
<tr>
<th>Site</th>
<th>Stem Density Mean (stem/ha)</th>
<th>Stem Density SD (stem/ha)</th>
<th>Basal Area Mean ( (m^2/ha) )</th>
<th>Basal Area SD ( (m^2/ha) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brookland’s Farm</td>
<td>600</td>
<td>162</td>
<td>23</td>
<td>7</td>
</tr>
<tr>
<td>Creasor Family Sugar Bush</td>
<td>510</td>
<td>155</td>
<td>31</td>
<td>10</td>
</tr>
<tr>
<td>Mark’s Muskoka Maple</td>
<td>685</td>
<td>195</td>
<td>28</td>
<td>17</td>
</tr>
</tbody>
</table>

The highest number of percent sugar maples was 98% at Marks Muskoka Maple site. Mark’s Muskoka Maple site has the highest average stem density for sugar maples (Table 2) with 685 stem/ha (SD of 195.40 stem/ha). The lowest percent of sugar maples of 92% was at Creasor Family Sugar Bush site which also has the lowest stem density with 510 stems/ha (SD of 155.25 stem/ha), and the highest average BA with 31 \( m^2/ha \) and a SD of 10 \( m^2/ha \).

3.2. Regional Soil Exchangeable Base Cation Concentrations

Calcium concentrations (Figure 4) were between 0.027 meq/100g soil and 27.63 meq/100g soil with the highest concentrations near Lake Huron, Lake Ontario and east Ottawa area. Soil Mg concentrations (Figure 5) displayed a similar pattern regionally with values between 0.021 meq/100g soil and 9.31 meq/100g soil. Soil K (Figure 6) exhibited different
spatial patterns with values between 0.020 meq/100g soil and 0.83 meq/100g soil with the highest concentrations near Muskoka, Ottawa and Niagara Falls. The Muskoka sites are among the lowest regionally for Ca, Mg and K.

Figure 3: Site map displaying sample locations of sugar maple stands (McDonough, 2011) in Southern Ontario, Canada. The sample locations in this study are indicated by colour in the legend. Note the names are abbreviated for conciseness in the legend and the sites are as follows brook (Brooklands Farm), Mark (Mark’s Muskoka Maple) and Wilf (Creasor Family Sugar Bush).
Figure 4: Map of Southern Ontario, Canada displaying regional Ca concentration data (McDonough, 2011). The three Muskoka sample locations in this study are indicated by the colours on the legend for approximate Ca concentrations in units of meq/100g. Note the site names are abbreviated for conciseness in the legend and the sites are as follows: Brook (Brooklands Farm), Mark (Mark’s Muskoka Maple) and Wilf (Creasor Family Sugar Bush).

Figure 5: Map of Southern Ontario, Canada displaying regional Mg concentration data (McDonough, 2011). The three Muskoka sample locations in this study are indicated by the colours on the legend for approximate Mg concentrations in units of meq/100g. Note the site names are abbreviated for conciseness in the legend and the sites are as follows: Brook (Brooklands Farm), Mark (Mark’s Muskoka Maple) and Wilf (Creasor Family Sugar Bush).
Soil baseline concentrations of Ca at the three Muskoka sites are among the lowest observed regionally (Figure 8). Calcium concentrations in the mineral layer of soil at all three sites are in the lower end of those observed regionally (Figure 4 and Table 3). Soil exchangeable base cations are highest in organic horizons compared with mineral soils at all sites. The highest mean Ca concentration of 1.69 meq/100g soil was found at Mark’s Muskoka Maple. While in contrast Mark’s Muskoka Maple had the lowest K of 0.09 meq/100g soil in the mineral layer (Figure 10). The highest Mg concentration was at Brooklands Farm with 0.23 meq/100g soil (Table 3 and Figure 9). As shown in Figure 7, the pH at all three sites in each soil horizon are below 5 indicating acidic conditions. The most acidic soil was in the mineral layer at Brooklands Farm with a pH of 3.72 (Table 3). Organic matter in the mineral soil is also low (<20%) at all three sites further suggesting acidic conditions (Figure 6).
Table 3: Mean concentrations of Ca, Mg, K (meq/100g per soil) and mean pH values for each soil depth at each of the three Muskoka sites.

<table>
<thead>
<tr>
<th>Value</th>
<th>Mark’s Muskoka Maple</th>
<th>Creasor Family Sugar Bush</th>
<th>Brooklands Farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca Litter (meq/100g)</td>
<td>18.51</td>
<td>13.91</td>
<td>13.99</td>
</tr>
<tr>
<td>Ca FH (meq/100g)</td>
<td>23.69</td>
<td>6.58</td>
<td>8.25</td>
</tr>
<tr>
<td>Ca Min (meq/100g)</td>
<td>1.69</td>
<td>0.55</td>
<td>1.51</td>
</tr>
<tr>
<td>Mg Litter (meq/100g)</td>
<td>2.84</td>
<td>2.98</td>
<td>3.06</td>
</tr>
<tr>
<td>Mg FH (meq/100g)</td>
<td>2.81</td>
<td>1.08</td>
<td>1.38</td>
</tr>
<tr>
<td>Mg Min (meq/100g)</td>
<td>0.17</td>
<td>0.16</td>
<td>0.23</td>
</tr>
<tr>
<td>K Litter (meq/100g)</td>
<td>1.67</td>
<td>1.65</td>
<td>1.44</td>
</tr>
<tr>
<td>K FH (meq/100g)</td>
<td>1.29</td>
<td>0.56</td>
<td>0.63</td>
</tr>
<tr>
<td>K Min (meq/100g)</td>
<td>0.09</td>
<td>0.13</td>
<td>0.11</td>
</tr>
<tr>
<td>pH Litter</td>
<td>4.60</td>
<td>4.23</td>
<td>4.60</td>
</tr>
<tr>
<td>pH FH</td>
<td>4.11</td>
<td>3.58</td>
<td>3.86</td>
</tr>
<tr>
<td>pH Min</td>
<td>3.91</td>
<td>3.83</td>
<td>3.72</td>
</tr>
</tbody>
</table>
Figure 6: Soil organic matter (LOI) by soil horizon at the three sugar bush sites in Muskoka. The error bars indicate the standard deviation.

Figure 7: The average pH values by soil horizon at the three sugar bush sites in Muskoka. The error bars indicate the standard deviation.
Figure 8: Regional calcium mineral soil (McDonough, 2011) concentrations (meq/100g soil) per number of samples. Arrows indicate the concentration found at each of the three Muskoka sites.

Figure 9: Regional magnesium mineral soil (McDonough, 2011) concentrations (meq/100g soil) per number of samples. Arrows indicate the concentration found at each of the three Muskoka sites.
3.3. Soil Base Cation Values in the Published Literature

Literary studies in Ontario, Quebec and north eastern United States were used to compile average sugar maple Ca, Mg, and K data (Table 4). The mean Ca concentration (Table 4) from sixteen studies in eastern North America was 7.81 meq/100g soil (SD 13.19 meq/100g soil) although, most of the research papers measured Ca concentrations below 7.81 meq/100g soil, with the lowest measured 0.003 meq/100g soil (Horsley et al. 2009). The mean Mg concentration (Table 4) was 2.46 meq/100g soil (SD 3.76 meq/100g soil), although most of the research papers measured Mg concentrations below 2.25 meq/100g soil with the lowest measured 0.003 meq/100g soil (Watmough et al. 2019). The mean K concentration (Table 4) was 2.39 meq/100g soil (SD 6.37 meq/100g soil) with the lowest measured 0.0005 meq/100g soil (Horsley et al. 2009).
Table 4: Calcium, Magnesium, and Potassium mineral soil concentrations of sugar maple forests in Ontario, Quebec and the north eastern United States in units of meq/100g soil. A ‘0’ means that that value was unavailable in the corresponding research paper. Original data has been converted into units of meq/100g soil for clarity of reporting an average value.

<table>
<thead>
<tr>
<th>Source</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bailey et al. 2006</td>
<td>40.31</td>
<td>9.10</td>
<td>20.49</td>
</tr>
<tr>
<td>Berger et al. 2001</td>
<td>13.70</td>
<td>5.62</td>
<td>16.75</td>
</tr>
<tr>
<td>Bélanger et al. 2002</td>
<td>0.005</td>
<td>0.009</td>
<td>0.002</td>
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<tr>
<td>Bilodeau-Gauthier et al. 2011</td>
<td>1.93</td>
<td>0.32</td>
<td>0.12</td>
</tr>
<tr>
<td>Casson et al. 2012</td>
<td>1.94</td>
<td>0.55</td>
<td>0.16</td>
</tr>
<tr>
<td>Carlson et al. 2005</td>
<td>1.35</td>
<td>0.46</td>
<td>0.18</td>
</tr>
<tr>
<td>Cho et al. 2010</td>
<td>1.37</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Duchesne et al. 2002</td>
<td>1.03</td>
<td>0.33</td>
<td>0.08</td>
</tr>
<tr>
<td>Horsley et al. 2009</td>
<td>0.003</td>
<td>0.0051</td>
<td>0.0005</td>
</tr>
<tr>
<td>Horsley et al. 1997</td>
<td>1.68</td>
<td>0.41</td>
<td>0.04</td>
</tr>
<tr>
<td>Juice et al. 2006</td>
<td>3.75</td>
<td>10.4</td>
<td>0</td>
</tr>
<tr>
<td>Long et al. 2000</td>
<td>40.5</td>
<td>9.1</td>
<td>0</td>
</tr>
<tr>
<td>McDonough, 2011</td>
<td>7.72</td>
<td>1.51</td>
<td>0.17</td>
</tr>
<tr>
<td>Miller and Watmough, 2009</td>
<td>5.30</td>
<td>1.01</td>
<td>0.14</td>
</tr>
<tr>
<td>Sharpe and Kogelmann, 2006</td>
<td>4.40</td>
<td>0.63</td>
<td>0.13</td>
</tr>
<tr>
<td>Watmough et al. 2019</td>
<td>0.02</td>
<td>0.003</td>
<td>0.0007</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>7.81</td>
<td>2.46</td>
<td>2.39</td>
</tr>
<tr>
<td><strong>Standard Deviation</strong></td>
<td>13.19</td>
<td>3.76</td>
<td>6.37</td>
</tr>
</tbody>
</table>

4.0. Discussion

The goal of the ASHMuskoka Project is to restore sugar maple forests soil to their pre-acid deposition conditions (Azan et al. 2019). However, research has shown that the response to nutrient amendments depends on the baseline site conditions and only nutrient poor acidic sites are expected to benefit from the addition of residential wood ash (Reid and Watmough, 2014). Soils throughout central Ontario have lost soil base cations because of historically high levels of acid deposition (Bailey et al. 2006; Bal et al. 2014). Casson et al. (2011) found that acidic sites had a lower percentage of base cations including Ca and Mg. Studies have shown that the
addition of Ca rich wood ash in sugar maple forests improved productivity, tree growth, stress response and increased cation exchange capacity (Hannam et al. 2018; Basiliko and Jones, 2019).

In the literature, critical base cation concentrations are usually based on foliar chemistry rather than soil value as it is a better representation of available base cations (Casson et al. 2012). Miller and Watmough (2009) found that sugar maple foliar Ca dropped below the critical value (6000 mg/kg) when surface mineral soil (Ah horizon) Ca concentration fell below 1.2 meq/100g soil. The average literary Ca value (Table 4) found was 7.81 meq/100g soil. Most studies had values above this critical value although some studies did report lower values and linked these to poor sugar maple health (Horsley et al. 2009; Berger et al. 2001).

In the present study, Ca, Mg and K concentrations at the three sites are among the lowest values that have been measured regionally. In this study, Creasor Family Sugar Bush was the only site that fell below the 1.2 meq/100g soil value in mineral soil (Table 3) with a value of 0.55 meq/100g soil although the other two sites had soil Ca levels close to this reported critical threshold. Critical soil levels for Mg and K have not been established, but values at the three Muskoka sites were found to have some of the lowest concentrations regionally. Studies in Quebec (Bernier and Brazeau, 1988; Ouimet et al. 1995) have suggested that sugar maple decline is caused by deficiencies of Mg and K, hence adding wood ash that is rich in the base cations Ca, Mg and K will likely be beneficial to sugar maples at all three sites.

5.0. Conclusion

This study shows that soil Ca, Mg and K at the three sites are among the lowest found regionally and are at or below reported critical values for sugar maple nutrition. All sites were
acidic and had soil pH values that were below the optimum pH (<5) for sugar maple. The addition of Ca rich residential wood has been shown to significantly increase the cation exchange capacity and increased the alkalinity (Pare et al. 1993; Hannam et al. 2018; Basiliko and Jones, 2019). The benefits of soil Ca amendments is dependent on-site conditions, duration of acid deposition, and the behaviour of the soil to nutrient amendments (Pare et al. 1993; Likens et al. 1997). Given the low nutrient status of the three Muskoka sugar bushes it is expected that soils and vegetation will respond positively to residential wood ash if soil Ca levels are raised above the limiting threshold.
6.0. References


