Wood Pellet Ash as an Agricultural Soil Amendment in the Northwest Territories

Research Study

Prepared by Ecology North

For the Territorial Farmers Association

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This study into the options for using wood pellet ash as an agricultural soil amendment in the NWT was commissioned by the Territorial Farmers Association in 2014 with funding from the Canadian Agricultural Adaptation Program. This report was researched and written by Alex Cool-Fergus, research intern at Ecology North, Yellowknife, Northwest Territories.

The Territorial Farmers Association (TFA) represents the interest of Northwest Territories farmers and gardeners at local, territorial and national levels. TFA actively promotes northern agriculture and supports relevant research related to growing local food.

Ecology North is an environmental non-governmental organization founded in 1971 in Yellowknife. Ecology North works on subjects relating to public environmental awareness and education, climate change and sustainable living. With a mission to bring people and knowledge together for a healthy northern environment, it has staffed offices in Yellowknife and Hay River and works in partnership with communities across the territory.

For more information or to access copies of this report, please contact the Territorial Farmers Association (www.farmnwt.com) or Ecology North (www.ecologynorth.ca).

ABSTRACT

Samples of fly ash and bottom ash from wood pellet boilers and stoves were analyzed to determine their suitability as an agricultural soil amendment, including testing physical characteristics and concentration of elements or compounds that could be toxic or limiting to plant growth. Wood pellet ash is rich in potassium and certain micronutrients. It is also highly alkaline and has high acid neutralizing values.

Results from this study showed that of the three bottom ash and three fly ash samples collected from wood pellet boilers in Yellowknife, two bottom ash samples were found to meet Alberta Environment (2002) standards as an agricultural soil amendment, provided the ash is amended with water to meet the minimum recommended moisture content, or it is added to moist compost. One bottom ash sample, and all three fly ash samples did not meet Alberta Environment (2002) standards, due to high boron levels. None of the three residential wood pellet stove ash samples tested met Alberta Environment (2002) standards for use as an agricultural amendment, due to high boron levels.

Soil or compost to be amended with wood pellet ash should be tested to determine the appropriate rate of wood pellet ash addition. Due to its very high pH, wood pellet ash is primarily suitable as a liming agent to increase the pH of low-pH soils, or as an amendment to compost. Care should be taken when adding wood pellet ash to soil or compost, due to its very high pH and reactive nature.

EXECUTIVE SUMMARY

The amount of wood pellet ash is increasing in the Northwest Territories (NWT) as biomass heating systems are developed. Wood ash from cordwood is used in southern Canada as a liming material for acidic agricultural soils. Other jurisdictions currently use wood pellet ash as an amendment for forested soils to recycle nutrients and increase forest regrowth. This study aims to fill the knowledge gap about the use of wood pellet ash as a soil amendment to increase garden productivity in the NWT. The goal is to assemble information about the properties of wood pellet ash produced in the Northwest Territories and if ash could contribute to vegetable production in this jurisdiction.

Samples of fly ash and bottom ash from wood pellet boilers and stoves were analyzed to determine the amount of nutrients and content of potential toxic or limiting materials. Results show that wood pellet ash is rich in potassium and certain micronutrients. It is also highly alkaline and has high acid neutralizing values.

We recommend that NWT residents or businesses that would like to determine if the wood pellet ash produced in their boiler or stove is suitable for use as an agricultural amendment test their wood pellet ash to determine if it meets the standards and guidelines identified in the *Standards and Guidelines for the Use of Wood Ash as a Liming Material for Agricultural Soils* (Alberta Environment 2002). This study showed that of the three bottom ash and three fly ash samples collected from wood pellet boilers in Yellowknife, two bottom ash samples were found to meet the Alberta Environment (2002) standards, provided the ash is amended with water to meet the minimum recommended moisture content, or it is added to moist compost. One bottom ash sample, and all three fly ash samples did not meet Alberta Environment (2002) standards, due to high boron levels. None of the three residential wood pellet stove ash samples tested met Alberta Environment (2002) standards for use as an agricultural amendment, due to high boron levels.

Soils or compost that are to be amended with wood pellet ash should be tested to determine the appropriate rate of addition of the wood pellet ash. Due to its very high pH, wood pellet ash is primarily suitable as a liming agent to increase the pH of low-pH soils, or as an amendment to compost. Care should be taken when adding wood pellet ash to soil or compost, due to its very high pH and reactive nature.

There is a need for further research on soil characteristics in NWT gardens to best determine recommended wood pellet ash application rates, and a need for agricultural trials using wood pellet ash as an agricultural amendment.

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LIST OF ACRONYMS

NWT	Northwest Territories
EN	Ecology North
CAAP	Canadian Agricultural Adaptation Program
GNWT	Government of the Northwest Territories
PAH	Polycyclic Aromatic Hydrocarbons
CSB	Combined Services Building
dS/m	Decisiemens per metre
SAR	Sodium Adsorption Ratio
EC	Electrical Conductivity
CCE	Calcium Carbonate Equivalent
ANV	Acid Neutralizing Value
$CaCO_3$	Calcium Carbonate
CCME	Canadian Council of Ministers of the Environment
CaO	Calcium Oxide
Zn	Zinc
Cu	Copper
Fe	Iron
Mn	Manganese
B	Boron
Ca	Calcium
K	Potassium
N	Nitrogen
P	Phosphorus
C	Carbon
Mg	Magnesium
Cd	Cadmium

INTRODUCTION

Rising fuel prices and environmental concerns have spurred a rapid increase in the installation of biomass heating systems in the Northwest Territories (NWT), most notably wood pellet boilers and wood pellet stoves. With the help of initiatives such as the Alternative Energy Technologies Program[1] and the Energy Efficiency Initiative Program[2], many institutions and home-owners are converting from using fossil fuels to installing commercial or residential wood pellet boilers as their primary source of heating. Across the NWT, wood pellet biomass systems produce approximately 90 tonnes of wood pellet ash per year (Pelkey, 2014). As the NWT Biomass Strategy is implemented and wood pellet stoves and boilers become more common in homes and institutions across the Territory, this number is projected to increase. Presently, wood pellet ash is discarded to NWT landfills, adding to the growing amount of garbage and resulting in management costs for businesses, residents and municipalities. However, there are many potential ways to reuse this waste material.

Wood pellets are made by compressing the woody by-products from sawmills and wood into highly uniform pellets of dried wood. They contain no additives or glue. Wood pellet stoves and boilers have long been used in Northern European countries to reduce the use of fossil fuel-based heating systems that are costly to operate and environmentally damaging. Wood ash, which has many similar physical and chemical properties to wood pellet ash, has a large variety of uses that make it a valuable product in many jurisdictions. It is commonly used as a liming material to increase soil pH on agricultural or forest soils. Wood ash is also used as a cover on mine remediation sites, or as an additive to concrete.

The use of wood ash in agricultural soils is by no account a new phenomenon. Wood ash has been used for centuries as a liming material to increase the pH of acidic soils and as a source of plant micronutrients. Adjustment of soil pH to an optimum range for growing plants is a critical component to ensuring plants can access essential nutrients in the soil. This study focuses specifically on the potential to use ash produced during the combustion of wood pellets in stoves and boilers in the NWT as a local agricultural soil amendment.

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[1] The Alternative Energy Technologies Program offers funding for small, medium and large-scale renewable energy projects in the Northwest Territories. More information can be found at: http://www.enr.gov.nt.ca/_live/documents/content/128-AETP%20Guidelines%202011_web.pdf

[2] The Energy Efficiency Initiative Program offers rebates for homeowners who purchase alternative heating appliances, including wood pellet stoves. More information can be found at: http://aea.nt.ca/programs/energy-efficiency-incentive-program

Many NWT soils lack certain elements that are readily available in wood ash, suggesting that wood ash may be a valuable resource to gardeners and farmers. As NWT soils generally have low fertility, and some NWT soils have pH levels that are lower than desired for agricultural production, wood pellet ash could potentially be an appropriate soil amendment and could be diverted from the waste stream while contributing to local food production.

This study aims to collate and document relevant information relating to wood pellet ash as an agricultural soil amendment elsewhere in order to inform NWT practice. The study further aims to test a representative selection of wood pellet ash from NWT residential and commercial boilers for a suite of parameters that will determine if it is an appropriate soil amendment for agricultural purposes. Ultimately, this report will assist decision-makers and individuals in identifying the most value added method to divert wood pellet ash from NWT landfills.

1. METHODOLOGY

This study addresses the need for specific information on the chemical and physical properties of wood pellet ash.

Although studies of the use of biomass ash as a soil amendment have been carried out in Europe and other parts of Canada, ash was mostly studied in regards to its use as a liming agent or as a fertilizer for forest soils. No previous research had been conducted on wood pellet ash as a soil amendment for northern agriculture. The combined growth of the wood pellet biomass sector and small-scale gardening and farming in the NWT created a demand for this type of investigation. This project aims to identify best-practice in the reuse of wood ash across Canada and other northern jurisdictions so as to inform individuals and decision-makers about the uses and limitations of ash as an amendment to agricultural soils. This study provides a base of information, which can be used to further develop wood pellet ash management strategies in the NWT.

An advisory committee consisting of experts in the fields of soil science, northern farming, biomass systems, centralized compost and waste reduction was established to guide project work. The committee assisted the author with research and writing of the report including determination of NWT soil needs, ash sampling and review of ash laboratory analyses. The NWT Biomass Energy Strategy 2012-2015 (GNWT, 2012) was used to provide a portrait of ash produced in Northwest Territories, as it both quantified the resource in different NWT communities and projected future growth in wood pellet use.

The lead author met with commercial, residential and institutional wood pellet boiler and stove owners to discuss their various needs in regards to ash collection and disposal. As Territorial farmers and gardeners currently import mineral fertilizers over long distances, sourcing soil amendments locally would reduce both their capital costs as well as their environmental footprint. Staff from the City of Yellowknife and Ecology North, who collaborate to manage the Yellowknife Centralized Composting Program, have also expressed interest in study conclusions in order to know if wood pellet ash is an appropriate addition to Yellowknife's centralized compost piles, and if so, in what quantity and with what treatment.

The Government of the Northwest Territories (GNWT) Department of Public Works and Services, City of Yellowknife Department of Public Works and Engineering, as well as several residences and commercial entities provided ash from their pellet stoves and boilers for analysis. A complete list of wood ash sources examined in this study is detailed in Table 1: Ash Sampled.

Based on the results of the lab analyses conducted on the wood pellet ash, documented best practices and specific details about local ash quantities and soil needs, conclusions and recommendations are developed. A short plain-language document has been created to summarize the main results from this research and provide information for the general public. This document can be obtained by contacting the Territorial Farmers Association or Ecology North.

Ash was analyzed from wood pellet boilers and wood pellet stoves. The differences between the two types of biomass technologies are that stove ash does not separate fly ash and bottom ash, whereas boilers collect the fly ash in a cyclone situated behind the combustion chamber. Wood pellet stoves also have a higher likelihood of containing matter that is not fully combusted because of their lower combustion temperature compared to wood pellet boilers.

The fly ash and bottom ash from wood pellet boilers were analyzed separately because of probable chemical variations in the ash. This information will help determine whether uniquely the fly ash or the bottom ash should be used in agricultural soils, or whether it is possible to mix both. Stove ash was also collected from wood pellet stoves and analyzed separately from the wood pellet boiler ash.

Because most of the pellet market in the NWT consists of La Crete pellets and because Pinnacle pellets are not sold in bulk, the analysis was done solely with ash produced from La Crete pellets. According to our review of wood pellet ash research, there should not be a significant difference between ash from the two brands because they are both composed of softwood trees. Chemical differences are mainly found between softwood and hardwood species used as biomass.

The nine ash samples analyzed were collected in various locations around Yellowknife. Every sample consisted of 450 mL of wood pellet ash collected from different parts of the ash pile. Samples were immediately stored in plastic Ziploc bags and refrigerated. Two additional samples were taken (one from bottom ash and one from stove ash) and stored in a glass jar to avoid contamination from plastic for the polycyclic aromatic hydrocarbon (PAH) analysis. No ash was sampled from outside of Yellowknife because of time and travel constraints. The ash was tested at Exova Laboratory in Edmonton for most parameters and the polycyclic aromatic hydrocarbons (PAHs) were tested at Taiga Lab in Yellowknife in March 2014.

Table 1: Ash Sampled

Type of Ash	Collected from	Boiler or stove size
Wood Pellet Stoves	Household 1	Residential stove
	Household 2	Residential stove
	Household 3	Residential stove
Wood Pellet Boilers, Fly Ash	Combined Services Building (CSB) - GNWT	540 kW
	Legislative Assembly	300 kW
	Yellowknife Arena	750 kW
Wood Pellet Boilers, Bottom Ash	Combined Services Building (CSB) - GNWT	540 kW
	Legislative Assembly	300 kW
	Yellowknife Arena	750 kW

1.1 Parameters Measured

Parameters that wood pellet ash samples were analyzed for were chosen in compliance with analysis requirements from *Alberta Standards and Guidelines for the Use of Wood Ash as a Liming Agent on Agricultural Soils* (Alberta, 2002) and the *Code of Practice for Soil Amendments* (British Columbia, 2008) under the BC Environmental Management Act. These documents provided the required analyses in both jurisdictions and were compared in order to determine the elements to be analysed for the purpose of this study. No guidelines or standards currently exist in the NWT regarding wood ash as a soil amendment.

The tested and analyzed parameters listed in this section are determining factors in the decision to use wood pellet ash as a compost additive or soil amendment. The following parameters were measured:

Electrical conductivity (EC) is an indirect measurement of the amount of dissolved salts in soils. It measures both the advantageous salts (potassium, calcium, magnesium, ammonium and nitrates) and the salts that can precipitate toxicity in the soil such as sodium and chloride (A&L Laboratories, 2005). Too much salt can have a negative impact on the ability of plants to uptake nutrients. Generally, crops aren't impacted by dissolved salt levels under 2 dS/m (decisiemens per metre) (Brady and Weil, 2002).

The ***Sodium adsorption ratio (SAR)*** compares the sodium to calcium and magnesium cations in the soil. This ratio provides a portrait of the amount of sodium in the soil in relation to the amount of calcium and magnesium, which moderate the impact of the sodium (Brady and Weil, 2002). High sodium levels can impact plant roots by creating a "burn" that reduces their water and nutrient uptake (A&L Laboratories, 2005). Higher SAR level indicate increased levels of sodium in relation to calcium and magnesium. Most crops thrive at SAR lower than 4, and SAR levels between 4 and 8 induce moderate limitations for plants (Alberta, 2002).

Expressed as a ***calcium carbonate equivalent (CCE)***, the ***acid neutralizing value (ANV***) measures the capacity of a material to raise the pH of soil. Materials rich in cations such as calcium, magnesium and potassium have a high ANV. It is a ratio of the alkalinity of ions contained in a material compared to the neutralizing capability of calcium carbonate ($CaCO_3$), which is considered to have a neutralizing value of 100%. Higher ANV or CCE can help neutralize overly acidic soils but can also create soils that are too alkaline, which has an impact on the capacity of plants to absorb many crucial nutrients (Alberta Environment, 2002) and (Brady and Weil, 2002). Demeyer et al. (2001) conclude that wood ash rapidly modifies soil pH following application, but its alkaline effects are short-lasted and micronutrients that are more readily available in acidic soils increase in mobility after the effects of the wood ash decrease (Demeyer et al., 2001).

Alkalinity and acidity are measured by ***pH***, which is a scale that goes from 1 to 14 (1 being most acidic and 14 highly alkaline). The availability of micronutrients such as zinc (Zn), copper (Cu), iron (Fe) and manganese (Mn) are strongly influenced by pH and are less soluble in soils with a pH higher than 7. Iron and zinc especially can become deficient in alkaline soils. Adding these elements via fertilizers do not generally resolve the deficiencies and gardeners must sometimes resort to spraying micronutrients onto foliage to ensure their absorption by plants (Brady and Weil, 2002). Modification of compost pH significantly alters the structure and nutrient availability during the decomposition process and in the end product. Micronutrients must be carefully monitored in alkaline soils to avoid deficiencies. High pH also limits the mobility of some elements such as aluminum, iron, zinc and manganese (Demeyer et al., 2001 and Estevez, 2006).

Additionally, the forms of iron, manganese, zinc and copper found in wood ash generally have a low solubility and rate of leaching (Steenari et al., 1999). Small quantities of these minor elements are necessary for plant growth, although if the dosage is too high, they become toxic for plants and soil life (Breton and Hébert, 2008).

Boron (B) is a micronutrient required for plant growth and development, but only in small concentrations. If the boron concentration of soil increases beyond a certain threshold it becomes toxic to plants and causes a plant disorder known as boron toxicity. When toxic boron levels are reached, plants typically exhibit leaf edge burning, discolouration, stunted growth, and sometimes older foliage will develop black spots. However, if boron concentrations decrease below the plant's requirements, they can experience boron deficiency. Plants deficient in boron usually show signs of stunted or deformed growth, low pollen production and browning or yellowing of the stem. Boron is typically more difficult to control in comparison to other micronutrients due to the very narrow range between deficiency and toxicity. This is complicated by the fact that the availability of boron depends on several factors (see Table 2). For example, boron availability is highly dependent on soil pH, as it is tightly bound to organic material and will not become available in alkaline soils. However, liming soils that are high in organic materials may encourage their decomposition, which liberates available B (Havelin et al., 2005).

Table 2 Factors Impacting Boron Soil Concentrations

Factor	***Influence on boron soil concentration***
Soil pH	Basic soils (pH greater than 7) are more likely to be boron deficient. This is because in basic conditions, boron exists in an undissociated form (boric acid), which plants are unable to absorb. In general, boron becomes decreasingly available for uptake by plants as pH rises.
Soil leaching rate	Highly leached sandy soils are more likely to be boron deficient because the boron will not be well retained by the soil.
Organic matter content	Most boron in soil is absorbed by organic matter. Therefore, soils with lower organic matter content (usually less than 1.5%) are typically more susceptible to boron deficiency.
Plant species	Plant species vary in their need for and sensitivity to boron. Plants that are among the most tolerant to boron include asparagus, parsley, vetch, alfalfa, beet, canola, celery, and tomato. Less tolerant plants include bean, cucumber, strawberry, apple, broccoli, carrot, and radish.

Boron tolerance limits for many plants are identified in Maas (1990). It is important to test the existing boron concentration of the soil prior to amending it with wood ash to ensure that the soil is in need of boron. In all cases, soil boron concentrations should be assessed just prior to planting in order to ensure that the boron levels are within the plants' tolerance limit.

Calcium (Ca) is a nutrient with acid neutralizing properties. It is essential to plant cell structure and plays a role in N metabolism. Ca regulates cation uptake, notably potassium uptake in plants. Calcium is important for the transportation of nutrients and carbohydrates in plants, which helps form stronger tissues in fruits and vegetables (Havlin et al., 2005).

Plant-available potassium (K) is often very deficient in soils, especially in the Canadian northwest. This essential nutrient plays an important role in photosynthesis, influences enzymes that participate in the nitrification process and assists plants in absorbing water. Because non-exchangeable K is slow to degrade towards exchangeable K, supplementing soils through potassium-rich fertilizers is a good option for increasing it in soils (Havlin et al., 2005). The K found in wood ash is nearly as available as in synthetic fertilizers (Demeyer et al., 2001). The potassium (K) efficiency of ash is estimated at 100% (Breton and Hébert, 2008).

Nitrogen (N) is a highly valuable and often deficient element in soils. Plant uptake of plant-available N (as $NH4+$) is optimal at neutral pH soils and decreases in acidic soils. Because N is typically absent from wood ash, any fertilizing plan that uses wood ash as the main fertilizer must also determine an alternate source of N (Demeyer et al., 2001).

Phosphorus (P) is a nutrient that is crucial for plant growth, although if too much is applied it can oversaturate a soil. While less mobile than N, phosphorus can be transported by surface runoff and degrade local water quality. The primary plant-available form of P in the soil is better absorbed by plants when the pH is lower than 7.2 (British Columbia, 2008). Research shows that the P contained in wood ash has a very low solubility, which makes it a poor source of phosphorus (Demeyer et al. 2001). The efficiency of phosphorus is determined by the amount of total P that is plant-available. Studies have found that the P efficiency of ash is of approximately 50%, which indicates that half of the total P from ash will have an effect on soil composition and plant growth.

Carbon (C) is one of the most essential elements for plant growth. It is an energy source and the main building block of all organic materials (A&L Laboratories, 2005). The amount of organic matter in the soil is measured by its total carbon content.

Magnesium (Mg) assists with the photosynthesis reaction and increases nutrient uptake in plants, especially phosphorus. An Austrian study found that the Mg in wood ash has a low leaching rate (Steenari et al., 1999).

Sulfur is measured as **sulphate**, which is crucial for plant structural development and an essential part of chlorophyll production (Havlin et al., 2005).

Chloride is a trace element that plays a role in reducing certain plant diseases. Chloride also suppresses nitrification, which leads to a decrease in pH. It can be present at toxic levels in the soil, although this generally only occurs when too much potassium chloride (a common fertilizer) is applied. In that case, the buildup of chloride can be harmful for some plants (Brady and Weil, 2002).

Zinc is a minor element that plays an important role in photosynthesis. It tends to be deficient in soils that have a pH lower than 6.8. Over-saturating soils with P fertilizer can create a Zn deficiency (Estevez, 2006).

Iron (Fe) helps plants create chlorophyll and protein. Soils with a high pH and calcareous soils with low organic matter tend to be Fe deficient. However, Fe deficiency in soils is common and acidic soils tend to be too deficient in Fe for plants. Iron becomes accessible to plants mostly by bonding with chelates (soluble organic compounds created by microbial activity and degradation of organic matter). Therefore, adding organic material contributes to the availability of Fe in the soil, although in many cases it is not enough to fully meet plant requirements (Havlin et al., 2005).

Copper (Cu) is involved in protecting plants against disease, photosynthesis, respiration and creating lignin. It is closely tied to organic matter, as plant roots absorb organically bound, chelated Cu. Soil solution and plant-available Cu increase with decreasing pH. This micronutrient is commonly deficient in excessively leached, coarse-textured soils. Crops such as beets, carrots, lettuce and spinach are highly sensitive to copper deficiency in soils (Havelin et al., 2005).

Cadmium (Cd) is not currently recognized as being valuable to plants or humans and is therefore considered a strict contaminant (CCME, 2005).

Polycyclic Aromatic Hydrocarbons (PAHs) are carcinogens found in materials that have gone through an incomplete combustion (Alberta Environment, 2002). Literature consistently describes fly ash as undergoing a complete combustion. The risk of PAHs forming in the bottom ash and stove ash is higher; therefore for the purposes of this study only the bottom ash and stove ash were tested for this parameter. According to the Alberta guidelines (Alberta Environment 2002), the limit for PAHs in agricultural soil is 4 mg/kg of benzo(a)pyrene and naphthalene, respectively. The Canadian Council of Ministers of the Environment (CCME) guidelines recommend testing feedstock that has could have potentially elevated levels of PAHs before integrating the materials into compost (CCME, 2005).

Moisture content should be over 1% to promote the conversion of oxides found in ash to hydroxides, which then adsorb carbon dioxide and become carbonates. This prevents the pH from becoming excessively high and creating alkaline shock (Breton and Hébert, 2008).

Chlorinated organic compounds such as dioxins and furans were not tested for the purposes of this study. These compounds are produced from materials that are combusted with chlorine-containing compounds (Alberta Environment, 2002). This was deemed highly unlikely for wood pellet ash because the wood pellets are composed uniquely of wood by-products and are not mixed with any chlorinated compounds (Dinwoodie, 2014).

Table 3: Laboratory Analysis of Parameters and Values

Parameter	Alberta Standards and Guidelines for the Use of Wood Ash as a Liming Material in Agricultural Soils (2002)	British Columbia Code of Practice for Soil Amendments (2003)	CCME Compost Quality Guidelines * (2005)
Moisture content	Minimum 1%		
Calcium Carbonate Equivalent			
pH			
Electrical conductivity	≤2 dS/metre is ideal; not a limiting factor		
Total Organic Carbon			
Sodium Adsorption Ratio (SAR)	≤4 is ideal; not a limiting factor		
Copper		2 200 mg/kg	400 mg/kg
Zinc	5500 mg/kg	1 850 mg/kg	700 mg/kg
Boron (hot-water soluble)	43 mg/kg		
Cadmium	46 mg/kg	20 mg/kg	3 mg/kg
Benzo(a)pyrene	4 mg/kg		
Naphthalene	4 mg/kg		
Nitrate			
Phosphorus- Plant available			
Potassium-Plant available			
Sodium			
Calcium			
Magnesium			
Sulfur			
Manganese			
Chloride			

*CCME (Canadian Council of Ministers of the Environment) Compost Quality Guidelines are for finished compost, not for compost feedstocks (in this case feedstock would be wood pellet ash).

2. BENEFICIAL REUSE OF WOOD ASH IN OTHER JURISDICTIONS

Previous studies that have investigated the properties of wood ash and its use in agriculture and small-scale food production were reviewed. Some studies that have examined other uses for wood ash are also presented, although the goal of this study was to determine recommendations regarding the uses of wood ash specifically in a food-production context. This information and the analysis of NWT wood pellet ash will help design useful application guidelines for gardeners and farmers across Northwest Territories. It must be noted that most of the studies reviewed in this section pertain to the characteristics of wood ash, most of which was sourced from cord wood, which has different properties than wood pellet ash. Some of the studies evaluated ash from hardwood pellets or from logs containing bark, which has a significantly different chemical composition than debarked wood. Therefore the conclusions drawn from this review could differ from the final results of the testing done for the purpose of this study.

There are various beneficial uses for wood ash such as the following: covering landfills and mine tailings, remediating groundwater and acid mine drainage and for constructing roads (Wood Ash Industries, 2014). In areas such as Scandinavia, where the forestry industry and wood biomass systems coexist, wood ash is often returned to the forest soil to complete the mineral cycle and increase tree regeneration (Swedish Forest Agency, 2006). As an agricultural amendment, wood ash is most commonly used for its liming properties in soils that have a pH of 7 or lower (Majeau, 2013). The increase in soil alkalinity from wood ash is intense but short-lasting as the potassium and sodium responsible for its acid neutralizing value are water-soluble and therefore non-persistent in the ground (Demeyer et al.,2001). For soils that do not need alkaline amendments, but would benefit from the nutrients found in wood ash, studies have found that it is possible to reduce the alkalinity in wood ash by exposing it to moisture and air (Hébert, 2014). Wetting and aging the ash transforms its oxides into hydroxides, which adsorb atmospheric carbon dioxide. The process is simple: small amounts of water are added to the ash, which is then exposed to air for a determined amount of time before application onto the soil. This process creates carbonates that reduce the pH level of the final product and prevent leaching of nutrients, especially calcium (Steenari et al., 1999). Low leaching rates for phosphorus, magnesium and iron were observed in an Austrian study looking at the leachate of wood ash after application to soil (Steenari et al. 1999). Through this wetting and aging process, ash is converted into a less-alkaline fertilizer that retains its nutrients without affecting microbial soil life (Swedish Forest Agency, 2006 and Majeau, 2013).

There are two different categories of biomass ash in wood pellet boilers: bottom ash is collected directly from a grate and/or tray in the bottom section of the boiler and fly ash is removed from the flue cleaner system. The relative proportions and composition of fly ash vary greatly in different boilers, although there is generally much more bottom ash than fly ash. Fly ash tends to have a finer texture and is richer in volatile metals than bottom ash, which increases its toxicity (Swedish Forest Agency, 2006). As opposed to wood pellet boilers, wood pellet stoves do not have fly ash.

Both fly ash and bottom ash have fairly high amounts of calcium (Ca) and magnesium (Mg), which are important structural agents for the soil. Wood ash is also rich in many trace elements that are necessary for plant growth and can increase plant immunity against illness in organic production (Breton and Hébert, 2008). Wood ash alone can replace most mineral fertilizers with the exception of nitrogen (N), which is fully lost from wood pellets during combustion (Swedish Forest Agency, 2006). Because wood ash has a high quantity of potassium (K), it could be a free, locally-generated source of that nutrient for garden soils in the Northwest Territories, which are typically potassium-deficient (Milne, 2014). However, the application of wood ash on soils to amend potassium levels must be monitored to avoid over-concentration of other elements (Weil and Duval, 2009), and to ensure that pH is maintained at suitable levels for plant growth. For example, some micronutrients such as iron, copper, manganese and zinc, which are mainly plant-available in slightly acidic soils, can become deficient in soils supplemented by highly alkaline wood ash, if pH levels become too elevated (Havlin et al., 2005). It is very important to test wood ash prior to using it as a soil amendment, and to test the receiving soil, so proper application rates can be determined.

Different varieties of wood pellet energy systems may produce wood pellet ash with varying characteristics, and therefore varying potential end uses. Factors such as combustion temperatures, boiler size and separation or mixing of fly and bottom ash create different end products with varying characteristics (Swedish Forest Agency, 2006).

In Scandinavia, where wood ash is used as a fertiliser for forest soils, compaction and granulation systems have been put in place to slow the decomposition and release of the ash in the soil. In this way the effects of the wood ash are gradual and consistent over the growing season. In agricultural systems, it is preferable to apply larger, more compact granules of wood ash rather than directly applying fine ash. Particle size directly influences the effects of wood pellet ash, and the compaction process tends to make wood ash slower to degrade, which reduces the chances of provoking alkaline shock or salinization of the soil (Swedish Forest Agency, 2006).

Because compaction is done mechanically by compressing ash mixed with water or binding agents, it requires specific equipment and knowledge. A 2006 Swedish compaction plant estimated the cost of pelletization to be between $10-15 per tonne, plus capital investment that varied between $5-13 per tonne processed by the plant (Swedish Forest Agency, 2006). Because of large distances between communities, and the relatively small quantities of wood pellet ash produced, compaction technology would likely be cost-prohibitive in the NWT.

As the needs of local food growers and farmers in the Northwest Territories are significantly different than those of Scandinavian forestry managers, other application techniques need to be considered. In this study, direct and indirect application methods are evaluated and compared in the context of NWT agriculture.

Most typical fertilizing equipment is not suitable for use with ash, although it is possible to use certain equipment, such as screw spreaders and pendulum spout spreaders. These types of spreaders are attached to the back of tractors and distribute the fertilizer material evenly on agricultural soil. Direct application with such pieces of equipment creates dust and should not be carried out in inhabited areas. Wetting the ash can make it a lot easier to deal with and prevent the expulsion of dust when handled. However, wet ash can become more compact, which could make it difficult to consistently apply the material (Swedish Forest Agency, 2006). Some studies have found that direct application of wood ash is less effective than incorporating the ash into soil, although direct application has the advantage of gradually providing nutrients over time (Nader and Thompson, 2013). The machinery required to directly apply ash or incorporate ash on agricultural land is labour-intensive and unlikely to be viable in most NWT communities. Mixing wood ash with manure is highly inadvisable as the ash stimulates nitrification which leaches the nitrogen from manure (Orbenberger and Supancic, 2009).

A number of studies have explored options for mixing wood ash with compost. Mixing wood ash with compost can be advantageous as it can be added directly to the compost without being sifted or hydrated. In addition, positive chemical interactions between ash and compost can increase the nutrient value of the final product. Adding ash to compost can accelerate the decomposition process, improve oxygenation, create higher pH and higher temperatures, absorb excess humidity and smother certain unpleasant odours. Ash has been proven to modify soil texture, mineral content and aeration. Generally, wood ash admixture has positive impacts on soil microbes because of improved chemical and physical properties. (Demeyer et al., 2001).

If wood ash is mixed with compost at 20% or less of the total compost weight, the final result can be compost enriched in potassium, phosphorus, calcium, magnesium and trace minerals (Majeau, 2013).

If the compost typically receives low levels of nitrogen-rich food scraps or yard clippings during the winter, it is advisable to reduce the amount of wood ash added to the compost until the spring. If the ratio of ash to green residues is too high, the ash can inhibit the microbial activity necessary for the decomposition of organics. Ash should either be kept separate from the compost until spring, at which time green residues become more readily available, or added into the compost in very small quantities during the winter and in slightly larger quantities in summer. Adding small proportions of ash to compost simultaneously with nitrogen-rich green residues such as freshly cut grass or leaves can create a well-balanced fertiliser that contains all the macro- and micro-nutrients needed by plants (Swedish Forest Agency, 2006). Replacing conventional inorganic fertilizers with fertilizers made from residual materials such as wood ash can result in important long-term agricultural and economic benefits (Nader and Thompson, 2013).

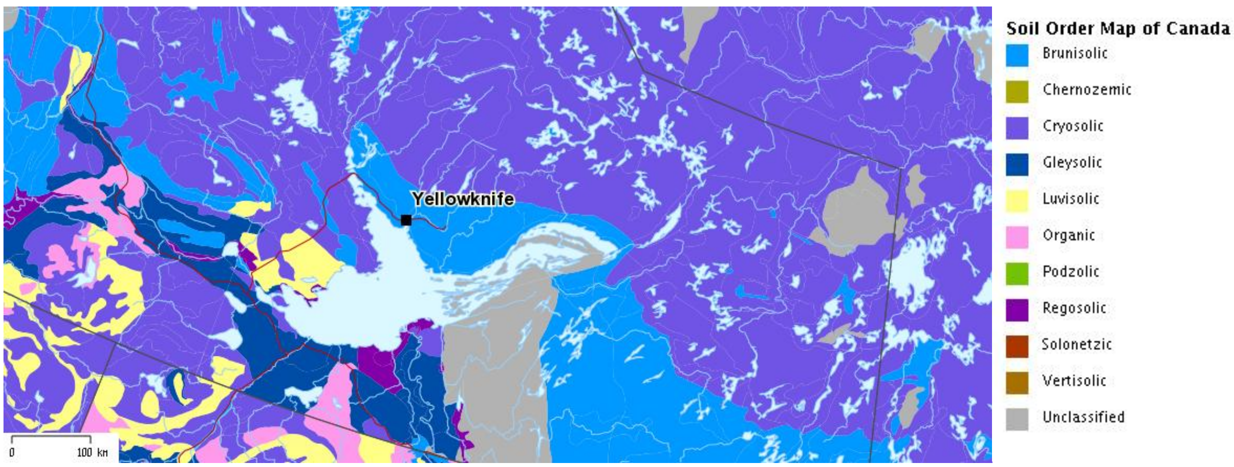
One study that explored the addition of wood ash to compost in Austria found that between 5 and 16% of the total weight of the compost pile can be added as wood ash, if the mixture is to be applied on agricultural soils (Orbenberger and Supancic, 2009). Another study from Québec concluded that ash can be sustainably added at a ratio of up to 20% of the total weight of compost (Majeau and Hébert, 2008). Exceeding these ratios can be harmful to microbial life and reduce the benefits of the resulting compost.

Overall, wood ash can affect soil or compost positively or negatively by modifying pH-related parameters such as nutrient absorption or inhibition, stimulating or impeding microbial activity and increasing nutrients and metals. The results from this review of wood pellet ash use in other jurisdictions suggest that provided that soil and wood pellet ash characteristics are tested, and that wood pellet ash is added at recommended amounts for the given soil and agricultural objectives, wood pellet ash can act as a beneficial soil amendment. Wood pellet ash can be particularly beneficial when added to the composting process.. Recommended dosages of ash vary between 5 and 20% of total compost weight, as too much ash can impede healthy compost decomposition. Additionally, ash should be tested before application into compost or garden soils to determine any potential hazards it may pose to human health or the environment.

3. SOILS IN THE NWT

As represented in Figure 1, the dominant soils in and around Yellowknife are of the Brunisolic order. This type of soil tends to be acidic (under 5.5 pH) and lacking in a well-developed mineral or organic surface horizon (Soil Classification Working Group, 1998 and Agriculture and Agri-food Canada, 2010). There are quite extensive Brunisolic, Organic and Gleysolic soils found throughout the southern part of the Mackenzie River Valley.

Table 4: Soil Order Map of North and South Slave Regions



Reference: Soil Orders of Canada, Agriculture and Agri-foods Canada (2010)

Hay River has Gleysolic soils, which indicate current or previously high levels of water saturation. These soils are typically shaped under anaerobic (oxygen-free) conditions, which mobilize iron (Fe) and manganese (Mn) (Agriculture and Agri-food Canada, 2010 and Soil Classification Working Group, 1998).

Most other regions of the NWT have Cryosolic soils, which are characterized by the proximity of permafrost to the thin mineral surface. This type of soil is prohibitive for agriculture: agricultural production must often take place above the ground surface in boxes and requires human-made earth such as compost (Soil Classification Working Group, 1998 and Agriculture and Agri-foods Canada, 2010). Most NWT soils are rated as ill-suited to agriculture. This is measured by plant hardiness, which is based on soil, climate and plants that are typically grown in a region. On these scales, NWT rates 0a in most regions, which is the harshest possible growing climate found in Canada (Natural Resources Canada, 2001).

Yellowknife has a centralized composting program that recycles approximately 200 tonnes/year of organic materials into finished compost. This program is in the process of expanding to divert further organic waste resources. Finished compost is sold to local residents for use in gardens and yards. The compost facility produces Grade A compost, rated according to compost quality guidelines established by the Canadian Council of Ministers of the Environment (CCME). Hay River is developing a municipal compost program, and other communities such as Fort Simpson are beginning work on the implementation of organic waste recycling (Ripley, 2014).

Over the past decade, small-scale subsistence farming and gardening has been increasing in the Territory, with community gardens, greenhouses and farming education programs being created to provide local food and support for food production. As interest in farming and gardening grows, so does the need for locally-sourced fertilizers. However, depending on a variety of factors and parameters, every garden soil has different needs. For this reason, it is difficult to determine general fertilizer application rates. Ideally, gardeners will test their soil for major parameters such as pH, nitrogen, phosphorus and potassium, , as well as the presence of calcium and magnesium. The results will provide a clear picture of what is present or lacking in the garden, which can then suggest courses of action.

4. WOOD PELLET ASH IN THE NORTHWEST TERRITORIES

Approximately ninety percent of wood pellets shipped to the Northwest Territories are La Crete brand pellets, consisting mostly of spruce with some aspen wood products. These wood pellets are produced in La Crete, Alberta. La Crete is currently the only provider of bulk pellets in the NWT (Arctic Energy Alliance, 2009). The other ten percent of pellets are provided by Pinnacle Pellets, and some other brands. The majority are made with sawdust from spruce, pine and fir wood (Pinnacle Renewable Energy Group, 2011). Apart from La Crete bulk pellets, all other wood pellets are sold in bags and are therefore mostly used for residential pellet stoves. Both La Crete and Pinnacle pellet brands produce less than 1% ash after combustion (Manuilova and Johnston, 2011).

An estimated 29 tonnes of ash were produced in 2013 in the NWT from commercial and institutional buildings, with a projected increase to 84 tonnes/year by 2016 (Pelkey, 2014). As biomass becomes a more popular heating alternative, the increase in ash will create a significant waste material requiring management.

Using wood pellet ash as a soil amendment can be particularly beneficial in the NWT. An ash collection system could potentially create an opportunity to produce a local soil amendment and stimulate the production of local produce in areas where fresh food is expensive. Additionally, businesses and institutions recycling ash may be able to reduce their waste management costs. It is difficult to quantify the savings gained from replacing conventional fertilizers or soil amendments with wood pellet ash because of the variability in fertilisation needs and the effects of local climate on garden soil requirements. However, because wood pellet ash is a free product and conventional fertilizers entail high transportation costs, the savings could be substantial, especially in remote communities.

5. SAMPLING AND ANALYSIS OF NWT WOOD PELLET ASH

The following section documents the analyzed contents of wood pellet ash samples.

5.1 Fly Ash Content

Table 5 Fly Ash Content

Parameters Measured in mg/kg unless otherwise indicated	Nitrate -N (NO_3^-)	Calcium (Ca)	Phosphorus (P)	Potassium (K)	Zinc (Zn)	Cadmium (Cd)	Boron (B)	Moisture (%)	CCE (%)	pH	Electrical Conductivity (dS/m)
Combined Services Building	2500	108000	1900	129000	1100	8.2	178	0.2	96.1	12.7	14.1
Legislative Assembly	810	1400000	3100	68500	108	2.5	85.2	0.1	90.9	12.7	11.7
Yellowknife Arena	980	127000	2700	66100	261	3.7	98.1	0.2	88.6	12.7	11.9

As summarized in Table 4, fly ash samples from wood pellet boilers had high levels of a variety of nutrients; in particular, calcium (Ca), potassium (K) and phosphorus (P). Fly ash is the most nutrient-rich component of wood pellet ash; however it also has the highest concentration of metals such as cadmium and zinc and of the non-metal, boron. Cadmium and zinc levels were below control limits identified by Alberta Environment (2002). However, the measured hot-water soluble boron levels of 85 to 178 ppm were well above the control limit of 43 ppm identified by Alberta Environment. As a result, it is recommended that fly ash from the boilers sampled not be applied to agricultural soils, as the ash could cause adverse impacts on soil and environmental health.

Moisture levels for the fly ash samples are below the minimum limit of 1% identified by Alberta Environment (2002). Moisture levels under 1% could react with oxygen to create calcium oxide (CaO), which is a highly caustic element that can endanger plant and human health. However, when weathered, the moisture levels should increase significantly and the Calcium Carbonate Equivalent (CCE) should be reduced (Havlin et al., 2005).

Fly ash pH is highly alkaline: all fly ash samples had a pH of 12.7. Such a strong alkalinity has the potential to incur damage to soil and plants. The Acid Neutralizing Value (ANV) as measured by the CCE is fairly high in all fly ash samples, with an average CCE of 91.8%. The CCE measures the relative alkalinity of materials by comparing them to calcium carbonate, which has a neutralizing value of 100%. With such high CCE, fly ash can be considered an efficient liming agent.

The electrical conductivity (EC), which measures the amount of dissolved salts in a material, is relatively high. However, Alberta Environment (2002) reports that field testing of wood ash has determined that electrical conductivity is not usually a limiting factor in the use of wood ash.

Polycyclic Aromatic Hydrocarbons (PAH) levels were not analyzed for the fly ash samples as the fly ash was considered to be fully combusted and therefore would not contain any PAHs.

5.2 Bottom Ash Content

Table 6: Bottom Ash Content

Parameters Measured in mg/kg unless otherwise indicated	Nitrate -N (NO_3^-)	Calcium (Ca)	Phosphorus (P)	Potassium (K)	Zinc (Zn)	Cadmium (Cd)	Boron (B)	Moisture (%)	CCE (%)	pH	Electrical Conductivity (dS/m)
Combined Services Building	810	97300	1400	55300	22.4	2.09	41.6	0.3	94.5	12.6	10.6
Legislative Assembly	30	135000	2200	10500	≤5	<0.02	111	0.3	103	12.7	11.8
Yellowknife Arena	270	28000	1000	44000	7	0.96	42.1	0.4	97.6	11.8	2.1

Bottom ash is not as nutrient-rich ash fly ash. Levels of Calcium (Ca), potassium (K) and phosphorus (P) were lower in bottom ash than in fly ash. Zinc and Cadmium levels were well below control limits set by Alberta Environment (2002). Bottom ash has much smaller quantities of zinc than fly ash. Boron levels for two bottom ash samples were within control limits set by Alberta Environment (2002), while one bottom ash sample had elevated boron levels (111 ppm). The bottom ash collected from the Legislative Assembly should not be applied to agricultural soils, as the ash could cause adverse impacts on soil and environmental health. Overall, the amount of boron in the bottom ash samples is lower than in the fly ash.

Moisture content in the bottom ash is below the recommended 1% of moisture for wood ash. As with fly ash, this means that the ash could potentially become reactive if it is not weathered properly.

Bottom ash pH is highly alkaline and greatly resembles the pH of fly ash. The calcium carbonate equivalent (CCE) is generally higher than fly ash CCE, which means that the acid neutralizing value of bottom ash is higher than that of fly ash.

It is interesting to note that two bottom ash samples had relatively high levels of electrical conductivity, between 11 and 12 dS/m; while another sample had a much lower level of electrical conductivity of 2 dS/m. Although Alberta Environment (2002) states that electrical conductivity should not be a limiting factor for wood pellet ash as a soil amendment in agriculture, the sample with the lower electrical conductivity, would be preferred from a salinity perspective, over the two samples with higher levels of electrical conductivity.Bottom ash samples were analyzed for Polycyclic Aromatic Hydrocarbons (PAHs). All PAHs that were sampled for were below detection limits for all three wood pellet bottom ash samples.

As with the fly ash, manganese levels were highly variable in the bottom ash. Chloride is present at much lower values in the bottom ash than the fly ash.

Comparing the parameters in the bottom ash to the standards and guidelines used in Alberta (Alberta Environment 2002), bottom ash from the Combined Services Building and the Yellowknife Arena could be recommended for use as an agricultural or compost amendment, if water is added to the ash to raise moisture content above the 1% minimum level, and the ash is applied at appropriate rates that take local soil or compost conditions into consideration.

5.3 Residential Pellet Stove Ash

Table 7: Stove Ash Content

Parameters Measured in mg/kg unless otherwise indicated	Nitrate -N (NO_3	Calcium (Ca)	Phosphorus (P)	Potassium (K)	Zinc (Zn)	Cadmium (Cd)	Boron (B)	Moisture (%)	CCE (%)	pH	Electrical Conductivity (dS\m)
Household 1	20	17900	1000	46900	33.5	1.7	64.7	0.7	94.5	12.6	10.6
Household 2	180	113000	1400	74700	37.4	1.0	96.7	0.4	103	12.7	11.8
Household 3	190	118000	2100	77700	37.2	2.2	86.0	≤0.1	97.6	11.8	2.1

Like the fly ash and bottom ash samples, all metals contained in stove ash are at levels beneath the control limits except for boron.

Generally, samples of wood pellet stove ash had higher levels of nutrients and other elements than most of the bottom ash samples, but less than fly ash samples. Zinc and Cadmium levels were well below control limits set by Alberta Environment (2002). However, the hot-water soluble boron levels of 65, 86 and 97 ppm were well above the control limit of 43 ppm identified by Alberta Environment (2002). As a result, it is recommended that wood pellet ash from the residential wood pellet stoves sampled not be applied to agricultural soils, as the ash could cause adverse impacts on soil and environmental health.

Moisture levels for the fly ash samples were below the minimum limit of 1% identified by Alberta Environment (2002). This means that calcium in the ash can react with oxygen to create the highly reactive CaO. This element can produce alkaline-related problems in the soil.

Stove ash had similar pH to the fly ash and bottom ash samples: all stove ash samples are highly alkaline. The Calcium carbonate equivalent (CCE) of stove ash is variable but is fairly similar to the CCE of fly and bottom ash samples. This means that stove ash has an elevated Acid neutralizing value (ANV) and can therefore greatly increase the soil pH if added at a large dose.

The Electrical conductivity (EC) in stove ash samples was variable, between 3 and 12 dS/m. However, Alberta Environment (2002) reports that field testing of wood ash has determined that electrical conductivity is not usually a limiting factor in the use of wood ash. The wood pellet stove ash samples did not contain PAHs higher than recommended by Alberta Environment (2002).

Pellet stove ash is believed to have the highest amount of uncombusted material in it because of the relatively low combustion temperatures compared to larger wood pellet boilers.. However, although there is more carbon in the stove ash than in bottom ash, this study found that the amount of carbon in the stove ash samples was lower than the fly ash average.

RECOMMENDATIONS

NWT residents or businesses that would like to determine if the wood pellet ash produced in their boiler or stove is suitable for use as an agricultural amendment should test their wood pellet ash to determine if it meets the criteria in the *Standards and Guidelines for the Use of Wood Ash as a Liming Material for Agricultural Soils* (Alberta Environment 2002).

Results from this study showed that of the three bottom ash and three fly ash samples collected from wood pellet boilers in Yellowknife, two bottom ash samples were found to meet the Alberta Environment (2002) standards, provided the ash is amended with water to meet the minimum recommended moisture content, or it is added to moist compost. One bottom ash sample, and all three fly ash samples did not meet Alberta Environment (2002) standards, due to high boron levels. None of the three residential wood pellet stove ash samples tested met Alberta Environment (2002) standards for use as an agricultural amendment, due to high boron levels.

Once a wood pellet ash sample has been tested for the parameters outlined in Alberta Environment (2002), and found to meet the standards, testing of the agricultural (soil or compost) receiving environment for the wood pellet ash should be conducted to determine the appropriate rate of addition of the wood pellet ash, to maximize the benefits of the wood pellet ash. Due to its very high pH, wood pellet ash is primarily suitable as a liming agent to increase the pH of low-pH soils, or as an amendment to compost. Care should be taken when adding wood pellet ash to soil or compost, due to its very high pH and reactive nature. Wood pellet ash should be weathered (exposed to water and air) before being added to compost or soil in order to reduce alkaline shock. Additionally, the pH of the soil or compost being amended should be monitored.

Proper management of wood pellet ash is important for human and environmental health, as well as long-term sustainability for gardens. To avoid leaching and to facilitate dust management, wood ash should be stored in a closed container (Steenari et al., 1999), preferably outside, before mixing with compost or soil. The container should also have a closed bottom so as to avoid raising the soil levels underneath it to prohibitively alkaline levels. The alkalinity and corrosive nature of ash mean that it must be handled carefully. If ash is to be mixed with compost over time, the storage capacity must take the amount of ash produced into account.

Given growing interest throughout the Northwest Territories in gardening, increasing concern about food security, and greater emphasis on waste diversion, finding an appropriate use for wood ash can be part of a more sustainable solution for this material. Using wood pellet ash as a soil amendment when appropriate presents an opportunity to divert ash from the waste stream transform it into a valuable product. In addition, because wood ash is produced in a variety of NWT communities, it can replace imported soil amendments thereby reducing costs for food producers and the energy required to transport amendments.

FURTHER STEPS

This study included a general overview of conclusions from previous studies investigating the use of wood ash in agriculture and analysis of wood pellet ash produced in different biomass systems from the NWT. However, no field trials investigating the use of wood pellet ash as a soil amendment have ever been conducted in the NWT, which would be a valuable next step. It would be valuable to conduct a trial in which bottom ash that met Alberta Environment (2002) standards is used in the NWT to amend soil with a low pH and as a compost amendment. Crop production from the soils amended with wood pellet bottom ash and a compost-wood pellet bottom ash mixture could then be compared to a control. Such field trials would provide increased practical and empirical knowledge about the potential benefits of using wood pellet bottom ash as a soil and compost amendment. Prior to amending soil or compost with wood pellet bottom ash, these media would need to be tested to determine appropriate wood pellet bottom ash application rates, as described in Alberta Environment (2002).

In addition to conducting field trials with soil and compost amended with wood pellet bottom ash, it would be valuable to conduct further research to explore if there are certain management techniques for wood pellet boilers that can improve the quality of the wood pellet bottom ash, so that more ash can be made suitable for use as a soil and compost amendment. Based on the results of this study, boron is the most limiting factor for use of wood pellet ash as a soil amendment and liming agent. It would be helpful to further compare the management of wood pellet boilers that are producing bottom ash that is suitable for use as an agricultural amendment with the management techniques for boilers that are producing bottom ash that has excessive boron levels. Are there management changes that can be undertaken that reduce the boron levels found in the bottom ash being produced?

The potential demand for wood pellet ash in NWT agriculture and gardening is far inferior to the amount of ash generated each year. Research should be done into alternative methods of recycling the surplus ash. In this way, larger quantities of ash could be diverted from landfills. This study notes the integration of wood pellet ash in cement, as a roadside herbicide and as an animal hide softener as potential topics of interest.

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