

A case study review of wood ash land application programs in North America

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ABSTRACT: Several regulatory agencies and universities have published guidelines addressing the use of wood ash as liming material for agricultural land and as a soil amendment and fertilizer. This paper summarizes the experiences collected from several forest products facility-sponsored agricultural application programs across North America. These case studies are characterized in terms of the quality of the wood ash involved in the agricultural application, approval requirements, recommended management practices, agricultural benefits of wood ash, and challenges confronted by ash generators and farmers during storage, handling, and land application of wood ash.

Reported benefits associated with land-applying wood ash include increasing the pH of acidic soils, improving soil quality, and increasing crop yields. Farmers apply wood ash on their land because in addition to its liming value, it has been shown to effectively fertilize the soil while maintaining soil pH at a level that is optimal for plant growth. Given the content of calcium, potassium, and magnesium that wood ash supplies to the soil, wood ash also improves soil tilth. Wood ash has also proven to be a cost-effective alternative to agricultural lime, especially in rural areas where access to commercial agricultural lime is limited.

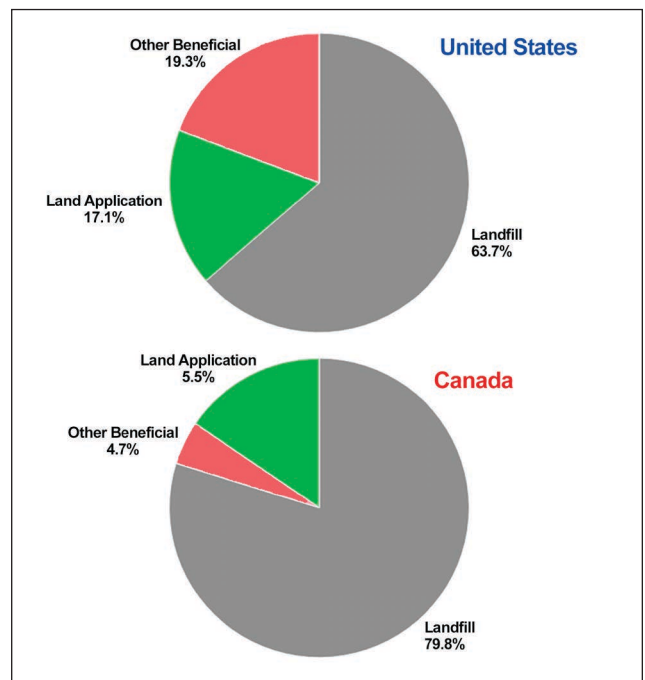
Some of the challenges identified in the review of case studies include lengthy application approvals in some jurisdictions; weather-related issues associated with delivery, storage, and application of wood ash; maintaining consistent ash quality; inaccurate assessment of required ash testing; potential increased equipment maintenance; and misconceptions on the part of some farmers and government agencies regarding the effect and efficacy of wood ash on soil quality and crop productivity.

Application: The information compiled and summarized in this article will be especially useful for forest products manufacturing facilities that would like to consider beneficial use of wood ash as a soil amendment. It can also inform discussions between ash generators, those engaged in agriculture, and regulators regarding alternative approaches used in other jurisdictions to enable and facilitate application of wood ash on agricultural soil.

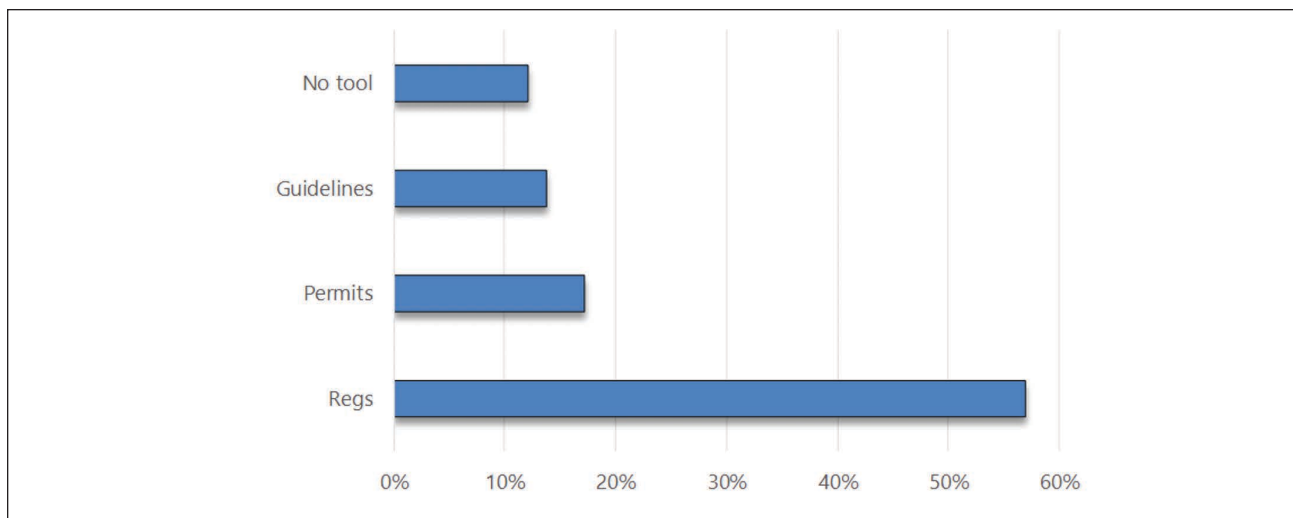
Pulp and paper and wood products facilities generate large amounts of boiler ash from combustion of woody biomass. Most of this ash is, however, not beneficially used. Recent data suggest that nearly 80% and 64% of boiler ash generated at pulp and paper mills in Canada and the United States, respectively, is either landfilled or lagooned, and only about 16% is land applied (Fig. 1). This situation likely reflects regulatory and logistical hurdles associated with developing a beneficial use program, and possibly lack of available local markets or receiving sites. Because disposing of these materials in landfills is costly, there is an opportunity to explore the conditions under which application of wood ash on agricultural land is carried out.

Benefits resulting from using wood ash for agricultural land application purposes are well documented [1-18]. Several regulatory agencies have published guidelines discussing use of wood ash as liming material for agricultural land and as a soil amendment and fertilizer [19-28].

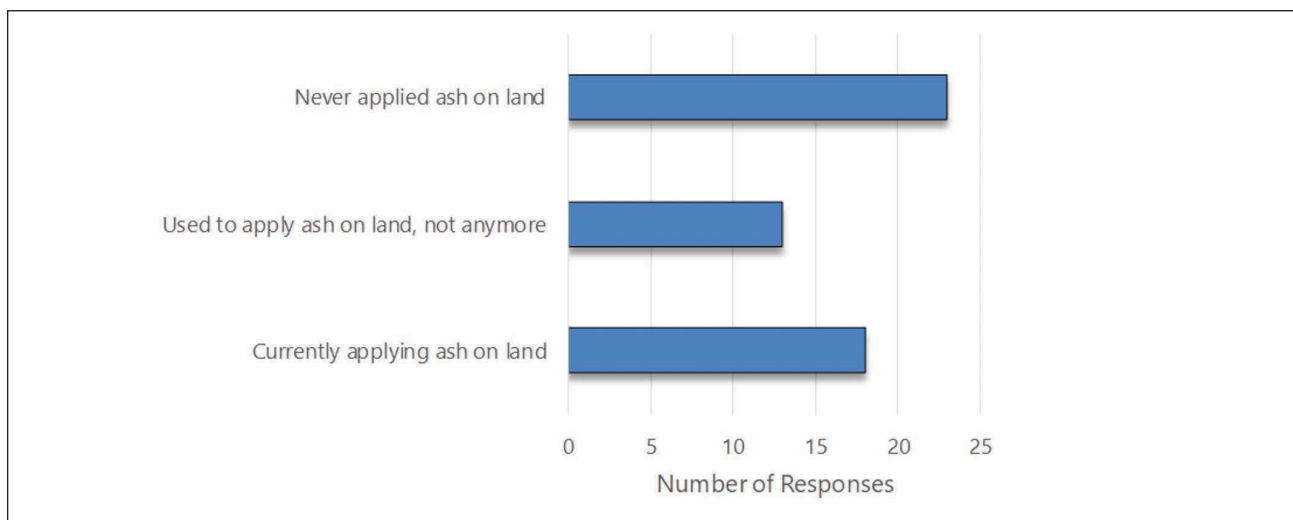
Obtaining approval for an agricultural application program in North America typically involves extensive ash characterization. Once approved, the program relies on the availability of wood ash that meets specific quality criteria for agricultural land application purposes and, depending on the permit or label requirements, may include soil test-



1. Options used by North American pulp and paper facilities to manage boiler ash. (Source: 2018 NCASI North American Pulp and Paper Benchmarking Survey Data.)



2. Regulatory tools used by North American governments for managing wood ash application on agricultural land (sample size: 32 United States and 22 Canadian forest products facilities). Results show percentages of nonexclusive responses to multiple-choice questions (e.g., ash application could be managed by both a permit and a government guideline).



3. Prevalence of ash application programs sponsored by North American forest products facilities as of December 2018 (sample size: 32 United States and 22 Canadian forest products facilities).

ing to determine appropriate application rates. Although program approval/permitting processes vary with jurisdiction, requirements regarding ash handling and storage, transportation, and recommended land application practices are similar across North America. This paper summarizes these practical aspects, in addition to identifying application benefits reported by landowners, as well as challenges involved in the implementation and operation of these programs. This information has been synthesized from surveys and questionnaires sent to wood ash generators and exchanges between the authors and consulting companies managing wood ash for agricultural purposes on behalf of wood ash generators. Information was collected in two phases. First, the authors conducted a preliminary survey among dozens of forest products manufacturing facilities (wood ash generators) to identify potential

participants. Fifty-four North American facilities participated in this initial survey (December 2018). Results showed that in most jurisdictions, governments manage land application of wood ash by means of regulations, guidelines, permits, or a combination of these tools (**Fig. 2**). About one-third of facilities indicated that they undertake a land application program for wood ash (**Fig. 3**). Most companies indicated their willingness to share detailed information about their programs. The authors followed up with these latter companies to explore their interest in participating in the second phase of the information collection exercise, which consisted of completing a detailed questionnaire. In total, 11 forest products manufacturing facilities (seven in Canada and four in the United States) provided wood ash data and completed detailed questionnaires documenting their wood ash land application experiences (**Fig. 4**).

KEY CHARACTERISTICS OF NORTH AMERICAN WOOD ASH APPLICATION PROGRAMS

Type of ash used for land application

Ash used for agricultural land application is generated from the burning of clean wood residues in power boilers. Occasionally, clean wood residues are co-combusted with small amounts of wastewater treatment biosolids and fossil fuel, such as natural gas. Two types of boiler ash can be generated: (a) fly ash, which is collected from emissions control devices installed on boiler stacks, and (b) bottom ash, which accumulates at the bottom of boilers [29]. Often, bottom and fly ash are combined prior to beneficial use or disposal. Recent data suggest that most ash generated and managed at pulp and paper mills in North America is fly ash, followed by mixed ash and bottom ash [30].

Fly ash, bottom ash, and mixtures of the two are all viable options for land application. The ultimate choice typically depends on whether wood ash meets quality criteria established in government guidelines. It is worthwhile to note that bottom ash can contain large “clinkers” and foreign matter (e.g., nails, wire, stone, glass). Farmers may consider a batch of wood ash unacceptable if the level of contamination is perceived as potentially detrimental to harvest machinery or pasturing.

Permitting process

Setting up a wood ash land application program varies with jurisdiction but generally involves the following:

- (a) Showing the benefits of applying wood ash on agricultural land by summarizing the findings from past studies or by carrying out field trials, in some cases under a signed agreement with the landowner.
- (b) Applying for approval from either a federal, provincial, or state agency (usually the responsibility of the wood ash generator).
- (c) Issuing of federal labeling (Canada only), a site-specific permit (United States and Canada), a beneficial use determination (United States only), or registration and labeling of the material as a soil amendment or liming product at the state level (United States only).
- (d) Application of the ash at the receiving site (often under agreement with the ash generator).

Federal labeling in Canada is administered by the Federal Canadian Food Inspection Agency (CFIA). Certain states in the United States allow for the wood ash to be registered and labeled as an agricultural product through their Department of Agriculture (e.g., Alabama, Georgia, Virginia).

The landowner is typically not required to apply for any permit. Information collected from the surveys suggests that the time needed to implement a wood ash land application program can vary from 20 days to six years; however, a typical implementation time ranges between three months and two years.



4. Geographical distribution of wood ash application programs reviewed by NCASI.

Roles and responsibilities

A land application program requires the participation of several parties, each playing different roles and with specific responsibilities. The *generator* is the forest products facility, which is usually responsible for ensuring that permitting requirements are met. The *broker* or agricultural service provider is typically a third-party company responsible for connecting the generator with potential ash users. Brokers can take on permitting/labeling responsibilities on behalf of the generator. Sometimes, the generator also acts as a broker. One U.S. case study enlisted the local soil and water conservation district office to act as the broker. The *landowner* is typically a farmer upon whose field wood ash will be applied. Landowners can spread and/or incorporate ash into the soil or rely on a hauler to undertake that task.

Wood ash testing requirements

Testing requirements and allowable limits are jurisdiction specific. In some cases, ash quality requirements are those established by government-based technical organizations such as the Bureau de normalisation du Québec (BNQ) or the CFIA. **Table 1** provides a summary of ash quality reported as acceptable for agricultural land application purposes. Common testing requirements include:

- Calcium carbonate (CaCO_3) equivalent (CCE)
- Fineness
- pH
- Moisture
- Foreign matter content
- Electrical conductivity
- Nutrients
- Trace and heavy metals
- Carbon content
- Dioxins and furans

ENVIRONMENTAL

Parameter	Units	British Columbia	Manitoba	Ontario	Quebec 1	Quebec 2	Minnesota	South Carolina	Georgia
		Based on...							
		Ash-Only Mean	2 Sample Average	Median	Median	Median	1 Sample	4 Sample Average	1 Sample
pH		12.8		10.6	12.3	12.3			10.7
Calcium carbonate equivalent	% CaCO ₃ eq. ^a			44.0	38.2	52.5		112	
Dry matter	%			44.7	89.7	74.9	68.4	73.4	
Total carbon (C)	% dry	1.82		60.1					
Total organic matter	% dry	2.2			5.4	7.3			
Electrical conductivity (total salts) ^b	mmhos/cm	43.4		3.89				9.25	
Antimony (Sb)	mg/kg dry	0.3					<2.2		
Aluminum (Al)	mg/kg dry		4980		29000	6550	8370		
Arsenic (As)	mg/kg dry	2	3.35	0.71	2.5	25	1.8	2.33	
Barium (Ba)	mg/kg dry	810					640		
Beryllium (Be)	mg/kg dry	0.3						ND	
Boron (B)	mg/kg dry				85	69	147		
Cadmium (Cd)	mg/kg dry	8.94	21.4		5.3	3.2	7.2	0.72	
Chromium (Cr)	mg/kg dry	21.8	9.93	45	57	26	14.9		1.4
Cobalt (Co)	mg/kg dry	7.2	3.8	3.6	7	4			
Copper (Cu)	mg/kg dry	26.1	81.4	23	99	47	37.1	37.2	8.3
Mercury (Hg)	mg/kg dry	<0.013	<0.01	0.01	0.05	0.14	0.032	ND	
Molybdenum (Mo)	mg/kg dry	2.7	5.51		9.5	3	12.1	1.74	
Nickel (Ni)	mg/kg dry	15	7.9		36	13	10	32.8	1.6
Lead (Pb)	mg/kg dry	3	3.65		15	38	2.7	11.6	0.3
Selenium (Se)	mg/kg dry	<0.3	1.5	0.59	0.5	0.25	<1.5	ND	
Silver (Ag)	mg/kg dry	<0.1		22					
Thallium (Tl)	mg/kg dry	0.07		1.5					
Tin (Sn)	mg/kg dry	0.50		0.04					
Vanadium (V)	mg/kg dry	39						37.1	
Zinc (Zn)	mg/kg dry	1420	2,010	91	441	708	1050	535	14

^a Calcium carbonate equivalence (CCE) compares the liming material to pure calcium carbonate; ground limestone has CCE near 100%.
^b Electrical conductivity can be used as a surrogate for total dissolved salt content of material.
 ND = non-detect.

I. Quality of wood ash used in agricultural land application programs reviewed by NCASI.

Most land application programs reviewed for this paper use calcium carbonate. Not all programs included fineness (or particle-size distribution) as a testing requirement. However, those that did used it in conjunction with CCE to calculate an effective neutralizing value (ENV) [31] or agricultural index [26] to estimate the effectiveness of wood ash in neutralizing the acidity of the soil. Wood ash with smaller average particle size and higher CCE tends to react more quickly in the soil [17,32,33]. Fineness, in particular, heavily influences the rate of dissolution and short-term neutralization [34]. In general, jurisdictions may impose criteria for agricultural liming materials based on acceptable CCE and particle-size distribution [26,31]. Agrologists and farmers use CCE and fineness to determine appropriate application rates.

Most facilities in the case studies reviewed have tested their ash for moisture. Moisture (or dry matter content) depends on storage conditions prior to application and may be used to adjust application rates [20].

Typically, wood ash is tested for several macronutrients, namely, bioavailable phosphorus (P_2O_5) and potassium (K_2O); total calcium and total magnesium; and micronutrients such as manganese, boron, copper, molybdenum, and zinc. Nutrient concentrations determine the fertilizing value of the ash.

Most facilities also test their ash for a suite of heavy metals (e.g., arsenic, cadmium, chromium, lead, mercury, nickel), often to comply with regulatory and labeling criteria. These criteria can consist of concentration limits in the wood ash or maximum allowed metal addition to the soil over a pre-specified period at a specific application rate.

Some facilities test their wood ash for electrical conductivity (EC), which provides an indirect measure of salinity or total dissolved salt content. Agrologists may take into consideration the EC of wood ash as they determine application rates.

Carbon content in wood ash is not typically required by regulators, but it may be measured by facilities to provide an indication of unburned carbon, which varies with the type of ash (fly or bottom), type of boiler, and combustion conditions. High levels of carbon suggest inefficient wood combustion, and may potentially dilute the liming and fertilizing effects of wood ash [35].

Dioxins and furans testing is a regulatory requirement in several jurisdictions. It is worthwhile to note that the limited dioxin and furan information reported by the participating facilities suggest very low concentrations (<10 ng TEQ/kg [dry]), which are expected for ash generated from the combustion of inland wood [36]. At those levels, ash meets known criteria for agricultural land application (e.g., 27 ng TEQ/kg [dry]) [20,37]. Incidentally, none of the programs reviewed for this paper involved the land application of ash generated from the combustion of salt-laden wood.

Ash storage at the generator's site

In most cases, ash is stored outside and uncovered at the forest products facility. Some facilities spray water on the

ash to control dust, but typically ash is stored dry. It can be stored for long periods (from weeks to several months), especially if covered and/or humidified, before being hauled to an eligible field in spring and fall. In some jurisdictions, the generator is required to store at least 50% of its ash production onsite. If not stored onsite, ash brokers can help generators find a storage location as close as possible to the land application site. Some facilities in the United States have reported use of indoor storage structures.

Transportation costs and distances

Typically, the generator (facility) or the broker cover the cost of transportation to the application site. Transportation and handling of wood ash are carried out in a manner that prevents release of fugitive dust; that is, all vehicle operators ensure loads are tarped. In certain jurisdictions, the hauler may be required to ensure that wood ash is delivered according to restrictions governing it as a “dangerous good,” and have an approved emergency response plan in place prior to transporting the material. During cold weather, ash may freeze to trailers and trailer liners or a chemical agent may be required for transport.

Personal protective equipment (PPE) is also recommended when handling wood ash, including wearing long-sleeved shirts, long pants extending over the top of work boots, gloves, eye goggles, and face masks. Wood ash is an alkaline material and can irritate the skin. If ash comes in contact with skin during transportation or application, it is recommended that the exposed area be washed thoroughly with water. Ash taken directly from a boiler can also contain hot embers that pose both a health and fire risk [11].

Transportation and delivery costs range from US\$1.8 to US\$32/short ton of ash (CA\$2.5 to CA\$46.5/metric ton), with a typical cost ranging somewhere between US\$8 to US\$20/short ton of ash (CA\$12 to CA\$29/metric ton). In general, transportation costs will vary with the location of the application site relative to that of the generator's site. Generators have reported transportation distances of up to 300 km (186 miles), although typical travel distances fall in the 50 to 190 km (31 to 118 mile) range. It should be noted that transportation distance is often constrained by the liming and fertilizing value of the ash. Brokers have indicated that ash with higher fertilizing value can be trucked farther.

Ash storage at the application site and timing of application

Ash is typically stored outside and uncovered at the application site, where it remains until the farm can spread it. This approach can be problematic when ash is delivered during the winter, as it can remain frozen in the spring when the farmer needs it the most. An approach used by farmers is to turn over the ash piles when they are dumped to prevent the ash from hardening too much.

Wood ash can spontaneously self-harden as the ash re-

acts with carbon dioxide (CO₂) and moisture to create a layer of carbonates and other minerals on the surface [38]. The reaction produces large ash particles with a dense stable structure. The rate of this reaction will depend on environmental factors (e.g., humidity), but the process can be accelerated by spraying the ash piles with water. During warmer seasons, when wind and dust dispersion are a concern, farmers may apply moisture onto their ash piles to promote self-hardening or they may choose to cover them. One location in Canada uses a temporary storage bunker consisting of ground tarp, three-sided bunker (which requires approval), and roof tarp.

In the spring and fall, farmers apply ash as soon as practically possible after delivery to the site, with a range of allowable storage times from seven days to a maximum of one year after delivery, depending on season and application site. Depending on the crop, it is possible that ash delivered later in the spring and summer will be stored on site until fall (i.e., after harvest). If ash is delivered in early spring while the ground is still frozen, landowners may clear a spot (e.g., remove snow) on the field and provide an access road for delivery trucks, but landowners generally do very little handling of the ash itself. Otherwise, ash is not stored for long, with farmers applying ash shortly after delivery.

Ash application practices

The mobile equipment used to land-apply ash is generally the same as that used to apply other soil amendments, including standard manure and agricultural lime spreaders (e.g., Lowlander 75 speed spreader from G.T. Bunning & Sons Ltd.) and standard tilling equipment. Occasionally this equipment is outfitted with large, high-flotation tires to reduce rutting of the fields. Government guidelines encourage farmers to wear appropriate PPE mentioned earlier for ash application.

Ash can be spread, but also spread and then incorporated into the soil. The approach often depends on the type of land use. Farmlands receiving wood ash have reported growing crops such as wheat, canola, corn, soybeans, barley, oats, potatoes, and peanuts. Other agricultural uses for wood ash include growing alfalfa, cotton, and hay. Ash is usually tilled into the soil when applied to land used for row crops and spread on the surface when applied to pasturelands (farmers would not typically till pastureland or land growing hay).

Care should be taken when surface applying fresh wood ash to fields, especially if plants are actively growing. The high alkalinity of wood ash can cause plant damage, or “burning,” if the ash is allowed to remain on the plant surface for an extended period of time. If plant damage is a concern, ash should be applied during dry weather conditions, where ash is less likely to stick to the plant surface, or it should be hardened and stabilized before application [39].

Site restrictions for storage and application

Site restrictions for storage locations and application areas vary with jurisdiction. They consist of setbacks; that is, minimum distances a storage or application location must be from a body of water, a source of potable water, or a specific type of building or urban area. In Canada, there is typically one set of setbacks for storage and another for application sites. In the United States, on the other hand, setbacks tend to apply to both storage and application sites. The following is a summary of setbacks reported in the case studies. These are provided as examples of setbacks that may be imposed.

• Canada

o Storage

- Municipal well: 100 m
- Other wells: 90 m
- Private well: 15 to 100 m
- Surface water: 50 m
- Water conveyance (e.g., ditch): 15 m

o Application

- Municipal well: 100 m
- Other wells: 20 m
- Private well: 3 to 50 m
- Property line: 5 m
- Surface water: 20 m

• United States

o Storage and application

- Municipal well: 1000 ft
- Private well: 100 to 200 ft
- Property line: 50 ft
- Residence: 100 to 200 ft
- Residential development or recreational area: 600 ft
- School, daycare, hospital, or park: 500 ft
- Surface water: 100 ft
- Often not allowed to store more ash than what can be used at the application site

Application restrictions based on soil pH

Wood ash is alkaline, and it can thus be used to increase soil pH. Typical soil pH in the areas surrounding surveyed forest products facilities varied between 4.5 and 6.5. Based on liming requirements, which are dependent on crop type, soil pH and type, and the ash's effective neutralizing value, farmers can determine the most appropriate application rate to increase the pH of the soil within a range that is optimal for the intended crop [4,11]. For most crops, the optimum soil pH range is 5.5–7.5 [26]. Raising the pH excessively (>7) in mineral soils may lead to reduced availability of certain nutrients (e.g., phosphorus, potassium, manganese, boron, zinc, copper, iron, sulfur), and thus potentially harm plant growth [7,9,26]. Hence, application restrictions based on soil pH are less challenging when soils are more acidic. Available information from wood ash generators and brokers indicates that soils with pH 6.5 or higher

can be ineligible for wood ash application. Nonetheless, higher limits for soil pH are allowed in Quebec, Minnesota, Maine, and South Carolina, with the highest allowable at pH 7.5. In Georgia, where wood ash is used as a soil amendment, there is no soil pH restriction.

Application rates

In general, application rates are primarily based on liming requirements for the intended crop and the neutralizing value of the ash under evaluation. However, information about the content of primary nutrients in the wood ash (e.g., potassium, phosphorus, calcium, magnesium) and relevant fertilizer recommendations from soil testing may be useful to adjust liming-based application rates [13,16]. Application rates reported by the cases studies range from 2 to 45 metric tons/hectare (0.9–20 short tons/acre), with a typical range between 8 and 14 metric tons/hectare (3.6–6.2 short tons/acre). The wide range of application rates reflects site-specific liming requirements, but also the significant variability in the quality of ash generated by different facilities or even from the same facility.

At very high application rates, adverse effects of wood ash on crops may occur due to a rapid and significant increase in soil pH beyond a level that is suitable for growth and nutrient uptake or due to specific phytotoxicity levels [8]. Such an event is typically known as a “pH shock.” The pH and reactivity of wood ash are higher than those of commercial agricultural lime [33]. Wood ash also has higher salinity, which may compromise the plant’s ability to take up water and nutrients [12,14]. The effect of a “pH shock” may be avoided or minimized by letting the ash harden while stored outdoors. It should be noted, however, that hardening will likely result in wood ash with reduced alkalinity and potentially reduced nutrient content due to leaching by rain [40].

While heavy metal concentrations in wood ash are relatively low and generally not considered a significant environmental concern [4,11–13], in rare cases some may exceed local jurisdictional or labeling criteria. Accordingly, application rates estimated purely on the basis of liming requirements may need to be adjusted, namely reduced, depending on ash pH, EC, and heavy metal concentrations.

Benefits of land-applying wood ash

The case study review revealed that wood ash can be a cost-effective alternative to agricultural lime. In rural areas surrounding a facility, it is often easier to obtain wood ash than agricultural lime, and it can result in significant savings for farmers. Land application also has the potential for significant cost reductions for the facility. When all costs are considered, one facility estimated that it would be four times more expensive to landfill its ash than to run a land application program.

Farmer testimonials suggest that crop yields can increase significantly in areas where wood ash has been ap-

plied. This observation is supported by results from the available literature regarding liming effects and fertilizing value of wood ash on soil tilth (soil suitability for planting or growing a crop), bacterial community, and plant growth. Lickacz [17] reported increases in crop yield associated with improvements in soil tilth brought about by the liming effect of wood ash. The high levels of calcium in wood ash are the primary drivers of these improvements. Calcium cations can improve soil structure by binding together sand, silt, and clay particles into stable soil aggregates [17,34,41]. In turn, aeration and water infiltration is typically enhanced in soils with better structure [17,34,42]. Arshad et al. [41] reported soil aggregation to be generally more positively affected by wood ash than by lime.

Arshad et al. [41] also showed that wood ash application resulted in significantly better crop yield increases than those achieved by agricultural lime at equivalent application rates. Increased phosphorus availability was identified as one of the reasons behind the enhanced productivity of wood ash-amended soils. Abundant literature supports the fact that wood ash increases soil concentrations of not only phosphorus, but potassium, calcium, magnesium and, sulfur; and if applied at agronomically recommended rates, it has no visible detrimental effects on plant growth and only negligible impacts on concentrations of heavy metals in plant tissue [3-7,12-14,18,33].

Finally, the agricultural services provider in one of the case studies indicated that wood ash is known to stimulate microbial activity in the soil, which is vital for plant growth. This effect is also supported by the available literature reporting increased soil bacterial growth rates, as well as changes in bacterial community structure and function, in response to wood ash application [43,44].

Challenges associated with land-applying wood ash

Obtaining application permits in some jurisdictions can be a cumbersome process that discourages participation. Elsewhere, misinformation about the beneficial properties of wood ash may hinder the approval process or limit rapid adoption of wood ash as a replacement for traditional agricultural liming material.

Some facilities and brokers have found it difficult to ensure that the correct ash testing procedures are used and that appropriate testing requirements are met. This is often the result of requirements that are set on a case-by-case basis or are jurisdiction-specific. Adoption of a permitting approach that employs more uniform requirements across multiple jurisdictions would allow companies and brokers to standardize their ash testing procedures and ensure testing requirements are always met. This approach would likely result in a larger number of successful land application programs.

Many of the challenges associated with wood ash delivery, storage, and land application are related to weather. In

wet conditions, it may be difficult to deliver or properly land-apply ash. Some jurisdictions have regulatory restrictions preventing land application on flooded or snow-covered fields; alternative storage space is needed during those times. Wet conditions may cause the ash piles to harden over time, making it difficult to handle and spread. Storage of ash over winter months can cause the piles to freeze, reportedly making them difficult to work with in the spring. When conditions are prime for application and ash demand is high, the limited number of delivery trucks and spreading equipment may prevent some farmers from receiving the amounts of ash needed. Controlling releases of fugitive dust can also be challenging during transportation and storage, especially under windy conditions.

Wood ash of significantly variable quality can be a challenge for users. Changes in chemical properties (e.g., changes in neutralizing capacity, nutrients) force farmers to constantly adjust appropriate application rates. Changes in physical quality (e.g., excessive foreign debris, clinkers, rocks, and dirt) can make ash difficult to handle and spread. If the level of foreign material contamination is perceived as potentially detrimental to harvest machinery or pasturing, the ash may become unacceptable to the spreader or landowner. Hardened wood ash may also be challenging to handle and apply to land.

The hard, abrasive nature of wood ash particles can cause grinding and physical wear to equipment over time, which can lead to increases in equipment maintenance compared to other land-applied materials. Standard farming equipment may not always be capable of delivering an even application of wood ash at low application rates. During times of high ash demand, suitable land application equipment may also be difficult to obtain for farmers needing to rent equipment. Because this is not an issue when using commercial soil amendments (several suppliers of commercial soil amendment also provide land application equipment), some farmers may be discouraged from working with wood ash.

CONCLUSIONS

This article presents an overview of wood ash land application programs informed by the experiences from 11 North American application sites. These experiences illustrate how some jurisdictions regulate land application of wood ash and how facilities in those jurisdictions have managed to accommodate the requirements and implement successful land application programs.

The present case study review suggests that the primary benefit associated with the land application of wood ash is the ability to increase soil pH, bringing it into an optimal range for plant growth. The available literature on this topic confirms additional benefits, such as providing a source of essential plant nutrients, improving soil condition, and supporting soil bacterial communities—all of which lead to increases in crop yields. Benefits of liming and fertilizing

effects of wood ash on plant growth are supported by farmer testimonials suggesting that crop yields can increase significantly in field areas where wood ash has been applied. Finally, wood ash was reported to provide a cost-effective alternative to agricultural lime for farmers, with the potential for additional cost reductions for the facility.

Reported challenges of applying wood ash on agricultural land include lengthy application approvals or regulatory hurdles limiting wider use of ash as a soil amendment in some jurisdictions. It is also challenging for facilities and brokers to ensure the correct ash testing procedures are used and that appropriate testing requirements are met. Often, weather-related issues during periods of excessive rain or winter conditions can negatively impact delivery and application of wood ash. Variability in ash quality can be a challenge for brokers and landowners who may need to constantly adjust their application rates and practices. Finally, the abrasive nature of wood ash can lead to increased equipment maintenance and repairs.

While most facilities in the case studies have adapted to the previously noted challenges, having more specific and clear government guidelines and permitting procedures, such as those already available in jurisdictions such as Alberta, Minnesota, Quebec, or the Maritimes, are necessary to enable and facilitate a wider application of wood ash on agricultural soil. **TJ**

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ABOUT THIS PAPER

Cite this article as:

Lama, I. and Sain, D., *TAPPI J.* 20(2): 111(2021).
<https://doi.org/10.32964/TJ20.2.111>

DOI: <https://doi.org/10.32964/TJ20.2.111>

ISSN: 0734-1415

Publisher: TAPPI Press

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ABOUT THE AUTHORS

We chose this research topic because implementing wood ash agricultural land application programs in some North American jurisdictions can be cumbersome and is often hindered by misinformation on the beneficial properties of wood ash. Previous research primarily focused on studying the properties of wood ash as a liming and fertilizing soil amendment. Our research focused on characterizing the experience of ash generators, landowners, and agricultural service providers in running successful wood ash land application programs, as well as the restrictions and challenges reported during program implementation.

The most difficult aspects of this research were to assemble the participation of forest products facilities that had run or were running wood ash land application programs, as well as to synthesize all their experiences into consistent case study narratives that would illustrate the implementation requirements and challenges experienced in the field. In undertaking this research, we learned that implementing wood ash agricultural land application programs in some North American jurisdictions can be cumbersome and is often hindered by misinformation on the beneficial properties of wood ash.

One of the most interesting findings from our work is that, in spite of the abundant research on the benefits of wood ash as a soil amendment, most of

the wood ash currently generated by the forest products industry is still being landfilled. We learned that wood ash land application programs are successful when farmer demand, logistical constraints, and reasonable approval requirements concur.

The information compiled and summarized in this paper will be especially useful for forest products manufacturing facilities considering beneficial use of wood ash as a soil amendment. It can also inform discussions between ash generators, those engaged in agriculture, and regulators regarding alternative approaches used in other jurisdictions to enable and facilitate application of wood ash on agricultural soil.



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