AGRICULTURAL WOOD ASH RECYCLING IN QUÉBEC AND IN NORTHERN CLIMATES: CURRENT SITUATION, IMPACTS AND AGRI-ENVIRONMENTAL PRACTICES

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ABSTRACT:

The use of wood ash to amend soil pH and increase soil fertility, formerly a common practice, was largely abandoned at the start of the 20th century when alternative products arrived on the market (agricultural lime, muriate of potash). Burning large quantities of wood industry residues for energy purpose, contributed to increase availability of wood ash in Québec. More than 300 000 tm (wet weight) are produced yearly in the province and approximately half of this amount was recycled as soil amendment in 2007; more than 80 000 tm being applied for agricultural purposes on 250 farms. Literature clearly shows that using ash is efficient for the correction of soil acidity and contributes to bring nutrients to crops. Ash applications to soil also generally allow increase in crop yields compared to agricultural limestone. Its economic value has been estimated between 20 and 65 $/tm for a normal ash. Its agricultural use could also reduce greenhouse gases emission, which may lead to credits of carbon. However, ash quality varies, mainly because of wood type, burning conditions and water addition. In addition, alkalinity, potassium and dust contents require both environmental and agronomic precautions. Government regulations and commercial standards (BNQ) govern their use. However, this underlying framework must be complemented with best agronomic practices. Both regulations and best practices allow safe and economical use of ash in agriculture, in accordance with sustainable development.

Key words: Ash, best practices, liming, regulation, yields.

RÉSUMÉ:

L'utilisation de la cendre de bois pour le chaulage et la fertilisation des sols, autrefois pratique courante, a été délaissée au début du 20^{e} siècle suite à l'arrivée de produits alternatifs (chaux agricole, muriate de potassium). Avec l'augmentation de la valorisation énergétique des résidus provenant de l'industrie du bois, la ressource redevient largement disponible au Québec. On évalue la quantité annuelle générée au Québec à plus de 300 000 tm (bh). Près de la moitié ont été recyclées comme matières fertilisantes en 2007, dont 80 000 tonnes pour un usage agricole sur 250 fermes. La littérature établit clairement que la cendre permet de corriger l'acidité du sol et fournit des éléments nutritifs aux plantes. Elles produisent d'ailleurs des rendements généralement supérieurs à l'usage de la chaux agricole naturelle. On estime leur valeur entre 20 et 65 $/tm (bh) pour des cendres moyennes, selon la méthode de calcul utilisée. L'usage de cendres permettrait aussi de diminuer les émissions de gaz à effet de serre en agriculture, ce qui pourrait éventuellement donner droit à des crédits. Cependant, la qualité des cendres est variable d'une usine à l'autre, notamment en fonction du type de bois brûlé, du mode de combustion et de l'ajout d'eau. De plus, leur alcalinité, leur contenu en potassium et leur texture fine et pulvérulente commandent des précautions particulières aux plans agronomique et environnemental. Une réglementation gouvernementale, ainsi que des normes commerciales (BNQ), encadrent l'utilisation de ce produit. Ce cadre doit toutefois être complété par de bonnes pratiques agronomiques. L'ensemble de ces mesures permet une utilisation sécuritaire et économique des cendres de bois en agriculture, compatible avec les principes du développement durable.

Mots clés : bonnes pratiques, cendres, chaulage, réglementation, rendements.

Historical facts on wood ash recycling

Documents from Nouvelle-France, dating from the second half of the 17th century, report commercial activities concerning wood ash (Gardiner (1949), quoted by Scott (1968)). At that time, wood was specifically burned to collect the ash from which potash was extracted (potassium hydroxide or KOH) by leaching with water. Indeed, the etymology of the word potash (pot-ash) indicates this origin. Towards the end of the 18th century, Lower Canada largely contributed to make the French-speaking British colony the largest world potash exporter. During all this time, heating houses with wood was common so both settlers and farmers had access to a certain quantity of wood ashes to fertilize and amend their gardens and fields.

Agricultural use of wood ash remained popular in Québec until the years 1930 when exploitation of potash salt deposits started in the United States (Scott, 1968). At the same time, agricultural lime became available at a very competitive price in the province of Québec (Ministry of Agriculture 1932). As a result, the exploitation of limestone and potassium muriate deposits (KCl) replaced traditional use of wood ashes with the beginning of modern agriculture in Québec.

In the following decades, the wood industry was however going to generate more and more ashes as residuals. In absence of a market, ashes were rather managed as a waste, in a more or less suitable way, until regulations appeared in the pulp and paper industry, in the years 1980 and 1990. These new regulations increased ash disposal cost. Besides, the *Ministère de l'Agriculture, des Pêcheries et de l'Alimentation* (MAPAQ) stopped subsidizing lime use in agriculture. These two phenomena, as well as agronomic studies done in New England and elsewhere, contributed to the renewed interest for ash spreading in Québec in the last 15 years.

Land application of wood ashes can be viewed as a recycling activity, because it allows the re-use of nutrients coming from forest plants (trees) in another cycle of plant production (agriculture). However, in order to make sure that this recycling is made safely, the *Ministère du Développement Durable, de l'Environnement et des Parcs* (MDDEP) developed guidelines in the 90's (MENV, 1997) which were later revised (MENV, 2004; MDDEP, 2008). The *Bureau de normalisation du Québec* (BNQ) also produced commercial standards to define quality requirements of certified ashes and directions of use (BNQ 1997, 2006). However, there is no existing reference document in Québec who gives an insight on the latest research progress and reports good agri-environmental practices. This article aims to fill part of this lack of information.

Amounts produced and recovered

At the end of the 80's, an estimated quantity of 45 000 tm (wb) of wood ashes was produced annually in Québec by the pulp and paper industry (AIFQ, 1990). In 2006, more than 300 000 tm (wb) of ashes were produced per year, two thirds coming from pulp and paper plants and the other one third from cogeneration plants for energy production, and from sawmills and other wood industries. Ash spreading is likely to increase with renewed interest for bio-energy.

In 2007, 150 000 tons of ashes were recycled as fertilizing residuals (Hébert *et al.*, 2008). A majority of recycled ashes (54%) were used in agriculture, and the rest for the revegetation of degraded sites, soil mixes manufacturing, composting activities and other uses. Half of the wood ashes resource produced annually are still landfilled.

Quantities recycled specifically in agriculture increased by 80% between 1999 and 2007 (Hébert *et al.*, 2008). In 2007, approximately 250 farms recycled 81 000 tm of ashes as soil amendments and to provide nutrients to crops.

Liming characteristics

Table 1 compares agronomic characteristics of wood ashes used in Québec with those of agricultural lime. The mean neutralizing value (NV) of ashes is 49% (calcium carbonate equivalent) on a wet basis, which is half the capacity of commercial agricultural lime. The NV of ashes in Québec varies greatly from one ash to another (coefficient of variation (c.v.) of 65%) as observed in the United States (Ohno and Erich, 1990; Siddique, 2008). This variability is mainly explained by water content, unburnt/coal fractions and soil particles. Indeed, ashes contain about 25% water. This water is added at the factory to extinguish ash, remove dust particles and transform the oxides forms (CaO and K_2O), according to an exothermic reaction, into hydroxide forms ($Ca(OH)_2$ and KOH), less chemically reactive.

Table 1: AGRONOMIC PROPERTIES OF WOOD ASHES AND AGRICULTURAL LIME (wet weight basis).

Parameter	Ashes		BNQ certified agricultural lime	
	Mean value[1]	c.v.[2]	Mean value[1]	c.v.[2]
Dry matter (%)	75	27%	99	-
NV (% CCE)	49	65%	94	5%
Effectiveness factor (E - %)	100 [3]	-.	81	8%
Agr. Index (AI - %)	49[3]	-	77	11%
pH	12,6	5%	9,1	5%
Organic matter (%)	12	61%	-	-
Ca (kg/tm)	160	50%	318	18%
P_2O_5 (kg/tm)	10[4]	70%	0,7	121%
K_2O (kg/tm)	22 [4]	61%	0,4	77%
Mg (kg/tm)	12	51%	35	105%
Ca+Mg /Na+K Ratio	7	90%	1300	80%

[1] Statistics established according to data from the MDDEP for 20 ashes, as well as data from the BNQ and the MDDEP for 22 BNQ certified agricultural limes.
[2] Coefficient of variation c.v. = standard deviation/ mean value x 100.
[3] Effectiveness factor (E) of ash considered close to 100% (BNQ, 2006). Sifting method used for agricultural lime is not appropriate for ash, because it tends to underestimate real effectiveness (see text).
[4] Effectiveness of P and K is respectively estimated at 50% and 100% in equivalence with mineral fertilizers (see text). Analysis of assimilable phosphoric acid, frequently used for mineral fertilizers, possibly underestimates real agronomic value because that method was not developed for strong alkaline substances.

Ashes have a mean content of 12% (wb) of unburnt organic matter, but this quantity varies greatly (c.v. = 61%). This biologically stable carbon form results from an incomplete combustion of wood and confers a blackish color to several ashes. The sand, silt and clay particles were not quantified. In fact, they adhere to barks and residues from wood that come in contact with the ground. They later concentrate in the ashes after combustion of the organic matter. These particles are more abundant in ashes with a weak NV (on a dry basis). These soil particles and stones are more concentrate in bottom ashes. Ashes coming from the burning of paper magazine de-inking residues also contain significant amounts of kaolinite clay. This type of clay is used in factories to produce icy paper. The quantity of soil particles can be estimated using the silicon content of ashes (extracted by hydrofluoric acid). The clay content can also be estimated by total aluminium content (Estes *et al.*, 1995).

The NV of ashes is mainly affected by the presence of calcium ($Ca(OH)_2$), potassium (KOH) and magnesium ($Mg(OH)_2$) hydroxides. It is measured in the laboratory by acid titration, but it can also be estimated from cations contents according to the following formula (MDDEP, 2008):

$$NV_{estimated}\ (\%CCE) = (\%Ca \times 2{,}5) + (\%K \times 1{,}2) + (\%\ Mg \times 4{,}2)$$

An estimated NV nearly identical to the mean NV measured (58 vs 61%, db) was obtained from analyses of 17 ashes recycled in agriculture. Statistical relation between the 2 parameters is expressed in Figure 1.

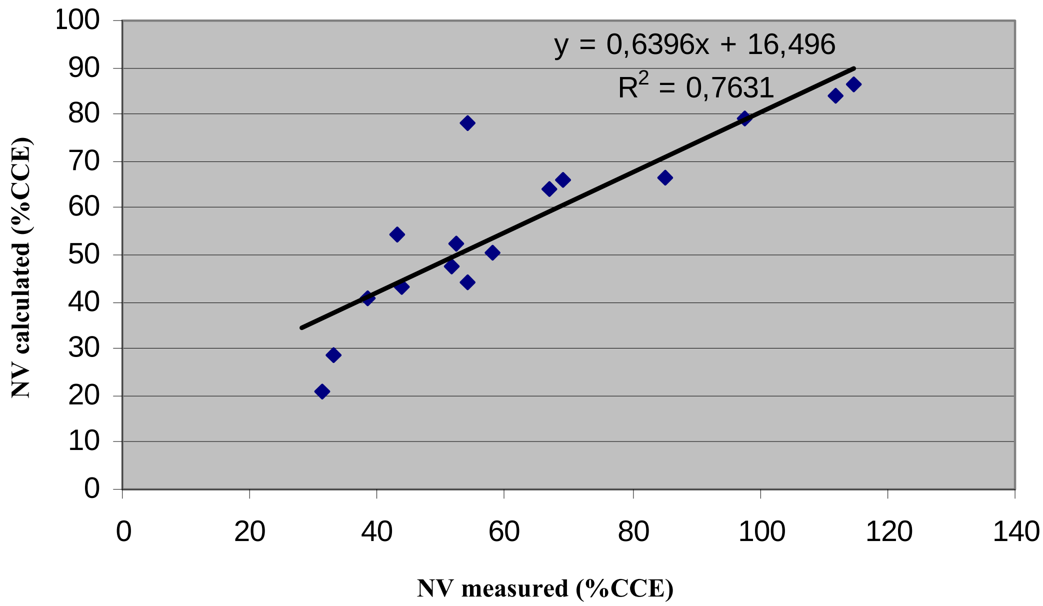

Figure 1: RELATION BETWEEN NV calculated AND NV measured BY CHEMICAL TITRATION FOR 16 ASHES VALORIZED IN AGRICULTURE IN QUÉBEC (data from the MDDEP, on a dry basis).

Since ashes are usually fine and powdery, an effectiveness factor (E) of 100% is conferred to its NV (BNQ, 2006). Sifting proved to be inadequate in estimating ash effectiveness, contrarily to agricultural lime. It may underestimate as much as 50% of real effectiveness, and thus lead to misinterpretation of agricultural index (AI) (Olivier, 1993; Chalifour, 1995). Indeed, ash sometimes contains large aggregates that are kept in fine sieves, but nevertheless remain soluble in water. However, a 100% E could lead to overestimating real effectiveness if hardened concretions (cementing) are abundantly found in ashes.

Using both NV and E, it is possible to calculate the AI of ashes (AI = NV * E). It appears that the AI of ash will be equivalent to its NV, that is to say 49% on average, which represents approximately 2/3 of the AI for limestone on a wet basis (Table 1).

Average pH value of ashes is 12,6 (Table 1), which is much higher than average pH value of agricultural lime (pH 8,2 - 10,3 according to the Mg content). It is explained by the presence of hydroxide forms. This alkaline pH is rather constant exiting the plant (c.v.= 5%). It can however decrease during storage in the field, before spreading. Hydroxides gradually react with carbon dioxide contained in the air to form calcium carbonates (Bordeleau, quoted by MDDEP, 2006). The pH can decrease to a value of 10,5 (MDDEP, 2006), which importantly reduces alkalinity. Following the spreading on ground surface, ash will also act as a temporary "CO_2 trap". Therefore, waiting a few days before incorporation in the soil will allow reduction of ash pH (Ohlsson, 2000), without reducing its neutralizing capacity. The protective effect of carbonation of the hydroxides forms will be even greater if ash is spread on meadow, without incorporation in the soil.

Nutrients

Calcium content of ashes is high, 160 kg/tm (wb) on average, but twice less than agricultural lime (Table 1). Potassium and phosphorus contents are also important, with mean contents ranging from 22 kg K_2O/tm and 10 kg P_2O_5/tm (wb), which is another distinctive feature between ash and lime. However, these concentrations are rather variable (c.v. around 65%). Ashes coming from the burning of wood particles and pulp and paper biosolids would tend to have lower P and K contents than ashes coming from branches or barks containing sapwood. Also, there can be a difference according to species (coniferous or deciduous trees) and natural richness of soils from which trees have grown. However, a regression analysis with 17 ashes showed that P and K contents are not related (r^2 = 0,04). The relation is also weak between Ca and K (r^2=0,15).

Since the majority of potassium from ashes is found in hydroxide form (KOH), therefore soluble in water, a 100% potassic effectiveness is considered as compared to chemical fertilizers. Besides, agronomic studies show that phosphoric effectiveness would range between 25 and 75% (Baziramakenga, 2003). In practice, the use of a 50% value may often be appropriate.

Wood ashes also contain significant quantities of magnesium (12 kg/tm), which corresponds to the mean value of calcic limes sold in Québec, but is quite less than quantities found in dolomitic and magnesian lime. However, Vigneux and Barnett (2001) showed that ash increased Mg availability in soils. A solubility test for Mg in ash will give an indication on this (BNQ, 2006). Sulphur content may vary from 1 to 29 kg S/t (MDDEP, unpublished data). Thus, no generalization can be made on S value of ashes. Ash is not a significant source of nitrogen (average content of 0,3 kg/t wb). This element is mostly lost in gases formed during combustion.

Wood burning concentrates micronutrients naturally occurring in trees, like manganese, iron and zinc. Levels in ashes are higher than with agricultural lime (Table 2). However, in order to avoid excess phytotoxicity following repeated applications, limit contents were established and will be detailed further ahead.

Other potentially beneficial properties of ashes for soils and crops

Researches done in Alberta suggest that ash spreading could improve soil structure (Lickaz, 2002). Indeed, the presence of divalent cations such as calcium (Ca^{++}) and magnesium (Mg^{++}) increase flocculation of soil particles (clay-humic complex). To the contrary, monovalent ions (Na^{+}, K^{+}) tend to disperse clays. This is why BNQ commercial standards (2006) include the following criteria:

$$\mathbf{(Ca^{++}+Mg^{++})/\ (Na^{+} + K^{+}) \geq 2,5}$$

Since ash ratio tends to be around 7 (Table 1), it is more considered as soil structural agent. The ratio is however much lower than for agricultural lime, mainly because of potassium content.

Table 2: MICRONUTRIENTS AND STRICT CONTAMINANTS CONTENTS OF WOOD ASHES AND AGRICULTURAL LIME SPREAD IN QUÉBEC (mg/kg dry basis).

Parameter	Ashes[1]		Agricultural lime[2]		FR content limits[3]		Agr. soils - clays[4]
	Mean value	c.v.	Mean value	c.v.	C1	C2	Mean value
Micronutrients for plants and animals							
As	2	65%	4[5]	124%	13	40	-
B	135	60%	<10	-	-	-	-
Co	10	46%	2	88%	34	150	23
Cr	40	91%	4	125%	210	1060	82
Cu	74	63%	12	365%	400	1000	33
Fe	8 490	38%	3 950[5]	80%	-	-	32 300
Mn	8 160	50%	862[5]	214%	-	-	589
Mo	< 5	-	1[5]	174%	5	20	-
Na	4 500	52%	92	63%	-	-	-
Ni	47	176%	3	71%	62	180	42
Se	< 1	-	<0,7	-	2	14	-
Zn	924[6]	76%	39	325%	700	1850	96
Strict contaminants							
Cd	6[6]	76%	<0,25[5]	-	3	10	1,4
Hg	< 0,1	-	0,07	57%	0,8	4	0,06
Pb	< 22	-	3	92%	150	300	42
Dioxins and furans	< 1 ng EQT/kg[7]	-	-	-	17	50	-

[1]Mean values from Charbonneau *et al*. (2001). Coefficient of variation calculated from raw data.
[2]Analyses done by the MDDEP for 22 BNQ certified agricultural limes.
[3]Fertilizing residuals limits from MDDEP (2008).
[4]From Giroux *et al.* (1992).
[5]Maximum contents observed on 22 agricultural lime samples are: 17 mg As/kg; 3,2 mg Cd/kg; 7 mg Mo/kg; 8300 mg Mn/kg and 12 000 mg Fe/kg. 3 out of 22 agricultural lime samples are classified C2.
[6]Average ashes spread exceed C1 category for Cd and Zn and the majority are then in the C2 category. Ashes submitted to a complete combustion and containing small quantity of soil have richer content of these elements, because of concentration phenomenon and might sometimes exceed the C2 category for Cd and Zn. In counterpart, they also have a higher NV and will be spread at lower rates, limiting metal loadings on the soil at levels similar to those of the C1 category. The BNQ Standards (Table 4) takes into account this double phenomenon establishing an NV/MTE ratio as quality criteria.
[7]Ashes from home wood stove may have much higher values, ranging from 0 to more than 1000 ng EQT/kg (MDDEP, unpublished data).

High percentage of organic matter would also improve total fertility of soils because of carbon type found in ashes that is biologically stable. It is suggested by studies made with “bio-char” (Guo, 2008). Greenhouses studies have also shown that the carbon from ashes can adsorb herbicides incorporated in soil, like atrazine. This phenomenon could theoretically reduce effectiveness of chemical weed control in the field, but could also reduce residual phytotoxicity for the following crop (Estes *et al.*, 1995).

Impacts on soil pH

One of the main interests in using wood ash is to neutralize soil acidity. Calculation of ash loadings is done in first approximation based on the same method used for agricultural lime (CRAAQ, 2003) that simultaneously includes agricultural index (AI) of liming amendment, soil analysis, texture and incorporation depth.

However, ash reacts more quickly than agricultural lime because of the predominance of hydroxides (OH^-) molecules rather than carbonates ($CO3^{2-}$) ions. For equivalent amounts of lime and ashes, based on AI, the behavior of each product in soil will be slightly different. Figure 2, derived from a study on various liming products incubated in soils in the province of Québec (Laverdière *et al*., 1992; Simard *et al*., 1998), illustrates typical behavior of hydroxide and carbonate forms. A similar behavior was observed during field tests in Abitibi (Figure 3). It was shown that for comparable rates (1x), based on AI, soil pH rise faster with ash than with lime. However, pH level reached with ashes is less important than with lime, contrary to expected behavior (Figure 2). In a subsequent test in Abitibi, with another type of ash on a muddy soil, Olivier (1997) obtained a final soil pH of 6,3, slightly lower than the target pH, considering 100% ash effectiveness.

As expected, half-dose of ash did not allow substantial pH rise, compared to control sample (Figure 3). Studies from Agriculture and Agri-food Canada in the Mauricie region (Ziadi *et al*., 2007) with relatively low ash loadings of 3 tm/ha spread annually, during 6 years, showed a progressive soil pH correction. However, soil pH was stabilized close to target value (6,5) in the last 3 years. Besides, trials done in Eastern townships (Vigneux and Barnett, 2001) highlighted that it is better to apply a single dose the first year, to quickly reach the target pH, rather than with lower annual applications.

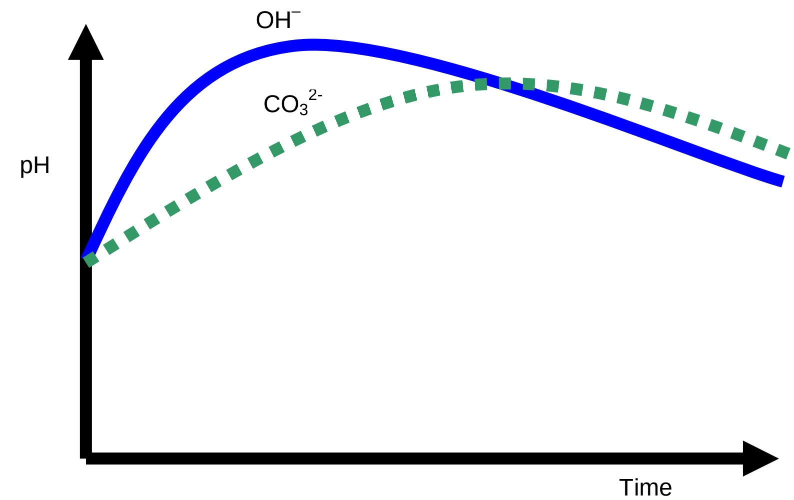

Figure 2: THEORICAL REACTIVITY OF CALCIC AMENDMENTS INCUBATED IN SOILS, ACCORDING TO PREDOMINANCE OF CARBONATE (CO_3^{2-}) OR HYDROXIDE FORMS (OH^-).

On the other hand, Abitibi trials (Figure 3) reveal that exceeding target pH may happen with ash rates exceeding liming requirement (2x), which could be excessive for cereal crops. Moreover, correction of soil pH with ash was prolonged 3 years after spreading. However, in another study in Lanaudière region, with high rates of both wood ash and lime (≈ 12 t/ha), soil pH target was not reached with both products (Royer *et al.*, 2004).

These results confirm that calculation of spreading rate based on AI is a safe approach and generally accurate. However, AI must be calculated considering ash effectiveness close to 100% (and therefore not considering the sifting method used for lime). Also, based on 2 studies from Abitibi, it is possible to affirm that real effectiveness (E) of ash would in fact be slightly lower than 100%, since target soil pH (6,5) is not entirely reached, contrary to lime use (Figure 3). To consider a 100% effectiveness however makes it possible to avoid overliming.

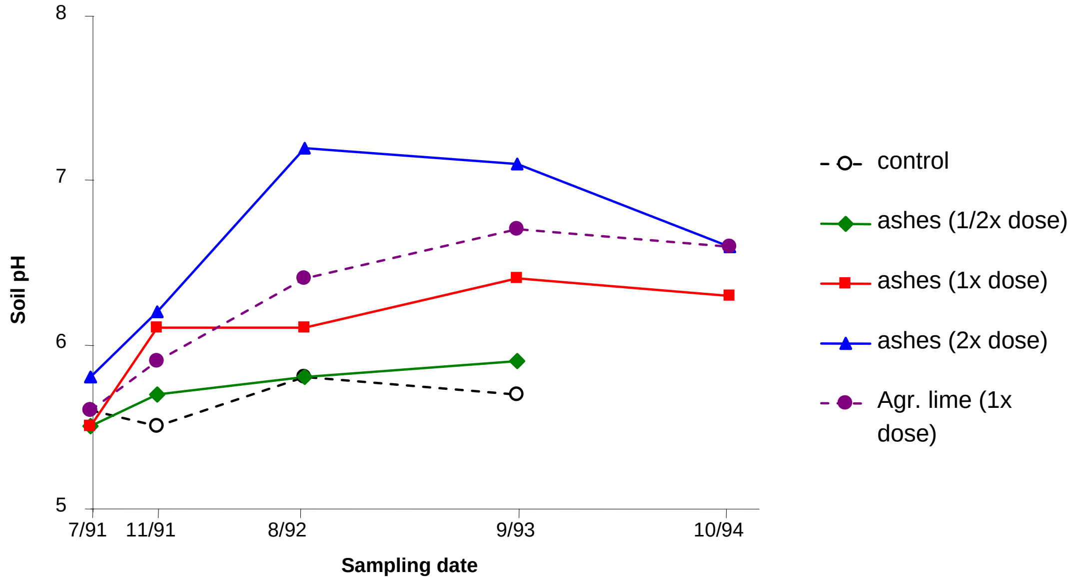

Figure 3: EVOLUTION OF SOIL pH OF A CLAY (FABRE SERIE) AMENDED WITH ASHES OR AGRICULTURAL LIME TO REACH A pH VALUE OF 6,5 (Adapted from Olivier (1993) and Chalifour (1995)).
Notes: The identification of rates has been revised considering that ashes efficiency was of 100%, according to the BNQ, and not 50% based on calculations realised with sifting trials. Only one pH value was considered each year, at the end of the season, to simplify presentation and remove seasonal variability effect of soil pH. Spreading was realised once in October of 1991.

In practice, mean loading rates of ash spreading are 8 tm/ha (wb) with a c.v. of 53% (Hébert *et al*., 2008). With an average AI of 49%, that would correspond to approximately 5 tm/ha of agricultural lime having an AI of 77% (Table 1), which is a normal rate for pH correction. In Saguenay-Lac-Saint-Jean region, after 20 years of ash spreading on tens of farms, no case of overliming was reported when using agronomic rates.

Impact on crop yields

Beyond measurable impact on soil fertility, the major aspect for farmers and agronomists is the impact on crop yield. In the years 1930, the Ministry of Agriculture indicated that "grain crops on light soils receive more benefits from ash use… which also improves clover growth" (MAPQ, 1932). Olivier (1997) reports that application on loamy soil in Abitibi, based on lime requirement (E estimated at 100%), increased barley yield by 83%, compared to control field, and of 30% compared to half-dose of ash. Research in Alberta confirms productivity increase for barley, as well as canola (Patterson *et al.*, 2004). The impact on canola could in part be caused by increased boron availability in soils as observed by other researchers (Vigneux and Barnett, 2001).

Other studies compared more precisely ash effectiveness with agricultural lime (Table 3). In corn fields, Ziadi *et al.* (2007) showed a 9% yield increase, compared to lime, with low rates of ashes (3 t/ha). Krejsl (1995) obtains similar results with wheat. Superiority of ash compared to lime is even more important with legumes. Ziadi *et al.* (2007) observed an increase of approximately 15% with soybeans and dry beans, whereas Krejsl (1995) observed an increase of 63% with green pea. However, this superiority of ash with corn and soy crops was not observed by Royer *et al.* (2004), possibly because of statistical variability of the results.

Table 3: YIELD INCREASES OBTAINED WITH USE OF WOOD ASH AS COMPARED TO AGRICULTURAL LIME, BOTH USED AT AGRONOMIC RATES, FOR DIFFERENT CROPS GROWN IN NORTHERN CLIMATES (FIELD STUDIES).

Crop	Yield increase compared to agricultural lime (%)	Province/State	Authors
Wheat	9%	Washington	Krejsl (1995)
Corn	9%	Québec	Ziadi *et al.* (2007)
Soybean	14%	Québec	Ziadi *et al.* (2007)
Dry beans	15%	Québec	Ziadi *et al.* (2007)
Green peas	63%	Washington	Krejsl (1995)
Hay (clover)	12-35%	Québec	Robitaille (1996)
Hay (alfalfa)	45-61%	New Hampshire	Estes *et al.* (1995)
Hay	28%	Alberta	Lickaz, 2002

Hayfields with legumes, like clover and alfalfa, show high yields increases with the use of ash (Scott, 1968; Seekins, 1986; Robitaille, 1996; Olivier, 1997), especially at implementation. Farm studies in New England showed that ashes also have a non-negligible impact when spread on old meadows, increasing productivity and number of plants (Coleman, 1995). Seekins (1986) in Vermont showed a 75% yield increase with alfalfa. However, Poisson and Vigneux (1994) who made field studies in Eastern townships, obtained smaller yield increases ranging from 5 to 18% for fields amended with ashes compared to control fields. Laroche *et al.* (1997) did not see any increased fodder yield in Lac St-Jean region when a low maintenance dose (1 t/ha (wb)) was applied. In a later study with hayfields on 5 selected farms over a three year period, Vigneux and Barnett (2001) obtained the highest yield increase (10%) when ashes (9 t/ha) were applied all at once, rather than split applications (Figure 4). The impacts of ash on yields were also noticeable the second year. This suggests, just like studies on soil pH, that one single application is generally better than splitted applications.

Experiments in Vermont revealed that exceeding lime requirement in alfalfa fields caused nutritional deficiencies with lime, but not with ash (Coleman, 1995). This protective effect of ash could possibly be explained by micronutrient contents, notably boron (Seekins, 1986). Field tests in New-Hampshire showed that foliar boron in alfalfa is correlated to ash rate (Estes *et al.*, 1995). This phenomenon was confirmed in Québec by Vigneux and Barnett (2001) who also observed an increase in K and Mn contents in plant tissues and soils, compared to control samples. Moreover, Royer *et al.* (2004) observed that fields receiving wood ashes have higher contents in extractable Mn, although contents return to normal after 2 years. The iron and sulfur contents of ashes could also possibly contribute to this protective effect.

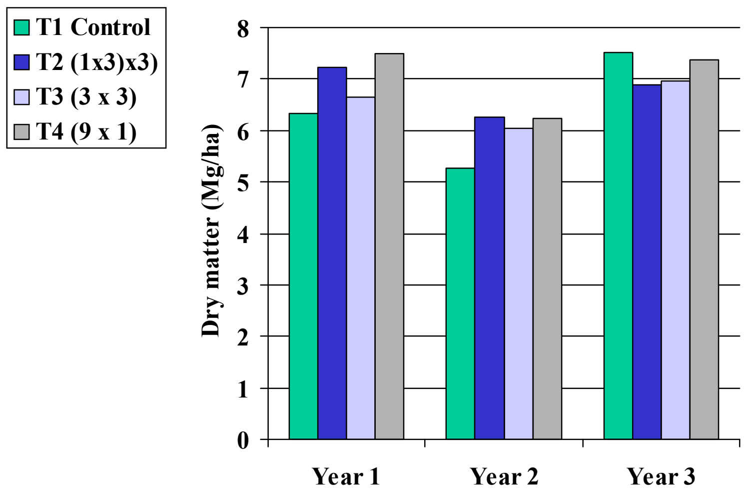

Figure 4: MEAN YIELD OF HAYFILEDS FROM 5 FARMS FOLLOWING ASH APPLICATION (9 tm(wb)/ha) WITH SINGLE SPREADING (T4), ANNUAL FRACTIONING (T3) OR DOUBLE FRACTIONING (T2-ANNUAL AND INTRANNUAL). From Vigneux and Barnett (2001). Differences between treatments and control were significantly different for first and second years, except with T3 the first year.

Other trials on hayfields compared ash with agricultural lime (Table 3). Studies in New-Hampshire (Estes *et al*., 1995), on acidic soils (pH 5,3), showed a 45% yield increase with alfalfa for equal rates of ash and lime (9 t/ha (db)) applied in pre-sowing. The yield increase reached 61% when using higher rates of ash (18 t/ha (db)). With sandy soils of the Bas-St-Laurent region (Québec), Robitaille (1996) obtained yield increases ranging from 12% to 35% for fields amended with ashes. In Alberta, a 28% increase was observed in comparison to lime treatment alone. The increase was 19% when compared to plots receiving both agricultural lime and phosphate fertilizer (Lickaz, 2002). Since ash is more soluble than agricultural lime, its nutrients and alkalinity would be more quickly available for plant roots already established (Lickaz, 2002).

Researches in Northern Europe show that yield of root vegetables, like potato and beet, is proportional to the amount of ash applied (Butkuvienè, 2005). A 6 tm (wb) rate gave a productivity gain of 26% for potato as compared to control field.

In Maine, Porter and Ocaya (2008) obtained similar potato yields when using lime and chemical fertilizers or ash and a reduced rate of fertilizers.

A more global study, done in Alabama, surveyed more than 50 farms that used agronomic rates of ash (lime requirement) and systematically showed positive effects on plant growth (Mitchell, 1995). This confirms once again that loading calculation according to lime requirement is safe for crops.

Impacts on crop quality

Considering major nutrient contents (N, P, K, Ca and Mg) of grains like corn, soybean and dry pea, Ziadi *et al*. (2007) did not notice any significant difference between treatments with ash or agricultural lime. Besides, these authors observed little or no impacts on the soil availability of major nutrients or micronutrients. Conversely, fodder crops can store excessive amounts of K (Estes *et al*., 1995), which can be at risk with dairy cows. Vigneux and Barnett (2001) indeed report an important increase in the foliar K/(Ca+Mg) ratio of hayfields. Therefore, ashes should not be applied with hayfields on soils rich in K (or low in Mg).

With potatoes, Porter and Ocaya (2008) showed no increased of the common scab when using a resistant cultivar.

Economical value of wood ash

Since ash is a substitute for agricultural lime and chemical fertilizers, theoretical value can be estimated according to selling price of competitive materials. Based on the average contents of ashes for AI, P_2O_5 and K_2O available fractions (Table 1), and based on the cost unit of agricultural lime (approximately 20$/t; AI=77%) and fertilizers (2,40 $/kg P_2O_5; 2,00 $/t K_2O), a mean value of 69$/tm (wb) is obtained for ashes, including 13$ for neutralizing value, 12$ for available P content and 44$ for available K content. By cutting off spreading cost of ash to the farmers (approximately 4$/t), a mean value of 65$/tm (wb) is obtained, without considering micronutrients. This mean value may also vary when considering transport costs for ash and lime in a given area, and also if the soil will benefit from potassium content of ash.

Another way of calculating retail value of ash is to consider lime replacement value, and increased productivity as compared to lime use. Based on market prices, average yields (Québec) and yield increases (Table 3), an increased value of about 190$/ha for corn and soybean, and of 90 $/ha for barley is obtained. By considering average rates of ashes (8 t/ha, wb), additional income varies from 11 to 24$/ton of ashes, according to type of crop. By adding liming value (13$/t), less the spreading cost assumed by farmer (4$/t), mean value of ash varies from 20 to 33 $/tm (wb), without considering costs of transport.

Independently of calculation method used, commercial value of ashes is much lower than its real value, because actual selling price vary from 0 to 25$ a ton (wb), delivery included. This suggests that in many cases ash is still considered as waste rather than a commercial high value product. The low selling price is an advantage for farmers who make important savings. It is however a barrier to recycle more industrial ashes that are currently landfilled.

Environmental benefits of wood ash recycling

Agricultural recycling of ashes reduces landfilling and replaces non-renewable resources (agricultural lime, chemical fertilizers) coming from mining and industrial activities.

A less known advantage is the reduction of greenhouse gases (GhG) by replacing agricultural lime. Indeed, lime from mining sites is hard and must be finely crushed before its agricultural use. This crushing implies a considerable quantity of energy. When this energy comes entirely from oil, the production of one ton of limestone would contribute to emit 0,36 kg C/kg of lime (Lal, 2004) or 1,3 tons of CO_2-eq/ton. However, in Québec, energy used for crushing is mainly hydro-electric, so greenhouse gas emissions would probably be less. In addition to GhG emissions associated with industrial production of lime, it is necessary to consider emissions of GhG after lime is spread on the soil (Environment Canada, 2003). Lime reacts chemically in soil solution, according to following equations:

calcic lime: $\mathbf{CaCO_3 + 2H^+ \rightarrow CO_2 + Ca^{++} + H_2O}$

dolomitic lime: $\mathbf{CaMg\ (CO_3)_2 + 4\ H^+ \rightarrow 2\ CO_2 + Ca^{++} + Mg^{++} + 2\ H_2O}$

This causes a direct release of CO_2 from fossil origin (old carbonate deposits). Based on mass balance and considering the proportion of various types of limes sold in Canada (Environment Canada, 2003), each ton of agricultural lime spread would contributes to the emission of 0,45 tons of CO_2. These emissions have been are considered by the federal government in GhG emission estimations from agricultural activities in Canada. Conversely, ash spreading does not directly cause a release of CO_2, because its alkalinity is from hydroxides instead of carbonates. Since a normal rate of 8t/ha of ashes (AI = 49%) avoids consumption of approximately 5 tons of agricultural lime per hectare (AI = 77%), this recycling would also reduce the emission of approximately 2,3 tons CO_2/ha. When considering fossil energy used to produce lime, GhG emissions reductions could vary between 2,5 and 9 ton CO_2/ha when using wood ash.

As an indication, it should be stated that CO_2 emission linked to wood burning (bioenergy) is not considered in these calculations, because it is about a biogenic carbon, not from a fossil carbon source. However the burning pulp & paper biosolids rich in nitrogen contributes to nitrous oxide emissions (N_2O), a powerful GhG. Burning of de-inking residues, which contain lime, also release fossil CO_2, just like agricultural lime spreading.

Environmental risk management

In Québec, spreading of wood ashes must follow nutrient regulations. Since ashes contain almost no nitrogen, are odourless and pathogen free, there are few nutrient constraints for land application. However, like other phosphoric fertilizers, ashes increase phosphorus availability in the soil hence risk of leaching to surface water. P application rates are then limited to crop needs. However, increases of soil P saturation index drops to normal 3 years after spreading (Vigneux and Barnett, 2001; Royer *et al.*, 2004).

Wood ashes also contain trace elements. Some are essential to life (ex.: Co, Cu, Mo and Zn). However, excessive and repeated applications of these micronutrients can impact soil quality, as with "strict" contaminants (Cd, Hg, Pb). Table 2 presents trace elements contents compared to agricultural lime. Cadmium and zinc are elements which often exceed Québec C1 limits (MDDEP, 2008). However, most ashes respect C2 limits. Mercury (Hg) and lead (Pb) contents of ashes are low and at the same level as natural soils.

Metal contents are influenced by same factors as for agronomic parameters (water content, burning level, wood type, etc.). Highest cadmium concentrations observed in Québec (40 mg Cd/kg) come from the burning of poplar barks and is from natural source. However, there is occasionally a contribution by co-combustion of industrial residues, like used oils. Chlorinated dioxins and furans contents of ashes are also generally negligible (Table 2), except in a few cases (burning wood that remained in sea water rich in chlorine, ash from home wood stoves burning at low temperatures).

Metals (ex.: Cd and Zn), as well as phosphorus, are not very soluble in alkaline matrix of ashes and are not likely to contaminate underground water or streaming towards rivers during their storage in the field (Morris, 1995; Baziramakenga, 2003; Envir-Eau, 2003). Short duration studies show that spreading at agronomic rates do not cause soil accumulations or affect soils nor crops quality (Krejsl, 1995), underground water quality (Williams *et al.*, 1995) and fauna (Sweeney and Jones, 1995). After 6 years of spreading, Ziadi *et al.* (2007) did not see a significant difference between ash and lime treatments on the Cd, Cu and Zn extractable contents of soils (Mehlich-3 method). Only Ni was slightly higher in the treatment with ash, which can be partly due to the fact that final pH of soils receiving ashes (6,6) was less than with fields receiving lime (7,1). Conversely, Mo content (water-extract), which availability increases with pH, was much lower in fields amended with ashes. Vigneux and Barnett (2001) observed a higher Zn content (Mehlich 3), in poor soils, but the enrichment did not exceed normal soil contents, dropped after 2 years and did not result in increase in foliar Zn.

Risks with trace elements thus seem negligible in the short or medium term. On the long run, repeated and excessive spreading of ashes by a farmer could be at risk, but it is unlikely. Indeed, a regular «overdose» would involve excessive pH rise which would encourage farmer to cease or reduce subsequent applications, in order to avoid yield decrease. Agronomic rates are considered to be safe by the MDDEP (2008).

However, because ashes have variable metal contents, and because of alkaline and dust particles, their agricultural recycling in Québec is subject to additional controls. Responsibilities for various organizations and control mechanisms are detailed in Guidelines for the beneficial use of fertilizing residuals (MDDEP, 2008). This quality control is performed by one of the 3 following mechanisms:

- Certification of conformity (BNQ);
- Certificate of approval (CA) (MDDEP);
- Project notice, by an agronomist, transmitted to the MDDEP, with quality control performed by an accredited sampling firm, and conformity to the BNQ standard.

It is important to mention that during field storage, ash surface of the pile is gradually dried, and becomes more susceptible to wind transport. However, during spreading, observations show that wind transport would be less important than with agricultural lime, because of higher moisture content of ashes (Hébert, 2006). Both farmers and agronomists must take preventive measures to avoid dust outside property limits.

Safety of workers and technical aspects

Water must be added to ashes at the factory in order to extinguish embers and to remove dust particles. This humidification must be sufficient to prevent risks of burning for workers during handling, risks of combustion during storage, and reduce dust. However, some ashes will tend to cement after humidification during storage in the field, which can damage spreading equipments and become a source of hazardous projectiles. In a preventive approach, it is thus necessary to avoid prolonged storage with these ashes. It is also necessary to make sure that spreading equipments have the capacity to break hardened lumps. Bottom ashes may also contain "ash rocks", as well as stones and may not be suited for land application.

Ashes that contain low moisture and few concretions can be spread with same equipment as with chemical fertilizers, while ashes with high humidity content can be spread with lime spreading equipment (Vigneux, 1991). However, these equipments are not easily available and do not spread important quantities of amendment. Manure spreaders can be used (Coleman, 1995) since they are more robust. However, older spreaders produce a variable pattern of distribution.

As dust is irritating for eyes and respiratory tracts, it is recommended to carry safety glasses and gloves during handling, and, if needed, to use a dust mask (Vigneux, 1991; Kopecky, 1995).

Labelling and consumer protection

All wood ash sold to farmers must respect labelling standards of the Fertilizers Act, managed by the Canadian Food Inspection Agency (CFIA). There are mandatory requirements, in order to avoid false information for customers. In particular, labels must show minimum nutrient contents guaranteed. CFIA internet site provides examples of correct labelling.

Commercial standards by the Bureau de normalisation du Québec (BNQ, 2006) goes further in terms of quality criteria, labelling requirements and product description with the inclusion of agronomic and environmental warning statements. These standards were produced by a committee made of members from ministries, forest industry, farmers union, research institutions, and the private sector. It applies to a whole range of industrial liming residues from egg shells to cement dust, while including ashes from the forest/paper industry. Table 4 presents a summary of BNQ standards with both technical and scientific justifications. These requirements aim at protecting the farmer, the consumer and the environment. Ashes that fail to meet all of these requirements cannot be certified by the BNQ. However, product certification is not mandatory.

Synthesis of best agri-environmental practices

Table 5 summarizes best agri-environmental practices applying to agricultural recycling of wood ashes. The information comes from scientific literature, guidelines, commercial standards, regulations, as well as verbal information provided by many specialists consulted during elaboration of this article. These beneficial practices are presented in chronological order. A majority of beneficial practices refer to crop selection, liming calculations, P-K fertilization, as well as protective measures for soils, plants, water, air, animals and humans. Ash will initially be used to correct soil acidity and quickly reach target pH to obtain higher crop yields, then at lower rates for annual or bi-annual maintenance fertilization based on P-K requirements.

Table 4: SUMMARY OF BNQ COMMERCIAL STANDARDS 0419-090[1] APPLYING TO WOOD ASHES.

Parameter	Requirement	Justifications
Ashes allowed	Ashes from combustion (with or without extra combustible) of wood, ligneous residues, animal dejections, residues from de-inking activities or from sludges of wastewater treatment of pulp and paper industries (fly ashes and bottom ashes resulting of combustion of these materials are produced either by sawmills, pulp and paper factories, energy factories, or by factories manufacturing wood particle boards.	Avoid ashes obtained from burning unknowed materials, especially hazardous wastes.
Minimum neutralizing value (NV)	≥ 25% (db).	Avoid residuals that cannot be considered as liming products.
Maximum size of aggregates	98% of raw sample must pass through 20mm sieve and 95% through 12,5 mm sieve.	Minimize the presence of hardened concretions, in order of ensure uniformity at spreading.
Minimum water content	≥ 1%	Avoid the presence of CaO, a strongly reactive component.
Divalent/monovalent cations ratio	(Ca+Mg)/ (Na + K) ≥ 2,5.	Avoid deflocculating clay-humic complex by monovalent cations (Na, K).
Maximum sodium content	PN/ Na > 0,0025.	Avoid deflocculating clay-humic complex by monovalent cations Na.
MTE minimal ratio = NV (%)/ MTE (mg/kg)	As (0,667); Cd (2,50) ; Co (0,333) ; Cr (0,047) ; Cu (0,066) ; Hg (10,0) ; Mn (0,004) ; Mo (2,50) ; Ni (0,278) ; Pb (0,100) ; Se (3,57) ; Zn (0,027).	Protect soil quality, while providing micronutrients. Criteria are expressed as ratios with NV, since products with a lower NV will be spread at higher rates than products with a high NV. For each parameter, ratio was established by dividing mean NV of 50% by C2 criteria of the MDDEP (Table 2).
MTE maximum content (mg/kg d.b.)	As : 75 ; Cd : 30 ; Cu : 1500 ; Ni : 420 ; Pb : 500 ; Zn : 2800.	Incentive for source reduction to minimize soil accumulation
Dioxins and furans	< 27 ng ETQ/ kg (d.b.).	Protect soil quality. Criteria from the MDDEP (2008). Analysed only in factories susceptible of burning residues containing dioxins and furans or to generate some during combustion.
Formaldehyd	< 50 mg/kg (d.b.).	Insure appropriate destruction of adhesive substances (used in particle board fabrication).
Mixes	Possible with agricultural lime and other products covered by the standard.	Allowing ashes/lime mixes that can be beneficial in certain situations. See text.
Labelling	Minimum guaranteed contents on wet basis (total NV, NV of carbonates, pH, AVI, Ca, total Mg, soluble Mg, B, K_2O, S, bioavailable P_2O_5; mean content in total $P\text{-}P_2O_5$.	Protect consumers and allow calculation of spreading dose in accordance with plant requirements and nutrient regulations. See note 4 in Table 1 for P analysis.
Warnings (on labels)	*It is first recommended to consult an agronomist before using this product.*	General measures to favorize good practices.
	It is recommended to wait 30 days following the application of this product before putting animals out to pasture or harvesting forage crops.	Avoiding ingestion of hydroxides by animals which could change rumen pH.
	Under certain conditions, this product can cause burning in growing plants.	Prevently avoid certain conditions – Literature does not report problem with ashes.
	This product can produce dust during handling.	Protecting air quality for farmers and neighbours.
	If ash piles are left in fields, they must be manage in order to minimize streaming.	Minimize streaming risk of phosphorus towards watercourses. P contained in ashes is however poorly soluble in water.
	To facilitate handling and spreading of this product, protect from precipitation during storage.	Avoid cementing with certain ashes that can damage spreading equipment.

[1] This table is a summary of commercial standards BNQ 0419-090/2005 including last modifications in 2006.

Table 5: SUMMARY OF AGRI-ENVIRONMENTAL PRACTICES APPLYING TO WOOD ASHES.

	Best practices	Comments/precisions
1	Have complete, representative and reliable analyses for soils and ashes.	Liming requirement must be made with representative soil sample to avoid overestimation of liming requirement.
2	Exclude ashes that cannot be recycled in agriculture.	e.g.: hardened ashes or exceeding TE limits.
3	Verify ash conformity to regulations.	See provincial/federal guidelines and regulations.
4	Crop selection.	All crops benefits from ashes, but particularly legumes and hayfields. Avoid spreading directly before implementing potato crop (risk of common scab), for non resistant cultivars.
5	Include most recent adjustments made to cultivation plan.	Farmers often make modifications in their cultivation plan according to grain price, time available, period of the year, etc.
6	Exclusion of fields with excessively high potassium content according to guidelines.	Avoid risk of grass tetany in livestock, if rotation plan includes fodder. Fodder analysis can however allow a different recommendation, especially with ash with lower K content.
7	Restrictions on fields with high phosphorus contents.	According to provincial nutrient regulations to prevent runoff to surface water.
8	Calculation of loadings by adapting method used for agricultural lime	Use average AI, rather than "minimum guaranteed content", in order to avoid overliming on sensitive soil/crops. This is especially important for sandy soils with low buffer capacity, and for a cereal crops which are more sensitive to overliming than leguminous plants. AI must be calculated considering ~100% effectiveness, and not according to sieving method.
9	For annual maintenance fertilization, P-K needs should not be exceeded, except on «poor soils».	Consider average P effectiveness of about 50% of total P_2O_5 and 100% of total K_2O.
10	Consider general agronomic guidelines recommendations for liming and P-K fertilization..	*In Québec : Guide de référence en fertilisation* (CRAAQ, 2003), *Guidelines for liming requirements* (Brunelle and Vanasse, 2004).
11	Consider restrictions and warnings of BNQ commercial standards in reference to crop type, pasturing and environmental protection.	See Table 4.
12	Spread as quickly as possible.	Avoid formation of hardened concretions during storage.
13	Prevent dust emission.	Select storage sites far from neighbours and avoid spreading in high wind conditions, incorporate into the soil (bare soils).
14	Use appropriate and calibrated spreading equipment.	Spreading equipment must allow spreading adequate dose of ash uniformly. It also has to resist hardened concretions.
15	Recommend safety measures to prevent dust inhalation and reduce eye contact for workers.	E.g.: safety glasses, dust masks if needed, avoid rubbing eyes with hands (wear gloves), wash skin after spreading. It is important to remember that wood ash must be extinguished and must not contain firebrands which are an important threat to safety and risk of fire.
16	Avoid soil compaction.	Before spreading, a field visit is necessary to make sure conditions are appropriate.
17	Respect distance regulations for spreading and storage.	According to provincial regulations.
18	Incorporate into the soil (except with hayfields and pastures).	Uniformity of pH in soil horizon. Incorporation delay will increase dust transport, but will reduce alkalinity of ashes (see text).
19	Wait a few days to a week before planting and avoid spreading on young seedlings.	Because of high alkalinity of ashes. This alkalinity will be reduced during stockpiling in the fields and if there is a delay before incorporating ashes into the soil.
20	Follow-up verifications.	Update the cultivation plan and soil pH. Discuss with farmers on positive or negative impacts of ash and ways to improve its uses.

Other possible uses of wood ashes as fertilizing residuals

Use in organic farming: Wood ash is one of the most effective and least expensive fertilizers to use in organic farming as source of calcium and potassium. Ash also indirectly provides nitrogen supply by increasing legumes yields, hence symbiotic N fixation in root nodules. In addition, ash increases manganese content of plant tissues. An increase in Mn could theoretically help natural crop resistance to plant diseases (Huber and Wilhelm, 1988). However, some ashes may not be allowed in organic farming, like ashes coming from the burning of pulp and paper biosolids.

Silviculture: The use of wood ash in forestry was studied in Europe and the United States where beneficial effects were reported: neutralization of soil acidity (Lundström *et al.*, 2003), increase in mineralization of organic matter (Fritze *et al.*, 1994), hence providing greater nutrient availability, in particular nitrogen and phosphorus (Hakkila and Halaja (1983) and Huikari (1989), quoted by Poisson and Vigneux, 1994). These authors mention that positive impacts on forest trees are lasting 30 to 40 years after spreading. Vance (1995) reports a Finnish study indicating that, 41 years after the ash spreading, productivity of Scottish pines was 32 times higher than with control plots. However, Vance reports that high rates (>40t/ha) can adversely impacts trees. He recommends using lower rates and apply on deciduous trees which have higher soil nutrients and pH requirements. At the operational level, existing forest equipment must be adapted for ash spreading. Applications on plantations are easier than in natural forests.

Degraded sites: Recycling of wood ashes in mining sites and gravel/sand pits can help revegetation. In 2007, approximately 35 000 tons of ashes were recycled in this manner in Québec (Hébert *et al.*, 2008). Sulfide-rich tailings spontaneously form sulfuric acid which contaminates water and solubilizes phytotoxic heavy metals, thus making revegetation strategies impossible (Howard *et al.*, 1988;

Stewart and Daniels, 1992). Wood ash, with its alkaline pH, can stop, slow down or neutralize acidity and solubilization of metals.

Composting and soil mixes manufacturing: The use of wood ashes in composting activities and soil mixes manufacturing can be useful to adjust pH and enrich mineral element contents of resulting products. Quantities must however be well-proportioned to achieve quality requirements for composts. Ashes containing coal carbonized are best suited (Coleman, 1994), because they reduce composting odours while conferring a beautiful dark color to soil mixes.

Use as materials

Certain ashes should be recycled for concrete production rather than as fertilizing residuals (Siddique, 2008). It is the case with ashes that do not respect maximum contaminant levels, have low nutrient contents (P-K) or which tends to cement at storage. Ashes from treated wood can reach high trace element levels (As,, Cu, Cr). Burning wood at low temperatures, or wood containing sea salt or wood treated with pentachlorophenol may produce ash with high levels of chlorinated dioxins and furans. Since ashes obtained from the burning of de-inking residuals contain clay (kaolin), they tend to cement with simultaneous presence of calcium oxide and water. Bottom ashes, containing sand, gravel and stones, were used successfully, in recent experiments, as surface materials for farm roads in Saguenay-Lake-Saint-Jean.

Needs for research and development

It would be important to better quantify the impact of wood ash on crop yields, in particular with respect to bio-char properties. Phosphorus efficiency should also be studied for various crops. Performance of other types of ashes, like ashes obtained from combustion of municipal sludges should also be investigated. Greenhouse gas emission reductions will have to be better quantified. On the technical side, simple preventive solutions will have to be found to minimize or counter cementing phenomenon. From an economical point of view, vulgarization efforts and marketing strategies should be made to promote ash value in order to increase recycling rates for high quality ashes. Developing commercial mixes ash/lime could be an interesting possibility (Magdoff *et al.* (1983); Clapham and Zibilske (1992). Researches are going on in Quebec to evaluate combined ash/gypsum granules for potato fertilization.

CONCLUSION

Agricultural use of wood ashes is an ancestral practice which was forsaken in the 30's and re-discovered In the 90's. In 2007, 80 000 tons (wb) of ashes were recycled on approximately 250 Québec farms. Ash neutralizes soil acidity, but also provides major nutrients and micronutrients to plants. These combined effects explain increased productivity as compared to agricultural lime. Regulations and mandatory quality control ensures that ashes are spread safely in Québec. Moreover, spreading avoids burying ashes in dumping sites, while reducing greenhouse gas emissions associated with agricultural lime use. However, ash retail price is still much lower as compared to its estimated mean value ranging between 20 and 65 $/tm (wb).

However, this amendment must be recycled under supervision of an agronomist who is familiar with this type of activity and who will consider best agri-environmental practices. Used at agronomic rates, ash spreading will safely increase crops productivity and financial gains. Global utilisation of wood ash spreading in agriculture, according to best agri-environmental practices, would make this recycling activity an example of sustainable development and successful partnership between wood industry and the agricultural sector.

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