Industrial wood ash as a soil amendment for crop production

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ABSTRACT

*Wood ash—produced as a by-product of energy generation by wood-products industries—has potential for use as a liming and nutrient source for crop production. We conducted greenhouse and field studies to evaluate the effects of landspreading industrial wood ash on the yield and elemental composition of forage crops and on soil nutrient levels. Greenhouse studies evaluated ash rates up to the equivalent of 40 tons/acre (90 Mg ha^{-1}) using alfalfa (*Medicago sativa *L.) and barley (*Hordeum vulgare*) as indicator crops. A limed and fertilized control (dosages based on soil tests) was included for comparison. In field trials, wood ash was applied to alfalfa at rates up to 20 tons/acre (45 Mg ha^{-1}) at two locations in Price County, WI. Biomass yields generally increased with ash application up to 20 tons/acre and decreased at applications exceeding this level. Wood-ash application usually produced yields greater than those obtained with the limed and fertilized control treatment. No undesirable elements accumulated in forage tissue at ash application rates up to 20 tons/acre. These results suggest that land application of wood ash is an environmentally safe alternative to landfilling and may replace conventional limestone and fertilizer for forage crop production.*

Application:

Greenhouse and field tests evaluating the effects of landspreading wood ash as a crop fertilizer.

MANY FOREST PRODUCTS industrial facilities burn wood waste and by-products to produce energy for plant operation. This generates substantial quantities of ash. In Wisconsin alone, industrial plants produce an estimated 50,000–80,000 tons (112,000–179,000 Mg) of wood ash each year.

Most mills simply landfill this ash. However, research demonstrates that ash is a valuable soil amendment with lime and/or nutrient value. With landfill space at a premium, dumping ash in landfills may not be the best way of handling this material.

Wood ash has probably been added to soil since the time it was first produced. Hopkins *(1)* reported field trials in Canada from 1891–1904 using leached and unleached wood ash in wheat, oat, and barley experiments. He implies that wood ash was regulated as a fertilizer material during this era. Indeed, the word "potash" originated from the potassium carbonate produced by leaching wood ash *(2)*, and a leaching process was patented as early as 1790. Wood ash has long been regarded as a source of potassium for plant growth (1–13% K by weight), but it also contains appreciable quantities of Ca (20–30%), P (0.3–0.4%), Mg (1–3%), and smaller amounts of S, Mn, Fe, B, Cu, and Zn *(3–5)*.

Wood ash is an effective liming material. When Lerner and Utzinger *(5)* added ash to a Brookston silty clay loam in Ohio, soil pH increased with increasing levels of ash application up to a value of 7.3 at the highest rate of 4.3 tons/acre (9.6 Mg ha^{-1}). Etiegni *et al. (3)* reported similar results from a greenhouse study using six Idaho soils amended with wood ash at rates up to 9 tons/acre (20 Mg ha^{-1}). Naylor and Schmidt *(6)* found that soil pH increased with wood-ash applications up to 22 tons/acre (49 Mg ha^{-1}) in greenhouse studies. Rabas *(7)* reported a soil pH increase from 5.3 to 7.1 with increasing ash applications up to 20 tons/acre in field studies in Minnesota.

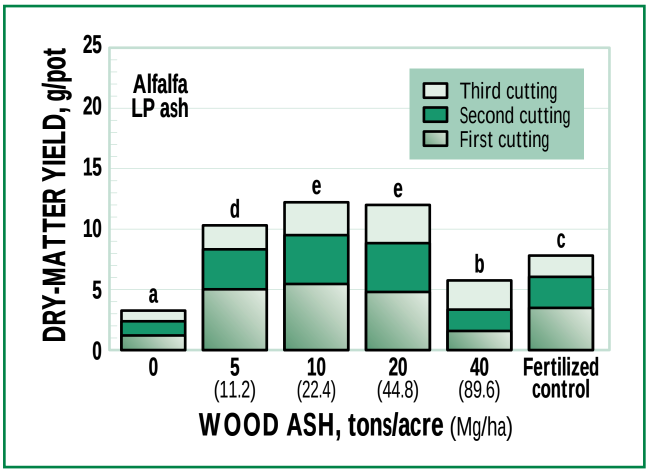
The content of essential plant nutrients such as P, K, Ca, Mg, and S makes ash beneficial for crop growth. Erich *(8)* reported that wood ash provided an agronomically effective source of P and K for corn (*Zea mays*) grown under greenhouse conditions. Etiegni *et al. (9)* reported increased wheat (*Triticum aestivum*) biomass in greenhouse studies at wood-ash applications up to 18 tons/acre (40.3 Mg ha^{-1}). Alfalfa yields have been shown to increase with increasing ash rates up to 40 tons/acre (90 Mg ha^{-1}) *(6, 7)*. Muse and Mitchell *(10)* reported significant yield increases of Dallis grass–fescue (*Paspalum dilatatum* Poir–*Festuca arundinacea* Schreb.) herbage following surface application of wood-derived boiler ash in Alabama.

Low quantities of heavy metals reported in ash *(3, 5, 6, 9, 11)* suggest a minimal environmental hazard with respect to heavy-metal contamination. Wisconsin solid waste statutes allow landspreading of ash, provided that it is valuable as a soil amendment, properly applied, and environmentally safe (Wisconsin Admin. Code, Chap. NR 518). Heavy-metal loads in ash cannot exceed levels currently allowed in landspreading of municipal biosolids.

Ash source[a]	ELEMENT, %				ELEMENT, ppm										
	Ca	Mg	P	K	B	Co	Al	Cr	Cu	Fe	Mn	Ni	Zn	Cd	Pb
JT	31.9	1.59	0.64	2.26	156	3.8	5,360	5.0	40.4	2790	1030	4.3	840	3.7	4.5
LP	23.5	1.59	0.63	3.74	193	4.7	11,400	9.6	49.0	7740	1050	6.3	3000	22	8.2
LI	22.0	1.40	0.60	1.50	25	…[b]	11,300	…[b]	…[b]	2490	1540	…[b]	1150	…[b]	…[b]

[a] JT = Johnson Timber, LP = Louisiana Pacific; LI = Lionite Hardboard
[b] Below detection limit

I. Elemental composition of oven-dried wood ash used in greenhouse and field studies (weight basis)



1. Total dry-matter yield for three cuttings of alfalfa grown in the greenhouse amended with five rates of wood ash supplied by Louisiana Pacific compared with a fertilized control. (Bars with the same letter are not significantly different at the 0.05 level of probability.)

The objective of our study was to determine the effect of industrial wood ash on crop production and to evaluate land application as a management option in wood-ash disposal. Since we were primarily concerned with disposal of ash, we did not separate the nutrient value of wood ash from the soil liming value of ash in measuring crop response to ash application. The purpose was to determine if disposal of ash by land-spreading was detrimental or beneficial to crop production and if application method (incorporation vs. topdressing) would influence crop response. Application rates selected for study reflect those likely considered for disposal rather than what might be considered normal for crop production.

MATERIALS AND METHODS

Industrial wood ash was applied to soils at rates ranging from zero to 40 tons/acre in three greenhouse trials and from zero to 20 tons /acre in field studies at two locations. All studies included a control treatment consisting of limestone and fertilizer at rates based on University of Wisconsin recommendations for soil tests *(12)*.

Ash characteristics

Since no data on characteristics of ash produced in Wisconsin were published in the available literature, we initially selected ash from a large producer (Louisiana Pacific) and a small producer (Johnson Timber) to determine if there were major differences among sources. The third source (Lionite Hardboard) was included because it is 100% fly ash. This is the ash that was evaluated in field studies.

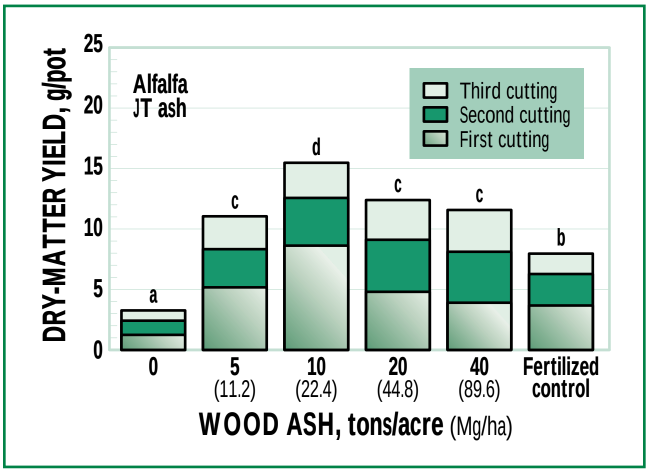
The ash supplied by Louisiana Pacific (LP) and Johnson Timber (JT)—both located near Hayward, WI—is commonly referred to as "bottom" ash, although 10–15% of the ash is collected from electrostatic precipitators or filter beds and mixed with the bottom ash as it is collected. The ash supplied by the Lionite Division (LI) of Georgia Pacific Corp. in Phillips, WI, is 100% fly ash collected from electrostatic precipitators serving a fluidized-bed combustion chamber. Ash is produced in these facilities from burning of wood, wood waste, bark, or sawdust to produce energy for plant operation.

Dry wood ash has a fine particle size and is dusty to handle. The LP ash used in these studies was collected from an outdoor open storage facility and had a calcium carbonate equivalent of 73%. The JT and LI ashes were collected directly from the production stream and had calcium carbonate equivalents of 103% and 96%, respectively. The ash samples had pH values ranging from 11.0 to 12.0 (water, 1:10). **Table I** shows the elemental composition of the ash samples.

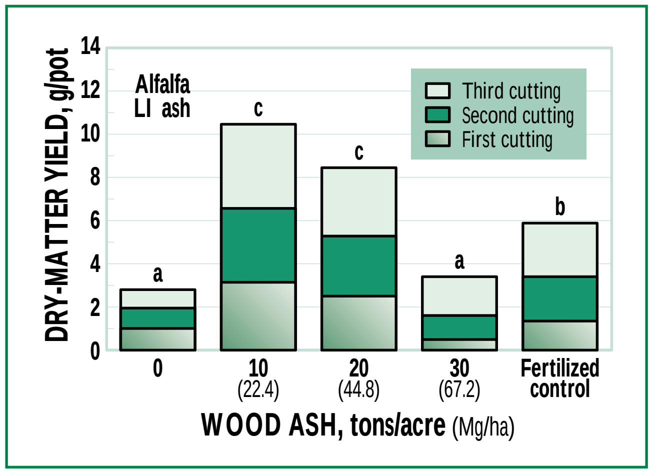
Greenhouse studies

Greenhouse studies utilizing two soils were conducted in 1990 and 1991 to identify appropriate application rates for the field studies. The soil used in the 1990 study was collected near Hayward, WI, from the surface horizon of a Padus silt loam (coarse–loamy, mixed, frigid Alfic Haplorthod). Pots were filled with 1.59 lb (3.5 kg) of air-dry soil and amended with rates of ash (both JT and LP) to simulate—based on 2 million lb of soil per acre 6 in. deep (2.24 million kg ha^{-1})—0, 5, 10, 20, and 40 tons per acre (0, 11, 22, 45, and 90 Mg ha^{-1}) for growing alfalfa and rates equivalent to 0, 5, 10, and 20 tons per acre for growing barley.

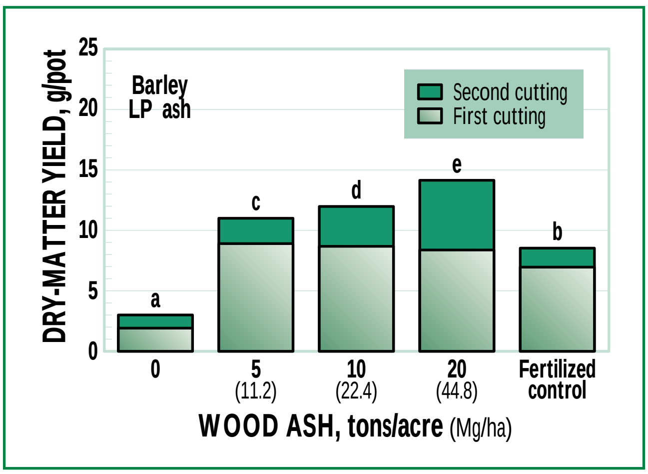
Other than ash application, additional nutrient sources for the greenhouse studies were supplied by the following reagent-grade chemicals: ammonium nitrate, diammonium



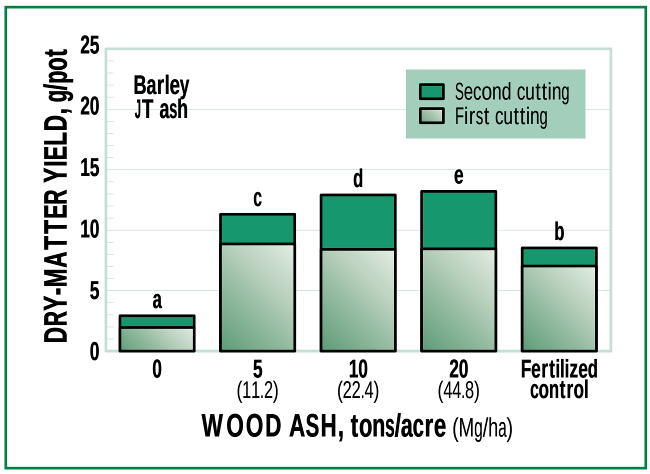
2. Total dry-matter yield for three cuttings of alfalfa grown in the greenhouse amended with five rates of wood ash supplied by Johnson Timber compared with a fertilized control. (Bars with the same letter are not significantly different at the 0.05 level of probability.)



3. Total dry-matter yield for three cuttings of alfalfa grown in the greenhouse amended with four rates of wood ash supplied by Lionite Hardboard compared with a fertilized control. (Bars with the same letter are not significantly different at the 0.05 level of probability.)



4. Total dry-matter yield for two cuttings of barley grown in the greenhouse amended with four rates of ash supplied by Louisiana Pacific compared with a fertilized control. (Bars with the same letter are not significantly different at the 0.05 level of probability.)



5. Total dry-matter yield for two cuttings of barley grown in the greenhouse amended with four rates of ash supplied by Johnson Timber compared with a fertilized control. (Bars with the same letter are not significantly different at the 0.05 level of probability.)

phosphate, potassium chloride, boric acid, and potassium sulfate. All treatments received an additional 60 lb of N and 60 lb of P per acre (67.2 kg ha^{-1}). We included a control that was limed and fertilized, based on recommendations of the Wisconsin State Soil and Plant Analysis Laboratory, which called for the addition of (on a 2-million-lb/acre basis) 4 tons (8.96 Mg) of limestone, 320 lb (358 kg) of K, 6 lb (6.7 kg) of B, and 125 lb (140 kg) of S in addition to N and P. All additions were measured on a per-pot basis, thoroughly mixed with the soil by hand, and returned to the pots. Each treatment was replicated six times.

Pots were randomly placed on the greenhouse bench. Once each week, pots were watered to a uniform weight of 1.95 lb (4.3 kg) (approximate field capacity) and returned to random locations on the bench following each weighing. Between weighing, water was added to all pots to provide adequate moisture levels for plant growth. Two wetting–drying cycles occurred prior to planting. For alfalfa, 20 seeds were planted per pot and thinned to 10 plants within one week of emergence. For barley, 15 seeds were planted per pot and thinned to six plants within one week of emergence.

Herbage was harvested at 35, 52, and 78 days after thinning for alfalfa and at 28 and 42 days after thinning

Ash treatment, tons/acre	SOIL pH Ash from LP	Ash from JT	Ash from LI
0	4.6	4.6	5.9
5	6.5	7.1	…
10	7.2	7.5	8.0
20	7.9	7.8	8.2
30	…	…	8.5
40	8.2	8.2	…
Fertilized control	6.3	6.3	7.4

II. Final soil pH values at the conclusion of the greenhouse alfalfa harvests for ash supplied by Louisiana Pacific (LP), Johnson Timber (JT), and Lionite Hardboard (LI)

for barley. Plant material was dried at 65°C for three days to determine dry-matter yield. Routine Wisconsin soil tests were used to determine pH (1:1 soil:water), and P and K levels by Bray P-1 *(12)* in each pot at the conclusion of the experiment.

The second greenhouse study was conducted in 1991 to evaluate yield response trends on a different soil and using the ash that would be used for the field studies. The methods used for the 1991 greenhouse study were identical to those in 1990 with the following exceptions: The soil used was collected in Sawyer County, WI, from the A horizon of a Sarona sandy loam (coarse–loamy, mixed, frigid, Alfic Haplorthod) and amended with fly ash supplied by Lionite Hardboard at rates equivalent to 0, 10, 20, and 30 tons/acre for growing alfalfa. All pots received the equivalent of 60 lb of N and 60 lb of P per acre (67.2 kg ha^{-1}). Based on soil-testing laboratory recommendations, the fertilized and limed control received the equivalent of 8 tons (17.9 Mg) of limestone, 230 lb (358.4 kg) of K, 3 lb (3.4 kg) of B, and 94 lb (103.4 kg) of S in addition to N and P.

Field studies

Two field studies were initiated on private farms in the summer and fall of 1991 near Phillips and Fifield in Price County, WI.

Phillips, WI. The study at Phillips was conducted on a Stambaugh silt loam, 2–6% slope (coarse–silty over sandy or sandy–skeletal, mixed, frigid, Alfic Haplorthod) using a completely random design with four replications. The study consisted of topdressing ash supplied by Lionite Hardboard to an existing alfalfa (*Medicago sativa*)–timothy (*Phleum pratense*)–bluegrass (*Poa pratensis*) stand at rates of 0, 2.5, 5.0, 10, and 20 tons/acre. A fertilized control treatment included topdressing 5 tons limestone and 400 lb muriate of potash (60% K_2O) per acre (224 kg ha^{-1}). Soil test values indicated that P, B, and S levels were adequate for alfalfa production. Likewise, nitrogen addition is unnecessary because of symbiotic nitrogen fixation by Rhizobium bacteria.

Treatments were applied to plots measuring 30 × 50 ft (9.1 × 15.2 m) using a 5-ft (1.5 m) drop spreader immediately following second cutting in July 1991. Forage was harvested in 1992 and 1993 with a 10-ft (3 m) self-propelled mower–conditioner making an initial windrow through the center of each plot. Duplicate 10-ft (3 m) sections of the windrow were collected from each replicate and weighed in the field. Two subsamples (300–400 g) were collected from each 10-ft (3 m) section, weighed in the field, and later dried at 65°C for 72 hours to determine dry-matter yield. The dried plant material was ground to pass a 1-mm screen for determination of protein and relative feed value by near-infrared analysis and for elemental composition by inductively coupled plasma (ICP) analysis following digestion of 0.2-g forage samples with nitric acid and hydrogen peroxide *(12)*.

Soil samples were collected from each plot at depth increments of 0–2, 2–6, 6–12, and 12–18 in. (0–5, 5–15, 15–27, and 27–46 cm) following the second cutting in 1992 and 1993 by compositing a minimum of five randomly selected cores within each individual plot. Wisconsin soil test procedures were used to determine pH, P, and K values *(12)* where pH is determined 1:1 in distilled water, limestone recommendation based on SMP buffer, and P and K extracted by Bray P-1.

Fifield, WI. At the Fifield location, the same ash was applied to a Pence very gravelly sandy loam, zero to 3% slope (sandy, mixed, frigid Entic Haplorthod) using the same ash rates and design as the Phillips location. However, in this study, treatments were applied in November to existing corn stalk residue and incorporated in the spring of 1992 using a moldboard plow and disk. The fertilized control at this location consisted of an application of 5 tons/acre of limestone, 335 pounds/acre (375 kg ha^{-1}) of 0–0–60, and 50 lb/acre (56 kg ha^{-1}) of S from calcium sulfate. Phosphorus levels at this location were adequate.

Commander alfalfa was direct-seeded into the plots using a grain drill-mounted grass seeder. Plots were clipped to control weeds during the establishment year, but yields were not measured. Dry-matter yields were determined for three cuttings in 1993 and two cuttings in 1994 using the procedures described for the Phillips location. Soil samples were collected from the upper 8 in. of each plot for routine soil tests following the second cutting in 1993 and 1994.

Statistical analysis

For both greenhouse and field studies, analysis of variance was used to identify treatment effects on dry-matter yield, crop elemental content, soil pH, and P and K. Means were separated using the Student–Newman–Keuls procedure ($p = 0.05$). We did not design the study to identify differences among ash sources but included three different ash sources and two different soils to evaluate if yield trends were similar.

Ash treatment, tons/acre	ELEMENT, %				ELEMENT,[b] ppm							
	Ca	Mg	P	K	B	Al[c]	Cr	Cu	Fe[c]	Mn	Zn	Pb[c]
Phillips[d]												
0	0.62±0.17a	0.32±0.10a	0.32±0.07a	1.7±0.40abc	24±17a	74±38	4.7±3.3a	13±3.7a	62±16	36±11b	31±13a	16±9
2.5	0.71±0.19a	0.30±0.08a	0.34±0.07a	1.6±0.30ab	33±22a	93±86	4.3±2.9a	13±3.3a	61±11	26±10ab	32±9a	15±9
5.0	0.70±0.24a	0.31±0.08a	0.32±0.07a	1.5±0.30a	35±28a	80±39	2.9±1.3a	13±3.6a	60±14	29±9ab	29±9a	5±2
10	0.63±0.17a	0.21±0.08a	0.33±0.08a	1.9±0.60bcd	32±18a	75±34	2.9±1.0a	14±3.1a	62±13	32±12b	36±11a	5±2
20	0.68±0.14a	0.27±0.07a	0.33±0.07a	2.0±0.40cd	32±17a	75±34	2.8±1.0a	12±2.7a	57±14	28±9ab	30±10a	<3
Control[e]	0.65±0.18a	0.29±0.07a	0.32±0.08a	2.2±0.40d	30±14a	74±30	2.6±1.0a	11±2.4a	56±14	22±6a	29±13a	<3
Fifield[f]												
0	1.5±0.62a	0.48±0.19a	0.40±0.09a	3.9±0.90a	80±28a	116±43	1.2±0.2a	11±4.5a	89±9	45±24a	34±11a	5±3
2.5	1.5±0.60a	0.48±0.15a	0.44±0.09a	4.1±0.90a	93±43ab	123±52	1.3±0.2a	10±3.4a	86±7	38±18a	39±20a	5±2
5.0	1.6±0.62a	0.46±0.15a	0.47±0.10a	4.4±1.0a	81±27a	125±32	1.1±0.1a	10±3.5a	82±7	41±14a	40±14a	5±2
10	1.9±0.7lab	0.52±0.19ab	0.55±0.26ab	4.9±1.0a	105±55ab	149±86	1.2±0.3a	11±3.6a	85±8	47±18a	36±8a	7±3
20	2.3±0.86b	0.57±0.24ab	0.75±0.46b	4.9±1.0a	120±54b	146±39	1.3±0.2a	11±4.2a	87±8	53±27a	38±17a	4±1
Control[e]	2.1±0.85ab	0.66±0.28b	0.66±0.43ab	4.8±1.0a	105±44ab	126±33	1.3±0.3a	11±3.9a	84±8	56±28a	40±16a	5±2

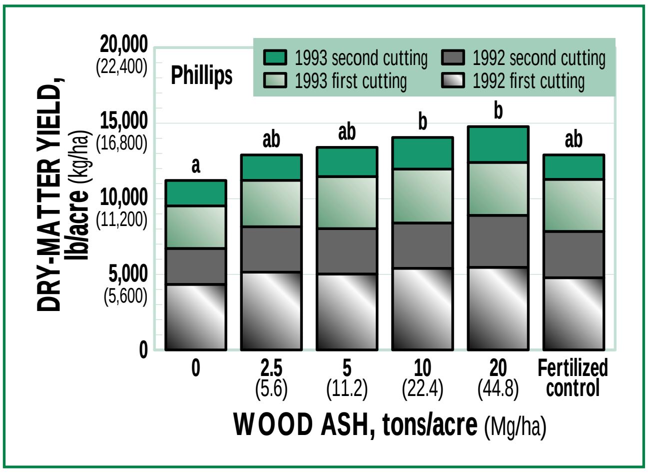
[a] Means and standard deviations followed by the same letter are not significantly different at the 0.05 level of probability.
[b] Concentrations of Co, Ni, and Cd below detection limit
[c] Incomplete data set prevented statistical analysis.
[d] Average of four field harvests after topdressing soil with ash (1992 and 1993)
[e] Fertilized control
[f] Average of five field harvests after plowing ash into soil (1993 and 1994)

III. Means and standard deviations of elemental concentrations in forage crops[a]

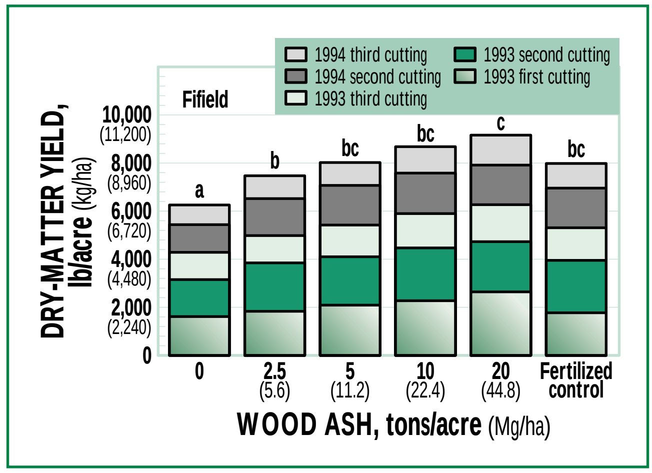
Ash treatment tons/acre	PHILLIPS, WI				FIFIELD, WI	
	0–2-in. depth		2–6-in. depth		0–8-in. depth	
	1st year (1992)	2nd year (1993)	1st year (1992)	2nd year (1993)	1st year (1993)	2nd year (1994)
			pH			
0	6.3 ± 0.2a	6.4 ± 0.2a	6.4 ± 0.2a	6.4 ± 0.3a	6.8 ± 0.3a	6.8 ± 0.0a
2.5	6.8 ± 0.2b	6.9 ± 0.2b	6.7 ± 0.3a	6.8 ± 0.2b	7.2 ± 0.2bc	6.9 ± 0.1ab
5.0	7.0 ± 0.3b	7.1 ± 0.1cd	6.7 ± 0.3a	7.0 ± 0.1bc	6.9 ± 0.2ab	7.0 ± 0.1ab
10	7.0 ± 0.1bc	7.2 ± 0.1de	6.7 ± 0.1a	7.0 ± 0.2bc	7.2 ± 0.1bc	7.0 ± 0.1b
20	7.2 ± 0.1c	7.4 ± 0.1e	6.9 ± 0.3a	7.1 ± 0.1c	7.5 ± 0.2c	7.5 ± 0.1c
Control[b]	6.5 ± 0.2a	7.0 ± 0.1bc	6.5 ± 0.2a	6.8 ± 0.1b	6.9 ± 0.1ab	7.2 ± 0.1b
			PHOSPHORUS, lb/acre			
0	86 ± 30a	74 ± 26a	34 ± 9a	37 ± 10a	90 ± 19a	75 ± 18a
2.5	111 ± 24a	108 ± 10bc	42 ± 5a	46 ± 6a	103 ± 15a	80 ± 21a
5.0	106 ± 18a	94 ± 12ab	37 ± 6a	36 ± 5a	118 ± 32a	103 ± 25a
10	122 ± 12a	129 ± 15c	49 ± 21a	54 ± 18a	100 ± 13a	80 ± 19a
20	116 ± 14a	111 ± 10bc	44 ± 13a	46 ± 3a	126 ± 37a	102 ± 25a
Control[b]	84 ± 10a	73 ± 8a	35 ± 5a	38 ± 5a	116 ± 33a	89 ± 30a
			POTASSIUM, lb/acre			
0	145 ± 44a	120 ± 14a	83 ± 21a	78 ± 10a	175 ± 66a	465 ± 152a
2.5	167 ± 49ab	160 ± 42a	90 ± 25a	90 ± 22a	152 ± 34a	445 ± 121a
5.0	200 ± 29ab	153 ± 13ab	83 ± 5a	78 ± 17a	180 ± 14a	552 ± 92a
10	247 ± 62b	203 ± 39bc	98 ± 31a	110 ± 29a	193 ± 41a	487 ± 162a
20	320 ± 36b	228 ± 26c	128 ± 51a	108 ± 21a	263 ± 84a	635 ± 120a
Control[b]	205 ± 24ab	158 ± 17ab	123 ± 21a	103 ± 5a	240 ± 76a	540 ± 152a

[a] Means and standard deviations followed by the same letter are not significantly different at the 0.05 level of probability.
[b] Fertilized control

IV. Two-year soil test values for Phillips (topdressed ash) and Fifield (ash incorporated with moldboard plow)[a]



6. *Total dry-matter yield for four cuttings of alfalfa–grass mixture over two years grown in the Phillips location amended with five rates of ash compared with a fertilized control. (Bars with the same letter are not significantly different at the 0.05 level of probability.)*



7. *Total dry-matter yield for five cuttings of alfalfa over two years at the Fifield location amended with five rates of ash compared with a fertilized control. (Bars with the same letter are not significantly different at the 0.05 level of probability.)*

RESULTS AND DISCUSSION

Greenhouse studies

Yields of alfalfa and barley in the greenhouse experiments increased with increasing ash rates through 20 tons/acre and are in agreement with those reported for field studies with alfalfa *(6, 7)* and for wheat grown under greenhouse conditions *(9)*. Results for the greenhouse experiments are presented in **Figs. 1–5**. In this study, ash-application rates equivalent to 5, 10, or 20 tons of ash per acre produced yields significantly greater than both the zero level and the fertilized and limed control for the three ash sources, both soils, and for both alfalfa and barley. Similar results in field studies have been reported for alfalfa *(7)* and Dallis grass–fescue stands *(10)*, but other reports *(4, 6, 9)* did not include a fertilizer or limestone treatment. We expect alfalfa to benefit from the application of wood ash, since it raises soil pH and provides a high level of Ca favorable to N_2-fixing organisms. In addition, ash contains B and S, both beneficial elements in alfalfa production. In this study, we attempted to eliminate differences due to N, B, and S by adding N as a fertilizer rather than depending on N_2-fixation and by providing adequate amounts of B and S. However, application of wood ash still produces yields significantly greater than the fertilized control for both alfalfa and barley, and these increases are not likely due to differences in N, B, or S levels.

Significant yield decreases occurred in two of the experiments with ash application rates equivalent to 20+ tons/acre (Figs. 1 and 3) and agree with results reported by Etiegni *(9)* for winter wheat. We speculate that the decreased yield at high rates of ash application is the result of elevated salt levels and/or altered nutrient availability at high pH. When yields decreased at application rates above 20 tons/acre, the final soil pH values were 8.2 or greater, as seen in **Table II**.

Results from the greenhouse studies led to three conclusions:

1. Wood-ash applications generally increased yields of alfalfa and barley relative to fertilized and unfertilized control treatments.
2. Wood-ash rates exceeding 20 tons/acre often reduced crop yields, so application rates above this should be avoided in crop production.
3. Growth response of both barley and alfalfa to ash application is similar, regardless of ash source.

Field studies

The response trends for alfalfa yield in the field were comparable with those observed in the greenhouse studies, although the differences were less significant, as seen in **Figs. 6 and 7**. Again, total yields over two years increased at ash rates of up to 20 tons/acre compared with the zero level. In both locations, ash rates of 5, 10, and 20 tons per acre produced total yields greater than those obtained with the fertilized control, although they are not significantly greater at the 0.05 level of probability. Treatment differences were more difficult to establish in the field

KEYWORDS

Ash, byproducts, soil conditioners, nutrients, alfalfa, barley, fertilizers, lime stone, disposal, crops, energy production, wisconsin, land use, wood waste, recycling, forage.

because we encountered a high degree of variation among replications, the result of variation in soil properties (past manure and nutrient management) and nonuniform wildlife damage in the plot area. In addition, the field soils had a much higher initial nutrient content compared with the soils used for the greenhouse studies.

Wood ash clearly results in yields greater than commercial limestone and fertilizer applied at rates recommended by the soil testing laboratory. We are not certain why this occurs. However, the data presented here—along with the data of Rabas *(7)*, other unpublished work in Wisconsin and Minnesota, and data we are currently collecting in a companion study—all show that wood ash often provides greater yields than limestone and fertilizer. We believe the positive effect of wood ash arises from a complex interaction of soil pH changes and undetermined nutrient and biological processes. We suspect that the high Ca levels provided by ash and/or the noncarbonate Ca source in ash may contribute to yield increases. We do not believe the yield response results from a physical conditioning at high ash rates, but we remain open to any possible explanations. This study, however, was not designed to investigate interactions or to separate the liming value from the nutrient value of ash.

Plant and soil analysis

No statistically significant differences in protein content or relative feed value occurred as a result of wood-ash or limestone and fertilizer applications in the field studies. Likewise, observed nutrient differences are minimal, as seen in **Table III**. The mean, standard deviation, and statistical differences in forage elemental concentrations are for four cuttings at Phillips and five cuttings at Fifield. Analysis of the data by individual cutting did not provide additional useful information.

Comparisons cannot be made between the Phillips and Fifield locations, since soils and forage stands differ. However, the higher Ca, Mg, P, K, and B levels at Fifield probably result from the 100% alfalfa stand at Fifield, in contrast to the mixed alfalfa–grass stand at Phillips. Elemental concentrations at both locations show that plant nutrient levels are adequate for optimum growth and that no toxic levels appear for any element tested. Lack of toxicity is encouraging, since even very high application rates (20 tons/acre) result in loading levels of regulated elements well below those established by the Wisconsin Department of Natural Resources for landspreading of wood ash. Concentration of metals in plant tissue is unaffected by application of wood ash at all application rates.

The soil-analysis data in **Table IV** can be summarized as follows: At the Phillips location, we sampled four depth increments to 18 in. to evaluate if treatment effects at various soil depths could be identified. No changes could be identified below 6 in. within two years following surface application of ash. Changes in soil pH were evident only in the 0–2-in. layer after one year of treatment and in both the 0–2- and 2–6-in. layers two years after treatment. All ash rates resulted in pH values as high or higher than the limed and fertilized control. Differences in soil P levels appear only in the 0–2-in. layer and are significantly higher in year two following application of wood ash. The higher P levels result from a small addition of P in the ash compared with no added P in the fertilized or zero-ash treatments. Differences in soil P levels did not contribute to differences in forage P concentrations within any harvest or combined average for all harvests. Forage P levels were above 0.3% in all treatments, as seen in Table III. Significant increases in soil potassium levels occurred at the higher rates of ash application but only in the 0–2-in. layer. Soil K levels where ash was applied were slightly higher, but nonsignificant, in the 2–6-in. layer. At the Fifield location, soil pH increased with both ash and limestone application, but no differences were evident in P and K levels in either of the two years following application and incorporation of ash prior to planting.

CONCLUSIONS

Wood ash is a valuable resource as a liming and/or nutrient source for crop production. In general, increasing rates of ash produce increasing biomass yields. In this study, wood-ash applications of up to 20 tons/acre in the field or equivalent rates in a greenhouse always produced yields equal to those resulting from applying recommended rates of commercial limestone and fertilizer and often produced greater yields.

Although the study was not designed to compare methods of application, crop-yield response to ash application appeared to be similar for both topdressing and preplant incorporation, indicating either method of application may be appropriate for forage production

Wood-ash application rates of up to 20 tons/acre have minimal effect on the concentration of elements in forage tissue. TJ

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