# THE USE OF BOTTOM ASH AS A PHYSICAL AMENDMENT TO SODIC SPOIL[1]

by

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Abstract. The objectives of this study were to determine the best rate and method of application of bottom ash to sodic spoil in terms of reducing the effects of excess sodium and promoting vegetative growth. Plots were set up as a randomized complete block design and the depths of bottom ash tested were 10, 20 and 30 cm. Ash was incorporated into the spoil surface using a disc, chisel plow and Kellough subsoiler. As a fourth method, ash was left as a blanket on top of the spoil. Results showed the best rate of ash to be 30 cm and the best method of incorporation to be subsoiling. Both increased moisture movement downwards and decreased soil strength values which promoted leaching, germination and root growth. The 30 cm rate also improved the chemistry of the surface 15 cm of the spoil and increased yield. All the methods plus the 20 and 30 cm rates produced toxic levels of plant available boron in the soil. The soil concentrations were not reflected in any plant toxicity symptoms.

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## Introduction

Since the passing of the Land Surface Conservation and Reclamation Act in 1973 in Alberta, Canada, reclamation activities have been undertaken in areas mined and abandoned before 1963 when there were few reclamation regulations. One area requiring information regarding reclamation was that of sodic mine spoil. Hence reclamation plots were initiated in 1981 on mine spoil at the Vesta Mine near Halkirk, Alberta.

Shaneman and Logan (1978) found that a surface 4 to 15 cm application of bottom ash to sodic spoil promoted forage growth. The bottom ash greatly improved the penetration of water, air and roots, and eliminated surface crusting. The authors felt that the loose, coarse-textured properties of the ash, combined with the excellent moisture-holding properties, were largely responsible for the success of the plots. Lutwick et al. (1981) found bottom ash to increase plant available boron, decrease surface crusting, increase water infiltration and increase soil salinity on sodic mine spoil materials.

Boron toxicity in plants is often associated with bottom ash amended spoil in greenhouse studies, as the ash contains extractable boron in quantities which are normally toxic to plants. Barley grown in bottom ash in a greenhouse study exhibited boron toxicity symptoms (brown spotting near leaf tips). However, in field plots barley did not exhibit toxicity symptoms and headed out normally. Preliminary evidence indicated that boron

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was washed from the ash into the spoil in field conditions, diluting the element to non-toxic levels (Shaneman and Logan 1978). Lutwick et al. (1981) also found bottom ash to increase the amount of plant available boron in soil and noted boron toxicities on barley plants grown in the greenhouse. The statement was made that if internal drainage could be improved with ash addition then the problem of boron availability would be temporary.

Although initial work in the utilization of bottom ash has provided positive trends as a surficial amendment to sodic spoil, its use is not without some problems. Due to the coarse texture of the bottom ash and its high water-holding capacity, seeding and fertilizing operations are difficult (Natsukoshi 1981). In order to minimize these difficulties, seeding and fertilizing is conducted in either early spring or late autumn, when the surface is frozen but snow cover is lacking.

The objectives of this study were to determine the best rate and method of application of bottom ash as a physical amendment to sodic spoil in terms of reducing the effects of excess sodium and promoting vegetative growth.

## Materials and Methods

### Experimental Design

The plots were set up in a randomized complete block design (Fig. 1). Each plot measured 10 m by 20 m and was separated from neighbouring plots by a 2 m buffer zone. There were three replicates consisting of 12 plots each. Each replicate was separated by a 10 m buffer zone. The three rates of bottom ash tested were 10, 20 and 30 cm. Ash was incorporated into the spoil surface using a disc, chisel plow, and Kellough subsoiler. As a fourth method, ash was left as a blanket on top of the spoil.

### Seeding and Fertilizing

All plot construction activities were completed by December 1981. Each

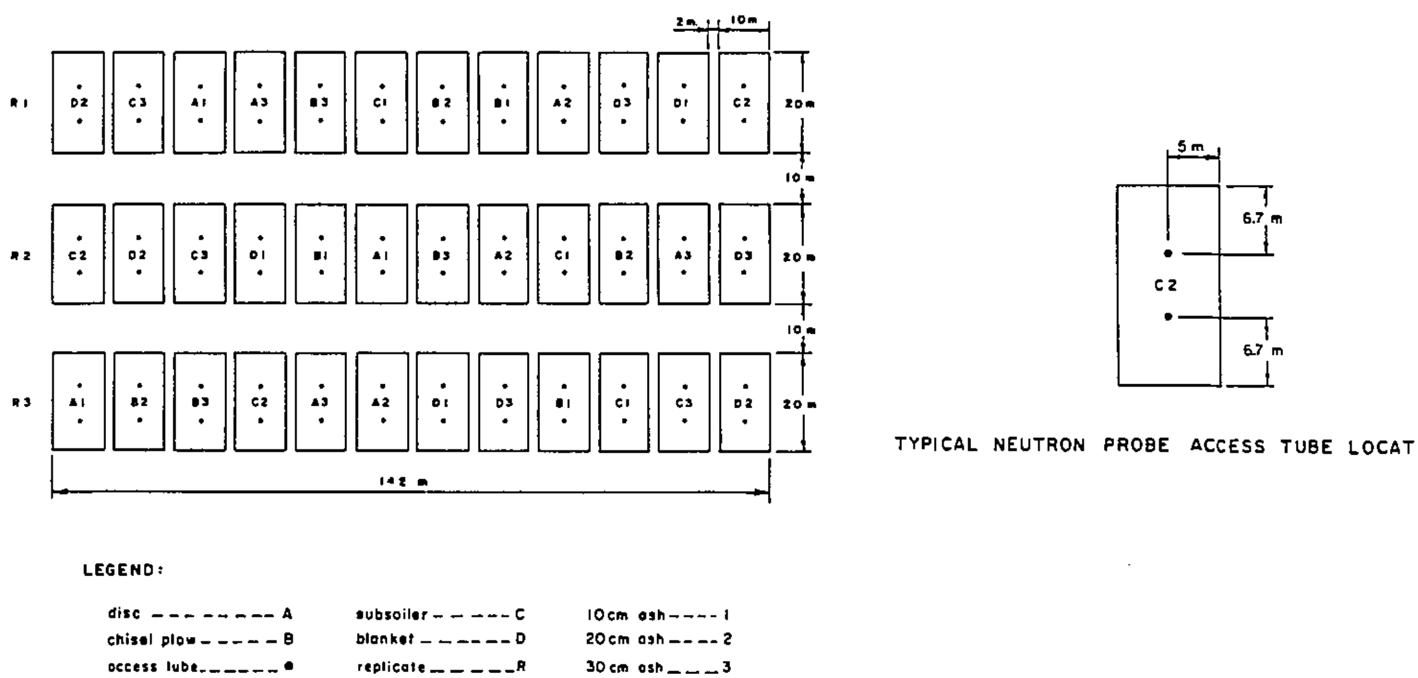


Figure 1.
Experimental design of the bottom ash plots and location of the neutron probe access tubes.

plot was hand-sown using a cyclone seeder in May 1982. A seed mixture comprised of Fairway Crested Wheatgrass, Tall Wheatgrass, Sodar Streambank Wheatgrass and Rambler Alfalfa (coated and pre-inoculated) was applied at a rate of 0.5 kg/plot. A fertilizer blend of 19% 11-51-0, 58% 34-0-0, and 23% 0-0-60 was also hand broadcast onto each plot at a rate of 6 kg/plot.

## Soil Sampling and Analyses

Soil samples were taken in the fall of 1983, 1984 and 1985. Samples were taken in 15 cm increments from the surface to 90 cm. Two subsamples per increment were mixed and bagged. Procedures used for the soil analyses are those outlined by McKeague (1978) as follows: pH (in water); EC (saturation extract); soluble salts (saturated paste extract); NH4 and NO3 (2N KCL); PO4 (0.03N NH4F and 0.03N H2SO4); K (NH4OAc at pH 7); B (hot water extractable); and total C (dry combustion).

A Campbell Pacific 501 neutron probe was used to monitor soil moisture on a monthly basis. Two access tubes per plot were installed to a depth of 1.5 m in order to monitor moisture in 15 cm increments from 0 to 120 cm (Fig. 1). The access tubes had the following specifications: 1.67 m long, an outside diameter of 5 cm, and an inside diameter of 4.8 cm. An aluminium plate was welded to one end of each tube to prevent movement of water into the tube.

A Mark 1 Model Bush Recording Soil Penetrometer was used to measure soil strength in 1985 only. Fifteen measurements were taken in 3.5 cm intervals from 0 to 52.5 cm. Ten replicates were taken from each plot.

## Plant Sampling and Analyses

A small plot-size Jari mower was used to cut down the vegetation on the plots each fall (1983 to 1985) leaving a 15 cm stubble. The harvested material from each plot was then raked and weighed on site to obtain a wet weight. One composite sample was taken at random from each plot. Plant analyses included N, P, K, Ca, Mg, and B, and were done using a HNO3-HC104 extraction. An atomic adsorption spectrophotometer was used for the elemental analyses.

## Statistical Analyses

The soil and plant variables were statistically analyzed over years and depths using a split-plot model by incorporating years and depths as split-plot factors (Steel and Torrie 1980). Statistical analyses were also done for each year with depth incorporated as a split-plot factor, and for each year at each depth. Trend analyses were performed for quantitative factors, and Tukey's test was used to evaluate significant differences between means.

In order to make the statistical analyses of the moisture data manageable, the monthly moisture observations were averaged to produce one moisture value for each plot for each of four seasons: spring (March, April, May), summer (June, July, August), fall (September, October, November), and winter (December, January, February). The moisture data were then analyzed in the same way as the soil and plant variables. Only the summer data will be discussed in this report as the trends were similar for each season.

Only those parameters significantly affected ($p<0.05$) by either method, rate, year, depth or any subsequent interactions will be discussed. When interpreting the results, unless a specific year is mentioned, there is no significant difference between years. When changes in parameters are discussed between increments, the depth used represents the lowest depth of a 15 cm increment.

## Results

### Soil Chemistry

Saturation Percentage (sat.%). Method of ash application affected the sat.% at depth in 1984 only (Fig. 2). The sat.% was lowest within the surface 15 cm for all methods, but increases occurred at different depths. Values significantly increased at: 30 cm using the disc; 15 cm using the chisel plow; 30 cm using the subsoiler; and 15 cm applying the blanket. Rate of ash application affected the sat.% at each depth monitored (Fig. 3). The 20 and 30 cm rates reduced the sat.% within the 0 to 15 cm depth compared to the 10 cm rate, but only the 30 cm rate decreased it within the remaining depths. Values for sat.% were not significantly different for the 10 and 20 cm rate below 15 cm. In general, the sat.% increased from the soil surface down to 90 cm for each rate and method of ash application.

pH. Values for pH decreased with increased rates of ash. Mean values were 8 for the 10 cm rate, 7.9 for the 20 cm rate and 7.8 for the 30 cm rate. Regardless of the rate or method of ash application, pH changed with depth in the plots. The pH increased from the soil surface (7.8) down to 45 cm (8.0), remained the same at 60 cm, and then decreased down to 90 cm (7.9) to values which were not significantly different than those within the surface 30 cm. These changes in pH were statistically different but not chemically or biologically significant.

Electrical Conductivity (EC). There were differences in values for EC between rates of ash at the 0 to 15, 60 to 75, and 75 to 90 cm depths (Fig. 4). Within the surface 15 cm, the EC decreased as the rate of ash increased. Values in mS/cm were 4.7 (10 cm), 3.8 (20 cm), and 2.3 (30 cm). The reverse occurred at the other two depths. Values for EC increased as the rate of ash increased. Mean values in mS/cm were 4.3, 5.0, and 5.8 at the 60 to 75 cm depth, and 3.8, 5.2 and 5.4 at the 75 to 90 cm depth. Values for EC decreased with increasing depth for the 10 cm rate, and increased with increasing depth for the 20 and 30 cm rates.

Soluble Calcium (Ca), Magnesium (Mg) and Sodium (Na). Both soluble Ca and Mg concentrations increased with

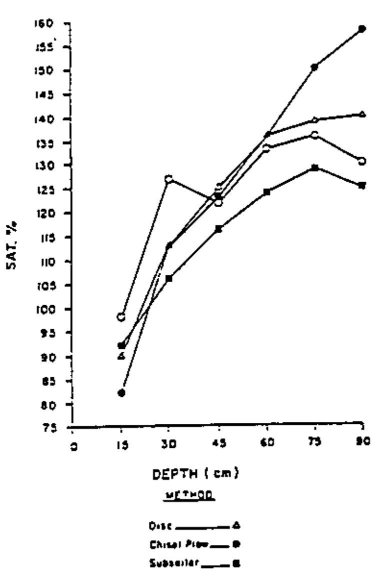


Figure 2.
Effect of method on the sat. % at each depth in 1984.

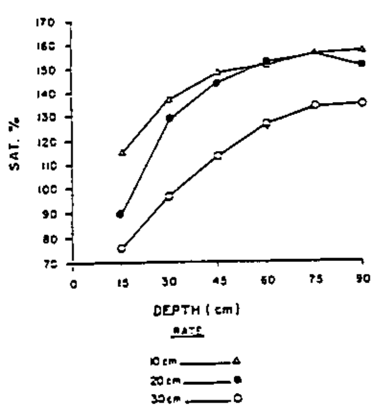


Figure 3.
Effect of rate on the sat. % at each depth.

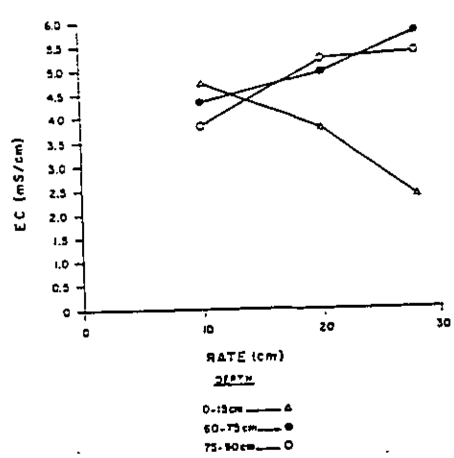


Figure 4.
Effect of rate on the EC at various depths.

increasing rates of ash at the 60 to 75 and 75 to 90 cm depths (Fig. 5). Concentrations of Ca in meg/L with increasing rates of ash were 2.6, 4.7 and 6.3 at the 60 to 75 cm depth, and 1.9, 5.4 and 6.0 at the 75 to 90 cm depth. Corresponding concentrations of Mg in meg/L were 1.1, 1.7 and 2.2 at the 60 to 75 cm depth and 0.7, 2.2 and 2.2 at the 75 to 90 cm depth.

Concentrations of soluble Na decreased within the 0 to 15 cm depth, and increased within the 75 to 90 cm depth with increasing rates of ash (Fig. 5). Concentrations in meg/L with increasing rates were 54.3, 42.0 and 25.0 within the surface 15 cm and 43.0, 56.7 and 61.1 at the 75 to 90 cm depth.

For each of the soluble cations, concentrations decreased from the soil surface down to 90 cm for the 10 cm rate, and increased down to 90 cm for the remaining rates.

Sodium Adsorption Ratio (SAR). In 1983 and 1985, the SAR decreased with increased rates of ash at the 0 to 15 and 15 to 30 cm depths (Fig. 6). Values in 1983 with increasing rates were 40, 23 and 14 at the 0 to 15 cm 30 cm depth. In 1985 values were 32, 30, 19, and 39, 34, and 29 respectively. In 1984 concentrations at all depths decreased in a linear fashion with increasing rates. Mean values were 41.5, 39.1 and 33.6. For each rate of ash, the SAR increased from the soil surface down to 90 cm.

Soluble Sulphate ($SO_4$). Sulfate concentrations were affected by the different rates of ash at the 0 to 15, 45 to 60, 60 to 75 and 75 to 90 cm depths. With increasing rates of ash, $SO_4$ decreased in a linear fashion within the surface 15 cm (Fig. 7). Concentrations were 48.1, 35.4 and 21.9 meg/L respectively. Below 45 cm, $SO_4$ concentrations increased in a linear fashion with increasing rates of ash. Concentrations in meg/L were 46.1, 57.8 and 61.2 at 45 to 60 cm; 44.0, 51.1 and 59.8 at 60 to 75 cm; and 38.5, 55.1 and 56.1 at 75 to 90 cm.

Concentrations of $SO_4$ decreased from the soil surface down to 90 cm for the 10 cm rate, and increased from the soil surface down to 90 cm for the 20 and 30 cm rates.

Soluble Boron (B). Of the three years monitored, concentrations of plant available B were highest in 1983 within the surface 30 cm (Fig. 8). Values in ppm were 12.23 in 1983 and a mean value of 5.64 in 1984 and 1985 for the 0 to 15 cm depth. Within the 15 to 30 cm depth concentrations were 6.39 in 1983 and a mean value of 3.48 in 1984 and 1985.

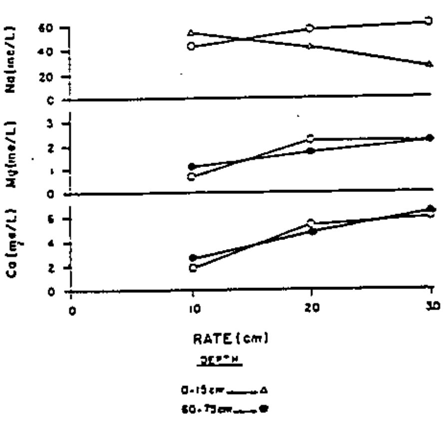


Figure 5.
Effect of rate on soluble Ca, Mg and Na at various depths.

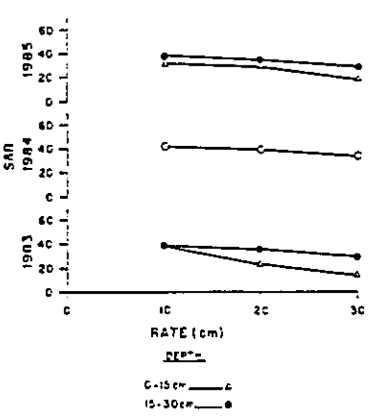


Figure 6.
Effect of rate on the SAR at various depths.

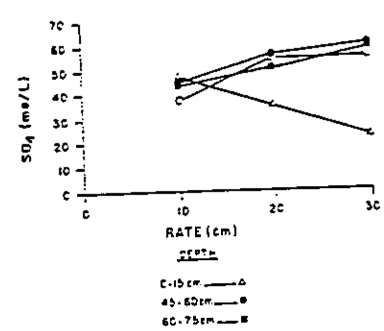


Figure 7.
Effect of rate on $SO_4$ concentrations at various depths.

B concentrations were higher in 1983 (8.12 ppm) than either 1984 or 1985 (3.72 ppm) for the 30 cm rate, and higher in 1983 (3.18 ppm) than 1985 (1.63 ppm) for the 20 cm rate.

Within the 0 to 15, 15 to 30 and 30 to 45 cm depths, concentrations of B increased with increased rates of ash (Fig. 9). Concentrations in ppm for the 10, 20 and 30 cm rates at each depth were: 3.94, 6.84, and 12.73 (0 to 15 cm); 1.72, 2.66, and 8.97 (15 to 30 cm); and 1.24, 1.77, and 3.86 (30 to 45 cm). In general, B concentrations decreased with increasing depth for each rate of ash.

Within the surface 15 cm, concentrations of B were lowest for the chisel plow method (5.56 ppm) and highest for the blanket method (10.44 ppm). The disc had lower B concentrations (6.99 ppm) than the blanket method, and the subsoiler had higher concentrations (8.36) than the chisel plow. Concentrations of B were highest within the surface 15 cm for each method, but the depth at which concentrations became significantly lower differed for each method. The depths were 15 cm for the disc and blanket, and 30 cm for the subsoiler and chisel plow. In general, concentrations of B decreased with increasing depth for each method.

Percent Organic Matter (%OM). In 1985 %OM was highest (10.5%) as compared to 1983 or 1984 (6.5%) which were not significantly different. The amount of OM also increased with increased rates of ash. Values in percent were 5.6, 6.3 and 11.8 for the 10, 20 and 30 cm rates.

Soil Strength

Method of ash application had no effect on soil strength within the surface 21 cm or depths below 45.5 cm (Table 1). Between 21 and 45.5 cm the subsoiler resulted in lower soil strengths than the disc, and between 24.5 cm and 42 cm it produced values lower than the chisel plow. From 35 to 45.5 cm the blanket method produced lower soil strengths than the disc and chisel plow methods. Therefore, in order of decreasing soil strengths between 21 and 45.5 cm the methods were rated as disc and chisel plow (0.34 bar), blanket (0.29 bar) and subsoiler (0.20 bar).

Rate of bottom ash had no effects on the surface 3.5 cm or depths below 49 cm. Between 3.5 and 49 cm, soil strength decreased with increased rate of ash (Fig. 10). In general, the soil strength decreased from 0.31 bar at the 10 cm rate, to 0.27 bar at the

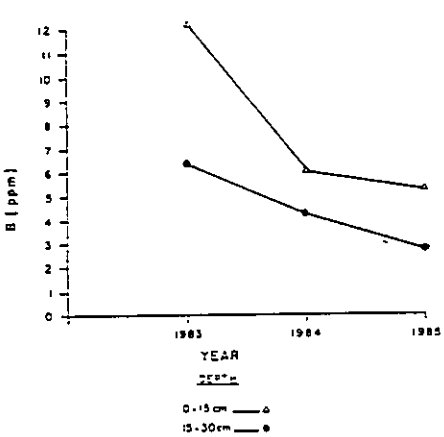


Figure 8.
Effect of year on B concentrations at various depths.

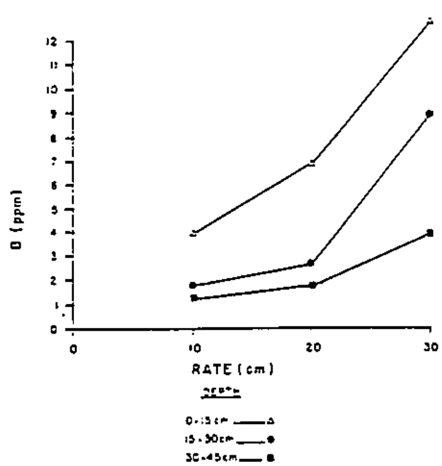


Figure 9.
Effect of rate on B concentrations at various depths.

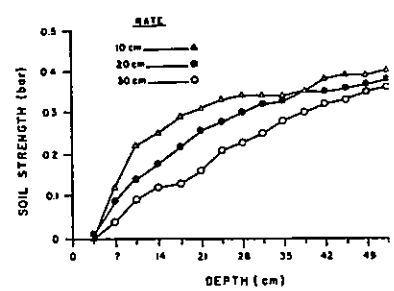


Figure 10.
Effect of rate on soil strength at depth.

Table 1. Effects of method on soil strength at each depth monitored.

| Method | Soil Strength (bar) 3.5 cm | 7 cm | 10.5 cm | 14 cm | 17.5 cm | 21 cm | 24.5 cm |
|---|---|---|---|---|---|---|---|
| disc | 0.00 a | 0.08 a | 0.16 a | 0.20 a | 0.24 a | 0.27 a | 0.30 a |
| chisel plow | 0.00 a | 0.08 a | 0.15 a | 0.18 a | 0.22 a | 0.25 ab | 0.29 a |
| subsoiler | 0.01 a | 0.10 a | 0.14 a | 0.17 a | 0.19 a | 0.21 b | 0.23 b |
| blanket | 0.00 a | 0.08 a | 0.16 a | 0.18 a | 0.21 a | 0.25 ab | 0.27 ab |

| Method | Soil Strength (bar) 28 cm | 31.5 cm | 35 cm | 38.5 cm | 42 cm | 45.5 cm | 49 cm | 52.5 cm |
|---|---|---|---|---|---|---|---|---|
| disc | 0.31 a | 0.34 a | 0.36 a | 0.37 a | 0.39 a | 0.40 a | 0.40 a | 0.41 a |
| chisel plow | 0.32 a | 0.34 a | 0.36 a | 0.37 a | 0.38 a | 0.38 ab | 0.38 a | 0.39 a |
| subsoiler | 0.25 b | 0.26 b | 0.26 b | 0.28 b | 0.31 b | 0.33 b | 0.35 a | 0.36 a |
| blanket | 0.28 ab | 0.29 ab | 0.30 b | 0.30 b | 0.31 b | 0.34 b | 0.35 a | 0.37 a |

Means with the same subscript (a,b,c) within a column are not significantly different at $p<0.05$.

20 cm rate, and to 0.21 bar at the 30 cm rate.

## Soil Moisture

The only difference between methods occurred at the 30 to 45 cm depth. The blanket had the highest moisture content (MC) (33.73%) and the disc the lowest (30.24%). The chisel plow and subsoiler were similar to both the blanket and disc and had a mean MC of 33.36%. In general, each method had increasing values for MC with depth (Fig. 11).

Within the surface 45 cm, MC decreased with increasing rates of ash (Fig. 12). Values in percent for increasing rates of ash were: 17.94, 14.96 and 10.26 (0 to 15 cm); 30.24, 27.46 and 22.43 (15 to 30 cm); and 34.11, 31.60 and 30.79 (30 to 45 cm). Below 45 cm MC values were not significantly different until the 105 to 120 cm depth. Within this depth, the trend was reversed. Moisture percentages increased with increasing rates (35.80, 37.25 and 38.04% respectively).

Moisture was highest at all depths in 1983 as compared to 1984 and 1985 which were similar (Fig. 13).

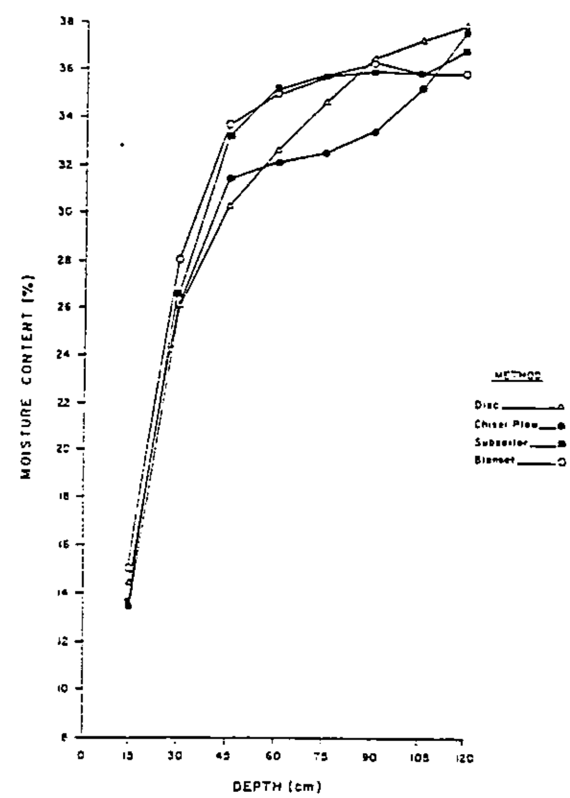


Figure 11.
Moisture content at different depths for each method.

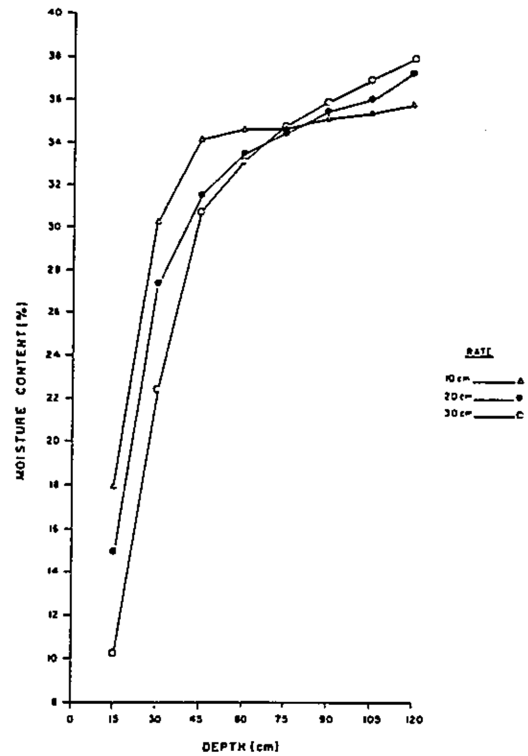


Figure 12.
Moisture content at different depths for each rate.

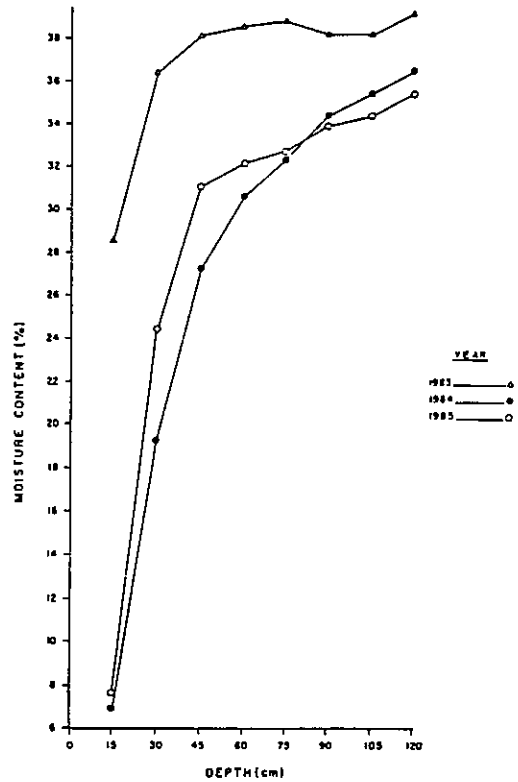


Figure 13.
Moisture content at different depths for each year.

## Plant Variables

There was a significant increase in yield with increasing rates of ash. In t/ha, yields were 1.07 (10 cm), 1.41 (20 cm) and 1.82 (30 cm). Yields were lower in 1984 (1.07) than either of 1983 or 1985 (1.62) which were not significantly different from each other.

Concentrations of B increased with increasing rates of ash. Concentrations in ppm were 43.4 (10 cm), 50.0 (20 cm), and 52.3 (30 cm).

Percentages of N, P, and K were lowest in 1983 and were not significantly different in 1984 and 1985 (Fig. 14). The reverse was true for Ca and Mg. Concentrations were highest in 1983 and not significantly different in 1984 and 1985.

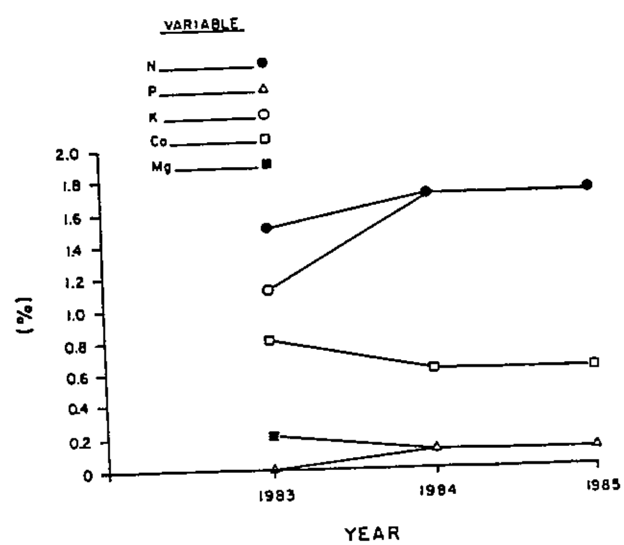


Figure 14.
Effect of year on plant variables.

## Discussion

### Method of Bottom Ash Application

The method of bottom ash application had few significant effects on the soil variables. The subsoiler method decreased the sat.% and increased B concentrations within the surface 30 cm of the plots. It was also the most effective method in terms of having the lowest soil strength measurements between 21 and 45.5 cm. The values for sat.% and B indicated that effective mixing of ash and spoil occurred down to a maximum depth of 30 cm. The low soil strength values indicate that the teeth of the subsoiler were able to penetrate down to 45.5 cm and loosen the spoil material.

Within the surface 15 cm the blanket method reduced the sat.% and had the highest B concentrations. Below 15 cm, this method had the second lowest soil strength measurements and had the greatest amount of moisture within the 30 to 45 cm depth. Field observations showed that moisture seemed to concentrate at the ash-spoil interface with the blanket treatments. This is confirmed by the high moisture at the 30 to 45 cm depth and reduced soil strength values. A problem with the 30 cm blanket treatment in the field was trafficability. At the higher ash rates, it was very difficult to use farm machinery to seed, fertilize and cultivate the plots.

In a similar fashion to the subsoiler, the disc method reduced the sat.% within the surface 30 cm. Unlike the subsoiler, the disc had increased B concentrations within the surface 15 cm. The disc had the highest soil strength values and had the lowest MC values at the 30 to 45 cm depth. The disc method had no effect on any of the soil parameters monitored below 30 cm. This reflects the fact that the disc is a surface tillage treatment.

The chisel plow method decreased the sat.% within the surface 15 cm and also had the lowest B concentrations within that depth. The chisel plow had increased B concentrations within the top 30 cm, and like the disc, had the highest soil strength values. The chisel plow had its greatest effect within the surface 30 cm of the plots.

As was mentioned previously, each of the methods had increased B concentrations within the surface 15 cm. Even though each method resulted in different B concentrations, all but the chisel plow had values in the toxic range of ≥5.7 ppm (Gupta et al. 1985) for plant growth. The chisel plow had values in the high range which is ≥1.5 ppm (Alberta Agriculture 1983). Concentrations of B within the surface 15 cm reflect the amount of mixing which occurred. The blanket treatment had the highest concentration and was not mixed while the chisel plow had the lowest and resulted in maximum mixing.

The method of ash application had no effect on plant yield or nutrients, therefore was not a limiting factor to plant growth.

## Rate of Bottom Ash Application

The rate of bottom ash application produced the most significant effects on both the plant and soil variables. As the rate of ash increased, the chemistry of the surface 15 cm of the plots was improved. The EC along with parameters reflecting sodicity (pH, sat.%, SAR, $Na_2SO_4$) were decreased. Along with an improvement in chemistry was a corresponding increase in yield and OM content in the soil. Therefore, as bottom ash was increased from 10 to 30 cm, the chemistry of the surface was improved which promoted increased crop growth. In terms of yield, on a wet weight basis from 1983 to 1985 the yields averaged 1.07, 1.41, and 1.82 t/ha respectively for the 10, 20, and 30 cm rates. Yields in Census Division No. 7 (Agricultural Reporting Area 4A) within which the plots fell, reported a mean yield of 2.9 t/ha, for the same time period. Yields for each of the application rates were below those reported but increased with increasing rates of ash.

While the surface of the spoil was improved, there was an increase in

EC and corresponding soluble salts below 60 cm. Therefore, increased rates of ash promoted leaching from the soil surface down to below 60 cm. This is also seen by observing the trends in the concentrations of soluble Na, Ca, Mg and $SO_4$. At the 10 cm rate, concentrations decreased down to 90 cm. At the 20 and 30 cm rates, concentrations increased down to 90 cm. Values for SAR, pH and sat.% decreased at all depths with increasing rates of ash. The changes in soil moisture with changing ash rates also reflected a leaching environment. As the rates of ash increased, the moisture within the 0 to 45 cm depth decreased, and increased within the 105 to 120 cm depth. Moisture movement downwards would have been enhanced by the decreased soil strength with increased ash rates between 3 and 48.5 cm.

B concentrations increased within the surface 45 cm with increased ash rates. B was present at medium to high levels (0.8 to ≥1.5 ppm) (Alberta Agriculture 1983) using the 10 cm rate. It was at toxic levels (≥5.7 ppm) (Gupta et al. 1985) within the surface 15 cm for the 20 cm rate, and within the surface 30 cm for the 30 cm rate. Even though B was at toxic concentrations within the soil, it was not reflected in the plant analyses (Table 2). All of the micro-nutrients in the alfalfa-grass hay mixture were in the sufficient range except for Fe, which was in the high range.

## Conclusions

Of the three rates tested (10, 20, 30 cm) the best rate of bottom ash to be applied to sodic spoil was 30 cm. A rate of 30 cm of bottom ash improved the chemistry, decreased the soil strength, and increased the soil moisture of the spoil. The 30 cm rate also promoted leaching as was seen by a decrease in moisture within the surface of the spoil accompanied by an increase in moisture at depth. The rate causing poorest results was 10 cm. B concentrations increased in both spoil and plant tissues as the rate of ash increased. Concentrations were at toxic levels in the soil at the 20 and 30 cm application rates, but the toxicities were never reflected in any plant toxicity symptoms.

Of the four methods tested (disc, chisel plow, subsoiler, and blanket) the best method of bottom ash incorporation into sodic spoil was

Table 2. Comparison of micronutrient concentrations in forage from the bottom ash plots and those in the Alberta literature.

| Nutrient | Alberta | Range | Bottom Ash Plots | Range |
|---|---|---|---|---|
| % Ca | 1.31[1] | | 0.66 | |
| % Mg | 0.25[2] | | 0.13 | |
| % K | 1.44[2] | | 1.26 | |
| % N | | | 1.65 | |
| % P | 0.20[1] | | 0.11 | |
| B (ppm) | 5.00[3] | low[3] | 49.57 | sufficient[3] |
| Cu(ppm) | 7.05[2] | marginal[3] | 11.42 | sufficient[3] |
| Fe(ppm) | 261.50[2] | high[3] | 346.33 | high[3] |
| Mn(ppm) | 36.50[2] | sufficient[3] | 38.97 | sufficient[3] |
| Zn(ppm) | 23.00[2] | sufficient[3] | 48.63 | sufficient[3] |

[1]Alberta Agriculture 1981
[2]Alberta Agriculture 1984 and Alberta Agriculture 1985
[3]Alberta Agriculture 1983

subsoiling. The subsoiler effectively mixed ash and spoil within the surface 30 cm, and decreased the soil strength at depth. The method producing the poorest results was the disc. All of the methods resulted in B concentrations in the toxic range for plants. These toxicities never occurred in the plant tissues.

The blanket method at the 30 cm ash rate created trafficability problems which made seeding, fertilizing and cultivation of the plots very difficult. Method of bottom ash application had no effect on any of the plant variables.

Hay yields for each of the rates were below those reported for adjacent farm lands, but increased with increasing rates of ash. Rate was more important than method in terms of significant effects on plant and soil variables.

Based on the results of this study, the most appropriate method and rate of bottom ash application to sodic spoil is to topdress the spoil with 30 cm of ash and mix it in using a subsoiler.

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