Prospects for Coal-ash in the Management of Australian Soils

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ABSTRACT

Many agricultural soils in Australia have inherent structural and nutritional limitations that pose major constraints to crop productivity. These soils are still productive due to intensive management that involves routine treatments with lime and gypsum at significant costs both to the farmer and the environment. There is therefore an opportunity to explore the use of the 13 million tonnes of coal-ash produced annually in Australia for soil management; at present most of the ash is disposed in landfills. In this paper we briefly describe examples of studies that showed beneficial use of coal-ash for crop production including our ongoing glasshouse study in which fly-ash increased early growth vigour and seed yield by 20% for canola (*Brassica napus*). There are several issues, including costs and regulation, and knowledge-gaps that need to be addressed before adoption of coal-ash for routine soil management.

INTRODUCTION

Soils in Australia are considered to be very old and highly weathered resulting in relatively thin topsoil that is generally low in nutrients. The A-horizon is underlain in many cases by dense clayey B-horizon; this strong structural and nutritional contrast between the topsoil and subsoil has led to these soils to be commonly referred to as *duplex* soils (1). The B-horizon is therefore largely impermeable to water and inhibits growth of roots, which is identified as a major constraint to water-use and crop productivity (2). Gypsum is routinely applied to these soils at rates of 2.5 to 30 tonnes per hectare to improve hydraulic conductivity and porosity (3). Furthermore, many of these soils are also acidic with recent estimates suggesting that almost half of the 100 million ha of Australian agricultural land has pH of less than 5.5 (3). Thus, lime is usually for neutralise acidity of which about 2.23 million ha of farmlands were treated in the late 1990s according to Australian Bureau of Statistics.

Coal-ash possesses many of the functional properties of lime and gypsum. Of about 13 million tonnes of coal-ash produced annually by power stations in Australia, more than 70% is currently disposed of in land fills at substantial financial cost. The long-term environmental and health hazards of this disposal process have been recognised (4). Recent studies on ash evaluation for soil management in Australia focused on improving the water-holding capacity of coastal sands with encouraging results (5, 6, 7), but these soils are of limited agricultural significance. Low interest in the use of ash in Australian agriculture, as else where may be largely due to waste classification of ashes, and also due to uncertainty about their buffering capacity and economic outcomes of their use. In this paper we shall briefly discuss how fly-ash be used in the management of these soils. We present some evidence from literature and our own unpublished data to demonstrate the benefits of fly-ash to crop production

COAL-ASH FOR AMELIORATION OF STRUCTURAL AND HYDROLOGICAL IMPEDIMENTS IN SOILS

Structural and chemical characteristics of most of agricultural soils in Australia are not optimum for water movement and root growth (Table 1). Porosity generally found on these soils is less than half that required for optimal plant growth, while the water holding capacity of these soils is often much less, but occasionally higher, than optimum. Coal-ashes with properties reminiscent of gypsum and dolomite (e.g. high Ca content, high percentage of fine particle size in the 2 to 200 μm range, and high solubility) would be expected to improve porosity and hydraulic conductivity. Successful previous studies of using fly-ash for amelioration of soil structure have been largely confined to coastal sands where reduction of hydraulic conductivity and improvement of water holding capacity were the main focus (5, 6, 7).

Table 1. Subsoil structural characteristics for optimum root growth and function and the values commonly observed under crops on the Australian duplex soils. Sources: Crockroft and Olsson (8), Hamblin (9, 10), McKenzie and McBratney (11), Yunusa et al. (12).

Soil attributes	Desirable values	Values commonly observed
Mechanical resistance (MPa)	< 0.5	0.1 – 3.5
Air-filled porosity (%)†	> 15	2.5 – 8.7
Volumetric water content at field capacity ($m^3\ m^{-3}$)	> 20	14 – 40
pH	6.0 – 7.5	Highly variable
CEC	40	Highly variable
SAR	6.0 –12.0	Highly variable

†Determined at –10kPa water potential

Applying fly-ash reduces the fraction of fine particles in clayey soils to increase porosity and conductivity, but reduce bulk density. With coarse textured soil, application of fly-ash would have a reverse influence to that with fine textured soils. Using the model of Jabro (13), we predicted changes in hydraulic conductivity as the particle size distribution changes from predominantly coarse texture to fine texture due as clay content increased. At a constant bulk density of 1.30, when 20% of coarse particles in sandy soils was replaced with fine fly-ash (<20µm, cf silt/clay particle range) hydraulic conductivity was reduced by up to 35% (Fig. 1); this would increase the water holding capacity of the soil. Using the same procedure with fine textured soils, when 20% of clay and silt particles were replaced with coarse fly-ash (>20µm) hydraulic conductivity increased by up to 25%. It should be noted however, that a practical implementation of these estimates would involve large amounts of ash. For a soil with a bulk density of 1.30, applying ash to the tune of 20% the weight of soil in the top 0.15 m of the profile requires close to 400 t/ha of ash. This may be appropriate for one-off land rehabilitation exercise, but definitely not for routine management of soils for which low rates are important. It is possible that for some soils, ash applied at rates similar to those of gypsum (1.0 – 4.0 t/ha) would suffice.

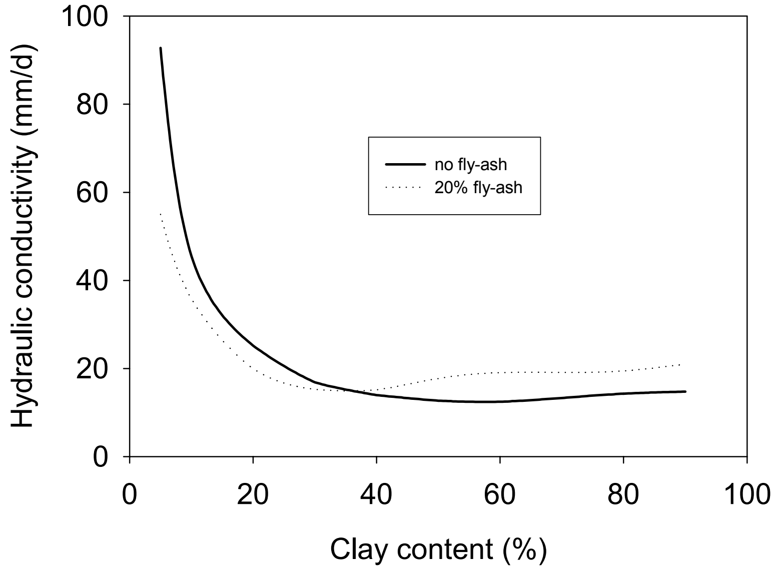

Figure 1. Estimated changes in hydraulic conductivity to clay content of the soil with or without addition of fly-ash.

POTENTIAL USE OF COAL-ASH FOR AMELIORATION OF SOIL ACIDITY

Agriculture in Australia as in elsewhere tends mine the soil through removal of cations by crops and/or by leaching, without appropriate management this process acidifies the soil. For coal-ash to be an effective ameliorant of low pH it needs to have fine texture, high Ca and Mg in the forms of hydroxides, carbonates or oxides, and low levels of impurities. These characteristics determine the neutralising (NV), i.e. the amount of acidity the ash will neutralise compared to pure lime that has (NV) of 100. The NV depends on carbonates of cations and other soluble oxides that are hydrolysed in soil to raise pH. Thus, a highly alkaline ash may not necessarily be effective neutralising agent, especially for coal-ash in which much of the carbonates and bicarbonates in coal are burnt off during power generation. This would explain why we found no substantial increase in pH of soils from 6.45 when treated with ash having a pH of 10.5 (Yunusa et al., unpublished data).

A number of studies in the US, such as that by Stevens and Dunn (14) reported increases by a unit of pH for every 3.7 t/ha of coal-ash applied to a fine sandy loam. A similar outcome was observed by McCallister et al. (15) in a laboratory study in which pH was equally raised by both coal-ashes and agricultural limes. These were quite encouraging outcomes given that many other studies found ashes to have poor NV (16, 17) and hence when applied to the soil the equilibrium pH would be closer to that of the soil than that of the ash.

GROWTH AND YIELD OF PLANTS ON ASH-AMENDED MEDIA

Growth of plants on soils amended with ash provides an overall benefit due to amelioration of both physical and nutritional constraints of soil. In the study of Stevens and Dunn (14) lint produced by cotton increased by 28% with application of 3.5 t/ha of coal-ash primarily due to neutralisation of acidity. In Australia, dry matter increases of almost 3-fold have been found for clovers (*Trifolium subterraneum*) on media treated with fly-ash (18). A 3-fold increases in water availability in coastal sands mentioned earlier produced up to 4-fold increase in biomass yield of turf grass (*Cynodon dactylon*) (6, 7). Aitken and Bell (5), however, found no improvement in the yield of bean (*Phaseolus vulgaris*) and Rhodes grass (*Chloris gayana*) despite increases in available water of ash-treated sandy soil, which they attributed to effects of B toxicity on the grass.

Improvements in the yield of crop treated with ash could be accounted for by enhanced physiological processes, such as photosynthesis or water-use efficiency, and/or growth pattern, but these have been little studied. We observed (Fig. 2) gradual increases in the net gas exchange or photosynthesis by canola (*Brassica napus*) grown on clay loam soil (~25% clay) with rates of fly-ash especially during periods before flowering (Yunusa et al., unpublished data). This increase in gas exchange early in the season enhanced early vigour for plants treated with up to 25 t/ha of fly-ash. Fly-ash increased seed yield by 25% compared to plants that did not receive ash treatment (Fig. 2, inset). There was no yield decline even at high rates of ash relative to that obtained with in the control treatment. This demonstrates that certain Australian coal-ashes can improve yield, contrary to the experience of Aitken and Bell (5).

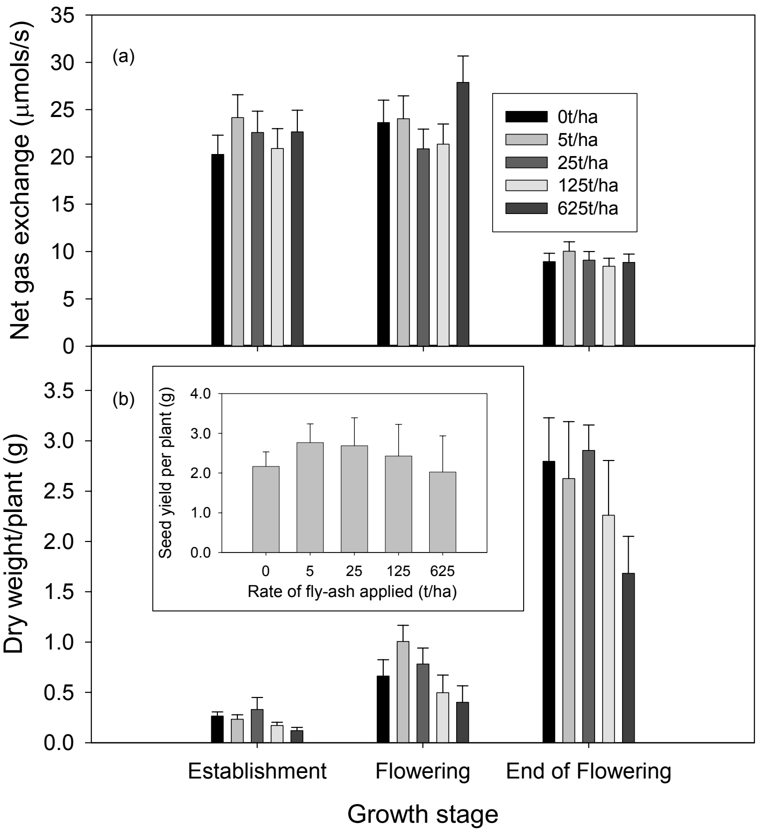

Figure 2. Influence of fly-ash on the growth and yield of canola at different stages of growth in the glasshouse in 2004: (a) net gas exchange and (b) dry weight of canola plants. The inset figure in (b) was for the seed yield per plant at harvest. (Source: Yunusa et al., unpublished data).

IMPEDIMENTS TO ROUTINE USE OF COAL-ASH IN SOIL MANAGEMENT

Regulatory barriers are impediments to the use of industrial by-products in agriculture. By far the main concern often revolves around heavy metal contents of the ash, which would either accumulate in the soil over time, or get into either the food chain or groundwater systems. Ash for agricultural use should have low contents of trace elements that are considered to be of either major (As, B, Cd, Hg, Mo, Pb, Se and S) or moderate (Cr, Cu, Ni, V, Zn and F) concern, based on the risk of their being released into the environment. Fortunately, these elements of concern (EOC) are generally low in Australian coals and, hence, in fly-ashes. The EOC are far lower than those found in coals from other major exporting countries (19). Killingley et al. (20) in Australia found lower concentrations of trace elements, especially As, Cd, Ni and Pb, in alkali generating than in acid generating ashes. For both ashes the ranges in their trace element concentration were mostly lower than found in common fertilisers and in some cases even lower than those found in uncontaminated soils. A further evidence for the cleanliness of Australian fly-ashes was borne out by the lower levels of trace elements we observed in the ash (Table 2) compared with two agricultural soils, which except for As, S, Mo and Mo, had higher concentrations than the ash (Yunusa et al., unpublished data).

Table 2. Comparison of concentrations (mg/kg) for selected trace elements considered of either major or moderate concern in the fly-ash and two selected agricultural soils in Australia. (Source: Yunusa et al., unpublished data).

Element	Coal-ash	Clayey soil	Sandy soil
Major concern			
As	7.0	3.5	0.8
Cd	< 0.3	< 0.3	< 0.3
Hg	0.13	0.02	0.02
Mo	6.1	0.5	<0.3
Pb	9.4	15.0	8.7
S	300	74	73
Moderate concern			
Cr	14.0	10.0	3.5
Cu	7.7	13.0	7.6
Ni	4.5	6.1	1.5
Zn	21.0	29.0	16.0
Others that may be of concern for soil management			
Ca	2100	2000	1400
K	1300	2500	800
Mg	470	430	280
Na	360	85	20
SAR	10.0	2.4	0.7

CONCLUDING REMARKS

In this brief review we have shown how coal-ash could benefit physical and nutritional characteristics of agricultural soils in Australia. Although, rigorous field evaluation of use of fly-ash is scarce and often limited to coarse sandy soils that are of limited agricultural significance in Australia, they indicate that ash could improve structural characteristics of coarse textured soils to enhance water holding capacity, while opening up fine textured soils to increase their porosity and hydraulic conductivity. With few exceptions, majority of the studies along with our unpublished data on canola showed that substantial yield increases are achievable with coal-ash.

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