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EFFECT OF COAL ASH ON SOIL WATER RETENTION, AND SOYBEAN (Glycine Max) GROWTH

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ABSTRACT

Coal ash (CA), a by-product of intense heat coal combustion, is globally considered as complex solid waste and its safe disposal is a growing concern. To minimize challenges associated with its disposal, some studies propose that coal ash can be used as a soil additive. Therefore, a greenhouse experiment was conducted to study the effect of coal ash amendment (0%, 1%, 1.5%, 3% and 5% v/v) on soil moisture retention, and Soybean growth on a Vertisol. It was found that the coal ash amendment significantly affected plant height ($p<0.05$), while nodulation and pod formation were not significantly affected. Coal ash amendment significantly reduced soil moisture retention at lower suctions (saturation) and higher suctions (pF 4.6). Being able to retain moisture at moderate potentials and supporting nodulation, which is an important factor in nitrogen-fixation, proves that coal ash has great potential to be used as an agricultural amendment especially in the often under-utilized Vertisols.

Keywords: coal ash, solid waste, soil water retention, soybean

1. INTRODUCTION

Coal ash, a by-product of coal combustion is increasingly becoming a major solid waste component of several industries. According to the World Energy Council, coal is currently the world's second largest source of primary energy [1], and is likely expected to replace oil as the largest source of primary energy, within a few years.This poses the challenge of increased solid waste management and pollution in production areas. Studies have shown that combustion of bituminous, sub-bituminous and lignite for the production of electricity in thermal power plants produces solid wastes, fly ash (FA), bottom ash, and boiler slag and flue gas desulfurization materials, commonly known as coal combustion by-products (CCPs) or coal ash (CA) in which approximately 75% of CCPs are FA. Ananthakrishnasamy*et al*., reported that FA contains macro and micro nutrient elements which could otherwise sustain plant growth [2].
Having appreciable amounts of Potassium, Calcium, Magnesium, Sulphur and Phosphorous, coal ash is a source of mineral elements essential for plant growth. Based on these favorable physicochemical properties, coal ash use is steadily increasingin agriculture and forestry over time [3]. Meanwhile, agricultural lime application is believed to contribute to global warming as Intergovernmental Panel on Climate Change (IPCC) reports that all the carbon in agricultural lime is eventually released as carbon dioxide(CO_2), to the atmosphere [4]. On the contrary, the use of fly-ash instead of lime in agriculture can reduce net CO_2 emission, thus reduce global

warming. However, sometimes the nature of the ash, the soil type, and the crop to be cultivated, cause barriers to the effectiveutilization of CA as a soil ameliorant [5].

Despite these set backs, coal ash has a vast potential to be used in different areas in agriculture, forestry, and wasteland reclamation. Nonetheless, environmental concerns have been raised as to the potential risk CA may pose to plants and consumers, as its irregular accumulation and inappropriate disposal over the years, may be dangerous to both human health and the environment [7]. Environmental hazards associated with coal ash are mainly due to its likeliness of possessing heavy metals. Furthermore, traces of radionuclides sometimes contained in this waste may present a risk to crops [8].

One of the possible ways of coal ash utilization is in drainage improvement [6]. According to Mutwale,[9] there are tons of coal ash produced by brewery industries and Thermal Power Plants (TPPs) in Zambia annually. A number of heavy clay soils, such as Vertisols, that are inherently poorly-drained and rarely, (if at all) used for production of cash crops are quite widespread in the region too. These soils are also susceptible to compaction when subjected to high levels of mechanization. Therefore, assessing the effect of coal ash amendment on soil moisture retention, and plant growth on these soils is very important. It is particularly important with the prevailingupsurge in population, which is likely to increase pressure on land and water resources.

In light of the many potential alternative uses of coal ash, a study was embarked on to assess the effect of coal ash on soil water retention and crop growth.The main objective of this study was to evaluate the effect of coal ash amendment on soil moisture retention, and soybean (*Glycine max*) growth.

2. MATERIALS AND METHODS

Experimental site

The experiment was conducted in the glasshouse at the School of Agricultural Sciences at the University of Zambia, located at 15º23'34" E and 28º20'03" S.

Soil and Coal ash characterization

Soil sample (a Vertisol) was collected from the School's field station. It was air-dried for 24 hours, ground and sievedusing a 2mm sieve. Then the soil was characterized for soil reaction (pH);organic matter content (Walkley-Black), [10];soil bulk density (using the core ring method, (Blake &Hartge) [11], [texture (Bouyoucos) [12]; available phosphorus (Bray 1 method) [13].; and total nitrogen was determined by the Macro Kjeldahl method [15] (Table 1).

The coal ash was obtained from Lusaka Breweries and characterized for pH, and selected heavy metals using standard methods, and results are given in Table 1.

Table 1 Soil and coal ash properties

	Soil	Coal ash
Total N (%)	**0.5±0.29**	**-**
pH	**6.55±0.32**	**6.7±0.13**
Organic matter (%)	**3.39±0.2**	**-**
Cd (ppm)	**-**	**<0.002**
Lead (ppm)	**-**	**<0.001**
Arsenic (ppm)	**-**	**4.0**
Cr (ppm)	**-**	**<0.002**
Selenium (ppm)	**-**	**<0.01**

Green house trials

17cm diameter plastic pots were used to grow the test crop(Soybean: Magoye variety, two plants/pot). Five (5) levels (0, 1, 1.5, 3 and 5%) of coal ash were put in different pots. In evaluating the effect of coal ash amendment on Soybean performance, 5 kg of soil was put in a pot and coal ash added at 5 levels and each treatment was replicated 4 times, these treatments were randomly assigned to experimental units (Table 2). The crop was then grown for a period of 8 weeks.After the 8th week, plant heightwas determined,after which, theabove and underground dry matter yield was harvested and dried. The number of pods and nodulation was determined too.

Table 2Treatments used in the evaluating soybean performance

Treatment	Description of Treatment
0% coal ash	5 kg soil only(Control)
1% coal ash	5kg soil + 50 g coal ash
1.5% coal ash	5 kg soil + 75g coal ash
3% coal ash	5 kg soil + 150 g coal

	ash
5% coal ash	5 kg soil + 250 g coal ash

Soil moisture retention characterization

Hanging water column (0 – 0.1 bar) was used to saturate the soils and determine the amount of water the soil can hold at a given suction. Mass of soils was measured starting from 2.5, 10.0, 32.0, 63.0 and 100cm at an interval of four (4) days. After getting the mass of samples at 100cm suction, an insert which fits exactly in the core was used to push the soil out of the core for exactly 1cm which was cut and put in pressure chambers. Soil water content at field capacity and wilting point was measured using the Pressure Chamber Apparatus (0.1 – 7.0 bar). Potentiometer apparatus was used to determine water content at high suction (15 – 1000 bars).

Van Genuchten equation (1980) was used to characterize the soil moisture retention curve using a non-linear curve fitting method with RETC Software [14].

$$\Theta = \Theta_r + \frac{\Theta_s - \Theta_r}{[1+|\alpha h|^n]^m} \quad (1)$$

Where

Θ=soil water content(cm^3/cm^3), Θr=soil residual water content (cm^3/cm^3), Θs=soil saturated water content (cm^3/cm^3), α,n and m are curve fitting parameters.

$$m = 1 - \frac{1}{n} \quad (2)$$

$0<m<1$.

3.RESULTS AND DISCUSSION

Expansive clays like Vertisols,are quite problematic to work with due to their swelling and shrinkage properties.Results in Table 3 show a significant decrease ($p<0.05$) in soil moisture retention at low and high suctions (at pF 0.4 and pF 4.6).

Table 3Effect of coal ash amendment on soil moisture retention at different suctions

…0.0.0..	$\Theta_{(pF=0.4)}$	$\Theta_{(pF=1.0)}$	$\Theta_{(pF=1.5)}$	$\Theta_{(pF=1.8)}$	$\Theta_{(pF=2.0)}$	$\Theta_{(pF=4.6)}$
			-- cm^3/cm^3--			
0.0	0.479^b	0.441	0.402	0.371	0.352	0.159^b
1.0	0.475^{ab}	0.437	0.384	0.350	0.333	0.147^{ab}
1.5	0.444^a	0.409	0.388	0.356	0.336	0.143^{ab}

3.0	0.446[ab]	0.416	0.383	0.346	0.327	0.137[ab]
5.0	0.452[ab]	0.423	0.387	0.351	0.330	0.107[a]
Mean	0.459**	0.425[ns]	0.389[ns]	0.355[ns]	0.335[ns]	0.1388**
CV(%)	4.8	4.6	4.9	4.8	4.9	7.7
$LSD_{(p<0.05)}$	0.0275	0.0334	0.0221	0.0236	0.0252	0.02779
Fpr	0.038	0.195	0.298	0.199	0.209	0.038

The plasticity index, activity, free swell, swell potential, swelling pressure and axial shrinkage percent possibly decreased with an increase in coal ash amendment [16], [17]. At low suction, coal ash particles are lodged in bottle necks of clay soils and reduce the large pore spaces.If the clay content is high, a double layer depression forms, resulting in considerable resistance to movement of particles over one another, hence the amount of water held by the soil reduces.

At high suction, coal ash showed a significant difference ($p<0.05$) in soil moisture retention. This is because coal ash acts as a cementing agent and once the soil is well aggregated, large pore spaces are created, whereas an increase in suction reduces the amount of water to be held by the soil (since soil water retained at high suction is mainly due to adsorptive effect while at low suction it is capillary effect). Dixit reported that changes in the physical properties and swelling potential is a result of additional non-plastic silt-size particles to some extent and due to chemical reactions that cause immediate flocculation of clay particles [18]. Overall, from the obtained means, there wasa decrease in soil moisture retention with increase in suction.

Soil moisture is a key variable of the climate system which imparts on water, energy, and biogeochemical cycles. Related to this, field and wilting points of the soil are important in crop production in determining available water content. It was found that coal ash amendment significantly ($p<0.05$) reduced water content at wilting point, but water at field capacity and available water holding capacity were not significantly ($p>0.05$) affected (Table 4). This is because ash acts as a cementing agent,which leads to creation of greater pore spaces. Furthermore, the application of high suction (e.g. – 15 bar) drains out water from the soil. It also binds the soil particles together, hence reducing the net charges on the soil exchange complex which leads to low water content at wilting point.

Table 4Table 1: Effect of Ash on water content at field capacity, wilting point and available water holding capacity

Ash content (%)	Θ_{FC} (cm^3/cm^3)	Θ_{WP} (cm^3/cm^3)	AWC (mm/m)
0.0	0.348	0.180[b]	168.0

1.0	0.326	0.169[b]	156.8
1.5	0.331	0.167[b]	164.5
3.0	0.326	0.159[b]	166.7
5.0	0.326	0.129[a]	196.9
Mean	0.332[ns]	0.161**	170.6[ns]
CV(%)	6.2	14.1	15.3
LSD$_{(p<0.05)}$	0.0154	0.0171	0.0196
Fpr	0.281	0.009	0.115

These findings were similar to those of Bar-Tal *etals'*[19], where addition of the pozzolanic coal ash increased the strength of the aggregates formed in the ash-loaded soil. According to Blanco et al.,addition of coal ash to sandy loam soil, resulted in significant improvement in the permeability [20].

Table 5Effect of Ash on Van Genuchten retention parameters

Ash content (%)	**ϴs (cm^3/cm^3)**	**ϴr (cm^3/cm^3)**	**α (cm^{-1})**	**n**	**m**
0.0	**0.4968**	**0.036**	**0.10**	**1.179**	**0.1490**
1.0	**0.5221**	**0.166**	**1.23**	**1.176**	**0.1463**
1.5	**0.4769**	**0.026**	**0.29**	**1.166**	**0.1406**
3.0	**0.4858**	**0.016**	**0.21**	**1.160**	**0.1372**
5.0	**0.4751**	**0.013**	**0.09**	**1.208**	**0.1715**
Mean	**0.4914[n]**	**0.051[ns]**	**0.3**	**1.17**	**0.148**

s			8ns	8ns	9ns
CV(%)	**8.9**	**314.7**	**313.8**	**5.0**	**28.2**
LSD(p<0.05)	**0.05215**	**0.1927**	**1.437**	**0.0701**	**0.04999**
Fpr	**0.355**	**0.446**	**0.449**	**0.668**	**0.654**

Knowledge of the evolution of water and solutes in the subsurface is required for most soil and water management, and environmental protection practices. The Van Genuchten (VG) function is often used to describe the soil water retention curve (SWRC) of unsaturated soils and fractured rock. From the results (Table 5), it is clear that coal ash amendment did not significantly ($p>0.05$) affect the soil saturated and residual water content.

Table 6 Effect of Ash on total aboveground biomass, underground biomass, ratio of above to underground biomass, nodulation and effectiveness at 8 weeks

Ash (%)	Tbm (kg/m²)	Rabm	Rubm	Nod	Eff
0.0	0.159	0.679	0.321	2.0	2.00
1.0	0.159	0.691	0.309	0.5	1.75
1.5	0.180	0.684	0.316	0.8	1.50
3.0	0.190	0.686	0.314	0.0	2.00
5.0	0.200	0.683	0.317	10.0	1.50
Mean	0.178ns	0.684ns	0.316ns	2.6ns	1.75ns
CV(%)	28.3	9.0	19.5	307.9	24.5

LSD$_{(p<0.05)}$	0.0774	0.0948	0.0948	12.57	0.6597
Fpr	0.710	0.999	0.999	0.423	0.304

Tbm=total biomass, Rabm=ratio of above ground biomass, Rubm=ratio of underground biomass, Nod=nodulation and Eff=effectiveness

Coal ash amendment significantly (p<0.05) affected the plant height; however other parameters were not significantly (p>0.05) affected (Table 6). This is because coal ash acts as a cementing agent (causes clay particles to flocculate) hence soil aggregation and air circulation in the soil improves. A well aggregated soil will have a good combination of large and small pore; large pores for water movement while small pores are for air circulation, which are good for nutrient circulation. The results showed that the biomass increased with increase in coal ash amendment. Aboveground biomass, underground biomass, total biomass, nodulation was not significantly affected because coal ash releases the nutrients at a considerably low rate. Similarly, according to Mutwalethe dry matter of finger millet was not significantly affected by coal ash amendment [9]. This could be alluded to the low organic matter in the ash. Organic matter plays a vital role in improving soil fertility. Similarly, Tinjum et al. observed that the impact of compaction effort is more significant for the high-plasticity soil like Vertisols [21].

The heavy metals in coal ash were found to be below the detectable levels (<0.01 ppm) except for Arsenic which was found to be 4ppm. Arsenic has always affected the mankind since ages, sometimes in a positive way as wood preservatives,rodenticides and medicines and sometimes in a negative way as poison and carcinogenic substance.

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