Fluidized Bed Bottom-Ash Effects on Infiltration and Erosion of Swelling Soils

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ABSTRACT

Fluidized bed combustion (FBC) bottom ash, rather than being used as fill at dumping sites, can be utilized to amend certain soils for erosion control. Because FBC bottom ash is a source of both electrolytes and alkalinity, its effectiveness in controlling runoff and erosion should be greater on soils with a predominance of permanent charges. Five soils, with and without addition of 5 Mg ha^{-1} surface-applied FBC bottom ash, were prewetted and subjected to 110 mm h^{-1} rain for 90 min. The critical flocculation concentration (CFC) varied from 0.5 mmol$_c$ L^{-1} for the smectitic-kaolinitic soil to 3.5 mmol$_c$ L^{-1} for the illitic soil. Steady-state infiltration rates (I_s) for the control were very low, ranging from 1.8 to 5.8 mm h^{-1}. These rates were increased 3.6- to 5.0-fold with the application of FBC bottom ash, with a lesser increase for the highly smectitic and illitic soils. For the control, total soil loss ranged from 220 to 1998 g m^{-2}, and total water loss from 78 to 112 mm, with the greatest losses for soils with a large cation-exchange capacity/clay ratio. The FBC bottom ash reduced total water loss by 1.1- to 2.0-fold and total soil loss by 1.5- to 3.9-fold. The CFC of the soil was correlated with I_s, while aggregate stability was correlated with erosion and total runoff. The FBC bottom ash effectiveness in increasing infiltration and controlling erosion on these soils is attributed to an increase in electrolytes in the runoff, thus decreasing soil swelling and the dispersion of clay platelets and preventing surface sealing.

THE DISPERSION AND SWELLING of clays are interrelated phenomena that diminish the soil's permeability and water infiltration. For soils with mixed mineralogy, the low ionic strength of rain water decreases the soil's permeability through the swelling and dispersion of expandable clays and, to a lesser degree, of nonswelling clays. The degree of dispersion can be related to the electrical double-layer effects (van Olphen, 1977) since repulsive forces between clay platelets increase as the ionic strength decreases, the cation hydration radius increases, and the pH, generally, increases. Increases in the concentration of exchangeable cations in suspensions of smectites tend to collapse the layers, while decreases tend to expand them (Borchardt, 1989).

Surface-applied phosphogypsum has been successfully used to reduce soil dispersion and erosion on semiarid region soils (Agassi et al., 1981; Chartres et al., 1985), on highly weathered kaolinitic soil (Miller, 1987), and on illitic, smectitic–vermiculitic, and kaolinitic soils of humid regions (Norton et al., 1993). With dissolution, gypsum increases the electrolyte and Ca concentrations of the soil solution and runoff, thus reducing swelling of soil and dispersion of clay particles.

An increasingly available source of gypsum-like material is the capture of SO_2 emissions from coal-fired power plants by $CaCO_3$. In the case of FBC bottom ash, the material produced is rich in anhydrite ($CaSO_4$), unspent sorbent ($CaCO_3$), and other materials. Thus this material is a source of electrolytes and of alkalinity as well. Increases in soil pH enhance dispersion particularly of variable-charge soils, and the electrolytes released by the FBC bottom ash may be insufficient to flocculate clay particles, which may actually increase erosion. For soils with a predominance of permanent-charge colloids, such as soils with 2:1 type clays, increases in pH have less effect on charge increases. Therefore, FBC bottom ash can be utilized for controlling soil erosion on agricultural land and construction sites, especially those with swelling soils. The objectives of this study were to: (i)

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Abbreviations: Al_d, aluminum extracted by DCB; CEC, cation-exchange capacity; CFC, critical flocculation concentration of electrolytes; COLE, coefficient of linear extensibility; DCB, dithionite-citrate-bicarbonate; EC, electrical conductivity; ESP, exchangeable sodium percentage; FBC, fluidized bed combustion; Fe_d, iron extracted by DCB; Fe_o, iron extracted by oxalate; I_s, steady-state infiltration rate; MWD, mean weight diameter; SA, surface area; SAR, sodium adsorption ratio.

Table 1. Soils studied and their classification.

Soil	Location	Classification
Grey Clay	Toowoomba, Queensland, Australia	Udic Chromustert
Heiden	Riesel, TX	Udic Chromustert
Hoytville	Hoytville, OH	Mollic Ochraqualf
Irving Clay	Toowoomba, Queensland, Australia	Typic Pellustert
Pierre	Jackson, SD	Ustertic Cambiothid

evaluate water infiltration and erosion on naturally highly Ca-saturated swelling soils with diverse clay mineralogy, and (ii) determine the effectiveness of FBC bottom ash on reducing runoff and erosion on these soils.

MATERIALS AND METHODS

Soil Characterization

Five swelling soils were studied (Table 1). Soil samples were collected from A horizons (0–15 cm) at field moisture, air dried, and gently sieved through an 8-mm sieve. The clay mineralogy of dispersed clay (<2 μm) was determined on oriented slides using a Phillips x-ray diffractometer with Co Kα radiation (35 kV, 25 mA). The samples were Mg saturated plus ethylene glycol solvated, Mg saturated, or K saturated (at 25, 300, and 550°C). Diffractograms for only the first treatment are shown in Fig. 1.

The CFC of electrolytes is defined as the minimum salt concentration of an electrolyte required to cause flocculation of a given colloidal (or soil) dispersion in a given time (van Olphen, 1977). In our study, the CFC was determined after 24 h (Oster et al., 1980), using a series of Purdue University FBC bottom ash and gypsum ($CaSO_4 \cdot 2H_2O$) solutions with 1 to 5 mmol$_c$ L^{-1} in a 1:37.5 soil/water solution in transparent tubes. These tubes were then shaken overnight, and the suspensions were allowed to settle for 24 h. Flocculation was then visually inspected and the pH of the supernatant measured.

The COLE was determined through the change in density of <2-mm air-dried soil that was capillary wetted for 4 h. Other selected soil properties (Table 2) were determined as follows: dispersed particle size by the pipette method (Day, 1965); undispersed particle size by the same method but without chemical dispersant; pH in H_2O and in 0.005 *M* $CaCl_2$ (1:1 soil/solution); total C by dry combustion with a LECO total carbon analyzer (Leco Corp., St. Joseph, MI); inorganic C and equivalent carbonates by gravimetric loss of CO_2 using 1 *M* H_2SO_4 containing $FeSO_4$ as an antioxidant to prevent release of CO_2 from organic matter; CEC and exchangeable cations determined by the NH_4OAc method at pH 7; EC of a 1:5 soil/water solution; MWD of aggregates by wet sieving of capillary-prewetted soil (4.76–8.00 mm) samples; Fe oxides (Fe_d) and Al oxides (Al_d) extracted two times with DCB (Mehra and Jackson, 1960); amorphous iron (Fe_o) extracted by pH 3 ammonium oxalate in the dark (Schwertmann, 1964); specific SA using the EGME method (Cihacek and Bremner, 1979); and water retention at −1500 kPa using pressure plates.

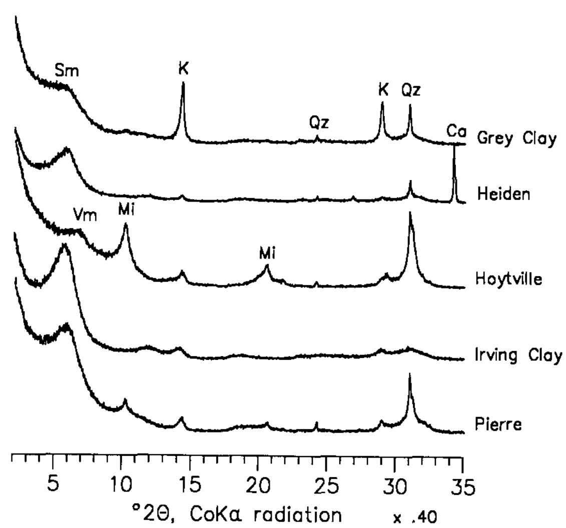

Fig. 1. X-ray diffractograms of oriented samples for clay (<2 μm) Mg saturated plus ethylene glycol solvated (Sm = smectite; Vm = vermiculite; Mi = mica; K = kaolinite; Qz = quartz; Ca = calcite).

Infiltration and Erosion

An erosion pan 32 cm wide, 45 cm long (1440 cm^2) and 20 cm deep was used. The pan had a 5-cm bottom layer of gravel, and a 12-cm intermediate layer of sand to control soil water tension. Sieved soil was packed to a maximum depth of 3 cm and then prewetted from the bottom for 2 h with deionized water, at a level position. The amount of soil used was calculated allowing compensation for the extensibility (COLE) of the soil. The pan was then set at 5% slope, and allowed to drain for 30 min. A 5-cm tension was maintained at the center of the pan during the drainage phase and the subsequent rainstorms.

Right before the rain, FBC bottom ash from the Purdue University power plant was surface applied at a rate of 5 Mg ha^{-1}. The FBC bottom ash was composed primarily of anhydrite ($CaSO_4$, 73%), lime (CaO, 23%), portlandite [$Ca(OH)_2$, 3%], calcite ($CaCO_3$, 1%), gypsum ($CaSO_4 \cdot 2H_2O$, traces), and oldhamite (CaS, traces). The elemental chemical composition was 55.0% CaO, 40.5% SO_3, 4.8% SiO_2, 1.1% Al_2O_3, 0.8% Fe_2O_3, 0.3% MgO, and small amounts of other elements. Total dissolved salts was 4700 mg L^{-1}, the EC of a 1:1 FBC bottom ash/water solution was 11 dS m^{-1}, and the pH was 12.5. The mixed nature of the FBC bottom ash indicates, therefore, that it is a source of electrolytes and of alkalinity.

To simulate natural rain, deionized water with an EC <0.018 dS m^{-1} was used as rainwater. Constant rainfall was applied

Table 2a. Selected physical and chemical properties of the studied soils.†

Soil	Sand	Silt	Clay			pH		Carbon						
			CDC	WDC	ratio	H_2O	$CaCl_2$	TC	IC	CCE	MWD	ESP	BS	CEC‡
	g kg^{-1}							g kg^{-1}			mm	%		cmol$_c$ kg^{-1}
Grey clay	278	262	460	22	0.05	8.2	7.6	32	7	64	0.9	0.4	90	40.8 (37)
Heiden	86	396	518	23	0.04	8.0	7.4	73	50	410	1.9	0.2	74	50.4 (33)
Hoytville	28	370	566	313	0.55	6.0	5.5	24	tr§	tr	4.3	0.3	60	33.5
Irving Clay	28	370	602	202	0.34	7.6	6.8	23	0	0	0.4	1.3	82	68.8
Pierre	422	276	302	208	0.67	7.2	6.4	17	tr	12	5.2	0.6	73	24.7

† CDC = chemical-dispersible clay; WDC = water-dispersible clay; ratio = WDC/CDC; TC = total carbon; IC = inorganic carbon; CCE = calcium carbonate equivalent; MWD = mean weight diameter of aggregates; ESP = exchangeable sodium percentage; BS = base saturation; CEC = cation-exchange capacity.
‡ Since NH_4OAc dissolves carbonates, CEC values from the literature (Freebairn and Wockner, 1986; Elliot et al., 1989) are also presented in parentheses.
§ Trace.

for 90 min at a target rate of 110 mm h^{-1} (to simulate intense tropical rain) using a programmable rain simulator equipped with 80100 Veejet nozzles (Spraying Systems Co., Wheaton, IL)[1]. Infiltrating water was collected from the bottom of the pan, while runoff and sediment yield were sampled at the bottom edge of the pan. Measurements of runoff and sediment included overland flow and splash onto the collecting trough. Measurements of the runoff and sediment amounts were made at 4-min intervals, except at the beginning of the rain when greater intervals were used. Infiltration measurements were taken at 5- or 10-min intervals. The EC of the runoff was measured at runoff initiation and at the end of the runs, when the MWD and particles <250 μm from the eroded sediment were determined by wet sieving and pipetting.

Statistical Analysis

All runs were replicated in a completely randomized experimental design. Means of calculated and measured parameters were compared using the Newman–Keuls sequential range test, which is a conservative test for means differences. Water infiltration was modeled using the Hortonian-type equation of Morin and Benyamini (1977). The model is:

$$I_t = (I_i - I_s)\exp(-\gamma_{pt}) + I_s$$

where I_t = infiltration rate in mm h^{-1} at time t; I_i = initial infiltration rate in mm h^{-1}; I_s = steady-state infiltration rate in mm h^{-1}; γ = decay coefficient; p = rainfall intensity in mm h^{-1}; t = time in h into the run. A nonlinear procedure of SAS (SAS Institute, 1988) was used to fit the model parameters to the observed infiltration data. The coefficient of determination (r^2) was calculated by linearly regressing the observed against the estimated infiltration rates.

RESULTS AND DISCUSSION

Soil Properties: Clay Mineralogy and Flocculation

The clay mineralogy (Fig. 1) showed the presence of expansive-type minerals (smectite and vermiculite) in all soils. Irving Clay was the most smectitic of all the soils. Hoytville was illitic, while some illite was also present in Pierre. Kaolinite was present in considerable amounts in the Grey Clay, while a well-defined calcite peak was observed for Heiden. Table 2 shows that most soils had high pH in water and in $CaCl_2$, high base saturation, and high CEC. Two of the soils (Grey Clay and Heiden) had significant $CaCO_3$ equivalent (Table 2). All five soils were essentially Ca saturated, with ESP <1.3% and SAR <0.2. The ranking of the soils from high to low was the same for CEC and −1500 kPa water, and somewhat similar for the SA. The SA showed the sequence: smectite > smectite–kaolinite > illite. Interestingly, the highly smectitic Irving Clay soil had SA (660 $m^2\ g^{-1}$ of clay) and CEC (114 $cmol_c\ kg^{-1}$ of clay) close to values reported for pure montmorillonites (Borchardt, 1989). This is consistent with smectite being the predominant mineral in the clay fraction (Fig. 1) and the soil's clay content (Table 2). Smectites usually exist only in the clay fraction (<2 μm) of a soil (Borchardt, 1989). A high Fe_o/Fe_d ratio (0.2–0.6) was observed for the soils, suggesting that the Fe oxides are highly amorphous. The Irving Clay had a quite high Fe_d content, probably due to its basaltic parent material. This soil occurs on catenas where Oxisols occupy the stable summit positions, while Vertisols are located on run-on positions such as toeslopes and footslopes.

The CFC of electrolytes using FBC bottom ash and pure gypsum is shown in Table 2. The FBC bottom ash increased the pH at flocculation for all soils, but the CFC was increased only for two of the soils (Grey Clay and Pierre). The ranking in CFC of our soils was: illitic > expansive (smectite and vermiculite) > kaolinitic was similar to the ranking observed by Norton et al. (1993) for natural clays. Studies on pure clays have shown a CFC value for Ca-illite of 0.25 $mmol_c\ L^{-1}$ (Greene et al., 1978), while for Ca-montmorillonite CFC ranged from 0.17 $mmol_c\ L^{-1}$ (van Olphen, 1977) to 0.25 $mmol_c\ L^{-1}$ $CaCl_2$ (Oster et al., 1980). However, small amounts of exchangeable Na rapidly increase the flocculation value of Ca-montmorillonite. Illite particles have irregular surfaces (Greene et al., 1978) and planar surfaces are terraced (Quirk, 1978); thus, on closer approach of illite particles, the mismatch of the terraces would lead to imperfect contact between the edges and the surfaces, resulting in smaller edge-to-face attraction forces, and consequently greater flocculation values (Oster et al., 1980). Conversely, kaolinite is usually difficult to disperse, but the presence of 2:1 minerals may inhibit the edge-to-face interactions and promote dispersion (Arora and Coleman, 1979). Soil surface kaolinite is more dispersible than reference kaolinite, possibly due to adsorption of anionic organic polysaccharides at the edges of soil clays (Miller et al., 1990).

Water Infiltration and Soil and Water Losses

The rate of infiltration decay (or rate of surface sealing), coefficient γ in Table 3, was greater for highly

[1] The use of brand names is for the reader's benefit and does not constitute endorsement by the USDA-ARS.

Table 2b. Selected physical and chemical properties of the studied soils.†

Soil	Fe_d	Al_d	Fe_o	EC	SA	COLE	θ_g at −1500 kPa	Gypsum CFC	Gypsum pH‡	Bottom ash CFC	Bottom ash pH‡
	g kg^{-1}			dS m^{-1}	$m^2\ g^{-1}$	m m^{-1}	g kg^{-1}	$mmol_c\ L^{-1}$		$mmol_c\ L^{-1}$	
Grey Clay	12.6	1.3	2.2	0.14	104	0.063	201	0.5	8.2	1.5	9.2
Heiden	7.4	0.9	1.7	0.15	208	0.072	224	1.5	8.2	1.5	9.3
Hoytville	14.6	1.8	9.0	0.13	94	0.037	200	3.5	6.1	3.5	7.5
Irving Clay	31.4	2.9	6.1	0.07	402	0.155	420	1.5	7.4	1.5	8.4
Pierre	11.2	1.1	2.2	0.06	110	0.048	134	1.5	6.7	2.5	8.5

† Fe_d = Fe extracted by DCB; Al_d = Al extracted by DCB; Fe_o = Fe extracted by oxalate; EC = electrical conductivity; SA = surface area; COLE = coefficient of linear extensibility; θ_g = gravimetric water content; CFC = critical flocculation concentration of electrolytes.
§ pH at flocculation.

Table 3. Initial infiltration rate (I_i), steady-state infiltration rate (I_s), infiltration decay coefficient (γ), coefficient of determination (r^2), total water loss, and total soil loss for studied soils with and without FBC bottom ash subjected to 110 mm h^{-1} rain for 90 min.

Soil	I_i†		I_s†		γ		r^2		Total water loss		Total soil loss	
	Control	FBC	Control	FBC	Control	FBC	Control	FBC	Control	FBC	Control	FBC
	mm h^{-1}								mm		g m^{-2}	
Grey Clay	108.0dB‡	164.6aA	5.8aB	25.0aA	0.153aA	0.063bB	0.966	0.978	96bA	57cB	1884bA	886bB
Heiden	212.3aA	147.6bB	4.4abB	22.2bA	0.051cA	0.025cB	0.959	0.965	84cA	49dB	455dA	118dB
Hoytville	166.0bA	54.4abA	1.8bB	7.0dA	0.035cA	0.030cA	0.996	0.956	78cA	70bB	639cA	418cB
Irving Clay	56.0eB	106.3cA	3.4abB	12.4cA	0.121bA	0.091aB	0.993	0.976	112aA	91aB	1998aA	1358aB
Pierre	127.6cA	134.6bA	5.6aB	26.8aA	0.043cA	0.026cB	0.954	0.989	85cA	42eB	220eA	77dB

† Values estimated by the infiltration model.
‡ Means followed by the same lowercase letter in a column or same uppercase letter in a row for a given property are not significantly different by the Newman-Keuls sequential range test at $\alpha = 0.05$.

smectitic (Irving Clay) and smectitic-kaolinitic (Grey Clay) soils, indicating that these soils have a surface less stable to raindrop impact. The FBC bottom ash decreased γ, possibly through the stabilization of aggregates and flocculation of clays. The Hortonian-type infiltration equation (Morin and Benyamini, 1977) properly fit to the observed infiltration data. The r^2 values ranged from 0.954 to 0.996. In all events, the infiltration rates decayed monotonically with the cumulative rainfall and eventually reached a steady state (Fig. 2). Since all soils were wetted prior to rainfall, the matric potential gradient was low, and the primary cause of infiltration reduction was due to swelling and surface sealing. This sealing was caused by the rupture of the soil surface aggregates by slaking and raindrop impact. Detached soil particles may illuviate and block pores, or stay at the surface, reducing the soil surface permeability.

The values of I_s (Table 3, Fig. 2) ranged from 1.8 to 5.8 mm h^{-1}. These rates are consistent with results obtained by Ritchie et al. (1972). The FBC bottom ash increased I_s by 3.6 to 5.0 fold. The effectiveness in

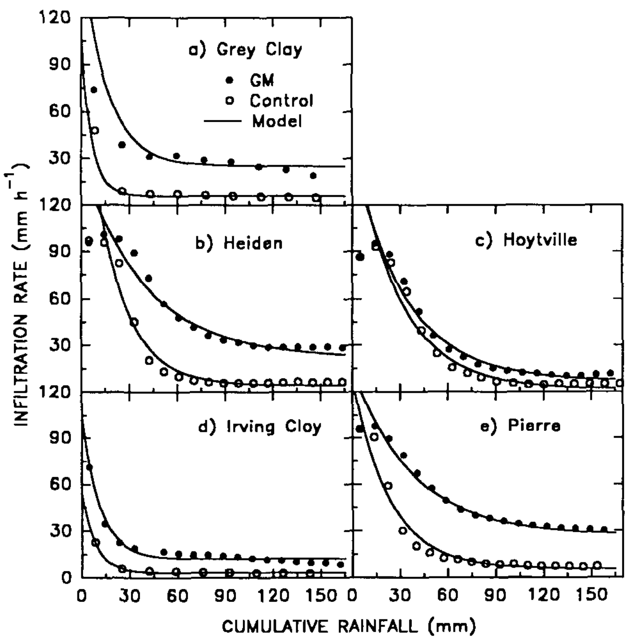

Fig. 2. Observed (data points) and estimated (curves) infiltration rates for (a) Grey Clay, (b) Heiden, (c) Hoytville, (d) Irving Clay, and (e) Pierre soils with and without FBC bottom ash subjected to 110 mm h^{-1} rain.

increasing I_s had the ranking: Heiden ≥ Pierre > Grey Clay ≥ Hoytville ≥ Irving Clay. This shows infiltration increased more with FBC bottom ash on smectitic soils, except when swelling (COLE, Table 3) was high. The illitic Hoytville and the highly smectitic Irving Clay established the lowest I_s for both treatments and had the smallest increase in infiltration with the FBC bottom ash. The values of I_s and γ were not related to clay dispersion. Borchardt (1989) mentioned that smectites in the surface of a soil may be responsible for the adhesive property that helps to prevent "sheet" erosion. However, estimation of soil erodibility on the basis of the Wischmeier nomograph, for instance, may be misleading in Vertisols (Loch, 1984), since high organic matter and aggregation in self-mulching Vertisols in the field may result in the estimation of low erodibility. But, Vertisols usually have aggregates with low saturated density (Loch, 1984) that are easily transported by the high volumes of runoff. In our experiment, surface depressions were formed through which water flowed preferentially, generating high shearing forces and, hence, high soil loss. This fact demonstrates a scale dependence of interrill and rill erosion since even on the small plots (45 cm long) used in this study, incipient rills could clearly be observed.

Sediment concentration (Fig. 3) at the beginning of the rain was high for the three soils with greatest aggregate stability (Heiden, Hoytville, and Pierre), due to splash of soil particles and aggregates, although very little runoff was observed. For these soils, the sediment concentration was greater for the FBC bottom ash than for the control at the beginning of the rainstorm, but the sediment loss rates were always greater for the control because of greater runoff. On the least stable soils (Grey Clay and Irving Clay), runoff started almost immediately after the rain onset, generating high sediment loss but also high runoff, thus having a dilution effect on the sediment concentration. It follows that a high sediment concentration does not necessarily translate into higher sediment loss rates.

The steady-state runoff was 70 mm h^{-1} for the Grey Clay, Heiden, and Pierre soils without FBC bottom ash, while the I_s values were also quite similar (Table 3). However, the sediment loss rate (Fig. 4) was much greater for the Grey Clay than for the other two soils. This suggests considerable differences in soil shear strength and erodibility for these soils.

The surface-applied FBC bottom ash was effective in

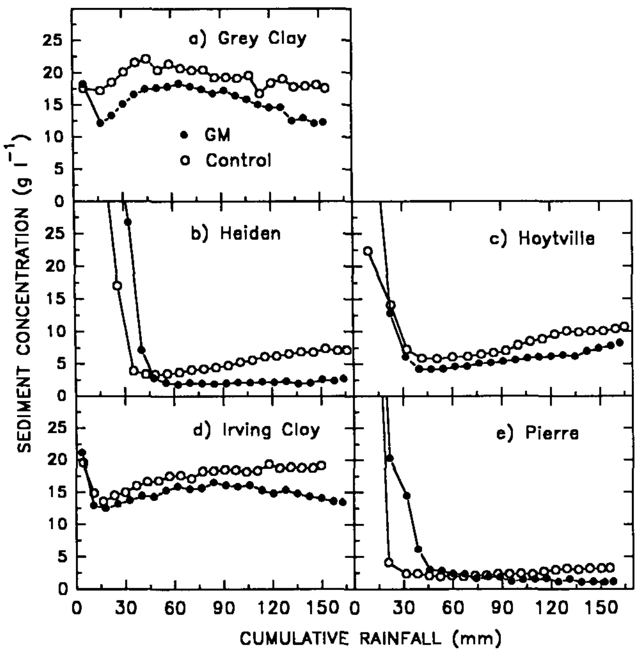

Fig. 3. Sediment concentrations for (a) Grey Clay, (b) Heiden, (c) Hoytville, (d) Irving Clay, and (e) Pierre soils with and without FBC bottom ash subjected to 110 mm h^{-1} rain.

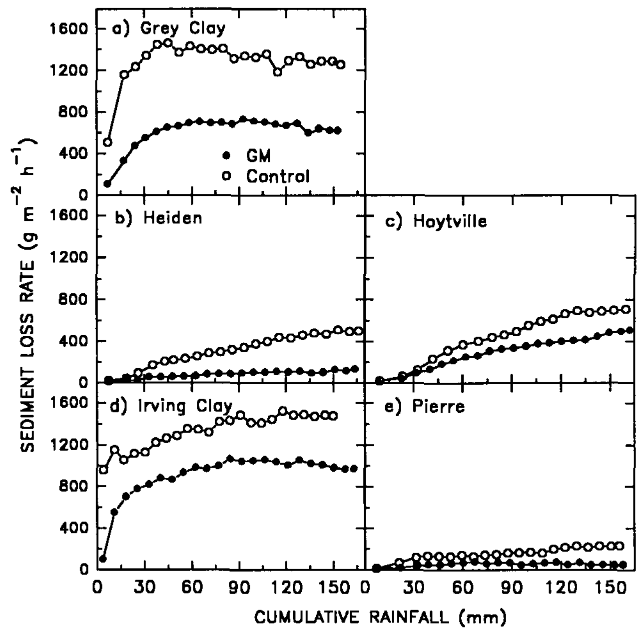

Fig. 4. Sediment loss rates for (a) Grey Clay, (b) Heiden, (c) Hoytville, (d) Irving Clay, and (e) Pierre soils with and without FBC bottom ash subjected to 110 mm h^{-1} rain.

controlling runoff and soil erosion. It reduced total water loss by 1.1- to 2.0-fold and total soil loss by 1.5- to 3.9-fold (Table 3). Interestingly, the ranking of soils (clay mineralogy and soil texture) in terms of FBC bottom ash effectiveness on increasing I_s, reducing runoff, and reducing soil loss was the same, i.e., smectite plus calcite (silty clay) > smectite (clay loam) > smectite–kaolinite (clay) > illite (clay) > smectite (clay). The FBC bottom ash considerably increased the MWD of eroded particles (individual particles and aggregates) in the runoff and decreased the percentage of particles <250 μm. The smectitic Irving Clay and the smectitic–kaolinitic Grey Clay maintained the lowest MWD and the highest percentage of <250-μm particles in the runoff at the end of the runs, consistent with their low aggregate stability measured by wet sieving. They also maintained the lowest EC in the runoff (0.250 and 0.100 dS m^{-1}, respectively), showing that considerable amounts of the FBC bottom ash had been dissolved, illuviated, or eroded away at the end of the 90-min rain. The presence of electrolytes in the runoff reduced swelling, enhanced flocculation and, possibly, sedimentation of soil clays, and reduced runoff, and overall erosion was low.

Total water loss for the control was in the following order: smectite (clay, very low MWD) > smectite–kaolinite (clay, low MWD) > smectite (clay loam, high MWD) > smectite plus calcite (silty clay, median MWD) > illite (clay, high MWD). With the FBC bottom-ash treatment, this order was slightly changed, namely the illitic soil had the second greatest water loss. Total soil loss for both the control and the FBC bottom-ash treatments showed the ranking: smectite (clay, very low MWD) > smectite–kaolinite (clay, low MWD) > illite (clay, high MWD) > smectite plus calcite (silty clay, median MWD) > smectite (clay loam, high MWD). Soils with a large MWD (Hoytville and Pierre) had the greatest times to runoff and lesser total runoff and erosion, but the MWD had much less effect in determining I_s.

Lebron and Suarez (1992) found no correlation between dispersion and aggregate stability for illitic and mixed mineralogy soils. They suggested that aggregate stability relates to the initial processes determining stability, but after disaggregation has occurred clay and colloid physicochemistry (flocculation characteristics) is probably the dominant process affecting stability. Stern et al. (1991) showed that soils which contained smectites, even in small amounts, were susceptible to sealing, sensitive to electrolyte changes in soil solution, and affected by phosphogypsum spread on the soil surface. Our data showed that, although all soils had low I_s and FBC bottom ash increased I_s and reduced water and soil losses, total water and soil losses were greatest for soil containing smectite with high CEC/clay (highly smectitic) and low aggregate stability. Our illitic soil maintained a very low I_s possibly due to its high flocculation value, but had intermediate water and soil losses, possibly because of its high aggregate stability.

CONCLUSIONS

Surface sealing and erosion were significantly reduced by the surface-applied FBC bottom ash on all studied soils, but with a lesser effectiveness on the illitic and highly smectitic soils. For infiltration, FBC bottom ash was most effective on the smectitic soil, except when swelling was high. The values of I_s for the control ranged from 1.8 to 5.8 mm h^{-1}, and were increased 3.6- to 5.0-fold with the FBC bottom ash. The increased electrolyte concentration reduced swelling and enhanced flocculation and, possibly, sedimentation of soil clays, thus decreasing sediment concentration in the runoff and runoff and sediment yield, and increasing the size of the sediment in the runoff. The CFC was greatest for the illitic soil, but was not related to clay dispersion. Neither of these two soil properties explained the total soil loss. The highly smectitic and smectitic–kaolinitic soils, with the lowest aggregate stability (MWD), were the most erodible and generated finer sediment in the runoff.

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