United States
Department of
Agriculture

**Agricultural
Research
Service**

ARS-74

August 1988

Manual for Applying Fluidized Bed Combustion Residue to Agricultural Lands

ABSTRACT

Stout, W.L., J.L. Hern, R.F. Korcak, and C.W. Carlson. 1988. Manual for Applying Fluidized Bed Combustion Residue to Agricultural Lands. U.S. Department of Agriculture, Agricultural Research Service, ARS-74, 15 pp.

Atmospheric fluidized bed combustion (AFBC) is a process that reduces sulfur emissions from coal-fired electric-generating plants. The residue from this process is a mixture of alkaline oxides, calcium sulfate, and coal ash constituent. Since 1976, USDA/ARS has investigated the potential agriculture use of this residue. The investigations comprised an extensive series of laboratory, greenhouse, field plot, and animal feeding experiments. The best and safest use of AFBC residue in agriculture was as a substitute for agricultural lime. This report contains guidelines for applying AFBC residue to agricultural lands.

KEYWORDS: Coal, gypsum, lime, reclamation, soil acidity, sulfur.

This research was conducted under Department of Energy Contracts Nos. DE-AI21-76-MC-10391 and DE-AI21-86-MC23160 and Tennessee Valley Authority Contract No. TV-67-131A.

CONTENTS

Copies of this publication may be purchased from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

ARS has no additional copies for free distribution.

MANUAL FOR APPLYING FLUIDIZED BED COMBUSTION RESIDUE TO AGRICULTURAL LANDS

W.L. Stout, J.L. Hern, R.F. Korcak, and C.W. Carlson

To conform to Environmental Protection Agency standards, coal-burning electric-generating plants must adopt effective methods to remove SO_2[1] from exhaust gases. One method is the atmospheric fluidized bed combustion (AFBC) process. In this process, crushed coal and a finely ground sorbent, usually limestone, are suspended or "fluidized" by jets of air. They are burned at a controlled velocity and optimum temperature. Sulfur in the coal reacts with Ca in the limestone to form gypsum, or $CaSO_4$. A part of the resulting residue is a dry granular mixture composed predominantly of CaO and $CaSO_4$, with small amounts of metal oxides.

AFBC residue contains alkaline oxides and plant nutrients that are useful in agriculture. It also has other elements that can be toxic to plants and animals if they enter the food chain in excessive amounts. To evaluate the potential benefits and hazards of AFBC residue to agriculture, the Agricultural Research Service (ARS) conducted research at several locations in the Eastern and Southeastern United States. This research was supported by the Department of Energy and the Tennessee Valley Authority National Fertilizer Development Center.

This report presents guidelines for the safe and efficient use of AFBC residue in agriculture based on ARS research. The AFBC residues used in this study were the spent bed materials from experimental bubbling bed combustors. However, the guidelines should also be applicable to similar AFBC residues. This report is intended as a manual for power plant managers, consultants, and Government agency personnel who utilize AFBC residues. It does not exempt AFBC residues from guidelines established by State and Federal regulatory agencies.

AGRICULTURAL CONSIDERATIONS

AFBC residue components important to agriculture are divided into four groups (table 1)—lime, essential plant nutrients, heavy metals, and phytotoxic elements (25). This division is not absolute because some of the components can be placed in more than one group depending on their relative and absolute amounts and their interactions in the soil system.

Lime, the first group in table 1, is mainly a mixture of CaO and MgO. If the residue is quenched after combustion, these compounds revert to the hydroxide form. They also revert to the hydroxide form when they combine with water in the soil.

Lime is expressed as the neutralizing potential of the residue compared with an equal amount of ground agricultural limestone, usually $CaCO_3$. The bulk of the AFBC residue research conducted by ARS included using the lime in the residue to increase low soil pH. Based on this research, the best agricultural use of AFBC residue is as a lime source for croplands (3, 5, 25, 26), orchards (6, 9-16, 27), pastures (23), and reclaimed surface mines (4-24).

Respectively, soil scientist, U.S. Regional Pasture Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture (ARS/USDA), University Park, PA 16802; research chemist, Appalachian Soil and Water Conservation Research Laboratory, ARS/USDA, Beckley, WV 25802-0867; soil scientist, Fruit Laboratory, ARS/USDA, Beltsville Agricultural Research Center (BARC), Beltsville, MD 20705; and retired, formerly assistant director, Soil Management Research, BARC, Beltsville, MD 20705.

[1]For meaning of chemical symbols, see Appendix III.

Table 1
Variations in some chemical constituents of 9 samples of atmospheric fluidized bed combustion (AFBC) residue and soils

Group	Component	AFBC residue[1] Average	AFBC residue[1] Range	Soils[2] Average	Soils[2] Usual range
		Percent of $CaCO_3$			
Lime	CaO and MgO	60	31-100		
		Micrograms per grams of dry material			
Essential plant nutrients	Ca	380,000	240,000-460,000		
	S	92,000	72,000-140,000	850	100-1,500
	Mg	7,100	5,000-12,000		
	K	2,500	500-8,000		
	P	430	380-500		400-3,000
	Fe	11,000	800-16,000	---	14,000-40,000
	Mn	485	210-685	850	200-3,000
	Mo	.19	.12-.28	2	.2-5
	B	110	95-170	10	2-100
Essential plant nutrients; Heavy metals	Cu	15	12-19	20	2-100
	Zn	55	29-105	50	10-300
Heavy metals	Ni	21	13-29	40	5-500
	Pb	3.2	1.5-7.5	10	2-200
	Cd	.5	---	.5	.01-.70
	Cr	15	9-23	200	5-1,000
Phytotoxic elements	Se	.29	.16-.58	---	.1-2
	Al	10,000	4,000-20,000	---	14,000-40,000

[1]From Stout, W.L., and others (25).
[2]From Baker, D.E., and L. Chesnin (2).

Essential plant nutrients (table 1) are those required for growth and reproduction of plants. The first five elements in this group (Ca, S, Mg, K, and P) are needed by plants in large amounts.

The large amounts of Ca in AFBC residues (table 1) occur not only as $Ca(OH)_2$ and CaO but also as $CaSO_4$, a compound commonly known as gypsum. Applying these compounds to acid soils has long been known to decrease soil acidity and promote root growth. This is particularly beneficial where crop production is limited by shallow rooting conditions.

Soils in the Eastern United States generally receive no direct S fertilization. In the past, sufficient S was applied to agricultural land as impurities in N and P fertilizers and through atmospheric fallout from fossil fuel combustion. In recent years, research in the Eastern United States has shown that if high crop yields are to be obtained, some crops require S fertilization. AFBC residues can be an effective source of this fertilizer (20). Although large amounts of S would be added to the soil with the land application of AFBC residues, these amounts should pose no threat to ground water quality (21, 22).

Magnesium, K, and P occur in lesser amounts than Ca or S. Magnesium and K likely appear as oxides, hydroxides, or sulfates in the residue. Phosphorus probably occurs as a form of calcium phosphate. Since these elements are regularly added to soil in the form of lime or fertilizer, their presence in AFBC residue is desirable.

The next six essential plant nutrients (Fe, Mn, Mo, B, Cu, and Zn) are required by the plant in minute amounts and are generally referred to as micronutrients. Because of the oxidizing conditions to which these elements are exposed during combustion, Fe, Mn, Cu, and Zn probably occur as oxides in the residue, and B and Mo as borates and molybdates. In the past, these elements have not been applied to agricultural land as extensively as the macronutrients. Native amounts of these elements and fertilizer impurities were relied on to supply sufficient amounts of micronutrients to crops. However, with more intensive cropping systems and purer, high analysis fertilizers, the need for micronutrient fertilization is becoming more apparent, and the presence of these nutrients in AFBC residues may be beneficial.

Although micronutrients are essential for plant growth, they can be toxic to plants or animals if they are excessive or disproportionate in the soil. The amounts of these elements in AFBC residues, with the exception of B, are within the range of these elements usually found in soils (table 1). No phytotoxic effects of micronutrients have been observed when AFBC residue was used as a lime source (25). However, the availability of micronutrients to plants depends not only on the amounts applied in AFBC residue but also on native amounts in the soil, the soil pH, interactions with other ions, the solubility of the compound containing the element, and the specific crop being grown. Therefore, their entrance into the food chain via AFBC residue application should be carefully monitored.

The amount of B in AFBC residue is higher than that found in soils. Generally B is not toxic in most agricultural soils unless supplied in excessive amounts of fertilizers (19). Some crops such as alfalfa require yearly applications of about 2 pounds per acre of B for maximum yields. Some sensitive crops have exhibited B toxicities and decreased yields when B was applied from 0.5 to 4.5 pounds per acre (19). Therefore, care should be taken when applying AFBC residues with high levels of B to sensitive crops such as cherry, peach, lupine, and kidney bean, especially when these crops are growing on sandy soils.

The next group is the heavy metals. Elements in this group probably occur as oxides. They are of concern, especially Cd, since they can cause serious metabolic problems in animals and humans when ingested in excessive amounts or when they accumulate in the food chain. Interest in heavy metals was stimulated by the increased use of sewage sludge on agricultural lands; thus, most of the work concerning heavy metals has pertained to using sewage sludge. Compared to sewage sludge, AFBC residues studied so far contain very low levels of heavy metals (25). Also, levels of heavy metals in AFBC residues are within ranges usually found in soils (table 1). In addition, the oxide form of heavy metals in AFBC residues renders them much less available to plants than the organic forms in sewage sludge. The accumulation of heavy metals by plants grown on AFBC residue-treated soils (25, 26) has not been shown to be a hazard to animals consuming these plants (7, 23). Nevertheless, loading of these metals on agricultural soils through AFBC residue application should not exceed loadings recommended for sewage sludge (table 2). Also, any enhancement of these metals in soils should be carefully monitored through appropriate soil tests.

Although Se can be toxic to plants, some species native to Se rich soils not only tolerate but may even require it (1). Although Se toxicities are common in the Great Plains and Rocky Mountain States, several areas in the United States such as the Pacific Northwest, Southeastern

Table 2
Maximum cumulative metal loadings on soils according to textural class[1]

Metal	Loamy sand, sandy loam	Fine sandy loam, very fine sandy loam, loam, silt loam,	Silt, clay loam, sandy clay loam, silty clay loam, sandy clay, silty clay, clay
	Pounds per acre		
Cd	2	3	4.5
Zn	50	150	300.0
Cu	25	75	150.0
Ni	10	30	60.0
Pb	100	300	600.0
Cr	100	300	600.0

[1]From Baker, D.E., and others (1).

Coastal Plain, and the Northcentral and Northeastern States, have Se levels in forages that are too low for grazing animals (17). Selenium in AFBC residues could be beneficial in these areas.

Levels of Al in AFBC residues are slightly less than those found in soils (table 1). Aluminum can be phytotoxic when it is solubilized at low pH, generally below pH 5.0. Since Al toxicity is easily corrected by liming, it is of minor concern in AFBC residues.

GUIDELINES FOR LAND APPLICATION

The best agricultural use of AFBC residue is as a lime source on cropland, pastures, or reclaimed surface mines. It is attractive to agriculture and the power industry because it attacks soil acidity, which is the major recurring soil fertility problem in humid regions, and it provides a means of using the maximum amount of AFBC residue that currently would be environmentally safe. A flow chart for applying AFBC residue to cropland is shown in figure 1 and an example of calculations is given in figure 2. For this example, soil data are taken from Appendix II and AFBC residue data from table 1. Soil texture is assumed to be silt loam and the crop is assumed to be alfalfa.

The first task is to determine the soil texture of the distribution area and the amount of lime required to raise the soil pH to the desired level for the crop to be grown (figs. 1 and 2, task 1). Information on soil texture can be obtained through the USDA Soil Conservation Service or county agricultural Extension offices. Lime requirement is best determined by using current soil tests provided by either State land grant university laboratories or private laboratories. Tests calibrated for local soil conditions should be used. Addresses of soil testing laboratories can be obtained from State agricultural Extension offices.

The first decision step is to determine whether lime is needed for the specific crop to be grown (fig. 1). In this example, 1.7 tons per acre of ground limestone (App. II) is needed to raise the soil pH to a desirable level for alfalfa (fig. 2, decision 1). If soil tests indicate that no lime is required, no AFBC residue should be applied.

Since the composition of AFBC residues is dependent on variables such as the composition of the coal and sorbent and the operating parameters of the combustion unit (8), the second task in using a specific AFBC residue is to determine its composition (fig. 1). This step is necessary to determine the level of residue components that can be useful in agriculture as well as of those that might have some adverse effects on the environment. Analytical methods developed by ARS for the elemental analyses of AFBC residues are detailed in Appendix I. Values obtained from these methods indicate the total amounts of constituents in a specific residue. Analyses for lime equivalency, heavy metals, and B will be critical in determining whether the tested batch of AFBC residue is acceptable for land application (fig. 2, task 2).

The second decision step (figs. 1 and 2) is to determine whether the lime equivalency of the AFBC residue is greater than 30 percent. Application of AFBC residues with lime equivalencies of less than 30 percent is not recommended. Research data used to develop this manual have been generated with residues having lime equivalencies of at least 30 percent, and extrapolation beyond the range of existing data is not recommended.

The third task is to determine the application rate of the AFBC residue (fig. 1). The application rate of acceptable AFBC residue during any one year should be controlled by the lime requirement of the soil, the lime content of the residue, and the heavy metal levels in the residue. This is done by dividing the lime requirement by the quantity of the carbonate equivalency in percent divided by 100 (fig. 2, task 3).

In this example, the AFBC residue application rate is 2.8 tons per acre. Application of AFBC residue above the calculated application rate is not recommended because of the risk of excessive levels of soil pH and soil salinity and the adverse changes in soil physical properties due to the cementitious properties of AFBC residue.

The fourth task is to determine the loading of heavy metals (fig. 1). This is done by multiplying the concentration of each heavy metal by the application rate (fig. 2, task 4).

The fifth task is to calculate the total heavy metal loadings for the distribution area (fig. 1). This is done by adding the previous heavy metal loadings to the current proposed heavy metal loadings (fig. 2, task 5). In the example, there was no previous heavy metal loading, so the total loading is equal to the current proposed loadings.

The third decision step is to determine whether the total loading of any of the heavy metals or the current proposed B loading is excessive (fig. 1). The decision on heavy metal loading is based on comparing the recommended loadings for heavy metals applied in sewage sludge (1). This is done by comparing the total loading with the recommended loading rates for sewage sludge (fig. 2, decision 3). In this example, heavy metal loadings were extremely low. The decision on B is determined on the sensitivity of the crop grown under local conditions to B application. In this example, B loading is below the amount of B that the grower would apply to the crop. Therefore, the grower may want to decrease the B applied in purchased fertilizer. Since the total heavy metal loadings and the current B loading were within limits, the decision in this example would be to apply this AFBC residue at the calculated application rate. If the calculated loading of any heavy metal or B is higher than the recommended loadings, do not apply the residue.

Task 1	Soil and crop information Soil type: Silt loam Crop: Alfalfa Lime requirement: 1.7 tons/acre
Decision 1	Lime is required for this crop. Proceed to next task.
Task 2	AFBC residue analyses (table 1)

Lime content	60% $CaCO_3$
Cd	0.05 ppm
Zn	55 ppm
Cu	15 ppm
Ni	21 ppm
Pb	3.2 ppm
Cr	15 ppm
B	110 ppm

Decision 2 — $CaCO_3$ is greater than 30 percent. Proceed to next step.

Task 3 — Calculate AFBC residue application rate.

Rate = Lime requirement/(lime content/100)
= 1.7 tons/acre/(60/100)
= 2.8 tons/acre

Task 4 — Calculate heavy metal and B loadings.

Loading = element content x rate x 0.002[1]

	Ppm		Tons/acre		Pounds/acre		
Cd	0.5	x	2.8	x	0.002	=	0.003
Zn	55	x	2.8	x	.002	=	.310
Cu	15	x	2.8	x	.002	=	.084
Ni	21	x	2.8	x	.002	=	.118
Pb	3.2	x	2.8	x	.002	=	.018
Cr	15	x	2.8	x	.002	=	.084
B	110	x	2.8	x	.002	=	.620

[1]0.002 is a conversion factor used when the concentration of the element is expressed in ppm, ug/g, or mg/kg.

Task 5 — Calculate total heavy metal loadings (pounds per acre); previous loading was 0.

	Current and total loading	Maximum loading[1]
Cd	0.003	4.5
Zn	.310	300
Cu	.084	150
Ni	.118	60
Pb	.018	600
Cr	.084	600

[1]Values for silt loam soil in table 2.

Decision 3 — Total cumulative heavy metal loadings below maximum and current B loading below 2 pounds per acre. Proceed with application.

Task 6 — Apply AFBC residue according to local cropping practices.

Task 7 — Monitor pH and heavy metals in the soil with appropriate soil tests.

Decision 4 — If there is no rapid increase in heavy metal above normal levels in the soil, go to decision 5; discontinue AFBC residue applications.

Decision 5 — If soil needs more lime, return to task 2; or go to task 7.

Figure 2
Example of calculations for applying AFBC residue to cropland.

The fifth decision step is to determine whether additional residue can be applied to the distribution area (figs. 1 and 2). If soil tests indicate no additional lime is needed, go to task 7 (figs. 1 and 2). If the soil requires more lime, return to task 2.

NONRECOMMENDED USES

Use of AFBC residue as a Ca or S supplement in animal diets has been reported (18). This use is not recommended because most likely the small amount of residue that could be used as a feed additive would not justify the work involved in the Food and Drug Administration approval process.

Research on disposal rates of AFBC residues on orchards has been reported (15). Disposal rates are defined as amounts in excess of those calculated from soil test recommendations. Applying AFBC residues to agricultural land at disposal rates is not recommended. The long-term and permanent effects of such high rates on the physical and chemical properties of soils and effect on ground water quality are not known.

CAUTIONS

AFBC residue is a highly caustic material that can severely damage unprotected skin, lungs, and eyes. When AFBC residues are exposed to water, an exothermic reaction will result. It should not be assumed that personnel who regularly spread agriculture lime are aware of the potential health hazards associated with spreading caustic AFBC residues. Proper safety precautions in compliance with OSHA and NIOSH standards must be observed.[2]

[2]OSHA = Occupational Safety and Health Administration; NIOSH = National Institute for Occupational and Safety Health.

In addition to the potential health hazard to humans, AFBC residues can be extremely corrosive to application equipment. Also, AFBC residues have similar cementitious properties and can form hard deposits. Therefore, equipment used to apply AFBC residues should be thoroughly washed with water to prevent costly equipment damage.

If it is necessary to store quantities of AFBC residues on site before spreading, care should be taken to protect the material from the weather. Exposure to precipitation can cause a hardened crust to form on the material or can contaminate surface runoff entering streams or ground water. Storage problems can best be eliminated by spreading AFBC residues as soon as they are delivered to the site.

The sale and use of AFBC residues as an agricultural lime are subject to State and Federal lime and environmental regulations.

LITERATURE CITED

1. Baker, D.E., D.R. Boulden, H.A. Elliot, and J.R. Miller. 1985. Criteria and recommendations for land application of sewage sludge in the Northeast. Pa. Agr. Expt. Sta. Bull. 851, 94 pp.

2. Baker, D.E., and Leon Chesnin. 1975. Chemical monitoring of soils for environmental quality and animal and human health. Adv. Agron. 27:305-374.

3. Bennett, O.L. 1983. Agricultural applications. Environmental aspects of AFBC. *In* Fennelly, P.L., and S.E. Tung, eds., Source book on fluidized bed combustion. Mass. Inst. Technol., Technol. Div., Bedford, MA.

4. Bennett, O.L. 1984. The use of domestic and industrial waste for reclamation of abandoned acid strip mine soils. Proc. Conf. on Reclamation of Abandoned Acid Spoils, Osage Beach, Missouri, Sept. 12-13, 1984, pp. 1-19.

5. Bennett, O.L., J.L. Hern, H.D. Perry, and others. 1985. Agricultural uses of atmospheric fluidized bed combustion residue (AFBCR) - a seven year study. Proc. 2d Ann. Pittsburgh Coal Conf., Sept. 16-20, 1985, pp. 558-577.

6. Edwards, J.H., A.W. White, Jr., and O.L. Bennett. 1985. Fluidized bed combustion residue as an alternative liming material and Ca source. Commun. Soil Sci. Plant Anal. 16(6):621-637.

7. Fashandi, E.F., R.L. Reid, W.L. Stout, and others. 1985. Effects of fluidized bed combustion residue on the composition and nutritional quality of food crops for hampsters and rats. Quality Plant Food Human Nutr. 35:359-374.

8. Fennelly, P.F. 1985. Fluidized bed combustion. Amer. Sci. 72:254-261.

9. Korcak, R.F. 1979. Fluidized bed material as a calcium source for apples. HortSci. 14:163-164.

10. Korcak, R.F. 1980. Effects of applied sewage sludge compost and fluidized bed material on apple seedling growth. Commun. Soil Sci. Plant Anal. 11:571-585.

11. Korcak, R.F. 1980. Fluidized bed material as a lime substitute and calcium source for apple seedlings. J. Environ. Quality 9:147-151.

12. Korcak, R.F. 1982. Effectiveness of fluidized bed material as a calcium source for apples. J. Amer. Soc. Hort. Sci. 107:1138-1142.

13. Korcak, R.F. 1984. Utilization of fluidized bed material as a calcium and sulfur source for apples. Commun. Soil Sci. Plant Anal. 15:879-891.

14. Korcak, R.F. 1985. Effect of coal combustion waste used as lime substitutes on nutrition of apples on three soils. Plant Soil 85:437-441.

15. Korcak, R.F. 1988. Fluidized bed material applied at disposal levels: Effect on an apple orchard. J. Environ. Quality 17(2). [In press.]

16. Korcak, R.F., J.J. Wrubel, Jr., and N.F. Childers. 1984. Peach orchard studies utilizing fluidized bed material. J. Plant Nutr. 7:1597-1604.

17. Kubota, Joe, and W.H. Allaway. 1972. Geographic distribution of trace element problems. <u>In</u> Micronutrients in agriculture, pp. 525-554. Soil Sci. Soc. Amer., Madison, WI.

18. Mitchell, D.M., J.D. May, and O.L. Bennett. 1983. Effect of fluidized bed combustion residue on performance and physiology of broilers. Poultry Sci. 62:2378-2382.

19. Murphy L.S., and L.M. Walsh. 1972. Correction of micronutrient deficiencies with fertilizers. <u>In</u> Micronutrients in agriculture, pp. 347-388. Soil Sci. Soc. Amer., Madison, WI.

20. Shaffer, J.A., G.A. Jung, and E.H. Quigley. 1984. Alfalfa (<u>Medicago sativa</u>) yield and quality responses to sulfur fertilization in Pennsylvania. Commun. Soil Sci. Plant Anal. 15(3):213-226.

21. Sidle, R.C., W.L. Stout, J.L. Hern, and O.L. Bennett. 1977. Leaching experiments on soil and mine spoil treated with fluidized bed combustion waste. Proc. 5th Internatl. Conf. on Fluidized Bed Combustion, Washington, DC, pp. 821-832.

22. Sidle, R.C., W.L. Stout, J.L. Hern, and O.L. Bennett. 1979. Movement of chemical constituents associated with fluidized bed combustion waste in acid soil and mine spoil columns. J. Environ. Quality 8(2):236-241.

23. Smedley, K.O., J.P. Fontenot, V.G. Allen, and others. 1985. Effects of fluidized bed combustion residue application to reclaimed land on yield and composition of forage and performance of grazing steers. Proc. Internatl. Grassland Symp. in Japan, Aug. 24-31, pp. 1055-1056.

24. Stout, W.L, H.A. Menser, O.L. Bennett, and W.M. Winant. 1982. Cover establishment on an acid mine soil using composted garbage mulch and fluidized bed combustion residue. Reclam. and Reveg. Res. 1:203-211.

25. Stout, W.L., H.A. Menser, J.L. Hern, and O.L. Bennett. 1979. Fluidized bed combustion waste in food production. In Solid waste research and development needs for emerging coal technologies, pp. 170-184. Amer. Soc. Civ. Engin./Power Res. Council--Elect. Power Res. Inst., San Diego, CA.

26. Stout, W.L., R.C. Sidle, J.L. Hern, and O.L. Bennett. 1979. Effects of fluidized bed combustion waste on the Ca, Mg, S, and Zn levels in red clover, tall fescue, oat, and buckwheat. Agron. J. 71(4):662-666.

27. Wrubel, J.J., Jr., R.F. Korcak, and Norman Childers. 1982. Orchard studies utilizing fluidized bed material. Commun. Soil Sci. Plant Anal. 13:1071-1080.

Sampling

Results of any technique can be seriously jeopardized if proper sampling criteria are not selected and implemented. Consideration of original AFBC residue lot size, its physical nature (size fractions), and accessibility affect the procedure adopted for obtaining representative samples. Sampling techniques for solid fertilizers may be employed as outlined in "Official Methods of Analysis of the Association of Official Analytical Chemists" (A.O.A.C., 2.001). If the material has been bagged, lay the bag horizontally and remove cores diagonally from end to end. From lots of more than 10 bags, take cores from at least 10 bags. When necessary to sample lots of less than 10 bags, take 10 cores but at least 1 from each bag. Bulk material or stockpiled sources can be sampled by drawing vertical cores or collecting samples as the material drops from the loading chute or belt (A.O.A.C., 2.001). Caution should be taken as to the caustic properties of this material, and proper safety procedures should be followed to avoid contact with and breathing of AFBC residue.

Samples should be delivered to the laboratory in sealed, clean glass or polyethylene containers and reduced in size using a sample splitter or riffle. Samples can be stored at room temperature for several months.

Grinding

Samples should be ground with a stainless steel or ceramic grinder. Adequate homogeneity can be achieved by reducing particle size fractions to 0.20 mm or less.

Assays

Calcium Carbonate Equivalency. To determine the lime content of AFBC residue, use a given amount to react with an excess quantity of HCl and then back-titrate with NaOH to determine its neutralizing potential with respect to $CaCO_3$. Units are expressed as $CaCO_3$ equivalency.

Procedure:

1. Weigh 1.00 g of dry AFBC residue (2 hours at 90°C) in a 125 mL Erlenmeyer flask. Add 10 mL of deionized H_2O and swirl. Let stand for 1 minute.

2. Slowly add 20 mL of 1 M HCl while stirring. Caution: Rapid addition of HCl may cause excessive heat and splashing. ADD HCl SLOWLY! Let stand for 15 minutes, stirring every 3 minutes.

3. Add 3 drops of phenolphthalein (1% percent phenolphthalein-methanol solution) and back-titrate to the end point with 1.0 M NaOH solution.

4. Record the milliliters of NaOH used and calculate the $CaCO_3$ equivalency (eq) as follows:

$$100 - \frac{(20 - \text{mL NaOH})}{0.2} = \%\ \text{calcium carbonate eq}$$

Macrocomponents (Al, Ca, Fe, Mg, and Na). Macrocomponents can be determined by atomic spectroscopy of acid digests of AFBC residue. Either flame atomic absorption-emission (AA) or inductively coupled plasma-atomic emission (ICP) can be used to adequately determine the levels of these components.

Procedure:

1. Place 1.00 g of dry AFBC residue in a 125 mL Erlenmeyer flask having a 24/40 ground glass joint.

2. Slowly and carefully add 5 mL of redistilled concentrated HNO_3. Heat for 30 minutes (do not boil).

3. Add 10 mL of redistilled concentrated HCl, connect the refluxing condenser, and reflux for 2 hours.

4. Quantitatively transfer the sample to a 50 mL volumetric flask using deionized H_2O and filter.

5. Dilute it appropriately with 1 M HNO_3 for spectroscopic technique of choice. A suitable ionization suppressor such as $LaCl_3$ will be necessary for AA determination of alkali metals. If ICP is employed with a capillary glass pneumatic nebulizer, adding a surfactant such as Triton-X (0.1 percent by volume) will improve the stability of the sample introduction system. Using a high-salt nebulization system will eliminate this need when employing ICP.

Metals (Cd, Cr, Cu, Mn, Ni, Pb, Sr, and Zn). Analysis of low level metals can be carried out on the digest prepared for macroelement evaluation prior to their being diluted. Depending on the final level of respective metals, determinations by flame AA or ICP techniques are normally suitable for these elements. However, if evaluation is needed at the subpart per million level, flameless AA techniques or electrochemical procedures such as differential pulse polarography may need to be employed.

Sulfur Content. If S content is of interest, combustion analysis techniques are adequate and very convenient for this determination. In this procedure a suitable combustion analyzer is used, such as the LECO model SC-132. Analysis is performed by rapid oxidation of the AFBC residue sample at approximately 1500°C to convert contained S components to gaseous SO_2. The combustion gases are purified and the level of SO_2 is determined as it passes through an infrared flow cell. Instrument responses are compared to previously burned sulfur standards and the results are directly reported as percent S. Sample requirements are minimal, requiring 100 to 200 mg of dry, ground AFBC residue per assay.

Boron Content. Boron levels can be estimated by evaluating the original acid extract by ICP. One must assume that the contribution from borosilicate glassware is consistent enough to allow for blank subtraction. In practice, the amount of B corrected for by outside contributors is small and normally less than 10 percent of the determined value.

References

Official Methods of Analysis of the Association of Official Analytical Chemists. Ed. 13. Assoc. Off. Anal. Chem., P.O. Box 540, Benjamin Franklin Station, Washington, DC 20044.

Hern, J.L., W.L. Stout, R.C. Sidle, and O.L. Bennett. 1977. Characterization of fluidized bed combustion waste composition and variability as they relate to disposal on agricultural lands. Proc. 5th Internatl. Conf. on FBC, v. II, Near-term implementation, Dec. 12-14, 1977, Washington, DC, pp. 833-839.

APPENDIX II. SAMPLE SOIL TEST REPORT

State University Soil Testing Laboratory
College Town, USA 10069

Test for: John Doe
Hill Side Farms
Beckley, WV 16865

Soil type: Dekalb stoney silt loam

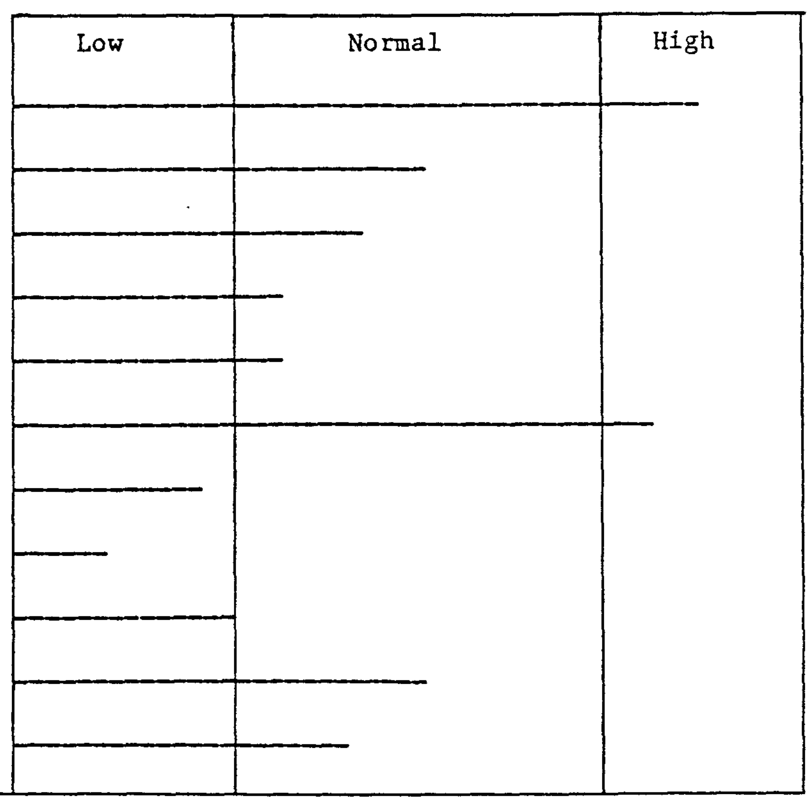
Field No.: S40

Crop: Alfalfa

Date	pH	Buffer pH	Lime required (tons/acre)	CEC (meq/100 g)
10/30/87	5.9	6.66	1.7	15.3

Test level

	Pounds/acre
Phosphorus	155
Potassium	620
Magnesium	728
Calcium	3,200
Manganese	81
Iron	226
Copper	4.0
Zinc	2.6
Lead	3.2
Nickel	7.0
Cadmium	.5



APPENDIX III. GLOSSARY

acre - unit of land area equal to 43,560 square feet.

cation - positively charged atom or group of atoms such as Ca^{2+}, Mg^{2+}, and NH_4^+.

CEC - abbreviation for cation exchange capacity, which is the sum total of exchangeable cations that a soil can adsorb, usually expressed in milliequivalents per 100 g of soil.

distribution area - land area where AFBC residue is applied to soil surface to raise soil pH.

hectare - unit of land area equal to 10,000 square meters.

ion - electrically charged atom or group of atoms.

meq - abbreviation for milliequivalent, which is 1 mg of hydrogen or amount of any other ion that will combine or replace it.

mg/kg - milligrams per kilogram.

phytotoxic - toxic to plants.

ppm - parts per million.

sinkhole - hole formed in carbonate rocks (for example, limestone, dolomite, and marble) by the action of water serving to conduct surface water to an underground water table.

soil texture - relative proportions of sand, silt, and clay in soil.

toxic substances - various chemicals that have a detrimental health effect on animals and humans if consumed in sufficient quantity. Some of these substances include trace metals, pesticides, chlorine-containing organic residues, and nitrogen compounds such as nitrate.

Chemical symbol	Chemical
Al	Aluminum
B	Boron
Ca	Calcium
$CaCO_3$	Calcium carbonate
CaO	Calcium oxide
$Ca(OH)_2$	Calcium hydroxide
$CaSO_4$	Calcium sulfate, gypsum
Cd	Cadmium
Cr	Chromium
Cu	Copper
Fe	Iron
HCl	Hydrochloric acid
HNO_3	Nitric acid
K	Potassium
$LaCl_3$	Lanthanum chloride
Mg	Magnesium
MgO	Magnesium oxide
Mn	Manganese
Mo	Molybdenum
N	Nitrogen
Na	Sodium
NaOH	Sodium hydroxide
Ni	Nickel
P	Phosphorus
Pb	Lead
S	Sulfur
Se	Selenium
SO_2	Sulfur dioxide
Sr	Strontium
Zn	Zinc