EFFECT OF APPLICATION OF FLUIDIZED BED COMBUSTION RESIDUE TO RECLAIMED MINE PASTURES ON FORAGE YIELD, COMPOSITION, ANIMAL PERFORMANCE AND MINERAL STATUS

by

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(ABSTRACT)

Reclaimed surface mined soils in Appalachia are typically infertile and must be amended for optimum vegetative growth. Fluidized bed combustion residue (FBCR), a by-product of coal-fired power plants, has high levels of Ca, S, Zn, Fe, and Al, and 50% of the neutralizing capacity of limestone. Three treatments were applied to three replicated .81 ha reclaimed mine pastures: control (no amendment), 6760 kg FBCR/ha, and 3380 kg limestone/ha. Based on forage availability, six steers were rotationally grazed on pastures receiving each treatment. Steers were weighed and blood samples collected at 14-d intervals and all animals were sacrificed for tissue sampling at the end of the 114-d trial. Amendment with FBCR or limestone increased soil pH ($P < .05$) above control levels. Forage yield and steer gain were not significantly affected by treatment. Forage samples collected during the trial indicated that FBCR and limestone amendments elevated forage ash, Ca, Mg, S, Cu and Ca:P ratio ($P < .05$). Cellulose and NDF were depressed in forage grab samples collected from FBCR- and limestone-amended pastures. The forage sampled the following spring was lower in hemicellulose, Zn, Mn and Ni; and higher in ash, Ca, S, the Ca: P ratio in the FBCR- and limestone-amended pastures. Mean serum mineral levels of steers were not affected by pasture treatment. The blood packed cell volume was higher in cattle grazing FBCR-amended pastures. Liver levels of Fe, Mn, Ni and Na were lower in cattle on pastures amended with FBCR or limestone. Bile levels of Mn were depressed in cattle grazing FBCR- and limestone-amended pastures. The level of Cu in the liver and serum was at deficiency levels and was not detectable in bile, regardless of treatment. Higher kidney levels of Ca, Mg and P were recorded for steers grazing FBCR- and limestone-amended pastures. Hair Zn was higher in cattle grazing the FBCR-and limestone-treated pastures. Rib Cr and long bone Cd levels were lower in animals grazing the limestone- and FBCR-treated pastures. This study suggests that FBCR amendment enhances nutrient quality of forage and mineral status of animals at least as well as limestone application to acidic reclaimed mine pastures.

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Chapter I
INTRODUCTION

Over 50% of the ever increasing amount of strip mined land has not been reclaimed. Without reclamation, mining these sites devastates the terrain and adds immensely to water pollution. Appalachian mine spoils are often high in Fe-pyrite and when left exposed will constantly acidify the surrounding area. Without proper management, the areas cannot be revegetated. An important step in reclamation of Appalachian mine spoils is combating soil acidity by liming.

Fluidized bed combustion residue (FBCR) is a by-product of specialized coal-fired power plants which use a suspended layer of limestone as a bed for combustion. This method effectively diminishes the amount of air pollutants associated with coal-generated power, and has been successful in minimizing acid rain derived from S pollutants. The resulting product generally has 50% of the buffering capacity of limestone and contains required plant nutrients, such as Ca, S, Mg and P. Acidic agricultural lands have been suggested as possible sites for utilizing FBCR. Greenhouse experiments have indicated that nutritional value and yield of forage grown on acidic soils are enhanced by liming with FBCR. Acid soils may be neutralized by FBCR, hence depressing acid-induced mineral toxicities. The mineral constituents of FBCR may also be helpful. However, since the FBCR results from complete coal combustion, it may also have highly undesirable levels of metals.

Application of FBCR to acidic minesoil may bring beneficial changes to promote forage growth. Alternatively, addition of a mineral-ladden material to a mineral-problematic area could induce further problems. Even if plants become established in such an environment, animals consuming the forage may not thrive. Animals would consume not only the plant accumulated minerals, but also the FBCR during and after application.

This study was designed to investigate the effects of repeated applications of FBCR to reclaimed minesoil on plant and animal responses, including yield, composition, in vitro dry matter digestibility and mineral content of forage and overall health, performance and tissue mineral composition of grazing steers.

CHAPTER II
REVIEW OF LITERATURE

Reclaimed Mine Land

Strip mining is presently the most common form of mining. Compared to deep mining, strip mining has many advantages (Bennett et al., 1976). Strip mining increases the output per man-day threefold, more of the coal may be recovered (90 vs. 50%), costs are reduced 35 to 45% and human safety is increased. By 1971, 3 million acres of land had been strip mined in the USA; however, only 50% had been reclaimed (Armiger et al., 1976). Of these 3 million acres, 952,000 are in the Appalachian region. Strip mining devastates the terrain and may increase water pollution by runoff and sedimentation, unless the land is properly reclaimed (Bennett et al., 1976).

Seams of coal are often less than 1.2 m thick, and deeply covered by overburden. Strip mining often mixes the top soil, subsoil and rock fragments into a heterogeneous mass (Armiger et al., 1976). The minesoil has virtually no soil structure, is devoid of organic matter, and cannot form water-stable aggregates. The water-holding capacity is low (4 to 10%) as the soil will form a crust, which is impermeable to water infiltration (Bennett et al., 1976). Appalachian minesoils may have high levels of Fe-pyrites, which degrade upon exposure to weathering conditions releasing SO_4 (Bennett et al., 1976; Vogel, 1981). The low pH may induce mineral toxicities or deficiencies (Vogel, 1981). The areas are typically high in available Fe, Mn, Cu, and SO_4 and deficient in N, P, K, Mg and Ca, (Armiger et al., 1976).

These factors make vegetation establishment or maintenance very difficult.

Vogel (1981) suggested that plant susceptibility to acidity is more directly linked to initial element concentration than to the actual pH of the soil. Gough (1984) did not find a consistent correlation between reclaimed minesoil metal content and forage metal content. When predicting metal availability for plant uptake, soil pH must be included in the predictive equation for an adequate correlation, thus, indicating the importance of pH on metal availability. Vogel (1981) suggested a pH greater than 5.5 may reduce cation toxicity normally associated with minesoils.

In a synopsis of years of research with mine reclamation, Armiger and coworkers (1976) reported essentially no establishment of vegetation in the Appalachian regions without limestone application. They also reported that phosphate rock, in which P is generally considered unavailable, reacts with the acid minesoil, thereby releasing P, Ca and Mg, thus alleviating some problems associated with minesoil revegetation.

Legumes are important in mine reclamation because of the N deficient nature of the minesoil, but are frequently difficult to get established. Symbiotic bacteria do not survive well in an environment deficient in organic matter (Armiger et al., 1976). Yamanaka and Holl (1984) suggest that when establishing grass-legume mixtures in mine reclamation, N fertilization should be at a minimum level, only sufficient to allow for seedling vigor. Also, they suggested that the seeding rate for legumes be greater than that for the companion grass.

New ideas on reclamation are constantly being evaluated. One which is being followed more closely is collecting the top soil separately and spreading it after the remaining strata has been replaced. Barker et al., (1977) found that within 2 yr of seeding, the number of viable forage plants was not affected by top soil replacement. However, top soil replacement was essential for plant vigor and production. Warm season plants did not survive regardless of top soil replacement. Alfalfa (Medicago sativa), birdsfoot trefoil (Lotus corniculatus) and sweet clover (Melitotus officialis) were the most productive legumes studied.

The species suggested for minesoil reclamation should be dependent on the goal of vegetation (Vogel, 1981). Tall fescue (Festuca arudinaceae) is the most commonly used grass species and is well adapted for most purposes. Weeping lovegrass (Eragrostis curvula) is an excellent nurse crop since it is an acid tolerant and vigorous forage which, upon non-management, dies in 2 to 4 yr. Birdsfoot trefoil will establish quickly and is tolerant of acid soils and high levels of Mn (Vogel, 1981).

Grazing reclaimed mine land at medium or light pressure has no significant effect on soil loss or runoff, when compared to ungrazed or grazed native pastures (Hoffman et al., 1983). Burning and grazing at high stocking rate (.24 ha/steer) did increase soil loss, runoff and soil loss/runoff in the reclaimed pastures. This would suggest that well managed grazing of reclaimed mine land should not have a detrimental environmental impact.

Fluidized Bed Combustion Residue

Fluidized bed combustion is a relatively new concept to energy production. Recently a limited number of coal-fired power plants have been converted to utilize the new technology (Keairns et al., 1976). This change allows for efficient combustion of any quality of coal and deminished S and other pollutants. The process involves suspending pulverized coal and limestone with pressurized air streams in a "fluidized bed" and combusting at 850 to 900 C.

The residue, FBCR, contains a large amount of $CaSO_4$ and CaO and potentially, $MgSO_4$ and MgO (Sidle et al., 1979). The CaO is quickly reduced to $Ca(OH)_2$ when in contact with air, especially at high humidity. The potential uses of FBCR are those normally associated with limestone including cement block, road beds, concrete structures (Minnick, 1980) and agricultural uses (Bennett et al., 1981). Application of the waste product to acidic agricultural lands seems to be one of the most potentially valuable uses of FBCR since it contains many useful minerals and retains 50% of the buffering capacity of limestone (Hern et al., 1978). Chemically, constituents in FBCR can be divided into four major classes: 1) essential plant nutrients (Ca, Mg, K, P, S, Fe, Mn, Mo, B, Cu and Zn); 2) toxic heavy metals (Ni, Pb, Cd, Cr, Al, Hg, and As); 3) possibly phytotoxic elements (B and Se); and 4) soil pH-amendment compounds (CaO, $Ca(OH)_2$) (Bennett et al., 1981).

Effect on Soil. The buffering capacity of FBCR is the obvious and primary benefit as a soil amendment. The $CaCO_3$ equivalency ranges between 31 and 100%, with a mean buffering capacity approaching 50% (Hern et al., 1978). Terman et al. (1978) suggested that the finely ground FBCR liming equivalency was 100% that of limestone. The coarse FBCR liming equivalent was found to be much lower; however, it may be considered a longer acting liming agent. Application of 20 g FBCR/kg of acidic minesoil (pH 3.3) increased the pH to 4.5 after 1 wk, and after 10 mo the minesoil pH was raised to 6.2. This shows the effectiveness of the FBCR as a liming agent. However, many other benefits may be discerned other than a direct result of increasing the pH of acidic soils.

In 1979, Sidle and coworkers published research pertaining to FBCR application to soil columns. Two different soils were utilized, acid silt loam soil (pH 4.6) and strip minesoil (pH 4.1). The FBCR was applied at two different rates to the minesoil, 1.7 and 4.2 g/kg, resulted in raising the pH to 4.6 and 6.1, respectively. Application rates of 2.4 and 8.4 g FBCR/kg of silt loam soil increased the soil pH to 5.0 and 6.0, respectively. The silt loam soil had much more buffering capacity than strip minesoil. A control of no amendment was also incorporated in both column types. Percolate samples from the FBCR minesoil columns taken during 14 leaching periods did not differ from control columns in any mineral analyzed (Sidle et al., 1979). The 60-cm columns were sectioned and analyzed for several minerals. Only Ca showed any appreciable downward migration and that was only to the 10- to 15-cm depth. The pH followed the same trend as the soil pH was only increased to the 10-cm level, the level to which the treatment was incorporated. Successive leachings linearly depressed the soil pH. After 14 leachings the pH of the minesoil receiving the low-FBCR treatment fell to 4.28. Percolate samples, from soil columns which were much higher in organic matter, had increased levels of Ca, Mg, Mn, and SO_4 in the highest FBCR treatment. No downward migration of B, Cd, Co, Cu, Cr, K, Na, Ni, Pb, or Zn was found. High-FBCR treatment increased pH in soil columns down to a depth of 15 cm. All soil columns, including the control columns, had percolate Fe levels above those for potable water. This study indicated that application of FBCR is most beneficial in soils which contain some organic matter. The authors suggested that the movement of Ca into the subsoil was probably related to the chelating ability of the organic matter in the silt-loam soil. Increased Ca movement resulting from added Ca may be attributed to mass displacement of inherent exchangeable soil Ca. The downward movement of Ca and Mg would be beneficial for marginal soils and may promote deeper root growth (Sidle et al., 1979). However, in regard to environmental impact and metal contamination of subsurface water, amendment with FBCR would be safer for minesoils with extremely limited organic matter.

Application of FBCR and composted garbage mulch to acidic minesoil increased soil pH and Ca (Stout et al., 1982). The high rate (23.3 t/ha) of FBCR reduced soil soluble Al to normal range. Extractable Mn was not influenced by treatment. Soil levels of Pb, Cu and Cd increased more following application of composted garbage than after FBCR application. Limestone was more effective in increasing soil pH than

FBCR, even though FBCR was applied at an equivalent liming capacity. This response was attributed to the granular nature of the FBCR.

In a chemical characterization of 23 samples of FBCR from one coal-fired power plant in Alexandria, VA, Hern et al. (1978) found a high degree of variability in all the mineral analyses performed. One objective of this study was to delineate potentially beneficial elements and possible environmental hazards attributed to Cd, Cr, Ni, and Pb with application of FBCR to agricultural lands. A total mineral analysis is shown in table 1. In general, micromineral levels were similar to those normally found in soil. Although the table indicates elevated levels of many minerals required by plants, plant availability was not measured.

Effect on Plants. Research has been conducted to study effect of FBCR on plant parameters in many situations including greenhouse, small field plot, orchards and recently, in a pasture setting. Results obtained throughout the past 8 yr have been variable; however, the overall trend indicates that effects of optimum FBCR application may be comparable to those of limestone application when FBCR is applied in equivalent liming capacities (Terman et al., 1978). However, "FBCR toxicity" may result if disposal rates are applied.

In preliminary research in which corn was the test crop, it was determined that the chelated S in FBCR was availabile to plants (Terman et al., 1978). In greenhouse trials, S-depleted soil was amended with varying rates of FBCR (coarse or finely ground), Na_2SO_4 or elemental S. It was ascertained from plant S levels that available S

Table 1. AVERAGE COMPOSITION OF FLUIDIZED BED COMBUSTION RESIDUE[1]

Item	Mean	Range
Al, %	1.4	.45 - 2.5
Ca, %	33.0	20 - 46
Fe, %	1.9	.08 - 4.2
Mg, %	.82	.5 - 1.2
Na, %	9.1	.14 - .19
S, %	9.1	6.5 - 14.1
$CaCO_3$ equivalency, %	60	31 - 100
Inert material, %	23	6 - 35
B, ppm	110	95 - 170
Cd, ppm	3	.5 - 8
Cr, ppm	42	9 - 120
Cu, ppm	33	12 - 175
F, ppm	41	11 - 79
K, ppm	420	210 - 530
Mn, ppm	369	160 - 685
Mo, ppm	.31	.12 - .61
Ni, ppm	40	13 - 78
P, ppm	430	380 - 500
Pb, ppm	29	1.5 - 85
Se, ppm	1.6	.2 - 4.9
Sr, ppm	404	160 - 745
Zn, ppm	96	29 - 170

[1] Dry basis. Adapted from Hern et al. (1978). Includes 23 samples collected from Alexandria, VA coal plant in a period from October, 1976 to June 1977.

in the finely ground FBCR was 95%, compared to 88% from Na_2SO_4-S, 82% from elemental S and 68% from coarse FBCR. In a similar study, the addition of S to the FBCR-treated soils had no effect on growth of corn and peanut leaf S, suggesting that FBCR adequately supplied the S requirement of both crops. Fertilization with FBCR significantly increased leaf Ca and depressed leaf B levels. Several rates of FBCR amendment were utilized in another experiment in which both peanuts and corn were grown. Application of FBCR at liming-equivalent rates had no effect on dry matter yield, compared to limestone. However, FBCR application at disposal rates (10 or 25% of soil weight) significantly depressed peanut growth. Leachate from the pots had a pH of 12.5 and 13.3, respectively, suggesting that the high alkalinity limited growth.

Research with potatoes indicated that FBCR had no effect on yield or elemental composition when compared with lime, MgO or $CaSO_4$ (Lundberg et al, 1979). The FBCR was applied at an equivalent rate with lime.

The Ca requirement is relatively high for apples. Corkspot disease, a common problem in apples, is often associated with Ca deficiency (Korcak, 1979). Experimental work with 12 yr old apple trees grown in sand containers indicated that FBCR was a good source of Ca (Korcak, 1979). Rates of FBCR application ranged from .5 to 16 times the required Ca level of 155 g/tree. Gypsum was applied at 0, 1, and 2 times (0, 1X, and 2X) the Ca requirement. Above the 1X FBCR treatment, the incidence of corkspot was reduced (48 vs 18%) compared to the no-additional-Ca (control). Leaf Ca was significantly elevated above the control value at the FBCR level of 4X and higher. Fruit flesh Ca did not vary with FBCR amendment; however, with both gypsum applications, it was elevated. Gypsum decreased the soil pH and increased leaf Mn, Cu and S. Application of FBCR increased soil pH and fruit flesh P, Mg and B.

In a continuation of the above study, over a 3 yr period, it was concluded that FBCR applied at twice the Ca requirement was the appropriate level as a Ca source for apples (Korcak et al., 1981). At this level, no detrimental effects of FBCR were noted.

Toxicity of FBCR was shown in work with apple seedlings in which FBCR was applied at three application rates (0, 12.5 and 25 t/ha) in a factorial design with three levels of composted sewage sludge (0, 25, 50 dry t/ha) (Korcak, 1980). Plant dry matter (DM) yield and leaf Ca levels were increased (quadratic response) with FBCR application. Sewage sludge and FBCR application decreased leaf Mn, a beneficial effect since the soil was approaching Mn-toxic levels. This effect was attributed to the decrease in acidity; however, Zn, Cu, and Ni levels in leaves were not affected by treatment.

Pecan seedlings were favorably affected by treatment with FBCR generated from dolomite (Bennett et al., 1981). There was a significant increase in growth and in Ca and Mg concentrations. Similar results were obtained with peach seedlings.

Greenhouse work has indicated that forage crops may benefit from

FBCR amendment as a lime, Mg, Ca and S source (Stout et al., 1979). Four plant species were grown at four liming levels (pH levels of 5.0, 5.5, 6.0, 6.5) using FBCR or $Ca(OH)_2$. Compared to plants treated with $Ca(OH)_2$, red clover which received FBCR treatment had elevated Ca levels. Buckwheat had higher DM yield with FBCR; however, Ca levels decreased linearly with increasing FBCR application rate. All herbage (red clover, buckwheat, tall fescue, and oats) responded to FBCR treatment with elevated S and Mg levels. However, with increases in pH by both treatments, forage Zn was depressed.

Research with vegetable crops has suggested that FBCR is not detrimental to metal-sensitive plants (Stout et al., 1989). No depression of growth or accumulation of heavy metals were noted in any species evaluated. Soybeans, which are considered Cd accumulators, had lower Cd levels when the soil was treated with FBCR than those grown on $Ca(OH)_2$-amended soils. However, oat grain had significantly elevated Cd levels in the FBCR treatment, although levels were within the safe range.

In small field plot research designed to provide feed for laboratory animals, soil amended with FBCR produced corn with significantly elevated levels of Na and Cu, oats with higher Cd levels and soybeans with lower Cd, when compared with limestone fertilization (Fashandi, 1981). Lettuce and carrots had higher Fe and Zn when grown on soil treated with FBCR.

Work with mine land reclamation has indicated that FBCR application is useful in establishment of vegetative cover on acid minesoil (Stout et al., 1982). This study utilized varying rates of liming material (either FBCR or limestone) with or without composted garbage. In general, the compost was more effective than lime in benefiting cover parameters. Even though 40% more FBCR was applied than limestone, forage Ca levels were elevated to a greater extent by limestone application. Composted garbage had a greater effect on Mg, micromineral and heavy metal levels than FBCR. However, some indication of high plant tissue Pb associated with high-FBCR treatment was shown, suggesting that Pb may be a problem with high-FBCR application rate.

Effect on Animals. Only a limited number of animal studies have been reported. Fashandi (1981) conducted research in which limestone- or FBCR-fertilized soybeans, corn and oat diets were fed to hamsters and rats. The control group of rats was fed commercial rat chow. Although there was no statistically significant difference in rat weight gain, hamsters fed a FBCR-treated soybean and corn diet gained more than hamsters fed an identical diet from fields fertilized with limestone. In another hamster trial in which a soybean and oat diet was fed, no significant difference was found in weight gain. Consumption of limestone-treated diets increased liver Cd in hamsters, compared to pretreatment values. Hamsters and rats fed diets in which the ingredients were obtained from plants fertilized with limestone exhibited increased whole-body Cu levels compared to animals fed diets from FBCR amended plants.

In studies with poultry, broilers fed FBCR as the dietary source of Ca had higher weight gains and a better feed-conversion ratio than those supplemented with limestone (O. L. Bennett, personal communication). The FBCR-treated birds also had increased liver lipid level and total liver weight.

Swine, fed diets composed of both vegetables from FBCR-fertilized gardens and boiled chickens which had been fed FBCR had lower daily gain in the first trial compared, to identical diets utilizing limestone (Whitsel et al., 1983). In the second trial daily gain tended to be lower (P = .06) with FBCR treatment. In the first trial, blood Pb and Hg, and urine As were higher for the FBCR treatment. However, no difference was found in trial 2 for blood or urine parameters.

A study of five types of S fertilization for alfalfa stands, including 1344 kg FBCR/ha, indicated significantly lowered DM digestibility in sheep fed the first hay cutting from FBCR-amended fields compared to those fertilized with other S sources (Reid et al., 1979). In some of the later cuttings, apparent absorption of Ca and P was decreased. No effect on blood mineral levels were discerned.

Calcium

Soils and Plants. Calcium makes up 3.6% of the earth's crust and is normally present in plants at higher concentrations than most other plant nutrients (Kirby, 1979). Rarely is Ca deficient in soils; although, highly unusual, exceptions such as soils derived from Mg-rich serpentine rocks or highly leached and acidic Al-saturated soils do occur (Bohn et al., 1979). Calcium is indispensable to productive soils as its role is three-fold: plant nutrient, acid neutralizer and floculator (McLean, 1975). Because of the normally high level of Ca in soils, accounting for 65 to 84% of the total cation exchange capacity, plant Ca uptake is passive and primarily follows water (Kirby, 1979). Calcium may be leached from porous soil. However, work with minesoil suggests Ca is relatively immobile in low-organic matter soils (Sidle et al., 1979), which may indicate application of Ca as limestone may have an extremely long term residual effect in some soils.

Research with Ca amendment to soil cannot easily be distinguished from that of liming. Calcium in buffered and non-buffered forms can be used to combat problems associated with soil acidity (Kirby, 1979). Lime increases soil pH, thereby decreasing Al and Mn solubility, and provides Ca to the soil. High levels of Ca in soils are desirable to counteract potentially troublesome exchangeable cations (Al and divalent metal cations). Part of the Al toxicity symptoms may be linked to Al replacing Ca at exchange sites on the root cell wall (Kirby, 1979). The actual plant Ca requirement, as determined in nutrient culture work, is extremely low as long as other divalent cations are maintained at a low concentration. Wallace (1979) considers the primary role of Ca is to protect plants against trace element toxicity.

Calcium is important as a competitor in chelation and transport of trace elements in plants; however, the addition of Ca may not only alleviate potential micronutrient toxicity, but may induce deficiencies (Brown, 1979). The effect of Ca depends not only on the level of the micronutrient in the soil, but is also dependent on the soil and the plant genotype. Brown (1979) concluded that liming had variable effects on soybeans, alfalfa and cotton grown on acid soil. Liming alleviated Mn toxicity in soybeans and alfalfa, induced B deficiency in alfalfa and induced B and Zn deficiency in cotton. Therefore, before a liming rate is recommended, knowledge of the nutrient requiremnets of the crop is critical.

White (1970) noted that liming drastically reduced soluble soil Mn and legume tissue Mn. In the greenhouse experiment Mn was at toxic levels (500 to 1000 ppm) in the control pots. Haynes and Ludecke (1981) have shown that lime decreases exchangeable Al and extractable Fe and Mn in acid soils, and that plant tissue Mn decreases linearly with increasing rates of lime application. In another study (Heylar and Anderson, 1974), lime application decreased exchangeable Al and extractable Mn, had no effect on Mg, K, and Na, and increased Ca in acid soils. Liming depressed tissue Al and Mn, had no effect on P or Mg, and increased Ca in the pasture forages. Work with crownvetch indicated lime decreased plant tissue levels of P, K, Mn, Zn, B, Na and Cu (Bennett and Mathias, 1973).

Wallace (1979) induced Ca deficiency in nutrient culture by adding excessive levels of Mo, Vn, Ag or Cd. The bush beans had depressed root, shoot and leaf Ca content. Fertilizing pots with 135 mg Al/kg soil, decreased Ca levels ($P < .05$) in annual ryegrass (Terrill, 1984).

Scaife and Clarkson (1978) report that not all apparent Ca deficiencies are related to Ca-deficient soil or mineral imbalances. Similar responses may be related to periods of environmental stress such as flooding or soil compaction. These stresses provide an anaerobic environment and temporary reduction of the distal undifferentiated region of the root. This area of the root is primarily responsible for Ca uptake and is most susceptible to physical and anaerobic stress.

The Ca requirement for legumes is generally thought to be greater than for grasses as Ca is in higher concentrations in legumes than in grasses. The increased Ca requirement may also be due to the Ca requirement for proper nodulation (Miller and Sirois, 1983). Alfalfa grown on Ca-deficient soil was retarded in growth and nodulation; moreover, subsequent Ca fertilization did not completely restore growth and nitrogenase activity. The authors suggested that a Ca:Mg ratio of 2 was required for proper nitrogenase activity. Rhizobia have a high requirement for Mg for ATP formation, and the Mg concentration must be high enough to compete with Ca; however, adequate Ca is needed for respiration.

Gross and Jung (1981) designed an experiment to study the effects of season, soil pH, temperature and $MgSO_4$ fertilization on a large number of cool season forages on plant Ca and P availability. Species of grasses and legumes reacted differently to most of the variables. Fertilization with 672 kg Mg/ha decreased Ca levels in legumes ($P < .05$), but had no significant effect on Ca:P ratios, due to high variability between species. Forage P levels were not affected by fertilization. Season had a large effect on forage mineral content; Ca was low and P was high in early spring growth. Red top was found to be the best grass for Ca accumulation and Kentucky bluegrass was the poorest Ca acumulator. Among legumes crownvetch accumulated the most Ca; whereas, birdsfoot trefoil and vernal alfalfa accumulated the lowest levels of Ca. They suggested forage species, in respect to mineral content, was an important consideration in designing year-round grazing systems.

Animals. Ninety-nine percent of the Ca in the animal body is found in the bones and teeth (NRC, 1984). The other 1% is vitally important for proper bodily functions which include nerve transmission, muscle contraction, blood clotting, enzyme regulation, milk secretion and hormonal balance. The Ca level in the blood is highly regulated and is constant at 9 to 12 mg/dl except in an extremely deficient state.

The Ca requirement for a 275 kg growing steer is 21 g/d (NRC, 1984) or about .18% of the DM consumed. For optimum growth a 2:1 Ca:P ratio is suggested; however, several authors (Wise et al., 1963; Rickets et al., 1970 and Beeson and Perry, 1975) have indicated that the actual level of Ca and P and the feed content of vitamin D to be more important than the Ca:P ratio. These authors indicate that ruminants will tolerate a Ca:P ratio in the range of 1:1 to 7:1 without a detriment to performance. A very low ratio of Ca:P (less than 1) depressed daily gain and feed to gain ratio (Wise et al., 1963).

Very high levels of Ca in ruminant diets (4.4%) have caused losses in protein and energy digestibility, hence production losses (Ammerman, et al., 1963). Although lime may contain impurities of Mn, Zn, Co, Cu, B, and Mo, liming generally decreases forage levels of B, Co, Mn, Ni, Cu, and Zn (Reid and Jung, 1974). A study by Fontenot and coworkers (1964) suggested that the feed-efficiency depression associated with feeding high levels of Ca may be alleviated by Zn supplementation.

Terrill (1984) found that flooding and Al fertilization decreased forage Ca levels. This depressed intake of Ca, however, did not affect the apparent absorption of Ca by the meadow vole. In sheep, ruminal infusion of Al citrate, sulfate or chloride resulted in an increased urinary excretion of Ca, but had no effect on apparent absorption of Ca (Allen and Fontenot, 1984). High Al levels in the diet have a pronounced effect on the availability of P (Valdivia et al., 1982 and Allen, 1984) which will indirectly affect Ca status.

Brink and coworkers (1984) conducted five experiments with a high corn diet supplemented with two different levels of limestone. Steer performance was significantly affected by limestone in only one of the experiments. They concluded that addition of limestone to diets does not significantly improve feed to gain ratio, even though there was an indication of increased starch digestion. Huntington's (1983) study was inconclusive as to the effect of supplemental Ca (as limestone) on weight gain. He did, however, suggest that a Ca level higher than .3% was required when feeding a high concentrate diet, as indicated by elevation in blood pH and HCO_3^-. The Ca status was not affected by treatment. A recent study by Brink and Steele (1985) suggested that the effect of limestone supplementation of high concentrate diets on starch digestion by steers was due to the buffering capacity of limestone, not the calcium levels, since diets were equivalent in Ca content. Limestone supplementation significantly altered the post-ruminal digestion of starch, in comparison to the non-buffered diet. Even though the starch component was over 50% of the diet and total tract starch digestion was significantly increased ($P < .05$), total organic matter digestion was not significantly affected. They suggested that altered starch digestion was due to minute changes in the pH of duodenum contents.

Calcium fertilzation may increase digestibility and voluntary intake in sheep due to structural change in grass. Rees and Minson (1976) found that fertilizing Pangola grass with 760 kg Ca/ha increased dry matter digestibility, which appeared to be due to elevated hemicellulose digestibility. They ruled out that the elevated Ca content of the forage was responsible for the increase since a companion treatment of the control forage plus supplemental Ca was used. They also noted a depression ($P < .05$) in the ADF fraction and an increase in total ash and Ca level in the Ca fertilized grass .

<u>Sulfur</u>

<u>Soils and Plants</u>. In the past 20 yr new interest has been shown concerning S in agriculture. Prior to that time, S was added to the environment in sufficient quantities from impurities in fertilizers, fungicides, insecticides and air pollution from use of high-S fuels (Reid and Jung, 1974) such that S fertilization was not necessary.

Recently, researchers have reported positive effects from S fertilization in some regions (Jones et al., 1982; Shock et al., 1983; Barney et al., 1984).

Sulfate-S is soluble and may be easily leached from soils. Sulfate is less likely to be leached from acidic soils, than from soils with high cation levels (Tisdale and Nelson, 1975). Williams (1975) suggested that SO_4 is held in soils which contain high levels of Al, Fe-oxides and clay. These parameters are most common to subsoils. Soil adsorption of SO_4 is negligible above a pH of 6.5 (Williams, 1975).

In a study of productive soils in South Carolina, Martin and Mutters (1984) found the highest S levels in acidic and clayey soils. An increase of 1 pH unit decreased the SO_4-S by 23 ppm in the A horizon of Piedmont soils and by 117 ppm in the B horizon. Research with these soils in greenhouse studies showed that S application doubled root length in grasses grown in unlimed soil and that the root S levels were .41%. In limed and S-fertilized soils root S content was .16%.

Because of SO_4 leaching, shallow-rooted plants are more susceptible to S deficiency (Reid and Jung, 1974). Legumes have a higher requirement for S than grasses. In a 2-yr study (Shock et al., 1983) Na_2SO_4 fertilization caused a botanical shift to increased subclover levels. Sulfate fertilization did not affect N uptake in grasses; however, legume N_2 fixation was increased by 60% and DM yield of grasses and legumes increased. Godbey (1985) found that S fertilization of acid soils had no effect on legume or grass seedling vigor. Red clover yield, however, was increased with application of 60 kg S/ha. Barney et al. (1984) concluded that increased soil pH depressed alfalfa S accumulation, but had no effect on orchardgrass or tall fescue S levels. Tall fescue accumulates more S than orchardgrass when they are grown under identical conditions. Also, the ratio of shoot S:root S is up to threefold higher in tall fescue than in orchardgrass or alfalfa.

Animals. The S requirement for cattle is .1% with a N:S ratio of appoximately 10 (NRC, 1984). The proper N:S ratio is important for optimal microbial activity in the rumen, which affects animal production. As the NPN content of the diet increases, the S requirement is raised so that synthesis of amino acids, proteins and vitamins is not limited. Sulfur is also required for structural and metabolic functions in the animal; therefore, S is present in every tissue (NRC, 1984). The overall body concentration is generally .15%. Bodily functions include protein synthesis and metabolism, fat and carbohydrate metabolism, blood clotting, hormone regulation, and cellular acid-base balance (NRC, 1984). The S requirement is elevated in sheep due to the high level of cysteine needed for wool production (NRC, 1973).

The maximum tolerable level for S in cattle is .4% of the diet (NRC, 1980). Elemental S is generally nontoxic; however, hydrogen sulfide is extremely toxic and is likely the cause of toxicity symptoms. Sulfur toxicity is characterized by restlessness, diarrhea, dyspnea, peritoneal effussion and darkened kidneys. Elevated dietary S increases the Cu requirement.

In vivo and in vitro digestibility experiments suggest that even though tall fescue accumulates more S than some other grasses, the S may be less available for microbial fermentation in the rumen (Spears et al., 1976). Sulfur fertilization increased in vitro cellulose digestibility of tall fescue, but had no effect on orchardgrass. Greenhouse and field experiments with tall fescue (Kentucky 31 and AF-4) and phalaris indicated that inorganic S levels decreased with N fertilization; however, these levels increased with S fertilization (Burmester et al., 1981). Sulfur levels of greenhouse grown plants were at levels considered toxic to animals (.4%), probably due to the retention of S in the rooting zone. Sulfur fertilization increased the yield of AF-4 tall fescue and decreased the N:S ratio to approximately 11.

Ryegrass and subclover grown on S-deficient soils had dramatic increases in yield with S fertilization (Jones et al., 1982). In vitro dry matter digestibility of subclover was not influenced by S fertilization; however, digestibility of ryegrass increased from 58% to 68%. The N:S ratio ranged from 8 to 13 in subclover and 6 to 13 in ryegrass. The average daily gain of lambs fed subclover fertilized with 90 kg S/ha increased by 50%, whereas, the lambs fed S fertilized ryegrass increased by 300%. This study poignantly shows the dramatic results S fertilization may have in S-deficient areas.

Buttrey (1985) reported increased N retention when lambs were fed S-fertilized corn silage. Even with S fertilization the N:S ratio was 33:1, far greater than what is considered optimal for animal performance.

Magnesium sulfate fertilization increased dietary SO_4 level by 300 ppm and increased availability of S and Mg; however, organic matter digestibility was depressed (Reid, et al., 1984). Rees and coworkers (1974) found that when pangola grass was fertilized with S or diets were supplemented with S, DM intake and digestibility in sheep were elevated.

Sulfur fertilization increased forage intake of Digitaria pentzii with no apparent effect on plant anatomy (Akin and Hogan, 1983). In vitro and in vivo incubation with rumen fluid showed that S fertilization of this highly fibrous C_4 grass increased digestion by rumen microbes. Other forages incubated with rumen fluid from sheep fed S-fertilized Digitaria pentzii also showed an elevation in in vitro DM digestibility. They suggested the observed differences in forage digestion were due to changes of the rumen microbial population.

<u>Iron</u>

<u>Soils and Plants</u>. Iron is more abundant in the earth's crust than the macronutrients (NRC, 1980). Iron exists in soils as Fe-oxides, Fe-hydroxides and as Fe-chelates in soils with a high organic matter content (Kabata-Pendias and Pendias, 1984). Iron in the divalent state (ferrous) is the more soluble form; therefore, it is more available to

the plant. Soil acidity and flooding increase Fe solubility many fold (Bohn et al., 1979). Water-logged soils have low oxygen, nitrate and sulfate levels; therefore, Fe and Mn are used as electron acceptors and may elevate soluble Fe to phytotoxic levels (Bohn et al., 1979).

Iron is required for plant cellular respiration and photosynthesis. Its roles include chloroplast function, electron transfer, chlorophyll formation, and nucleic acid metabolism (Kabata-Pendias and Pendias, 1984). Legumes typically have higher concentrations of Fe than grasses; however, Fe content is extremely dependent on environment.

Forage Fe content is generally 100 to 500 ppm (NRC, 1984). Although plant Fe toxicity is uncommon, it has been observed in acidic or flooded areas in tropical and arid regions (Kabata-Pendias and Pendias, 1984). Tap rooted plants are more susceptible to Fe toxicity than fibrous rooted plants. Fortunately, toxic levels for plants are well below toxic limits for animals (NRC, 1980).

Iron deficiency is not usually a problem due to absolute levels, but more likely a problem of availability. Calcareous and alkaline soils often induce Fe-deficiency chlorosis in plants (Kabata-Pendias and Pendias, 1984). High levels of other metals (Mo, Cu, Zn and Mn) may also induce Fe deficiencies (Mortvedt et al., 1972). Erosion may decrease Fe availability by loss of organic matter which decreases the formation of Fe-chelates. Recent research (Agarwal and Mehrotra, 1984) suggests that Fe and Mg may be mutually antagonistic for growth and metabolism. Their work with nutrient solutions indicated that regardless of Fe and Mg levels, the optimum ratio of Fe:Mg was .12 At elevated levels of Mg, radishes exhibited visual and enzymatic symptoms of Fe deficiency. Magnesium-deficiency symptoms were noticeable at high Fe levels. Elevated Fe or Mg resulted in depressed root and top Mn.

Manure was found to be more effective than conventional fertilization for amelioration of Fe deficiency in sorghum grown on calcareous soils (Thomas and Mathers, 1979). The conventional fertilizers included ferrous sulfate, ammonium nitrate, diammonium phosphate and potassium chloride. This study indicated the importance of organic matter for increasing Fe availability by formation of Fe-chelates. Manure application had at least a 3 yr residual effect.

Animals. Iron is necessary for every cell within an animal for O_2 transport and cellular respiration (NRC, 1984). Iron is conserved by the body. Excess Fe is stored in the spleen and liver. The Fe requirement is 100 ppm for calves and 50 ppm for cattle; however, dietary levels of Cu, Zn, Mo and Mn may alter the Fe requirement. Iron-deficiency symptoms include microcytic hypochromic anemia (reduction in hemoglobin and packed cell volumes), depression in transferrin saturation, atrophy of tongue papillae and decreased appetite. Iron toxicity symptoms include reduced feed intake, depressed average daily gain, metabolic acidosis and increased homosiderin of reticulosa-endothelial cells of liver, kidney and spleen (NRC, 1980). Toxic levels of Fe are 1000 to 2500 ppm.

Supplementation of lamb diets with 760 ppm Fe resulted in reduced feed intake and average daily gain (Rosa et al., 1982). Supplementary

Fe increased blood hemoglobin and packed cell volume and elevated Fe levels in the liver, kidney, spleen and muscle and decreased kidney Zn and spleen Ca. High levels of dietary P decreased liver Fe, probably due to Fe-P binding in the gut. High dietary Al levels increased liver Fe and decreased bone ash. These effects were related to soil ingestion. Standish et al. (1969) found many similar effects of Fe supplementation. Standish and Ammerman (1971) found supplementation of 1,600 ppm Fe depressed plasma Cu in cattle; whereas, Rosa et al. (1982) found elevated serum P levels with Fe supplementation.

CHAPTER III

APPLICATION OF FLUIDIZED BED COMBUSTION RESIDUE ON RECLAIMED SURFACE MINED PASTURES: I. FORAGE YIELD AND COMPOSITION AND ANIMAL PERFORMANCE

ABSTRACT

Fluidized bed combustion residue (FBCR), a by product of coal-fired power plants, contains high levels of Ca, S, Zn, Fe and Al and has approximately 50% of the neutralizing capacity of limestone. Three treatments were applied to three replicated .81 ha reclaimed mine pastures: control (no amendment), FBCR (6760 kg/ha) and dolomitic limestone (3380 kg/ha). Six yearling steers per treatment were rotationally grazed on three pastures which received each treatment. At the start of each grazing period, forage samples were obtained from one esophageally-cannulated steer/treatment twice daily for 2 d. Treatment had no effect on forage yield or cattle gain. Amendment of the pastures with FBCR or limestone increased soil pH ($P < .05$), compared to that of control pastures. Plant cell wall constituents were lower in FBCR- and limestone-treated pasture grab samples during the grazing trial and in the following spring growth. During the grazing trial, the esophageally collected samples had higher hemicellulose content ($P < .05$) in the FBCR- and limestone-amended pastures, compared to control pastures. In vitro dry matter digestibility was not altered by treatment. Forage grab samples taken prior to each grazing period from FBCR- and limestone-amended pastures had higher levels of Ca, Mg, S, and Cu, and a higher Ca:P ratio ($P < .05$). Treatment with FBCR increased forage S levels and lowered forage Mg ($P < .05$), compared to limestone amendment. Esophageally collected samples followed the same pattern in macromineral levels as grab samples. Application of FBCR and limestone increased forage ash, Ca, S, and Ca:P ratio and decreased Zn, Mn and Ni levels ($P < .05$) in the following year's early spring growth, compared to the control pastures. Amendment with FBCR increased forage S, Ca, Pb, and Ca:P ratio ($P < .05$), compared to limestone application in these May, 1984 samples. Limestone application increased forage Mg levels ($P < .05$) in these samples. Overall, FBCR amendment levels caused no deleterious effects on forage yield or composition or animal performance. Moreover, nutrient quality of the forage was elevated above limestone amendment levels, suggesting that a good alternative site for disposal of the FBCR would be reclaimed surface mined pastures.

(Key words: Reclaimed Mine Pastures, Fluidized Bed Combustion Residue, Forage Minerals, Forage Utilization, Grazing Cattle, Performance).

INTRODUCTION

Reclaimed surface mined land is potentially valuable as pasture land in the Appalachian region. Unfortunately, these surface minesoils have many inherent problems which cause them to be infertile (Armiger et al., 1976). Problems typically include acidity and high levels of Fe, Al, Mn and Cu (Vogel, 1981). Essentially no vegetative establishment was achieved on reclaimed mine land without limestone application (Armiger et al, 1976). Fluidized bed combustion residue is the waste product resulting from addition of limestone to coal to remove potential environmental contaminants during combustion (Keairns et al., 1976). The granular waste product has approximately 50% of the neutralizing capacity of limestone, is high in Ca, S, Fe, Al, and may contain heavy metals (Hern et al, 1978). The actual mineral make-up of FBCR is dependent of the quality of the coal burned and the type of limestone used.

Controlled greenhouse experiments indicated that yield and nutritive value of forages were enhanced by FBCR application (Stout et al., 1979). At high disposal rates (10 to 25% of soil weight) in greenhouse studies plant growth was depressed (Terman et al., 1978). The amendment of mineral-problematic soils with mineral-ladden FBCR may produce mineral imbalances, hence, decrease productivity. Recent research has indicated that multiple trace metal contamination may result in a shift in the threshold toxicity levels (Wallace and Berry, 1983); therefore, metals at seemingly safe levels may yield toxicity symptoms.

Daily gains of swine fed diets composed of vegetables from FBCR-fertilized gardens and boiled meat of chickens which had been fed FBCR were decreased, compared to swine fed identical diets utilizing limestone (Whitsel et al., 1983).

The purpose of the research reported here was to determine the effect of repeated applications of FBCR to acidic reclaimed mine pastures on forage yield and composition and performance of grazing cattle.

Experimental Procedure

The experimental site consisted of a total of 7.2 ha located south of Beckley, WV on an area which had been mined by mountain top removal and reclaimed 6 yr previously. The predominant forage at the site was tall fescue (Festuca arundinaceae) and birdsfoot trefoil (Lotus corniculatus); however, in the third replicate the forage was primarily fine leaf fescue (Festuca rubra), red top (Agrostis alba) and sericea (Lespedeza cuneata). The area had not been previously managed. This area included nine .8-ha pastures (three replications of each of the three pasture treatments). The pasture treatments were broadcasted and included: control (no amendment), 6.76 t FBCR/ha, and 3.38 t dolomitic limestone/ha. Treatments were applied in two applications, with two thirds of the total amount used in the first application. All pastures were fertilized with 0-25-25 (488 kg/ha) prior to the grazing trial. Detailed procedures may be found in the appendix.

Pastures were rotationally grazed, based on forage availability, by six yearling Angus steers/treatment. Treatments were applied just prior to rotating the cattle to new pastures. One esophageally-cannulated steer was grazed with the six experimental animals on each treatment pasture for forage sampling at the beginning of each grazing period. At the start of each period, four consecutive morning and afternoon samples were collected/treatment. At the beginning and end of each grazing period, forage grab samples were taken at intervals as each pasture was diagonally crossed four times, and four yield strips were collected by rotary mower. Cattle were weighed at 2-wk intervals throughout the 112-d trial.

Forage grab and yield samples were dried at 65 C for at least 4 d; whereas, esophageal samples were lyophilized prior to grinding. Esophageally collected and grab forage samples were ground first through a Wiley mill, fitted with a .5 cm screen then through a cyclone mill fitted with .5 mm screen.

In vitro dry matter digestibility (IVDMD) was determined by the Tilley and Terry (1966) two stage technique with modifications by Barnes (1969). Goering and Van Soest's (1970) procedure for neutral detergent fiber (NDF) and acid detergent fiber (ADF) was used. Permanganate lignin and cellulose were determined on the ADF residue (Van Soest and Wine, 1968). Total N was determined by an automated N, C and H analyzer (Leco Corp., 1984). Forage S was determined using an automated S analyzer (Hern, 1984). Forage Mo levels were determined by a modified thiocyanate procedure (Carel and Wimberly, 1982). Forage samples were acid digested with nitric and perchloric acids, as described by Hern (1979). Mineral analyses (Ca, P, Mg, Na, Cu, Fe, Al, and Zn) were completed on an inductively coupled plasma emission spectrophotometer. Heavy metals (Pb, Cd, Ni, and Cr) were determined by atomic absorption spectrophotometry. The residual effects of treatments were determined by grab samples of early spring growth collected the following year (May, 1984). These forage samples were analyzed identically to the other forage grab samples.

Soil samples were collected after the grazing trial (November, 1983) at a 0 to 10 cm depth. The pH was determined after a 1:1 (wt to volume) dilution with .01 M $CaCl_2$.

Data on forage grab samples taken during the grazing trial were statistically analyzed with regard to treatment, effect of grazing, pasture replicate, season and application rate. The main effects were tested with the mean squares of their respective two-way interactions with pasture replicate. If grazing had a significant effect, results were presented as pre- and postgrazing. Data on esophageally collected samples were analyzed with regard to treatment, sampling date, and pasture replicate. Treatment was tested with the mean square of the two-way interaction with pasture replicate. Data on the early spring samples (May, 1984) and soil samples were tested with regard to treatment and pasture replicate. Orthogonal treatment contrasts were control vs FBCR and limestone, and FBCR vs limestone.

Results and Discussion

The main differences in the mineral composition of the amendments used in this study were higher levels of Ca, S, Zn, Fe and Al and lower Mg in FBCR compared to limestone (table 2). The FBCR had 50% of the liming capacity of limestone, as indicated by the similar

TABLE 2. MINERAL CONTENT OF FBCR[a] AND LIMESTONE

Item	FBCR[b]	Limestone[b]
Calcium, %	28.6	21.6
Phosphorus, %	.04	-
Magnesium, %	.50	9.29
Sulfur, %	9.95	-
Copper, ppm	29.4	17.5
Zinc, ppm	69.2	7.73
Iron, ppm	5850	240
Aluminum, ppm	5015	280
Manganese, ppm	61.9	267
Sodium, ppm	213	268
Lead, ppm	1.61	1.79
Chromium, ppm	1.16	.28
Cadmium, ppm	.26	.20
Nickel, ppm	-	-

[a] Fluidized bed combustion residue.
[b] Dry basis.

elevation of pH in the limestone- (5.11) and FBCR- (5.25) amended pasture ($P < .05$), compared to the control pastures (4.65). Soil analysis indicated that FBCR amendment elevated soil SO_4 levels compared to control pastures (168 vs 21 ppm). Calcium levels were also highest with FBCR treatment compared to limestone and control pastures (1024, 670 and 557 ppm, respectively). Organic matter, P, K, nitrate and Zn were not affected by treatment, and averaged 2.25%, and 37, 71, 3.1 and 3.6 ppm, respectively. The soil analysis was completed by the Virginia Tech Soil Testing Laboratory in Blacksburg.

The average yield of forage, when expressed as forage available for grazing or residual forage present after grazing, was not affected by treatment (table 3). The high SE reflects variability of the forage stand, which is likely due to the highly variable soil composition typically observed in reclaimed strip mines and the previous lack of proper management. The pastures were grazed until one of the pastures within a replication was at an overall height of 4 to 6 cm; however, due to variability of site, at times other pastures within the replicate contained a larger amount of forage, which resulted in a seemingly inflated postgrazing yield.

The chemical composition of the pasture grab samples, averaged over the entire period, irrespective of grazing, was not significantly affected by treatment. However, in the pregrazing samples, NDF and cellulose levels were lower ($P < .05$) in FBCR-treated pastures compared to limestone-amended pastures (table 4). Grazing had a significant effect on the crude protein, NDF, hemicellulose and

TABLE 3. AVERAGE FORAGE YIELD OF PASTURES THAT RECEIVED DIFFERENT TREATMENTS

	Pasture treatment			
Sampling time	None	FBCR[a]	Limestone	SE
	kg DM/ha			
Pregrazing	1128	1095	1210	113
Postgrazing	515	453	638	64

[a] Fluidized bed combustion residue

TABLE 4. AVERAGE COMPOSITION[a] AND IN VITRO DRY MATTER DIGESTIBILITY (IVDMD) OF FORAGE GRAB SAMPLES TAKEN DURING THE GRAZING TRIAL

		Treatment			
Time	Item	Control	FBCR[b]	Limestone	SE
		%			
Pregrazing	Crude protein[c]	15.2	16.5	14.8	1.2
	NDF[c,d]	55.6	51.5	55.8	2.9
	ADF	34.2	33.1	34.5	1.2
	Hemicellulose[c]	21.5	18.5	21.3	2.1
	Cellulose[d]	27.2	25.2	26.8	.8
	Lignin	5.66	6.56	5.94	.38
	IVDMD[c]	60.0	58.9	58.1	2.0
Postgrazing	Crude protein[c]	10.9	11.5	11.8	.7
	NDF[c]	67.7	64.2	65.3	1.1
	ADF	39.3	39.5	38.9	2.6
	Hemicellulose[c]	28.4	24.6	26.4	1.8
	Cellulose	30.7	29.5	29.3	1.4
	Lignin	6.10	7.24	6.40	.96
	IVDMD[c]	50.6	48.2	49.5	2.6

[a] Dry basis.
[b] Fluidized bed combustion residue.
[c] Mean for pregrazing samples differs from postgrazing ($P < .05$).
[d] Mean of FBCR-treated pastures differs from that of limestone-treated pastures ($P < .05$).

cellulose contents of the forage (table 4). Previous research with S fertilization of orchardgrass has indicated NDF and cellulose levels were reduced (Panditharatne, 1982). The increase in cell wall constituents found in the postgrazing samples was likely due to the increased forage maturity and selective grazing of the less fibrous components by the steers. Hemicellulose was higher ($P < .05$) in esophageally collected forage samples from FBCR-amended pastures, when compared to limestone-treated pastures (table 5).

In vitro dry matter digestibility was not significantly affected by soil amendment in any of the forage samples (tables 4 and 5). Postgrazing samples had lower IVDMD ($P < .05$) than the pregrazing forage, suggesting again the effect of grazing selection by the steers. Previous work has suggested that S fertilization may increase in vitro digestibility of cool-season grasses by enhancing fiber-digesting rumen microorganisms (Akin and Hogan, 1983); however, such a response would not be likely in this trial because of the relatively high S level of soils found in Appalachia. Also, Ca fertilization has been shown to increase in vivo digestibility by increasing hemicellulose digestion (Rees and Minson, 1976). However, the amendments did not produce these responses. Esophageally collected samples were significantly higher in forage IVDMD and lower in lignin content, compared to grab samples collected at similar times within the grazing period.

The residual effect of the amendments in the following spring growth suggested FBCR decreased the hemicellulose content of the grab samples (table 6). There was a trend for decreased NDF and ADF and

TABLE 5. AVERAGE COMPOSITION[a] AND IN VITRO DRY MATTER DIGESTIBILITY (IVDMD) OF ESOPHAGEALLY COLLECTED FORAGE SAMPLES

Item	Treatment			SE
	Control	FBCR[b]	Limestone	
	%			
Crude protein	17.0	15.6	16.1	1.1
NDF	53.4	57.5	52.9	2.0
ADF	32.2	32.9	31.8	1.0
Hemicellulose[c]	21.2	24.6	21.1	1.3
Cellulose	24.8	26.1	24.8	.9
Lignin	5.04	4.73	4.90	.29
IVDMD	65.7	63.2	66.8	1.5

[a] Dry basis.
[b] Fluidized bed combustion residue.
[c] Mean of FBCR-treated pastures differs from that of limestone-treated pastures ($P < .05$).

TABLE 6. AVERAGE COMPOSITION[a] AND IN VITRO DRY MATTER DIGESTIBILITY (IVDMD) OF FORAGE SAMPLES TAKEN IN MAY, 1984

Item	Treatment			
	Control	FBCR[b]	Limestone	SE
	%			
Crude protein	22.9	23.5	22.7	.3
NDF	45.7	41.3	44.8	1.0
ADF	25.1	23.6	24.3	.8
Hemicellulose[c]	20.6	17.7	20.5	.3
Cellulose	22.7	21.3	21.8	.6
Lignin	1.35	1.29	1.40	.2
IVDMD	73.1	73.1	73.4	.8

[a] Dry basis.

[b] Fluidized bed combustion residue.

[c] Mean of control pastures differs from those of FBCR- and limestone-amended pastures ($P < .01$) and FBCR-amended pastures differs from limestone-amended pastures ($P < .01$).

increased crude protein in these samples.

Amendment of pastures increased ($P < .05$) ash, Ca, Mg, S, Cu, and the Ca:P ratio in pasture grab samples taken at the start of each grazing period (table 7). Forage from FBCR-treated pastures were higher in ash, S and Cu and lower in Mg than forage from limestone-treated pastures. All forage samples had a Mo content of approximately .05 ppm, DM. Of the eight grazing periods, six had the treatments applied immediately prior to sampling and rotating the cattle into the pastures. The treatments may have directly contaminated the surface of the forage samples available for consumption. This possibility is supported by the mineral content of esophageally collected samples, also procured at the start of each grazing period (table 8). Generally, the macromineral levels of the esophageally collected samples were similar to those of the pregrazing grab samples. Esophageally collected samples are usually higher in ash, Zn and Na than grab samples, undoubtedly due to saliva contamination (Holchek et al., 1982). Esophageally collected samples were significantly higher in ash, Zn, Al, and Fe, and lower in P and S, than grab samples collected at similar times within the grazing period.

Differences in Ca, Mg, S and Cu between postgrazing forages treated with the two amendments followed the same trends as the pregrazing FBCR- and limestone-amended pastures (table 7). Treatment contamination was possible in these samples since these pastures were sparce and generally under 6 cm high, and rain splash and trodding may have allowed for treatment and soil contamination. Moreover, results

TABLE 7. AVERAGE MINERAL LEVELS[a] OF FORAGE GRAB SAMPLES COLLECTED AT THE START OR END OF EACH GRAZING CYCLE DURING THE GRAZING TRIAL

		Pasture treatment			
Time	Item	Control	FBCR[b]	Limestone	SE
Pregrazing	Ash, %[c,d]	8.36	8.94	9.54	.41
	Ca, %[c,e]	.521	.938	.907	.071
	P, %	.341	.326	.349	.022
	Mg, %[c,d,e]	.404	.392	.596	.030
	S, %[c,d]	.305	.367	.318	.014
	Ca:P[c,e]	1.71	3.22	3.08	.40
	N:S	8.16	7.38	7.61	–
	Cu, ppm[c,d]	7.54	9.04	8.05	.45
	Zn, ppm	65.9	72.3	62.7	4.2
	Fe, ppm	293	358	424	82
	Al, ppm	470	489	634	145
	Mn, ppm	572	575	585	46
	Na, ppm	55.2	66.7	71.5	13.0
	Pb, ppm	3.20	2.85	3.85	.73
	Ni, ppm[e]	10.33	9.73	8.13	.63
Postgrazing	Ash, %	7.88	8.70	9.48	.29
	Ca, %[c,e]	.360	.588	.608	.013
	P, %	.325	.330	.300	.005
	Mg, %[d,e]	.365	.361	.443	.009
	S, %	.29	.323	.284	.007
	Ca:P[c,e]	1.23	2.07	2.45	.15
	N:S	6.24	5.75	6.80	–
	Cu, ppm[c]	5.88	7.12	6.47	.13
	Zn, ppm	70.2	73.8	60.4	1.8
	Fe, ppm	558	696	830	74
	Al, ppm	1019	1208	1421	179
	Mn, ppm	829	776	656	19
	Na, ppm	57.2	92.0	77.4	7.2
	Pb, ppm	3.31	3.84	4.23	.93
	Ni, ppm[e]	8.80	5.62	7.12	1.30

[a] Dry basis. Cadmium and Cr levels were below detectable limits (.20 ppm).
[b] Fluidized bed combustion residue.
[c] Mean for control pastures differs from those of FBCR- and limestone-treated pastures ($P < .05$).
[d] Mean for FBCR-treated pastures differs from that of limestone-treated pastures ($P < .05$).
[e] Mean for pregrazing samples differs from postgrazing ($P < .05$).

TABLE 8. AVERAGE MINERAL LEVELS[a] OF ESOPHAGEALLY COLLECTED FORAGE SAMPLES

	Pasture treatment			
Item	Control	FBCR[b]	Limestone	SE
Ash, %	11.4	13.2	12.5	1.4
Ca, %[c]	.555	.761	1.140	.110
P, %	.467	.494	.485	.029
Mg, %[d]	.304	.301	.725	.084
S, %[d]	.265	.350	.258	.022
Ca:P	1.37	1.61	2.52	.30
N:S	10.3	7.13	9.97	-
Cu, ppm	8.71	9.71	9.81	.54
Zn, ppm	59.9	54.6	57.9	2.8
Fe, ppm	917	1113	937	107
Al, ppm	1526	4042	1269	1000
Mn, ppm	503	535	528	39

[a] Dry basis. Cadmium and Cr levels were below detectable limits (.2 ppm).
[b] Fluidized bed combustion residue.
[c] Mean of control pastures differs from those of FBCR- and limestone-amended pastures (P = .06).
[d] Mean of FBCR-amended pastures differs from that of limestone-amended pastures ($P < .05$).

are confounded by an increase in maturity and selective grazing. Grazing had a significant effect on the Ca, Mg and Ca:P ratio of the forage; the pregrazing grab samples had higher levels of these constituents. This may be due to changes in forage morphology or to amendment contamination.

The residual effect of treatment on forage mineral levels in early spring growth collected the following year is shown in table 9. Forage from pastures treated with limestone and FBCR were higher in ash, Ca, S and the Ca:P ratio ($P < .05$), compared to control pasture forage. Both limestone and FBCR amendments decreased forage levels of Zn, Mn and Ni ($P < .05$). The lush new growth and the 8-mo period since the last treatment application should have diminished the level of direct foliar contamination and the forage mineral levels may represent the plant mineral uptake. Liming, by its effect on pH and addition of Ca, may reduce plant divalent cation levels (Brown, 1979). He demonstrated that lime induced Zn deficiency and alleviated Mn toxicity in some plant species. Other researchers have shown that lime decreases exchangeable Al, Fe and Mn in acidic soil and that plant tissue Mn decreases linearly with increasing lime application (Haynes and Ludecke, 1981). The addition of Ca and the elevation of the pH have beneficial effects on legume establishment and growth (Miller and Sirois, 1983). Therefore, a botanical shift is possible and the expected shift in chemical composition should occur. We did not observe a shift in NDF, lignin or Mg content in the treated, compared to control pastures, indicating that a botanical shift did not occur.

TABLE 9. AVERAGE MINERAL LEVELS[a] OF FORAGE GRAB SAMPLES TAKEN IN MAY, 1984

	Pasture treatment			
Item	Control	FBCR[b]	Limestone	SE
Ash, %[c,d]	7.91	8.64	8.25	.08
Ca, %[d,e]	.387	.646	.453	.042
P, %	.517	.515	.512	.009
Mg, %[d]	.234	.205	.254	.008
S, %[e,f]	.306	.338	.300	.004
Ca:P[d,e]	.758	1.26	.888	.074
N:S	12.0	11.1	12.1	-
Cu, ppm	9.08	10.0	9.24	.21
Zn, ppm[e]	39.5	35.8	33.8	1.1
Fe, ppm	111	107	108	6
Al, ppm	58.1	52.8	56.6	8.0
Mn, ppm[c]	244	175	167	11
Na, ppm	24.0	21.4	23.9	.9
Pb, ppm[d]	.178	.202	.143	.014
Ni, ppm[c]	.726	.555	.551	.021

[a] Dry basis Cadmium and Cr below detectable limits (.2 ppm).
[b] Fluidized bed combustion residue.
[c] Mean of control pastures differs from those of the FBCR- and limestone-amended pasture ($P < .01$).
[d] Mean of FBCR-treated pastures differs from that of limestone-amended pastures ($P < .05$).
[e] Mean of control pastures differs from those of the FBCR- and limestone-amended pastures ($P < .05$).
[f] Mean of FBCR-amended pastures differs from that of limestone-amended pastures ($P < .01$).

The May, 1984 samples from FBCR-amended pastures had elevated ash, Ca, S and Pb ($P < .05$), compared to limestone-amended pastures (table 9). The levels of Pb found in these samples were 50-fold lower than the maximum tolerable level for ruminants (NRC, 1980). The enhanced macromineral content of the forage from FBCR-amended pastures and the depressed Mn and Ni levels suggest that FBCR application is effective for elevating nutritional quality of forage by interfering with potentially harmful element uptake. In these early spring samples, only FBCR amendment elevated the Ca:P ratio to acceptable levels (NRC, 1984). Limestone application increased forage Mg levels ($P < .05$) above FBCR amended forage; however, if power plants used dolomitic limestone as the source of limestone, FBCR would also be a supplemental Mg source.

The overall cattle gains expressed as daily gain, gain/ha or total gains were not significantly affected by pasture treatment (table 10). The decrease in gain associated with feeding FBCR in swine (Whitsel et al., 1983) was not observed in this study. The overall poor performance of the cattle was likely due to the minimal rainfall during the growing season resulting in inadequate forage availability.

In conclusion, no detrimental effects of repeated applications of FBCR on reclaimed mine pastures were ascertained on forage yield, composition or on cattle performance. In contrast, FBCR amendment elevated forage nutritional quality as measured by a decrease in some cell wall constituents, an increase in Ca levels and Ca:P ratio and a decrease in Mn and Ni.

TABLE 10. EFFECT OF TREATMENT ON CATTLE PERFORMANCE

Item	Pasture treatment			SE
	Control	FBCR[a]	Limestone	
Gain/head, kg	34.5	34.2	23.5	5.7
Daily gain, kg/d	.31	.31	.21	.05
Gain/ha, kg	86.4	85.4	58.4	14

[a] Fluidized bed combustion residue

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Chapter IV

APPLICATION OF FLUIDIZED BED COMBUSTION RESIDUE ON RECLAIMED SURFACED MINED PASTURES: II. TISSUE MINERAL RESIDUES OF GRAZING STEERS

ABSTRACT

This study was designed to determine the effect of repeated applications of fluidized bed combustion residue (FBCR) or limestone to acidic reclaimed mine land on the tissue mineral status of grazing steers. Six yearling steers per treatment were rotationally grazed on three pastures which received each treatment. Treatments were control (no amendment), 6760 kg FBCR/ha, and 3380 kg limestone/ha applied in split applications. Packed cell volume was elevated ($P < .05$) and hemoglobin levels tended to be higher in steers grazing FBCR-treated pastures throughout the 112-d grazing trial, compared to cattle grazing limestone-amended or control pastures. Serum levels of Ca, P, Mg, S, Na, Cu, Zn, and Fe were not significantly affected by treatment. Ruminal Ca was higher and Ni was lower ($P < .05$) in cattle grazing FBCR- and limestone-amended pastures. Zinc and Mg in rumen contents were higher in cattle grazing limestone-treated, compared to FBCR-amended pastures ($P < .05$). Liver Fe, Mn, Ni, and Na were lower ($P < .05$) in cattle grazing limestone- and FBCR-amended pastures. Liver Ni was lower ($P < .05$) in cattle grazing FBCR- than in those grazing the limestone-amended pastures. Bile levels of Mn were depressed ($P < .05$)

by FBCR and limestone amendment. Kidney levels of Ca, Mg, and P were higher ($P < .05$) in animals grazing FBCR and limestone pastures. The similar levels of lung divalent metal levels between treatments suggest that inhalation of FBCR was not a problem. Mineral levels in longissimus muscle were not affected by treatment. Hair Zn was higher ($P < .05$) in cattle grazing FBCR- and limestone-amended pastures. Rib Cr and long bone Cd levels were lower in animals grazing both FBCR- and limestone-amended pastures. This study suggests that FBCR amendment to reclaimed mine land provided no deleterious effects to the mineral status of grazing steers.

(Key words: Grazing Steers, Reclaimed Mine Pastures, Tissue Mineral Residue, Fluidized Bed Combustion Residue).

INTRODUCTION

Reclaimed surface mined land is a potentially valuable source of pasture in Appalachia. However, its inherent infertility precludes vegetative vigor without amendment (Armiger et al., 1976). The acidic nature of reclaimed minesoils may induce mineral toxicities and deficiencies in forage (Vogel, 1981), causing depressed animal production. The minesoils are typically high in exchangeable Fe, Al, Mn, and Cu and deficient in N, P, Mg, and Ca (Armiger et al., 1976). Fluidized bed combustion residue (FBCR) characterized previously (Chapter III), has approximately 50% of the neutralizing capacity of limestone and is high in Ca, S, Fe, Zn and, potentially, heavy metals.

Swine fed diets composed of both FBCR-fertilized vegetables and boiled FBCR supplemented broiler chickens had depressed daily gain, compared to swine fed limestone-fertilized and conventionally supplemented feedstuffs (Whitsel et al., 1983). Blood levels of Pb and Hg and urine As were elevated in swine fed the FBCR-derived diets. Hamsters fed soybean and corn diets from FBCR-fertilized fields had higher daily gain in one of the two trials, compared to hamsters fed diets grown on limestone-fertilized soils (Fashandi, 1981). Limestone fertilization increased liver Cd and whole-body Cu, compared to FBCR fertilization. In a study in which FBCR was utilized as a source of S on alfalfa fields, dry matter digestibility was depressed in lambs that had consumed first cutting FBCR fertilized hay (Reid et al., 1979). Subsequent cuttings, indicated that Ca and P absorption was decreased ($P < .05$) in lambs fed the FBCR fertilized hay. There was no effect of FBCR fertilization on blood mineral levels.

The purpose of this portion of the study was to evaluate the effects of repeated applications of FBCR to reclaimed surface mine pastures on the mineral status of grazing cattle, as determined by tissue mineral levels.

Experimental Procedures

Detailed procedures used in the experiment are provided in the preceeding paper (Chapter III). Briefly, three pasture treatments were: a control of no amendment, 6760 kg FBCR/ha and 3880 kg dolmitic limestone/ha.

Each treated pasture consisted of .8 ha of acidic reclaimed mine land replicated three times. Pastures were rotationally grazed by six intact and one esophageally-cannulated steer per treatment, based on forage availability. Treatments were applied in split applications just prior to rotating the steers in a new grazing period; therefore, steers were subjected to newly amended pastures for a total of six times.

Blood samples were collected via jugular puncture initially and at 2-wk intervals. After 114 d of grazing, all cattle were slaughtered by exsanguination. Body fluids collected included bile, urine and rumen fluid. Animal tissues collected included a random sample of the cubed liver, unattached portion of spleen, both kidneys, lower right bronchial tubes, entire heart, entire brain, longissiumus muscle spanning the 9th to 11th rib, hair sample from the 13th rib cranially on the midline, the 13th rib (cancellous bone), both proximal phalanx bone (long bone), 1 m of duodenum caudal to the bile duct, and .5 m of the large intestine just anterior to the rectum. All tissues were rinsed with deionized-distilled water prior to freezing. The intestinal lumens were repeatedly flushed to remove contents.

Soft tissues were lyophilized and the fat was removed prior to grinding in a stainless steel blender. Fluids were analyzed on an as-is basis. Bone samples were obtained with a 1.1 cm high speed twist drill and the shavings were analysed after defatting by a Soxtet system (Tecatur, 1984) and dry ashed at 600 C (24 hr). Hair samples were washed by first shaking for 6 h in 5% Tween-80, then by rinsing numerous times with distilled-deionized water.

Biweekly blood samples were analysed for mineral levels. Also, whole blood packed cell volumes (PCV) were determined by microhematocrit and hemoglobin levels were determined colorimetrically[1]. Serum glutamic oxaloacetic transaminase (SGOT)[2] was determined by colorimetric analysis.

All tissues and fluid samples (generally 2 g or 2 ml) were acid digested in a 4:1 nitric:perchloric acid mixture prior to mineral analysis (Hern, 1979). The room-temperature predigestion period was lengthened to 24 h for bone, brain and hair samples. Mineral levels were determined by an inductively coupled plasma emission spectrophotometer, except for Pb, Ni, Cd, and Cr, which were analyzed by atomic absorption spectrophotometry.

The statistical model for tissue and fluid analyses included the effects of treatment, block and their interaction. The residual was used to determine the significance of each main effect. The model for the biweekly blood samples included the effects of treatment, date and animal block by date within treatment. Orthogonal contrasts used to separate treatment means, were control vs FBCR and limestone, and FBCR vs limestone.

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[1] Fisher Scientific, Allied Chemical Co., Springfield, NJ. Cat. # 2365-22.
[2] Sigma Chemical Co., St. Louis, MO. Kit #56-UV

Results

Use of limestone and FBCR amendments increased the Ca and depressed Ni levels ($P < .05$) in the rumen contents of grazing steers, compared to steers grazing control pastures (table 11). Zinc and Mg levels were higher ($P < .05$) in steers grazing limestone-amended, compared to FBCR-amended pastures.

Packed cell volume was increased throughout the grazing trial in cattle grazing FBCR-amended pastures ($P < .05$, figure 1). Analyzed across all treatments, PCV exhibited a linear increase ($P < .05$) with time. Hemoglobin levels were not signficantly affected by treatment, however, there was a trend for cattle grazing the FBCR-amended pastures to have a higher hemoglobin concentration (figure 1). Levels of SGOT were highly variable throughout the study and there were no significant differences between treatments. However, there was a quadratic respone with time in all the cattle.

Serum mineral levels, averaged throughout the trial, were not significantly altered by treatment (table 12). Steers grazing the control pastures showed a linear decrease in serum Ca over time; whereas, Mg and P were quadratically affected. Steers grazing FBCR-amended pastures had a very slight but linear decrease in serum Cu, Fe and Ca during the trial ($P < .05$); whereas, Mg increased linearly and serum P was affected quadratically ($P < .05$) with time. Serum of steers grazing the limestone-amended pastures had a linear decrease in Cu and Ca, whereas, Zn, P and Mg were quadratically decreased with time.

TABLE 11. EFFECT OF PASTURE TREATMENT ON MINERAL LEVELS[a] RUMINAL CONTENTS

	Pasture treatment			
Item	Control	FBCR[b]	Limestone	SE
Ca, %[c]	.374	.500	.511	.029
Mg, %[d]	.181	.160	.217	.015
P, %	.680	.653	.660	.020
Na, %	1.63	1.62	1.52	.08
S, %	.241	.230	.241	.004
Cu, ppm	11.5	20.9	12.0	3.9
Zn, ppm[e]	89.3	84.8	102	4
Fe, ppm	369	433	430	31
Mn, ppm	659	585	606	26
Al, ppm	347	392	308	44
Pb, ppm	.336	.317	.324	.016
Ni, ppm[f]	.688	.599	.629	.028

[a] Dry basis. Cadmium and Cr levels were below detectable limits (.2 ppm).
[b] Fluidized bed combustion residue.
[c] Mean for cattle grazing control pastures differs from those of FBCR- and limestone-amended pastures ($P < .01$).
[d] Mean for cattle grazing FBCR-amended pastures differs from that of limestone-amended pastures ($P < .05$).
[e] Mean for cattle grazing FBCR-amended pastures differs from that of limestone-amended pastures ($P < .01$).
[f] Mean for cattle grazing control pastures differs from those of FBCR- and limestone-amended pastures ($P < .05$).

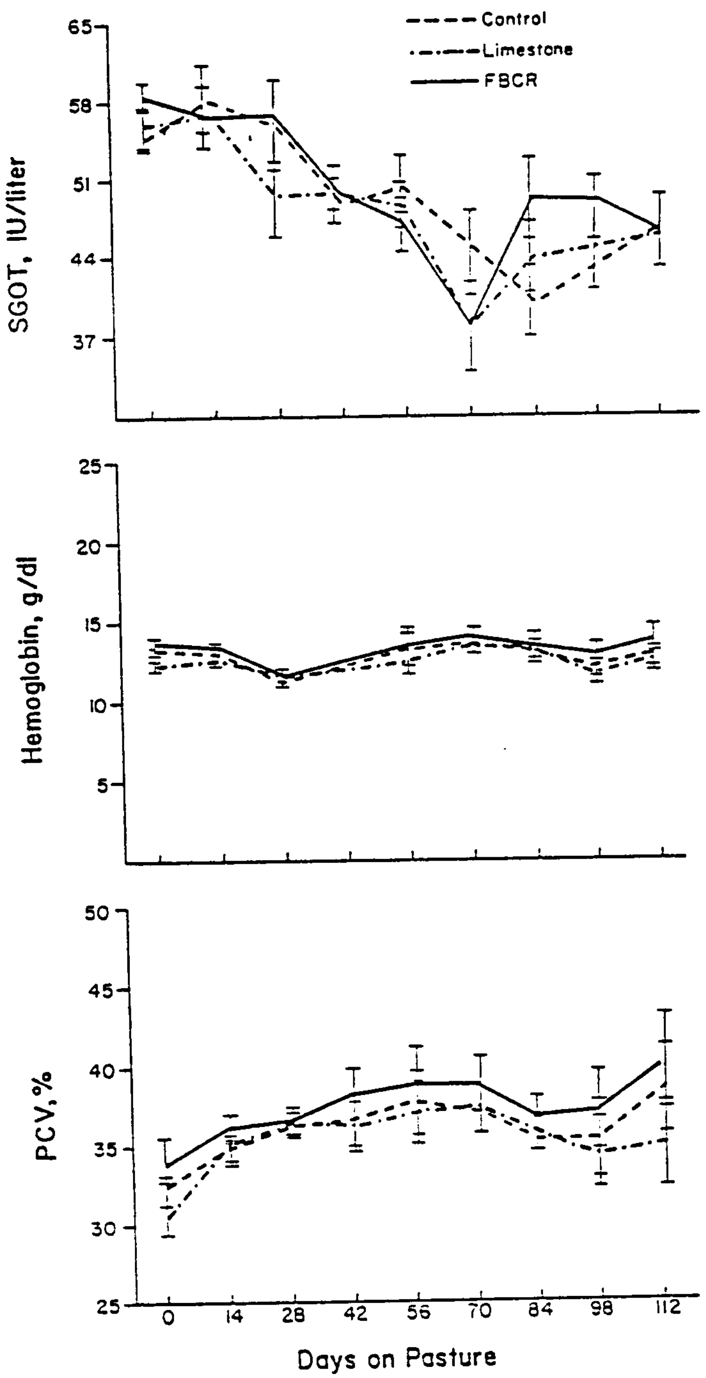

Figure 1. Blood parameters during the grazing trial Packed cell volume (bottom graph) was higher ($P<.05$) in steers grazing FBCR-amended pastures for the entire grazing trial and hemoglobin concentration was higher ($P<.05$) on d 14 for cattle grazing FBCR-amended pastures, compared to limestone-amended pastures.

TABLE 12. AVERAGE MINERAL LEVELS[a] OF SERUM SAMPLE TAKEN DURING THE GRAZING TRIAL

Mineral element	Pasture treatment			
	Control	FBCR[b]	Limestone	SE
	mg/dl			
Calcium	9.33	9.37	9.54	.057
Phosphorus	11.2	10.9	10.6	.2
Magnesium	2.11	2.11	2.11	.024
Sulfur	79.0	78.3	80.3	1.5
Sodium	308	310	309	1
Copper	.0662	.0556	.0584	.004
Zinc	.122	.120	.131	.011
Iron	.231	.233	.230	.014

[a] Lead, Ni, Cd, Cr, Al, and Mn were below detectable limits (.06, .02, .02, .02, .06, .06 mg/dl, respectively).
[b] Fluidized bed combustion residue.

Liver levels of Fe, Mn, Ni and Na were depressed ($P < .05$) in cattle grazing FBCR- and limestone-amended pastures (table 13). Nickel levels were lower in cattle grazing FBCR-amended pastures, compared to those grazing limestone-amended pastures ($P < .05$). Bile Mn was also lower in steers grazing FBCR- and limestone-amended pastures (table 13). Spleen mineral levels were not affected by treatment (table 14).

Kidney levels of Ca ($P = .08$), Mg and P ($P < .05$) were higher in animals grazing FBCR- and limestone-amended pastures (table 15). Lung mineral levels were similar between treatments, with the exception of decreased Na and increased Zn in steers grazing the FBCR-treated pastures, compared to those grazing pastures amended with limestone (table 16).

The longissiumus muscle of cattle grazing FBCR- and limestone-amended pastures had higher concentrations ($P = .09$) of S than the muscle of those grazing the control pastures (table 17). Rib levels of minerals, expressed on a fat-free ash basis, were similar between treatments except for Cr which was lower in cattle grazing FBCR and limestone-amended pastures (table 18). Long bone mineral levels were similar to the rib levels; however, Cd levels were lower in cattle grazing FBCR- and limestone-amended pastures, compared to levels of the control animals ($P < .05$). Zinc levels in the hair were lower in cattle grazing the amended pastures ($P < .01$, table 19). Heart levels of P were higher ($P = .056$) in cattle grazing FBCR pastures (.974 %, dry basis). Brain Ca was elevated ($P < .05$) in cattle grazing FBCR-amended pastures (.0967%, dry basis), compared to those grazing

TABLE 13. EFFECT OF PASTURE TREATMENT ON MINERAL LEVELS IN LIVER [a] AND BILE[b]

		Pasture treatment			
Tissue	Item	Control	FBCR[c]	Limestone	SE
Liver	Ca,. %	.0128	.0128	.0140	.0005
	Mg, %	.0642	.0639	.0639	.0013
	P, %	1.21	1.20	1.12	.03
	Na, %[d]	.223	.205	.214	.006
	S, %	.675	.688	.687	.016
	Cu, ppm	37.2	25.5	41.6	7.4
	Zn, ppm	118	119	135	9
	Fe, ppm[d]	253	200	219	34
	Mn, ppm[d]	14.6	13.6	13.7	.5
	Ni, ppm[d,e]	1.09	.574	.990	.160
	Pb, ppm	3.10	3.15	3.29	.12
	Cr, ppm	1.87	2.12	2.16	.20
Bile	Ca, mg/dl	14.16	14.26	14.73	.52
	Mg, mg/dl	2.67	2.67	2.81	.25
	P, mg/dl	18.2	19.2	20.7	1.6
	Na, mg/dl	423	420	431	8
	S, mg/dl	68.3	62.2	63.7	7.6
	Zn, mg/dl	.166	.121	.187	.062
	Fe, mg/dl	.0500	.0685	.0773	.016
	Mn, mg/dl[d]	.402	.241	.321	.036

[a] Dry basis. Aluminum and Cd was below detectable limits (.6 ppm and .2 ppm, respectively).

[b] Lead, Cd, Cr, Ni, Cu, and Al were below detectable limits (.06, .02 .02, .02, .024, and .06 mg/dl, respectively).

[c] Fluidized bed combustion residue.

[d] Mean for cattle grazing control pastures differs from those of FBCR- and limestone-amended pastures ($P < .05$).

[e] Mean for cattle grazing FBCR-amended pastures differs from that of limestone-amended pastures ($P < .05$).

TABLE 14. EFFECT OF PASTURE TREATMENT ON MINERAL LEVELS[a] IN SPLEEN

	Pasture treatment			
Item	Control	FBCR[b]	Limestone	SE
Ca, %	.0213	.0217	.0183	.0026
Mg, %	.0675	.0683	.0609	.0053
P, %	1.13	1.16	1.04	.09
Na, %	.336	.354	.303	.026
S, %	.608	.627	.576	.031
Cu, ppm	3.83	3.63	3.33	.39
Zn, ppm	91.9	89.7	74.2	7.7
Fe, ppm	1073	811	791	250
Mn, ppm	1.61	1.59	1.26	.17
Al, ppm	3.03	2.73	2.49	.19
Pb, ppm	1.50	1.56	2.04	.34
Ni, ppm	.768	.845	.753	.12
Cr, ppm	1.49	1.48	1.52	.04

[a] Dry basis. Cadmium levels were below detectable limits (.20 ppm).
[b] Fluidized bed combustion residue.

TABLE 15. EFFECT OF PASTURE TREATMENT ON MINERAL LEVELS[a] IN KIDNEY

	Pasture treatment			
Item	Control	FBCR[b]	Limestone	SE
Ca, %[c]	.0314	.0360	.0388	.0025
Mg, %[d]	.0738	.0792	.0777	.0010
P, %[d]	1.10	1.16	1.17	.01
Na, %	.721	.749	.819	.026
S, %	.763	.790	.759	.015
Cu, ppm	20.2	20.4	20.9	.4
Zn, ppm	80.50	85.38	83.51	2.0
Fe, ppm	195	198	207	15
Mn, ppm	6.48	6.61	6.44	.28
Ni, ppm	1.29	1.22	1.26	.040
Mo, ppm	4.42	4.56	4.07	.16
Pb, ppm	3.45	3.46	3.75	.19
Cr, ppm	1.164	.876	.642	.263

[a] Dry basis. Aluminum was below detectable limits (.6 ppm).
[b] Fluidized bed combustion residue.
[c] Mean for cattle grazing control pastures differs from those of FBCR- and limestone-amended pastures ($P = .08$).
[d] Mean for cattle grazing control pastures differs from those of FBCR- and limestone-amended pastures ($P < .01$).

TABLE 16. EFFECT OF PASTURE TREATMENT ON MINERAL LEVELS[a] IN LUNG

	Pasture treatment			
Item	Control	FBCR[b]	Limestone	SE
Ca, %	.0405	.0429	.0459	.0034
Mg, %	.0535	.045	.0541	.0011
P, %	.949	.957	.941	.022
Na, %[c]	.766	.713	.772	.014
S, %	.717	.704	.725	.018
Cu, ppm	5.96	5.99	5.82	.25
Zn, ppm[c]	81.2	84.3	78.7	1.7
Fe, ppm	302	355	298	38
Mn, ppm	.891	.962	1.025	.045
Al, ppm	2.29	2.33	2.43	.60
Ni, ppm	1.04	1.09	1.04	.05

[a] Dry basis. Lead, Cr and Cd were below detectable limits (.6, .2, .2 ppm, respectively).

[b] Fluidized bed combustion residue.

[c] Mean for cattle grazing FBCR-amended pastures differs from that of limestone-amended pastures ($P < .05$).

TABLE 17. EFFECT OF PASTURE TREATMENT ON MINERAL LEVELS[a] IN LONGISSIMUS MUSCLE

	Pasture Treatment			
Item	Control	FBCR[b]	Limestone	SE
Ca, %	.0126	.0126	.0131	.0025
Mg, %	.0883	.0891	.0892	.0021
P, %	.807	.813	.794	.019
Na, %	.148	.148	.151	.005
S, %[c]	.657	.685	.679	.011
Cu, ppm	3.48	2.92	3.22	.32
Zn, ppm	127	133	147	8
Fe, ppm	64.9	66.3	63.6	2.7
Mn, ppm	.459	.487	.429	.025
Al, ppm	.890	.971	1.248	.17

[a] Dry basis. Lead, Ni, Cd, and Cr were below detectable limits (.6, .2, .2, and .2 ppm, respectively).
[b] Fluidized bed combustion residue.
[c] Mean for cattle grazing control pastures differs from those of FBCR- and limestone-amended pastures (P = .09).

TABLE 18. EFFECT OF PASTURE TREATMENT ON MINERAL LEVELS[a] IN RIB

	Pasture treatment			
Item	Control	FBCR[b]	Limestone	SE
Ash, %	65.1	64.8	64.4	.7
Ca, %	33.5	33.2	33.7	.4
Mg, %	.647	.647	.644	.014
P, %	16.8	16.7	16.6	.2
Na, %	.896	.904	.871	.012
S, %	.040	0.46	0.41	.01
Cu, ppm	13.7	13.8	13.6	.2
Zn, ppm	89.2	94.4	104	4
Fe, ppm	49.3	52.1	60.6	9.4
Mn, ppm	1.62	2.11	1.87	.18
Al, ppm	21.6	24.8	23.8	2.3
Pb, ppm	50.8	49.3	51.0	1.1
Cd, ppm	6.20	5.98	6.16	.17
Cr, ppm[c]	13.4	12.7	12.7	.2

[a] Ash weight basis. Nickel was below detectable limits (.2 ppm).
[b] Fluidized bed combustion residue
[c] Mean for cattle grazing control pastures differs from those of FBCR- and limestone-amended pastures ($P < .05$)

TABLE 19. EFFECT OF PASTURE TREATMENT ON MINERAL LEVELS[a] IN HAIR

Item	Pasture Treatment			
	Control	FBCR[b]	Limestone	SE
Ca, %	.260	.318	.254	.038
Mg, %	.0550	.0597	.0596	.0051
P, %	.0218	.0243	.0197	.0014
S, %	2.68	2.89	2.92	.12
Na, ppm	90.0	81.6	160	57
Cu, ppm	7.60	7.58	7.43	.31
Zn, ppm[c]	114	126	126	2
Fe, ppm	70.3	153	61.4	43
Mn, ppm	60.8	75.2	51.8	11.0
Al, ppm	26.4	64.5	29.5	17.0
Pb, ppm	3.25	3.11	3.25	.45
Ni, ppm	1.15	1.35	1.62	.22
Cr, ppm	.768	.822	1.01	.22

[a] Dry basis. Cadmium was below detectable levels (.2 ppm).
[b] Fluidized bed combustion residue.
[c] Mean for cattle grazing control pastures differs from those of FBCR- and limestone-amended pastures ($P < .01$).

limestone-amended pastures (.071%, dry basis). The Ca level in the brain of cattle grazing control pastures (.090 %, dm) were similar to levels of cattle grazing the FBCR pastures. Small and large intestine mineral levels were not significantly affected by treatment.

Discussion

The abscence of treatment effect on serum mineral levels suggests that no gross alteration of mineral metabolism was caused by pasture amendments (table 12). Calcium , Mg (NRC, 1980), Na and Zn (Kirk et al., 1985) were similar to previously reported levels. Sulfur and P are given in total amounts (including inorganic and organic), therefore, are higher than levels reported in the literature (Rosa et al., 1982; and Kirk et al., 1985). Copper levels, averaged throughout the grazing trial, were at or below .06 mg/dl. This is the level considered as deficient, suggesting that liver Cu stores were suboptimal for maintaining normal circulating levels (Claypool et al., 1975). Liver Cu was below 40 ppm (table 13), reported as the deficiency threshold level (Claypool et al., 1975).

Excretion of Cu is primarily by biliary excretion and bile Cu levels were nondetectable (table 13) in all steers. This would suggest that the liver was conserving Cu stores. Strain et. al. (1974) reported human bile Cu levels of 148 ± 142 ppm and that these levels were highly related to diet and health. Brain Cu levels are also an indication of Cu status (Hennig et al., 1974). Goats with brain Cu levels below 8.9 exhibited deficiency symptoms. Average brain Cu levels in the present study were between 8.14 and 8.86 ppm, further supporting the hypothesis that the grazing steers were in a Cu-deficient status. Although black hair is more variable than white or red hair, it may reflect gross alteration in Cu intake (O'Mary et al., 1970). The hair Cu levels (table 19) were closest to the levels (6 ppm) O'Mary et al. (1970) found in Cu-deficient diets.

Previous grazing trials in Oregon suggest that tall fescue may induce Cu-deficiency in cattle (Stoszek et al., 1979). Tall fescue accumulates S and Mo which may inhibit Cu absorption; however, these authors suggested that other factors such as soil consumption may be involved. Suttle (1975) reported that soil consumption at 10% of the diet may inhibit Cu-availability by 50%, regardless of the soil Mo content. All forage levels of S were approaching toxicity limits (NRC, 1980) especially forage from FBCR-amended pastures (Chapter III). Soil sulfur levels were high in all pastures (Chapter III), likely due to the release of SO_4 from Fe-pyrites commonly found in Appalachian reclaimed minesoils (Vogel, 1981). The high S level may inhibit Cu-availability to the animal with or without high levels of Mo (Suttle, 1984). Interestingly, the additional S found in FBCR-amended pastures did not further diminish Cu-availability. The low level of Mo (.05 ppm) in the forage, suggested the Mo-S-Cu interaction was not important.

The elevated PCV (figure 1) and lower liver Fe (table 13) and a trend for lower spleen Fe (table 14) in cattle grazing FBCR-amended pasture may suggest FBCR amendment partially ameliorated Cu deficiency. Copper deficiency reduces ceruloplasmin levels, hence lowering transferrin levels and increases tissue Fe stores (Roeser et al., 1970). Ceruloplasmin is a ferreoxidase (Frieden, 1977). Ruminal Cu levels were elevated in steers grazing FBCR-amended pastures (table 11) as well as increased forage grab sample Cu levels (Chapter III).

Lower liver levels of Fe, Mn, Ni, and Na (table 13) in cattle grazing pastures with liming amendments suggest that the treatments affected plant and/or animal uptake. Forage Mn levels were not affected by treatment (Chapter III), suggesting that other dietary factors were responsible for the decreased Mn concentration in the liver and bile (table 13). Symonds and Hall (1983) suggest that almost all of the absorbed Mn is cleared by the liver and bilarly excreted; therefore, liver and bile Mn levels are a good indicator of Mn-availability. Absorption of Mn, a divalent cation, may be influenced by the Ca level of the diet. Nickel levels were decreased in the rumen contents (table 11) and forage (Chapter III) suggesting that the decrease in liver Ni was due to the decreased intake.

The increase in kidney Ca, P, and Mg suggested that steers grazing limestone- and FBCR-amended pastures were in better status for these minerals than those grazing control pasture (table 15). Kidney Cu, Mn, P, Na and Mg were at levels reported for grazing cattle in Panama (Ammerman et al., 1974). All steers had lower kidney Fe levels than levels previously reported (Doyle and Spaulding, 1978 and Ammerman et al., 1974). This suggests that cattle were conserving Fe stores.

Kidney Ca levels were also lower than previously reported (Rosa et al., 1982).

Spleen Cu was lower than the levels reported by Ammerman and coworkers (1974), but similar to the lowest level reported by Rosa et al. (1982). Magnesium and Zn levels were also lower than previously reported levels (Ammerman et al., 1974; and Rosa et al., 1982). Treatment did not alter the mineral levels of the spleen (table 14). The heavy metal content was lower than the reported levels for accumulation in the liver; therefore, they would be assumed as safe (Doyle and Spaulding, 1978).

The absence of treatment effect on the Ca and S level in the lung suggests that FBCR inhalation was not a problem (table 16). In cattle grazing FBCR-amended pastures, lung mineral levels were similar to control levels; whereas, limestone amendment caused decreased Zn and increased Na lung levels.

Hair levels of Zn were at normal levels (table 19); however, Zn levels were higher in animals grazing FBCR and limestone pastures compared to the control. With the exception of Zn, mineral levels of hair are only indicative of grossly elevated or deficient dietary mineral contents, whereas Zn is more responsive to smaller dietary changes (Combs et al., 1982). Compared to previously reported values, Fe and Mn levels were higher in grazing steers. This may suggest either elevated dietary levels, or perhaps, inadequate washing of the hair samples.

Mineral levels of longissimus muscle were within the ranges previously reported (Ammerman et al., 1974; and Rosa et al., 1982) with the exception of Na and Cu which were slightly lower (table 17). The lower Cu levels probably reflect the lower circulating Cu levels.

Rib (table 18) and long bone mineral content were extremely similar; however, rib Cr and long bone Cd levels were lowered by limestone and FBCR amendment. This suggests liming amendment decreased uptake of these heavy metals. Since 90% of the absorbed Pb is deposited in the bone (Ammerman et al., 1977) and there was no difference between treatments, the elevated Pb concentrations found in the following year's spring growth in FBCR-amended pastures suggest Pb content of FBCR must not be a problem,

Although all cattle seemed to be in suboptimal Cu status, FBCR had no deleterious effect associated with cattle grazing on amended pastures. In fact, FBCR may have slightly ameliorated Cu-deficiency. Amendment with FBCR seemed to be at least as beneficial as limestone in diminishing potential mineral toxicities and did not cause any additional imbalances.

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CHAPTER V

General Discussion

Reclaimed mine land typically has an imbalanced mineral complement (Armiger et al., 1976) that may adversely affect forage and animal production. The inherent acidic nature of Appalachian minesoils is such that high levels of exchangeable Fe, Al, Mn, Cu, and SO_4 are available for plant uptake (Vogel, 1981). The high SO_4 levels is often a result of degradation of Fe-pyrites, releasing SO_4 to the surrounding area. In the present study, changes in forage macromineral content are more pronounced than the micromineral levels. These changes, especially in Ca, could be responsible for alteration of mineral residue levels in grazing steers. Calcium is a strong suppressor of cation uptake in the gut (Ammerman et al., 1963). Soil acidification increases the plant availability of most metals, thereby elevating the levels ingested by the grazing animals. The addition of a liming agent should reduce availability of these metals and thereby reduce forage levels of potentially toxic cations. However, liming may induce deficiencies. In this study, forage levels of potentially toxic cations (Al, Mn, Fe and Cu) were not depressed by FBCR or limestone amendment during the grazing trial. However, the levels were not excessive in the control forage. In contrast, forage Cu levels were increased with amendment of FBCR.

In samples of early spring growth collected the following year, forage Mn, Zn and Ni levels were lower in the FBCR- and limestone-amended pastures. These early spring forage samples may be more indicative of treatment effect, since results were not confounded with grazing effects, treatment application contamination and variations in maturity. The availability of Mn was decreased in cattle by pasture limestone and FBCR application as indicated by liver and bile Mn levels.

Levels of Ca and Ca:P ratio in the forage samples taken during the grazing season were sufficient for grazing beef cattle (NRC, 1984). The samples taken during the early spring of the subsequent year had lower than desireable Ca:P ratios for all treatments except FBCR. The depressed Ca:P ratio is normal in early spring growth forages due to the low Ca and elevated P found in forage at this time of year (Gross and Jung, 1981). The elevated Ca in these pastures is an important consideration since trefoil is one of the few legumes that is not a good Ca accumulator (Gross and Jung, 1981).

The high S levels in FBCR may also play an important part in forage and animal nutrition. However, soil SO_4 levels were high in the soil samples taken (appendix table 3). High levels of SO_4 are released upon exposure of Fe-pyrites (Vogel, 1981). Sulfate is adsorbed in soils with high levels of exchangeable Al, Fe-oxides and clay (Williams, 1975). The pH of the soil directly influences the availability of SO_4 such that an increase of one pH unit may drastically reduce SO_4 availability (Martin and Mutters, 1984). Therefore, the additional S may be important with liming. Sulfur fertilization may also enhance legume production (Jones et al., 1982). The forage S levels and the reported N:S ratios in our study suggest that S was not limiting. The S requirement for growing steers is .1% and an optimal N:S ratio is 10:1 (NRC, 1984). Forages were well above these requirements. The maximum tolerable limit for S is .4% (NRC, 1980). The FBCR treatment approached this upper limit and all treatments were above .3%. The most critical effect of high dietary S levels is the associated decrease in the availability of Cu. Forage was adequate in Cu; however, the suboptimal Cu status of cattle grazing all the pastures may have approached Cu deficiency. Serum Cu levels and liver Cu levels were below the deficiency threshold (Claypool et al., 1975). This may have resulted from the high dietary S or may have been related to any of the other dietary factors which may interfere with Cu-absorption from the gut. Factors interfering with Cu absorption include: Mo, Cd, Zn, Ni, Fe, Ca, P, Pb, Al and others (Ammerman et al, 1977; Bremener, 1979; Merry et al., 1983; Speers, 1984; and Rosa et al., 1982).

The availability of Cu within the gastrointestinal tract may be diminished by excessive levels of Mo and SO_4 in the diet (Huisingh et al., 1969; Suttle, 1974; and Bremner and Young, 1978). A 2:1 Cu:MO ratio can cause Cu deficiency in cattle and sheep. The production of inorganic Cu-thiomolybdates, Cu-sulfide and Cu-molybdates inhibit Cu availability. However, an additional proposal suggests that excess Mo and SO_4 may also be taken up and induce the de novo synthesis of a protein which selectively binds Cu and sequesters it into the kidney for excretion (Bremner and Young, 1978). The low Mo level (.05 ppm) of the forage did not likely interfere with Cu-availability.

In sewage sludge-amended fields, forage Cu levels were six-fold greater than control pastures but the cattle grazing sewage-amended pastures had one-fifth the liver Cu stores (10-fold below deficiency levels) of those grazing the control pasture (Baxter et al., 1983). This exemplifies the importance of mineral interactions and the lack of knowledge the absolute levels of minerals impart on true availability. Hartmans (1974) suggested that Cu levels in the diet are not indicative of Cu-availability, and that the most diagnostic indicator of Cu status is primarily liver Cu levels and secondarily, serum Cu levels. He also asserts that availability of Cu is most influenced by digestibility of the diet more so than the Mo, S, energy or protein content.

The high S levels in the forage may interfere with Cu availability. Previously, researchers have suggested that S interfered with Cu availability only by being a part of a Cu-Mo-SO_4 complex (Huising et al., 1969); however, recent work has suggested that elevated S per se may also depress Cu absorption. Suttle (1974) found .4% S decreased Cu-availability 16 to 44% when the source was Na_2SO_4, cysteine or methionine. Cysteine-S had the greatest effect on Cu-availability. When 4.5 ppm Mo was added to the SO_4-supplemented diets Cu-availability decreased by 42 to 70%. No effect of additional Mo without S supplementation was reported. Sulfur as an environmental pollutant decreased body gain and brain, liver and heart Cu levels (Hennig et al., 1974). In research in which .2% SO_4 or elemental S was supplemented to ovine, sulfate reduced serum Cu, PCV and hemoglobin, as well as Cu retention and liver Cu stores (Goodrich and Tillman, 1966). Sulfate also reduced Ca retention. Elemental S had no significant effect on blood or tissue parameters. It appears that an organic or inorganic S source may decrease Cu-availability. Sulfate is reduced in the rumen, and made available for formation of CuS which is relatively insoluble and unavailable for absorption.

Previous research suggested that grazing tall fescue pastures may induce Cu deficiency in cattle (Stoszek et al., 1979). Cattle that grazed tall fescue pastures had decreased weight gains, liver Cu, plasma Cu and ceruloplasmin levels, compared to cattle grazing quackgrass (Agropyron repens). These symptoms were ameliorated by Cu supplementation. The tall fescue was similar to quackgrass in crude protein and ADF; however, it had elevated levels of S (.34 vs .16%), Mo (2.3 vs 1.2 ppm), Cu (6.6 vs 4.6 ppm) and a tendency for decreased Cu:Mo ratio, compared to quackgrass. The authors suggested that the S and Mo interfered with Cu absorption, but postulated that other factors may also be involved. One of the factors mentioned was soil consumption.

Because of the low forage availability, soil consumption may have been a problem; this was confirmed by the visible signs of soil in many of the esophageally collected samples. Suttle (1975) suggested that Cu availability was decreased by soil consumption, independent of soil Mo level (2, 30, or 41 ppm Mo). He also noted that swayback (caused by Cu deficiency) was most common in winter, even though the Cu:Mo ratio was fairly constant throughout the year. He also noted that, during mild winters in which supplemental feeding was at a minimum, the cases of swayback increased.

Elevated Cd and Zn levels greatly suppress Cu availability for absorption (Mills, 1974). An increase in dietary Cd from .7 to 3.5 ppm reduced liver Cu repletion levels by 80%. Liver Cu levels were also decreased by 100 ppm dietary Zn. Hennig and coworkers (1974) found that additional Cd decreased liver, heart, hair, and total carcass levels of Cu in goats. In sorting goats by brain Cu levels, they found that animals with brain Cu levels below 8.9 ppm had a 10-fold reduction in liver Cu levels and twofold increase in liver and kidney Cd levels. All animals in the present grazing trial had brain Cu levels below 8.9 ppm. Cadmium levels in forages collected during the grazing trial were nondetectable ($< .2$ ppm). Early spring growth collected the following year had depressed forage Zn in the amended pastures, as would be expected by the increase in soil pH.

Blood PCV was higher ($P < .05$) and the hemoglobin levels tended to be elevated in cattle grazing FBCR-amended pastures. In a study of the effect of age on cattle blood parameters, hemoglobin levels decreased with age from 13.5 to 10 mg/dl with an average of 12.5 mg/dl; whereas, PCV ranged from 54 to 47% with an average of 49% (Shirley et al., 1968). In a report of supplementary Fe effect on Fe status, PCV of nonsupplemented calves ranged from 33.8 to 34.4% whereas, orally Fe supplemented calves had PCV ranging from 34.3 to 38.5% (Getty et al., 1968). Hemoglobin levels were 9.0 and 10.3 mg/dl in the nonsupplemented and supplemented calves, respectively. This would indicate that PCV of cattle in our grazing study averaged low-normal, and hemoglobin levels were normal. Thus the increased PCV in the steers grazing FBCR pastures may have biological significance. In low-Cu status lambs PCV and hemoglobin levels averaged 36% and 15.5 mg/dl, respectively, and in high-Cu status lambs, the PCV and hemoglobin levels averaged 42% and 17.4 mg/dl, respectively (Kline et al., 1971).

Copper deficiency may produce hypochromic, microcytic anemia (NRC, 1984), as does Fe deficiency. In Cu deficiency there is a reduction of circulating levels of the Cu-containing protein, ceruloplasmin (Frieden, 1977). Ceruloplasmin is thought to be a ferroxidase which reduces the tissue Fe^{+++} so that it may be transported by transferrin to the reticulocyte for hemoglobin synthesis. Therefore, in Cu deficiency there is a decrease in serum Cu, ceruloplasmin, serum Fe, hemoglobin, and adequate or elevated tissue Fe stores are found. In Cu deficiency, however, subsequent Fe release from tissue stores into circulation and hemoglobin synthesis do not occur at the normal rate (Roeser et al., 1970). Spleen and liver Fe levels of all the grazing cattle were adequate compared to previously reported levels (Rosa et al., 1982; Ammerman et al., 1974; and Doyle and Spaulding, 1978). However, in the present study liver Fe levels of cattle grazing FBCR- and limestone-amended pastures were lower ($P < .05$) than those of control cattle, and spleen Fe levels tended to be lower. This may indicate that cattle grazing FBCR-amended pastures were in better Cu status than control cattle. In cattle grazing ranges in Panama, tissue samples from one of three ranges showed reduced liver Cu (21 ppm) and highly elevated spleen and liver Fe, suggesting that geographic location and soil parameters may greatly influence Cu availability (Ammerman et al., 1974). The cattle in our study were in suboptimal Cu status. This deficiency may have been brought about by the high level of S in the pastures. Also the poor pastures may have induced a large amount of soil ingestion. There is some indication that FBCR may have somewhat elevated the Cu status of the grazing steers. If this assumption is correct, it would seem that the additional complement of S was not interfering with Cu absorption.

The residual effect of FBCR elevated forage Pb above limestone amendment. Lead is generally insoluble in soils and liming normally decreases Pb availability (Kabata-Pendias and Pendias, 1984). Movement of Pb within the plant is minimal. The level of forage Pb from the FBCR-amended pastures was 50-fold lower than the maximum tolerable level for ruminants (NRC, 1980) which suggests that Pb would not present a problem. Lead levels in bone, liver, kidney, spleen, and brain were similar to those found in sheep fed 0 or 10 ppm Pb, in contrast to those fed 500 to 1000 ppm Pb, suggesting that Pb levels were normal (Frick et al., 1976). Lead levels in the rumen contents were not significantly affected by treatment. In the tissues in which Pb was detectable (liver, kidney, hair, spleen, brain, rib and long bone), the level was similar in all treatments. Lead accumulated to the greatest extent in the bone samples. Ninety percent of the Pb in the body is found in bone (Ammerman et al., 1977). Elevated Pb in the animal may cause anemia due to interference in heme synthesis; however, high levels of dietary Ca protects against Pb toxicity (Ammerman et al., 1977). Lead supplemented at 1000 ppm decreased brain Fe levels and increased Zn levels; however, it had no other effect on the Mn, Cu, Fe, Zn, Mg, Ca, or P levels of liver, kidney, heart, spleen, bone or muscle (Frick et al., 1976).

In samples of the early spring forage taken during the following year, Ni levels were depressed as was the level in the rumen contents of cattle grazing pastures amended with FBCR and limestone. Soil pH greatly influences Ni uptake by plants (Kabata-Pendius and Pendia, 1984) such that, Ni may be decreased several fold by a change in one pH unit. Also important in Ni availability is the Ni:Fe ratio. Nickel level in forage is extremely stable and independent of geography at levels from .1 to 1.7 ppm (Kabata-Pendias and Pendias, 1984). Nickel has recently been determined to be an essential micronutrient in animal nutrition. The requirement for Ni is approximately 1 ppm for growing steers (Spears, 1984). It is infrequent to find a Ni deficiency in cattle. Nickel may exacerbate Fe deficiency and elevated Fe, Cu and Zn may interfere with Ni absorption. Nickle deficiency symptoms include anemia, decreased bone and liver Zn and depressed SGOT activity. During the grazing trial, detectable levels of Ni were found in the liver, spleen, kidney, lung and hair samples. Liver, kidney, and lung levels were below control levels in a trial in which 0 to 1000 ppm Ni were supplemented to cattle (O'Dell et al., 1971). At the extremely high dietary Ni levels, kidney Ni was elevated 10-fold. In the present study liver Ni levels were lowest in cattle grazing FBCR-amended pastures. The lower level of Ni suggests one more reason for a seemingly increased Cu status in cattle grazing FBCR-amended pastures.

The Cd levels of forage samples taken during the grazing trial were below .2 ppm (undectable). Cadmium solubility is directly affected by soil pH; however, Cd is most soluble at a pH range of 4.5 to 5.5 (Kabata-Pendias and Pendias, 1984) and least soluble in soils with a pH greater than 7.5. Cadmium levels of plants are generally < 1 ppm, dry basis. In animals Cd is generally deposited in soft tissues. The tolerance to Cd increases with higher dietary Cu and Zn levels (Ammerman et al., 1977). Chronic Cd toxicity may depress Cu status; however, high dietary levels of S and Ca will decrease toxicity symptoms (Ammerman et al., 1977). Cadmium levels were only detectable in the rib and long bone samples. Long bone levels of Cd were depressed in animals grazing FBCR- and limestone-amended pastures.

Chromium levels were below .2 ppm in all forage samples collected during the grazing trial. Generally, Cr is found in plant samples at levels of .02 to .20 ppm (Kabata-Pendias and Pendias, 1984). Chromium levels were detectable in liver, kidney, spleen, rib, long bone and hair samples. In the rib samples, Cr was depressed by FBCR- and limestone-amendments. None of the samples exhibited Cr levels higher than typically reported.

Calcium and S fertilization has been shown to alter digestibility of forage components (Rees and Minson, 1976 and 1978; Glenn and Ely, 1981 and Jones et al., 1982). Calcium fertilization of pangola grass grown on a Ca-deficient site increased dry matter, hemicellulose and organic matter digestibility in sheep (Rees and Minson, 1976). The ADF content was depressed and the ash and Ca level were increased by Ca fertilization. The increased intake of Ca-fertilized hay was not only due to the increase in digestibility, but also due to a decrease in retention time within the reticulo-rumen (Rees and Minson, 1976). The authors concluded that the increased digestibility of Ca-fertilized grass was due to the alteration of the structural composition of the grass, since a companion treatment of nonfertilized grass plus Ca supplementation did not exhibit the same effect. They could not explain the differences in retention time. In our work, there was no difference in in vitro dry matter digestibility.

Sulfur levels in forage samples were higher in FBCR-amended pastures. Pangola grass dry matter digestibility was not significantly altered by S fertilization; however, cell soluble digestibility was depressed (Rees and Minson, 1977). The decrease in cell soluble digestibility was attributed to a decrease in reticulo-rumen retention time. The ADF level was depressed in the S-fertilized hay. The overall increase in nutritive quality was due to an amelioration of S deficiency. Sulfur fertilization of orchardgrass increased crude protein and decreased NDF, lignin and hemicellulose levels (Panditharatne, 1982). Supplemental S also increased IVDMD (Jones et al., 1982). The ADG was elevated in lambs fed S-fertilized subclover or ryegrass hay; however, IVDMD was elevated only in the ryegrass hay. Serum-S levels were well correlated with dietary sulfate intake ($r = .90$); whereas, total S intake had a lower correlation ($r = .41$). Glenn and Ely (1981) suggested that S fertilization may increase ruminal utilization of tall fescue which may be the limiting factor in tall fescue digestibility. The S levels of forage in our grazing study were well above minimum requirements. Therefore, the effect of S fertilization, often attributable to an amelioration of S deficiency, is not important in this study. This may suggest that use of FBCR as a source of S for Appalachian reclaimed mine pastures high in S is not useful.

There seems to be no problem associated with the use of FBCR at the levels used. However, higher rates of application and prolonged use may induce mineral problems in grazing animals. Of the minerals studied in this project, Cu seems to be the most limiting as far as animal availability. With prolonged use, other mineral deficiencies or toxicities may appear. Since the heavy metals were not found at high levels in the FBCR, perhaps the most toxic component of the FBCR is S. The soil levels of sulfate-S were increased sevenfold with the application of FBCR and the forage levels were increased .05 percentage unit above the already dangerously high levels. However, associated with the FBCR-amended pastures is an increased soil pH and Ca levels which may ameliorate some of the effects of the additional complement of SO_4. In future studies, further work with the Cu and Fe status of the grazing animals is warranted. Metabolism trials with the forage from the trial site should be conducted. This may also give some information as to the importance of soil ingestion. A possible additional diet of native forage with 10% reclaimed mine soil may give even more information. Particular attention to Fe and Cu metabolism is warranted. Early metabolism work with native forage from Sullivan surface mine suggested that lambs were in negative Fe balance. One other facet of the metabolism trial could be the effect of FBCR on cell wall component digestibility as has been assessed in previous research with S and Ca fertilization. Levels of ceruloplasmin and the health and normality of red blood cells need to be quantified.

Amendment with FBCR seemed to result in an overall elevation of forage quality as seen by the reduction of cell wall components and an elevation in Ca and Cu and a decrease in Mn and Ni. The additional Ca level may cause a beneficial environment for botanical shift and this effect needs to be quantified.

In conclusion, FBCR applied to reclaimed mine pastures for 1 yr at 6760 kg/ha was not detrimental to forage yield and composition, or to animal health and performance. In contrast, FBCR amendment may have resulted desireable changes in the forage composition which enhanced Cu availability to be enhanced in the grazing steers.

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APPENDIX

MATERIALS AND METHODS

Field Trial

The area used for the grazing trial is located approximately 8 km south of Beckley, WV. The area had been previously (6 yr ago) mined by mountain top removal and the overburden was replaced with little regard to strata in relation to chemical or physical characteristics. The area was seeded shortly after replacement of the overburden. The soil bulk density, porosity, sand, silt and clay component of the third replicate was 1.60g/cm^3, 32.1%, 30.0%, 46.0% and 24.0%, respectively (Robinson, 1984). The experimental site included 7.2 of the 100 ha at the Sullivan mine site.The area was divided into three replicates of three .8 ha pastures. The treatments applied to the pastures were a control, 6.76 t FBCR/ha, and 3.38 t dolmitic limestone/ha. The amendments were applied in split applications to the .8 ha pastures in which two-thirds of the total amendment was applied in the first application. All pastures were fertilized with 488 kg 0-25-25/ha at the start of the trial. Reclamation of the first and second replicate included seeding with tall fescue (Festuca arundinacea), orchardgrass (Dactylis glomerata), and birdsfoot trefoil (Lotus corniculatus). At the time of grazing, these replications were predominately tall fescue and birdsfoot trefoil. The third replicate contained a highly varied assortment of forage including fine leaf fescue (Festuca rubra), red top (Agrostis alba), sericea lespedeza (Lespedeza cuneata), tall fescue and some clover (Trifolium spp.).

The sericea was eliminated after the first grazing. Since the time of seeding, the pastures had not been managed to any extent except for occasional clipping of the third replicate.

In April, 1983, 80 yearling steers were brought in for a 5 d period to mob graze the first and second replications. This practice effectively removed most of the mature and dead forage. Cutting and removal of the dead forage was not possible because of the extremely rough terrain.

On May 24, 1983, 18 yearling Angus steers were randomly allotted to treatments based on three blocks formed by initial weights. The initial weight spread for the long yearlings was 255 to 326 kg. The steers had been used the previous winter in Middleburg, Virginia on a tall fescue silage experiment. One esophageally-cannulated steer was added to each treatment group of cattle on June 4, 1983. This steer periodically grazed with the experimental cattle and was used for forage sampling. Pastures were rotationally grazed based on forage availability. Steers from all treatments were moved at the same time. Amendments were applied immediately prior to rotating the cattle into a new pasture. Cattle were exposed to the pasture treatments a total of six times (twice on each replicate). Cattle were rotated to a new pasture for grazing eight times (replicate 1 and 2 were grazed three times each).

Steers were weighed initially and at 2-wk intervals throughout the grazing trial. At each weight date, blood samples were collected via jugular puncture from all experimental steers. At the end of the grazing trial all steers were slaughtered by allotment block (two steers per treatment/day) during the week of September 14, 1983. Tissue weights and samples were taken.

Forage yield strips were collected pre- and postgrazing by rotary mower. The mower was set at a height of 4 cm and four strips/pasture were collected. Random grab samples were also procured pre- and post-grazing in each grazing period. These samples were taken at every 10 paces as the pasture was crossed diagonally four times; each crossing was treated as a separate sample. Esophageal samples were collected twice per day for 2 d upon rotating into a new pasture. Grab samples and esophageal samples were analysed for quality components and mineral content. On May 8, 1984, the following year, grab samples and yield strips were taken from all pastures. These samples were used to determine the residual effect of the previous year's treatment.

In November, 1983 soil samples of the surface horizon (0 to 10 cm depth) were taken from each pasture. Three samples, consisting of twenty 2 X 10 cm cores, were taken in each pasture.

<u>Forage Analysis</u>

Yield samples were dried in a 65 C oven for a least 4 d prior to weighing. Dry matter yields from the 4.5 m x 75 cm strip, were calculated. Pasture grab samples were also dried at 65 C for at least 4 d. The dried samples were ground through a stainless steel Wiley mill fitted with a .5 cm screen. If warranted, a subsample was taken at that time. These samples were then ground through a cyclone mill fitted with a .5 mm screen. Compositing of samples (two samples composited into one bag) was completed at this stage for some of the analyses.

Esophageally collected samples were freeze dried for a 5-d period prior to grinding through the Wiley and the cyclone mill. These samples were also composited at this time so that there was one sample representing the AM and PM collection for each pasture on each sampling day.

Esophageally collected samples and pasture grab samples (1983 and spring, 1984) were analyzed as follows: Dry matter and ash were determined (AOAC, 1980). Forage samples were acid digested (Hern, 1979) prior to mineral analysis. In this method 2 g of plant tissue where predigested (10 h at room temperature) with 20 ml of double distilled nitric acid prior to hot digestion with 5 ml of redistilled perchloric acid. After the digestion, the samples were diluted to 25 ml in 2.5 M nitric acid; the volume included the appropriate amount of Triton-X[3] (a surfactant) and standard Co solution[4] to be .05% and 40 ppm, respectively.

Quantitative analyses for Cu, Fe, Co, Mn, Zn, Na, Al, P, Mg, and Ca were completed with a Bausch & Lomb inductively couple plasma (ICP) emission spectrophotometer. The relative presence of heavy metals (Pb, Cd, Cr, and Ni) was also determined by ICP. Upon evidence of measurable levels of these elements, they were quantitated by atomic absorption spectrophotometry. Total S was determined on the dry plant material by using a Leco automated sulfur analyzer (Hern, 1984).

In vitro dry matter digestibility (IVDMD) was determined by the

[3] Fisher Scientific, Allied Chemical Co., Springfield, NJ. Cat. # C5282-100.

[4] Fisher Scientific, Allied Chemical Co., Springfield, NJ. Cat. # SC193-500.

Tilley and Terry (1963) two stage technique as modified by Barnes (1969). The analysis was completed in duplicate on all forage grab samples and esophageally collected samples.

Plant cell wall components were determined on all forage samples. The procedures described by Goering and Van Soest (1970) were used for the neutral detergent fiber (NDF) and acid detergent fiber (ADF). Permanganate lignin and cellulose were determined on the ADF residue (Van Soest & Wine, 1968).

The total N of the plant material was determined by an automated N, C, H analyzer (Leco Corp., 1980). After combustion of the dry plant material the released N is analyzed by thermal conductivity.

The mineral content of FBCR and limestone was determined by the ICP after digestion. These materials, because of their low level of organic matter and physical characteristics, were acid digested by refluxing for 2.5 h with a nitric-hydrochloric acid mixture (Hern et al., 1978).

Animal Tissue

Animal tissue samples were collected within 30 min of exsanguination. Each sample was rinsed in distilled-deionized water prior to freezing. Liver, kidney, brain and spleen were quick-frozen in liquid N. All other samples were placed on ice prior to being placed in a freezer within 3 h.

The entire liver was weighed intact before subsampling. The liver was cubed (approximately 3 cm cubes), then randomly sampled. Both kidneys were weighed and kept for analysis after the kidney fat was removed. The spleen was weighed intact and the lower unattached portion was frozen for analysis. The entire brain was taken for analysis. The heart was also frozen intact after it was weighed.

The lower section of the right bronchial tubes was taken as the lung sample. The portion of the longissimus muscle spanning the 9th to 11th ribs was collected for analysis. Hair samples were obtained, while the carcass was hanging, by clipping the coat on the back cranially from the 13th rib.

One m of duodenum was sampled just post the bile duct entrance; the large intestine (colon) was collected just anterior to the rectum. The contents of the intestines were emptied and the tissues were rinsed with distilled-deionized water. Rumen fluid and contents were sampled by entering the rumen under the spleen. The rumen fluid was filtered through four layers of cheese cloth prior to freezing. Urine was collected by puncturing the bladder with a 18 gauge needle fitted to a 50 ml syringe. The gall bladder was slit and the bile was collected into an acid-washed glass jar. The final blood sample was taken upon exsanguination.

The right 13th rib and both proximal phalanxes were taken for analysis. The bones were kept frozen until they were sampled using a drill press fitted with a 1.1 cm tungsten steel high speed twist bit. Approximately 12 holes/bone were drilled and the shavings were collected for analysis. The samples were defatted by ether extraction with a Soxtet system by Tecatur (1984), then dry ashed in a 600 C muffle furnace for 36 h prior to wet ashing for mineral analysis.

Soft tissues were freeze dried for 5 d. Once dry matter exceeded 90%, the tissues were pulverized in a stainless steel blender. Subsampling, if warranted, was completed after pulverization. Fluid samples (serum, urine, bile and rumen fluid) were analysed on a wet basis. The hair samples were washed by continually shaking with 5% Tween-80 for 4 h. The hair was rinsed numerous times with distilled-deionized water through a filtration funnel, and dried at 60 C for 12 h.

All tissue and fluid samples (generally 2 g or 2 ml) were acid digested using a 4:1 nitric:perchloric acid mixture. Details of the analyses are as described for forage analysis samples. The analytical procedure was altered for the brain and hair samples in that the predigestion included a 20 min period on a preheated hot plate (at full temperature) to insure complete breakdown of organic matter prior to addition of perchloric acid. The room temperature predigestion period was lengthened to 36 h for the bone samples. The quantities of nitric and perchloric acids were halved for serum, urine and bile samples because of the low level of existing organic matter. Mineral levels were determined by ICP as stated in the forage analysis section.

Blood analysis. The biweekly blood samples were procured to determine the overall nutritional status of the steers. The determination included: packed cell volume (PCV), hemoglobin levels, serum glutamic oxaloacetic transaminase (SGOT) activity and a mineral profile. Hemoglobin levels[5] and SGOT[6] were determined colorimet-

[5] Fisher Scientific, Allied Chemical Co., Springfield NJ. Cat. # 2365-22

[6] Sigma Chemical Co., St. Louis, MO. K.#56-UV.

rically; whereas, the whole blood PCV was determined by microhematocrit. Serum minerals were determined by ICP spectrophotometry as previously described.

Soil Analysis.

The pH of the soil samples was determined after dilution (1:1, soil wt:volume) with water or .01 M $CaCl_2$. The dilution with .01 M $CaCl_2$ masked the ionic interference which would be intrinsic to these soils and exacerbated by the treatment.

Statistical Analysis.

Five separate statistical models were utilized to analyze the data. Orthogonal contrasts of control vs. amendment and FBCR vs. limestone were used to determine differences of treatment means.

Forage grab samples were analyzed with regard to treatment, application rate which took into account the split applications and seasonal effect, the effect of grazing (pre- or postgrazing sampling) and the pasture replication. Since the pasture replication was the only random effect, the main effects were tested against the respective two way interactions with pasture replication.

Esophageal samples required a different statistical model since the samples were only procured when the cattle were rotated into a pasture. The model took into account treatment, sampling date, and pasture replication. The sampling date was nested within pasture replication and tested against the date x treatment interaction; treatment was tested with treatment x pasture replication; and pasture replication was tested by date within pasture replication.

The statistical model for steer tissue, carcass weight and the cattle data averaged throughout the entire grazing trial included the effects of treatment, animal block and the animal block x treatment interaction. The interaction effect was used to test whether steers within blocks were affected differently by treatment.

The data from the biweekly blood samples and weight measurements were analysed with regard to treatment, sampling date and animal block nested within treatment. The effect of treatment was tested with the block within treatment error mean square; however, the remainder of the effects were tested against the residual.

The data from the soil samples and 1984 grab samples were statistically analyzed with the effects of treatment and pasture replicate.

APPENDIX TABLE 1. AGENDA OF THE 1983 GRAZING TRIAL

Date	Activity
5/20/83	Eighteen Angus steers were weighed, bled, and allotted to blocks in Blacksburg, VA.
5/23/83	Moved steers to Sullivan surface mine, Beckley, WV.
5/24/83	Applied treatments to Replicate 2; 3628 Kg FBCR, 1814 Kg limestone[1]. Cattle grazing initiated.
6/2/83	Applied treatments to Rep. 1; 3628 Kg FBCR, 1814 Kg limestone. Moved steers to Rep. 1.
6/6/83	Weighed and bled steers.
6/16/83	Observation - pasture 3(L) has minimum forage available, pasture 2(F) has much more forage.
6/20/83	Weighed and bled steers.
6/27/83	Moved steers to Rep. 2 - No application of amendments.
6/30/83	Brushhogged Rep. 1 at about 50 cm height.
7/5/83	Weighed and bled steers.
7/7/83	Moved 1 heaviest steer/treatment off pastures.
7/11/83	Applied treatments to Rep. 3 (3628 Kg FBCR, 1814 Kg limestone).
7/12/83	Moved all steers to Rep. 3.
7/18/83	Weighed and bled steers.
8/1/83	Weighed and bled steers.
8/8/83	Applied treatments to Rep. 1; 1814 Kg FBCR, 907 Kg limestone. Moved steers to Rep. 1.
8/15/83	Weighed and bled steers.
8/24/83	Applied 907 Kg limestone to Rep. 2 - Thunderstorm.
8/25/83	Applied 1814 Kg FBCR to Rep. 2; Moved steers to Rep. 2.
8/29/83	Weighed and bled steers.
9/6/83	Applied Treatments Rep. 3 (1814 Kg FBCR, 907 Kg limestone).
9/7/83	Moved steers to Rep. 3.
9/12/83	Bled steers - scales broken.
9/13/83	Moved steers to Rep. 1.
9/14/83	Weighed steers with beam.
9/15/83	Slaughtered block 1 steers.
9/16/83	Slaughtered block 2 steers.
9/20/83	Slaughtered block 3 steers.
11/83	Soil samples taken
5/8/84	Early spring forage grab samples collected.

[1] Every time animals were moved into a new pasture yield and quality samples taken from the old and new pastures.

APPENDIX TABLE 2. EFFECT OF TREATMENT ON SOIL pH IN SURFACE HORIZON (0-10 cm)

	Treatment			
Solution	Control	FBCR[a]	Limestone	SE
H_2O[b]	5.19	5.52	5.54	.10
.01 M $CaCl_2$[b]	4.65	5.25	5.11	.11

[a]Fluidized bed combustion residue.
[b] Mean of control pastures differs from those of FBCR- and limestone-treated pastures ($P < .01$).

APPENDIX TABLE 3. SOIL COMPOSITION IN THE SURFACE HORIZON (0-10 cm) IN NOVEMBER, 1983.

	Pasture Treatment			
Item	Control	FBCR[b]	Limestone	SE
Organic Matter, %	2.29	2.22	2.23	.11
P, ppm	32.3	44.7	31.9	3.8
K, ppm	72.4	69.7	73.6	23.2
Ca, ppm[c]	557	1024	670	88
Sulfate-S, ppm[c,d]	20.7	167.9	40.0	23.0
Nitrate-N, ppm	3.00	3.22	3.00	.12
Zn, ppm	3.48	3.94	3.35	.30

[a] Air dry basis. Magnesium and Mn levels were above 120 and 16 ppm, respectively. All soil chemical analysis was completed by the Virginia Tech Soil Testing Laboratory, Blacksburg.
[b] Fluidized bed combustion residue.
[c] Mean of FBCR-treated pastures differs from that of limestone-treated pastures (P < .05).
[d] Mean of control pastures differs from those of FBCR- and limestone-amended pastures (P < .05).

APPENDIX TABLE 4. AVERAGE COMPOSITION[a] AND IN VITRO DRY MATTER DIGESTIBILITY (IVDMD) OF FORAGE GRAB SAMPLES TAKEN DURING THE GRAZING TRIAL.

Item	Treatment			SE
	Control	FBCR[b]	Limestone	
		%		
Protein	13.86	14.76	14.07	.74
NDF	60.82	57.16	59.67	2.35
ADF	36.32	36.02	36.31	1.19
Hemicellulose[c]	24.50	21.14	23.36	1.61
Cellulose	28.70	27.42	27.81	.76
Lignin	5.75	6.77	6.11	.33
IVDMD	56.31	54.52	54.24	1.80

[a] Dry basis

[b] Fluidized bed combustion residue

[c] Mean of control pastures differs from those of FBCR- and limestone-amended pastures ($P < .10$)

APPENDIX TABLE 5. AVERAGE MINERAL LEVELS[a] OF FORAGE GRAB SAMPLES TAKEN DURING THE GRAZING TRIAL

	Pasture treatment			
Item	Control	FBCR[b]	Limestone	SE
Ash, %	8.48	9.11	9.79	.26
Ca, %[c]	.483	.803	.804	.053
P, %	.334	.329	.333	.016
Mg, %[d]	.370	.353	.516	.023
S, %[f]	.297	.343	.305	.011
Ca:P[e]	1.54	2.98	2.85	.29
Cu, ppm[e]	6.68	7.96	7.30	.33
Zn, ppm	62.3	66.1	59.1	3.3
Fe, ppm	415	506	624	75
Al, ppm	712	903	1040	153
Mn, ppm	594	585	576	34
Na, ppm[e]	62.9	80.3	78.1	10.5

[a] Dry basis.

[b] Fluidized bed combustion residue.

[c] Mean of control pastures differs from those of the FBCR- and limestone-treated pasture ($P < .01$)

[d] Mean of FBCR-treated pastures differs from that of limestone-treated pastures ($P < .01$)

[e] Mean of control pasture differs from those of the FBCR- and limestone-treated pastures ($P < .05$)

[f] Mean of the FBCR-treated pastures differs from that of limestone-treated pastures ($P < .05$)

APPENDIX TABLE 6. EFFECT OF PASTURE TREATMENT ON STEER TISSUE WEIGHTS[a] AT SLAUGHTER.

	Treatment		
Tissue	Control	FBCR[b]	Limestone
	g		
Liver	4270	4650	4370
Kidney	753	764	784
Spleen	1472	1577	1519
Heart	1267	1296	1273

[a] Fresh basis.
[b] Fluidized bed combustion residue.

APPENDIX TABLE 7. EFFECT OF PASTURE TREATMENT ON MINERAL LEVELS[a] IN HEART

	Pasture Treatment			
Item	Control	FBCR[b]	Limestone	SE
Ca, %	.0188	.0197	.0193	.0015
Mg, %	.102	.102	.0993	.0014
P, %[c]	.971	.974	.947	.009
Na, %	.416	.402	.413	.015
S, %	.628	.661	.627	.020
Cu, ppm	15.3	15.3	15.0	.5
Zn, ppm	68.9	68.0	67.2	1.4
Fe, ppm	201	201	197	4
Mn, ppm	2.11	1.74	1.76	.17

[a] Dry basis. Lead, Al, Ni, Cd and Cr were below detectable limits (.6, 1, .2, .2, and .2 ppm, respectively).

[b] Fluidized bed combustion residue.

[c] Mean for cattle grazing FBCR-amended pasture differs from that of limestone-amended pastures (P = .056).

APPENDIX TABLE 8. EFFECT OF PASTURE TREATMENT ON MINERAL LEVELS[a] IN BRAIN

Item	Pasture Treatment			
	Control	FBCR[b]	Limestone	SE
Ca, %[c]	.090	.096	.071	.007
Mg, %	.054	.054	.053	.001
P, %	1.38	1.42	1.41	.03
Na, %	.570	.562	.554	.014
S, %	.479	.478	.476	.011
Cu, ppm	8.23	8.86	8.14	.52
Zn, ppm	38.0	36.5	38.3	1.1
Fe, ppm	201	201	164	25
Mn, ppm	1.52	1.44	1.37	.05
Pb, ppm	1.01	1.26	.975	.200

[a] Levels expressed on dry basis. Aluminum, Cd, Cr, and Ni are below detection limits (.6, .2, .2 and .2 ppm, respectively).

[b] Fluidized bed combustion residue.

[c] Mean for cattle grazing FBCR-amended pastures differs from that of limestone-amended pastures ($P < .05$).

APPENDIX TABLE 9. EFFECT OF PASTURE TREATMENT ON MINERAL LEVELS[a] IN LONG BONE

Item	Pasture Treatment			
	Control	FBCR[b]	Limestone	SE
Ash, %	66.4	66.3	66.7	.3
Ca, %	33.4	33.4	33.6	.2
Mg, %	.580	.597	.604	.009
P, %	17.0	17.0	17.1	.1
Na, %[c]	.866	.860	.833	.007
S, %	.0333	.0333	.0377	.0027
Cu, ppm	13.0	12.9	12.8	.1
Zn, ppm	99.2	91.4	101	4
Fe, ppm	14.5	12.8	12.8	1.1
Mn, ppm	1.07	1.15	1.12	.05
Al, ppm	21.6	21.3	21.6	1.5
Pb, ppm	52.0	52.0	50.9	1.4
Cd, ppm[d]	12.6	12.1	12.2	.1
Cr, ppm	4.01	4.02	4.13	.086

[a] Ash basis. Nickel was below detectable limits (.6 ppm).

[b] Fluidized bed combustion residue.

[c] Mean for cattle grazing FBCR-amended pastures differs from that grazing limestone-amended pastures ($P < .05$).

[d] Mean for cattle grazing control pastures differs from those of FBCR- and limestone-amended pastures ($P < .05$).

APPENDIX TABLE 10. EFFECT OF PASTURE TREATMENT ON MINERAL LEVELS[a] IN DUODENUM

Item	Pasture Treatment			
	Control	FBCR[b]	Limestone	SE
Ca, %	.0489	.0504	.0453	.0023
Mg, %	.0748	.0783	.0768	.0020
P, %	1.07	1.12	1.14	.04
Na, %	.828	.759	.749	.033
S, %	.698	.715	.713	.011
Cu, ppm	4.58	4.57	5.00	.24
Zn, ppm	92.0	91.9	91.5	2.4
Fe, ppm	83.2	98.8	96.9	6.7
Mn, ppm	17.9	16.3	16.6	1.9
Al, ppm	4.55	4.12	3.82	.78

[a] Dry basis. Lead, Ni, Cd, and Cr were below detectable limits (.6, .2, .2, and .2 ppm, respectively).
[b] Fluidized bed combustion residue.

APPENDIX TABLE 11. EFFECT OF PASTURE TREATMENT ON LARGE INTESTINE MINERAL LEVELS[a]

Item	Pasture Treatment			
	Control	FBCR[b]	Limestone	SE
Ca, %	.0489	.0585	.0536	.0071
Mg, %	.0736	.0736	.0748	.0052
P, %	.786	.815	.822	.015
Na, %	.677	.652	.736	.028
S, %	.667	.697	.708	.015
Cu, ppm	3.84	3.56	4.18	.36
Zn, ppm	103	108	107	2
Fe, ppm	42.1	48.2	55.7	7.4
Mn, ppm	22.6	18.7	19.0	10
Al, ppm	9.57	11.1	11.8	5.1

[a] Dry basis. Lead, Ni, Cd, and Cr were below detectable limits (.6, .2, .2, and .2 ppm, respectively).

[b] Fluidized bed combustion residue.

APPENDIX TABLE 12. EFFECT OF PASTURE TREATMENT ON MINERAL LEVELS[a] IN URINE

Mineral	Pasture treatment			
	Control	FBCR[b]	Limestone	SE
	mg/dl			
Ca	3.06	.612	5.32	2.2
Mg	1.94	2.04	2.99	.63
P	1.13	2.71	--	.13
Na	1.31	1.89	2.55	.51
S	34.4	5.39	4.88	14.3
Zn[c]	.724	.445	.560	.72
Fe[c]	.0930	.0585	.0561	.013

[a] Copper, Al, Mn, Pb, Cd, Cr, and Ni were below detectable limits (.024. .06. .04, .06, .02, .02 and .02 ppm, respectively).

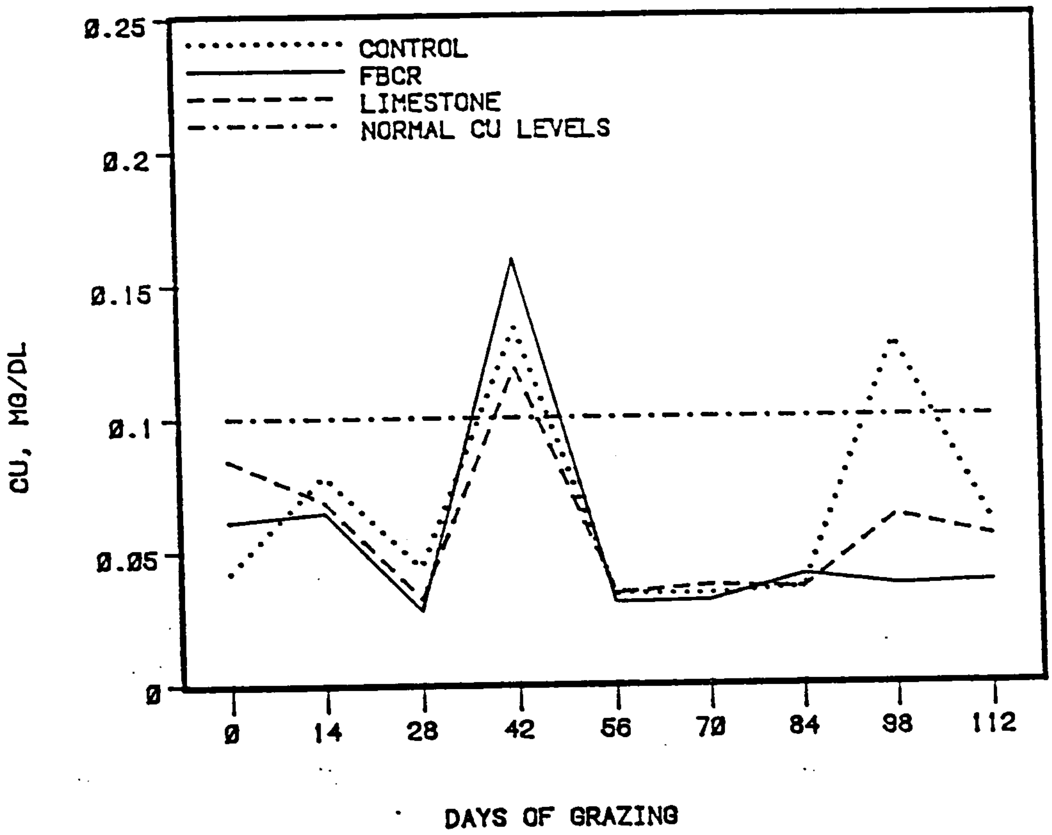
[b] Fluidized bed combustion residue.

[c] Mean for cattle grazing control pastures differs from those of FBCR- and limestone-amended pastures ($P < .05$).

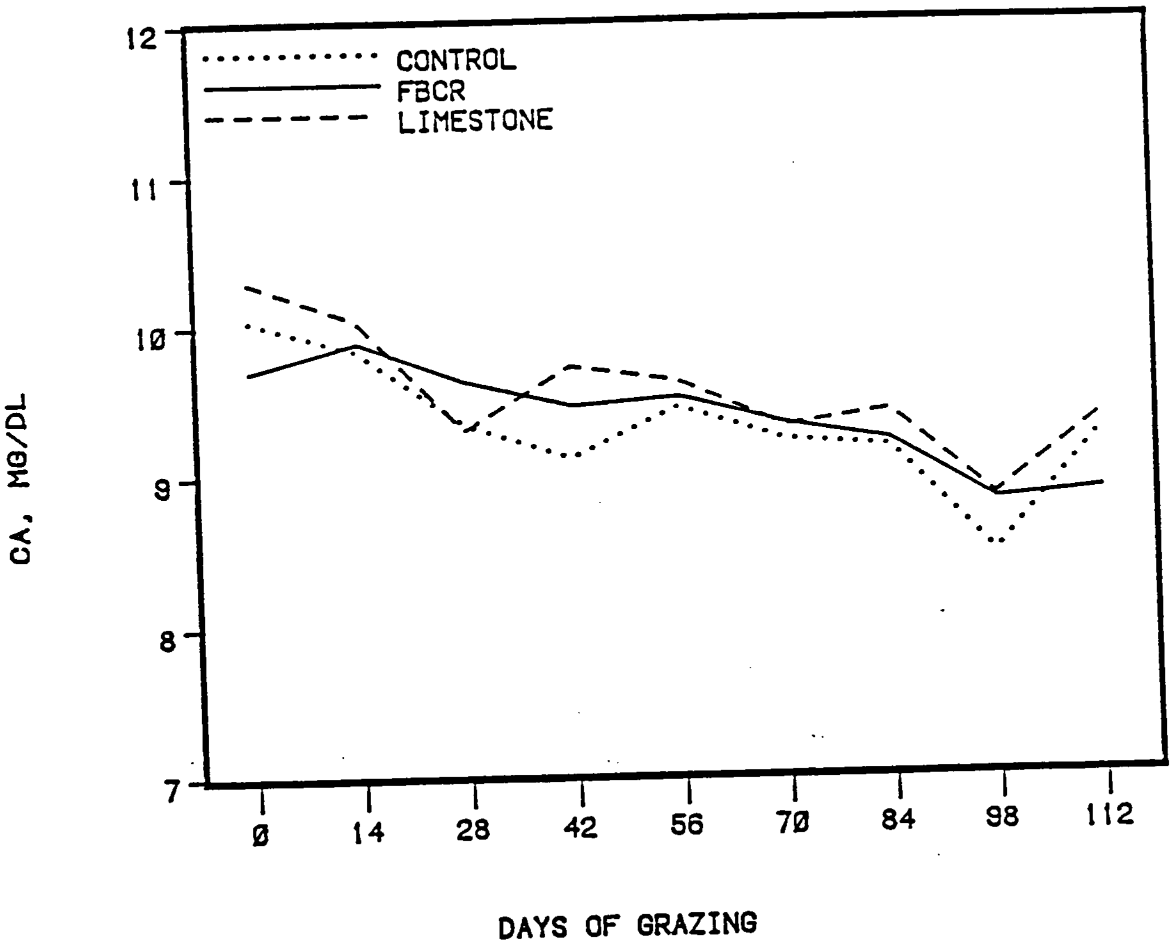
APPENDIX TABLE 13. EFFECT OF PASTURE TREATMENT ON MINERAL LEVELS[a] IN RUMEN FLUID

Item	Pasture Treatment			SE
	Control	FBCR[b]	Limestone	
Ca, %	.0216	.0219	.0258	.0026
Mg, %	.0168	.0132	.0169	.0020
P, %	.0618	.0568	.0637	.0040
Na, %	.235	.249	.237	.014
S, %[c]	.0091	.0067	.0096	.0076
Cu, ppm	.342	.244	.329	.007
Zn, ppm	5.39	4.74	5.50	.39
Fe, ppm	14.8	14.1	17.1	2.0
Mn, ppm[d]	43.6	28.4	36.3	3.8
Al, ppm	9.82	9.29	11.2	2.5

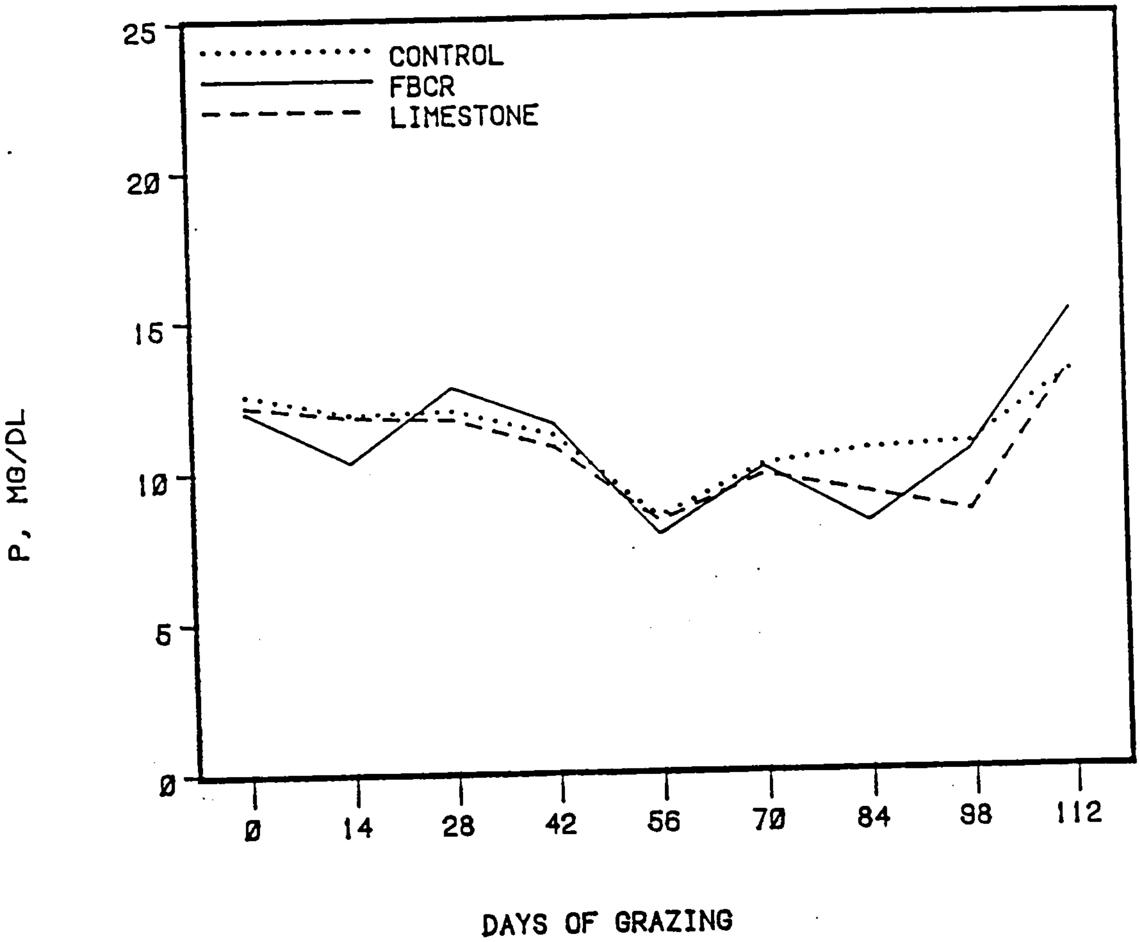
[a] Dry basis. Lead, Ni, Cd, Cr were below detectable limits (.6, .2, .2, .2 ppm, respectively).
[b] Fluidized bed combustion residue.
[c] Mean for cattle grazing FBCR-amended pastures differs from that of limestone-amended pastures ($P < .05$).
[d] Mean for cattle grazing control pastures differs from those of FBCR- and limestone-amended pastures ($P < .05$).



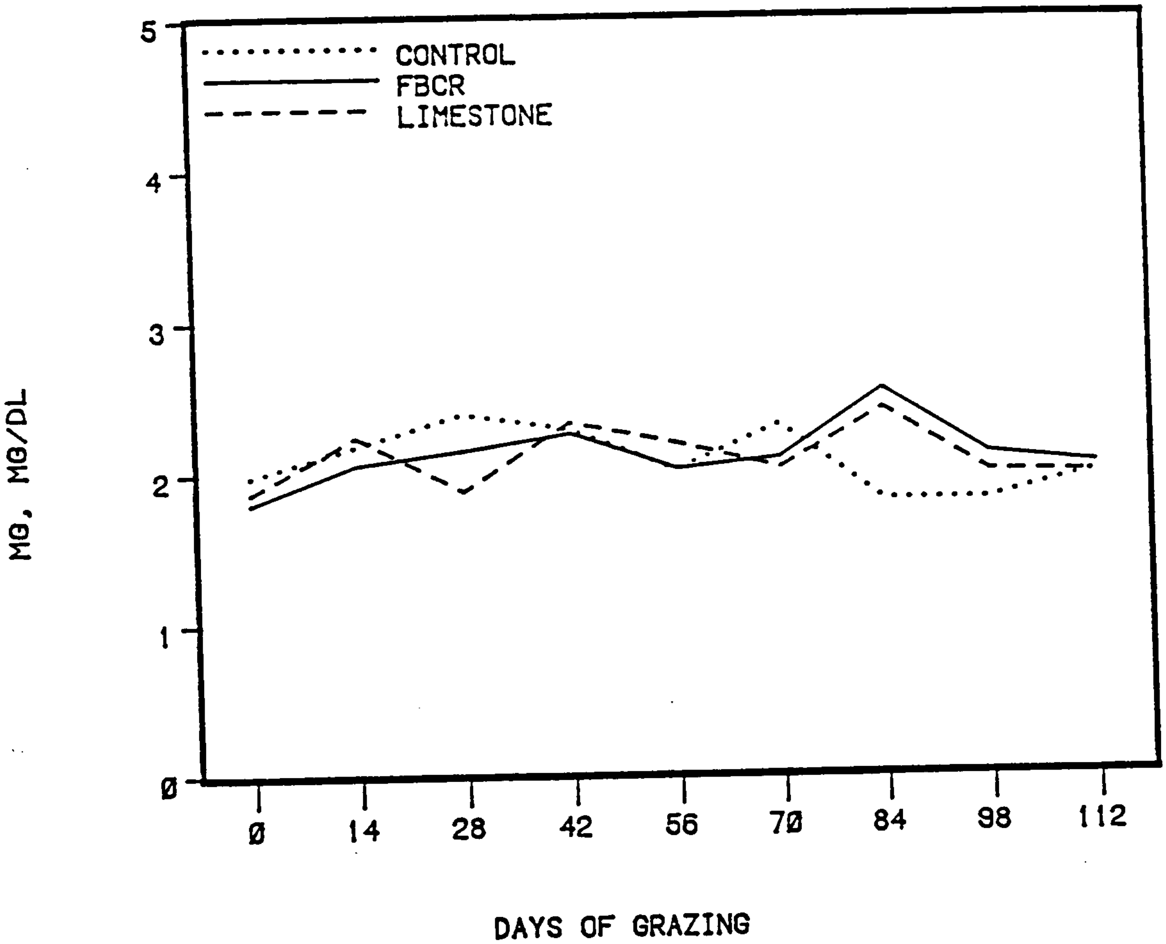
Appendix figure 1. Serum Cu levels during the grazing trial. On d 98 cattle grazing control pastures had higher (P<.01) serum Cu levels than steers did grazing FBCR- or limestone-amended pastures.



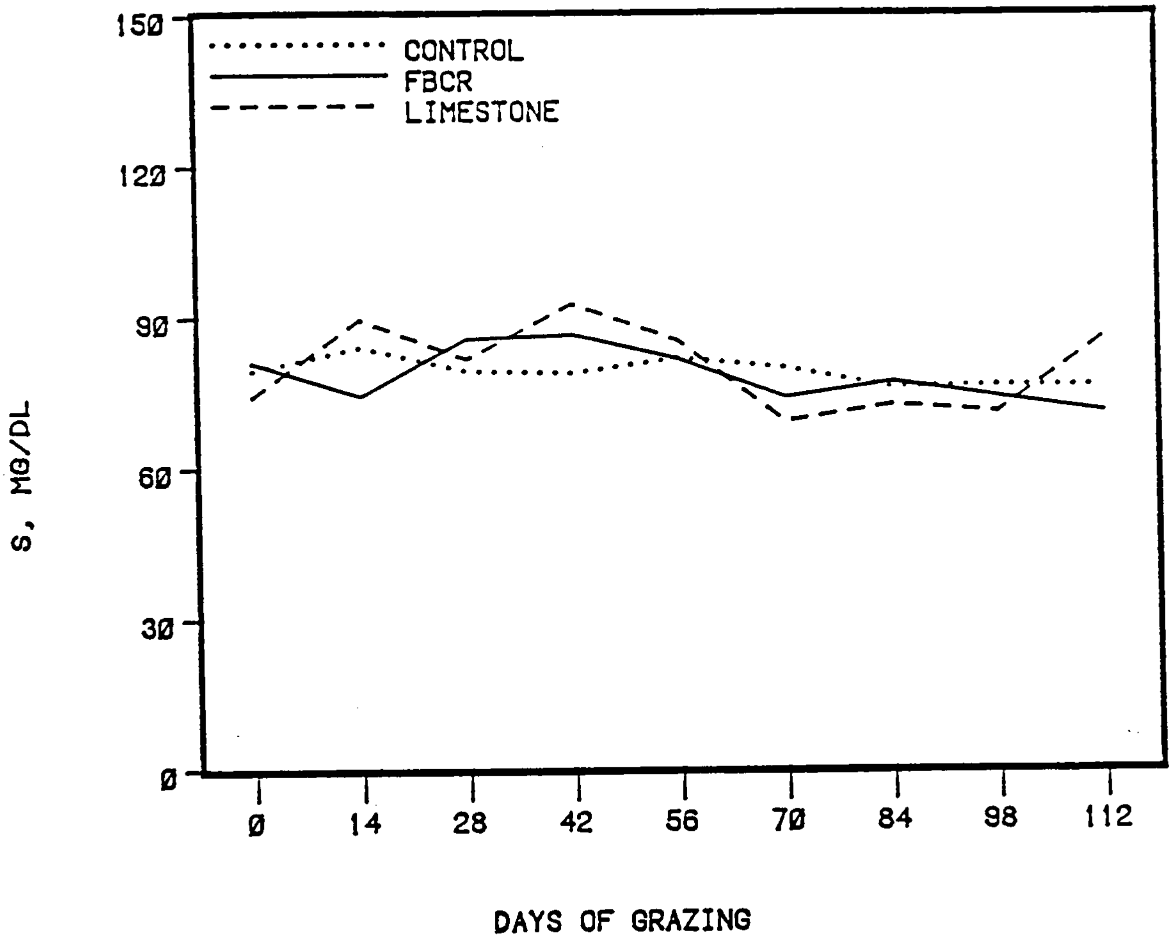
Appendix figure 2. Serum Ca levels during the grazing trial. Steers grazing FBCR-amended pastures had lower serum Ca than did those grazing limestone-amended pastures on d 112 (P<.05).



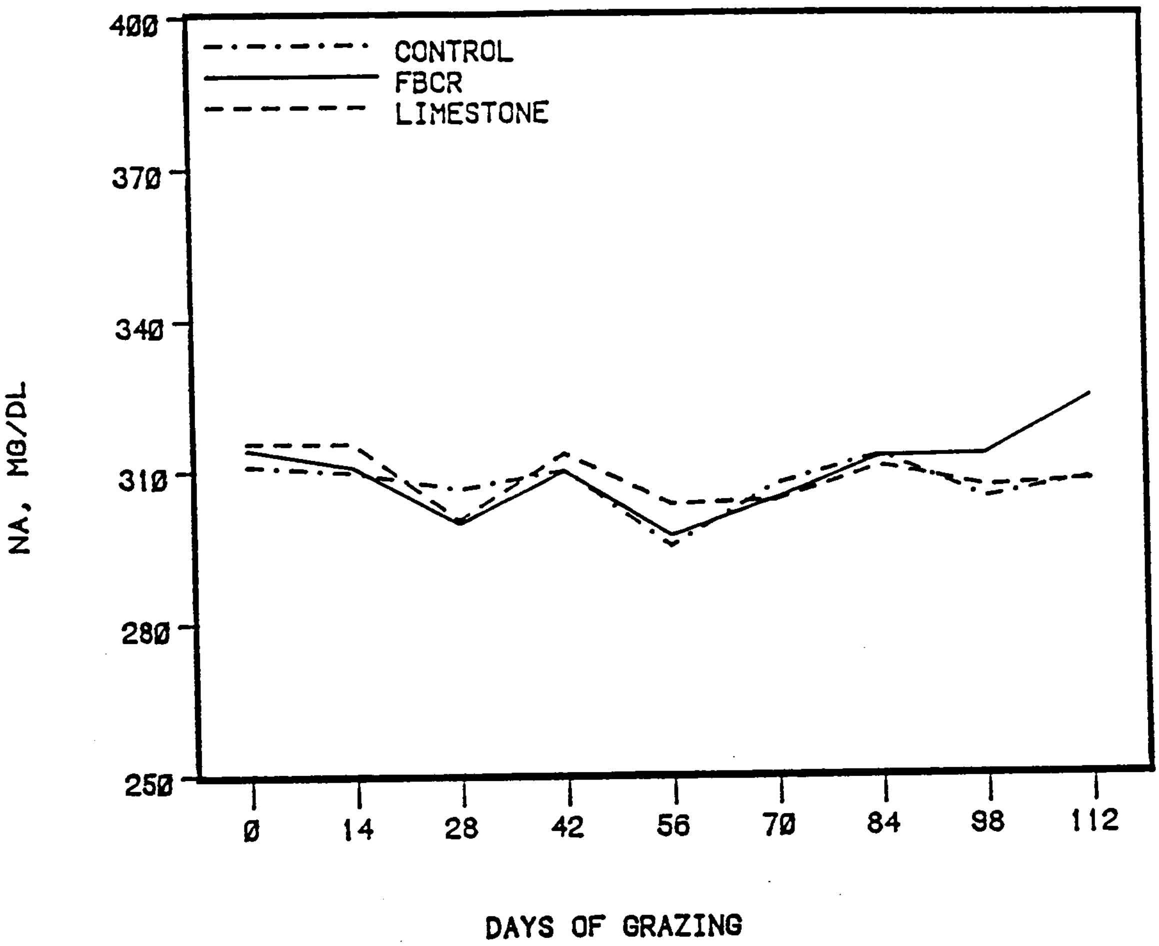
Appendix figure 3. Serum P during the grazing trial. On d 84 steers grazing amended pastures had lower serum P levels compared to those grazing grazing control pastures ($P<.05$). On d 98 steers grazing FBCR-amended pastures had increased serum P compared to thoses grazing limestone-amended pastures ($P<.05$).



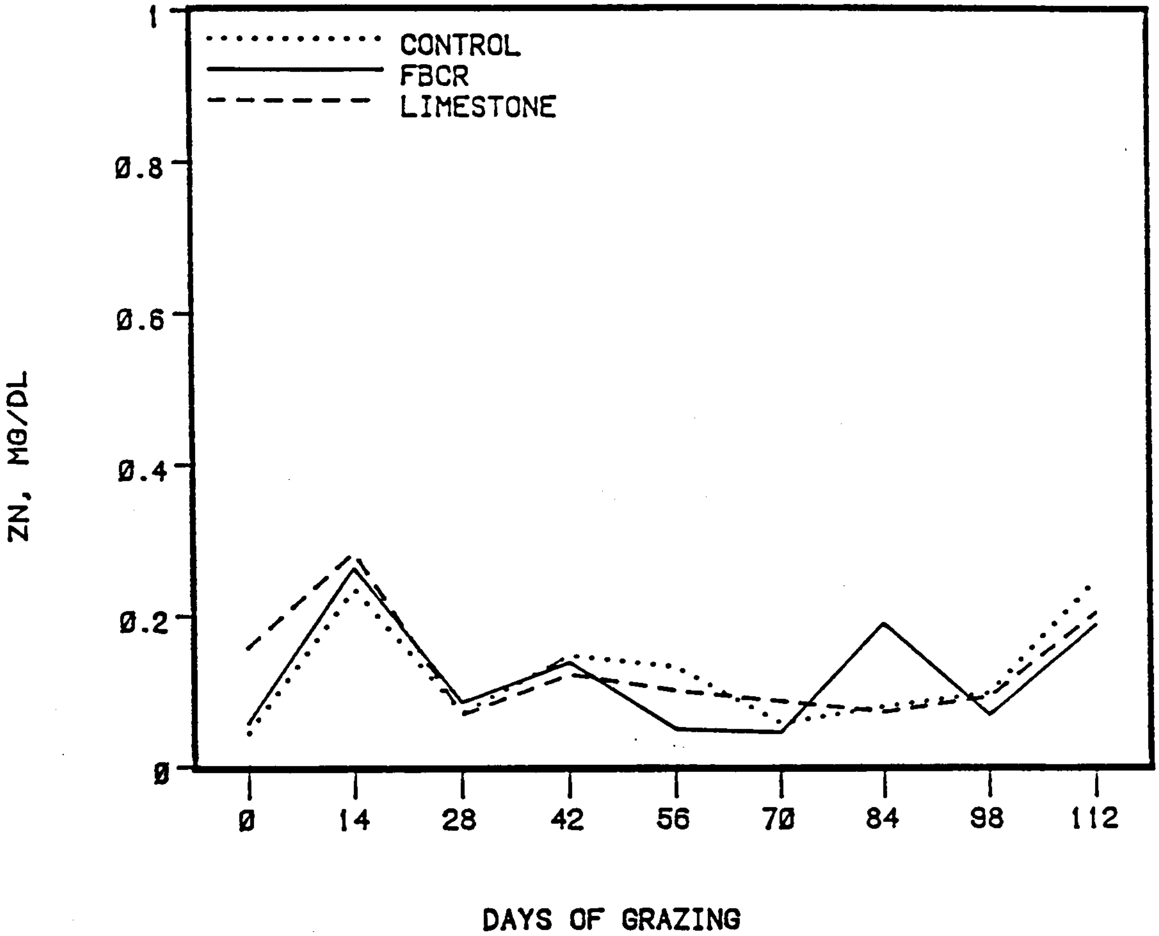
Appendix figure 4. Serum Mg levels during the grazing trial.



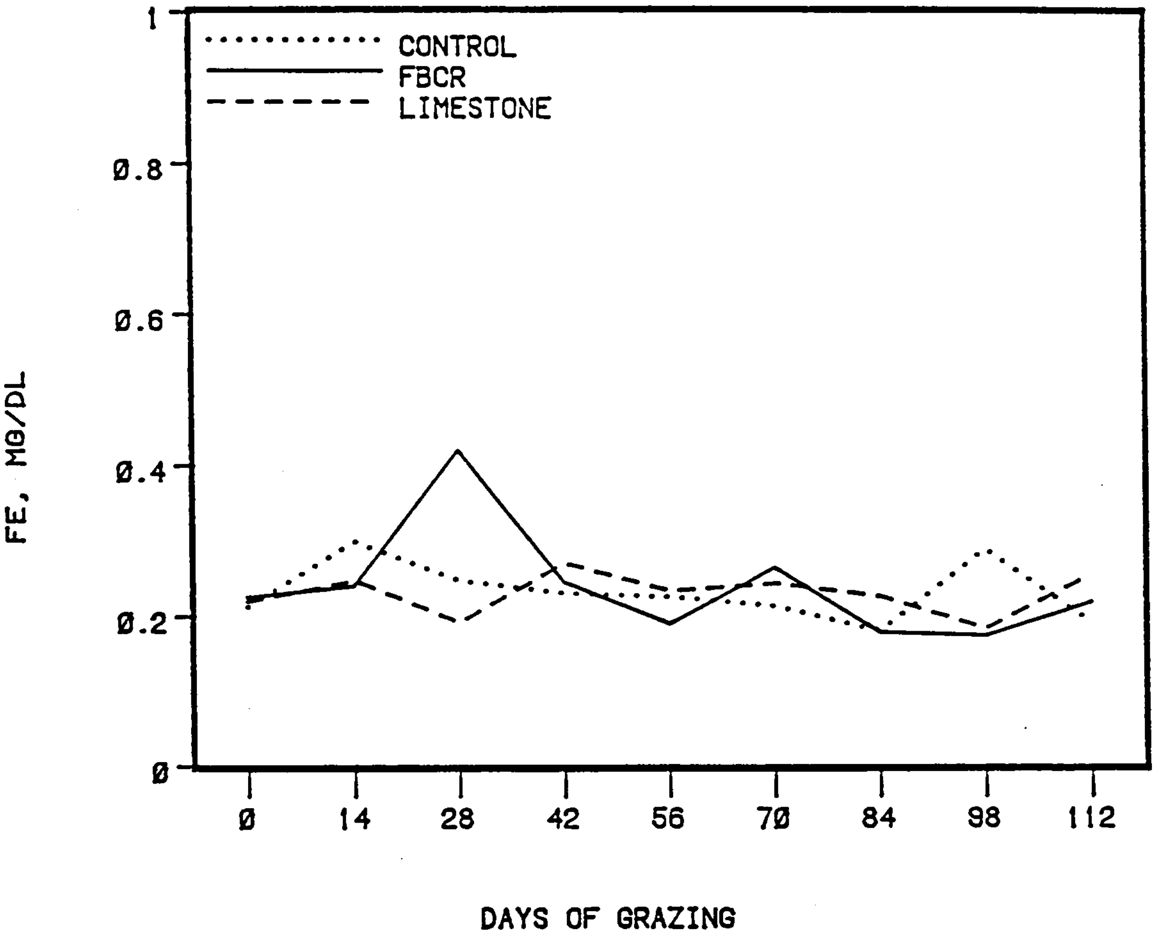
Appendix figure 5. Serum S levels during the grazing trial.



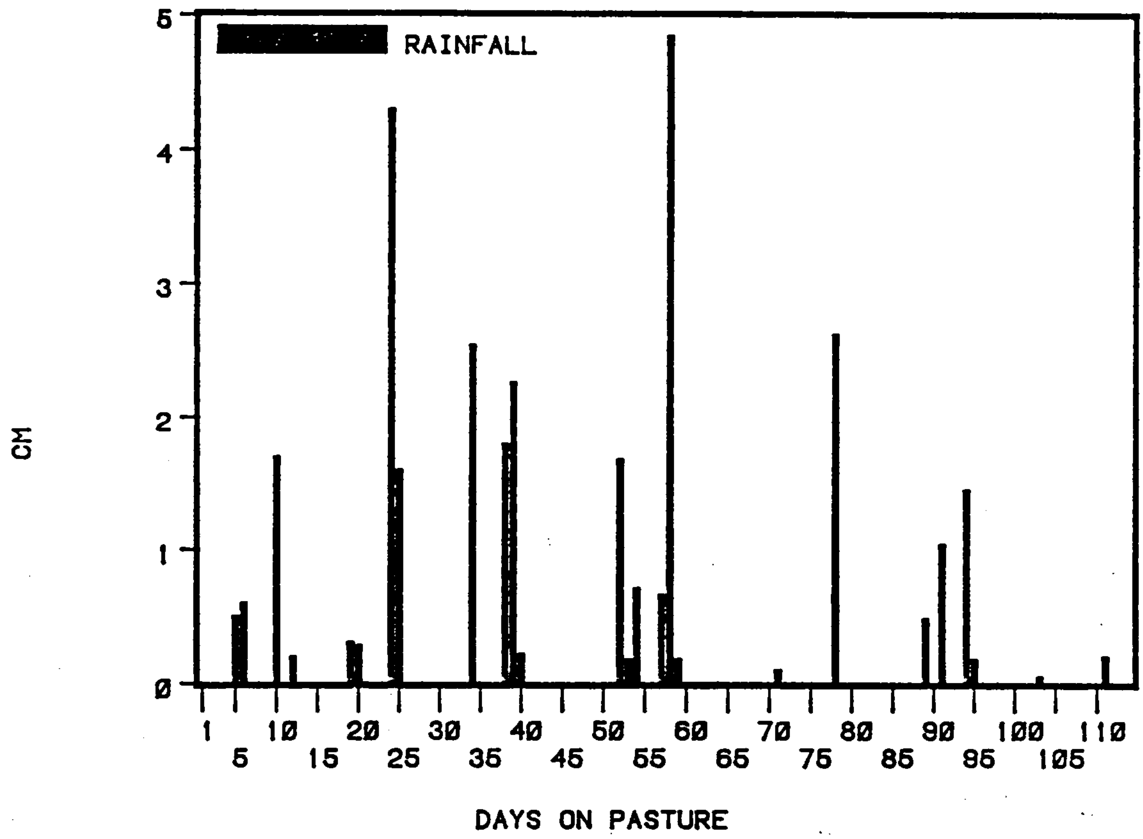
Appendix figure 6. Serum Na levels during the grazing trial. On d 112 steers grazing FBCR-amended pastures had elevated serum Na compared to those grazing limestone-amended pastures (P<.05).



Appendix figure 7. Serum Zn levels during the grazing trial. On d 84 steers grazing FBCR-amended pastures had elevated serum Zn levels compared to cattle grazing limestone-amended pastures (P<.05).



Appendix figure 8. Serum Fe levels during the grazing trial. On d 28 steers grazing FBCR-amended pastures had higher serum Fe levels compared to steers grazing limestone-amended pastures (P<.05).



Appendix figure 9. Rainfall data on each day throughout the grazing trial.

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