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Surface coal mine land reclamation using a dry flue gas desulfurization product: Long-term biological response

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HIGHLIGHTS

- ▶ Flue gas desulfurization (FGD) product effectively remediated acidic coal mined-land.
- ▶ Plant biomass was higher by FGD than by soil treatment 16 years after application.
- ▶ Heavy metals measured in plant tissues were not significantly increased.
- ▶ Bacterial populations and microbial biomass C were greatly increased by treatments.

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ABSTRACT

Abandoned surface coal mined lands are a worldwide environmental concern due to their low productivity and potential negative impact on water and soil quality. A field study was conducted to investigate the use of a dry flue gas desulfurization (FGD) product, i.e. a fluidized bed combustion (FBC) product, for reclamation of an abandoned surface coal mined land in Ohio, USA. The FGD product was applied to the mine site at a rate of 280 Mg ha^{-1} alone or with 112 Mg ha^{-1} yard waste compost, and these treatments were compared to a conventional reclamation treatment that included 20 cm of resoil material plus 45 Mg ha^{-1} of agricultural limestone. A grass-legume sward was planted, and plant biomass yields and elements in plant tissues were determined as long as 16 years after treatments. Bacterial populations and diversity and microbial biomass C in the reclaimed surface coal mined land were analyzed in the 16th year after treatments. Compared with the conventional soil treatment, plant biomass on plots treated with FGD product was lower in the first and third years, not different in the 14th year, and higher in the 16th year after application. Magnesium, S, Mo and B concentrations in plant tissues were increased by the treatments with FGD product in the first three years but not in the 14th year after application, and the heavy metals measured were not significantly increased. Bacterial populations and diversity and microbial biomass C in the reclaimed coal mine plots were significantly increased compared to adjacent untreated area and were generally similar among reclamation treatments. These results suggest that use of FGD product, used alone or in combination with compost, for reclamation of acidic surface coal mined lands can provide effective, long-term remediation.

1. Introduction

Coal mining and coal preparation practices in the years prior to the 1977 enactment of stringent environmental protection and reclamation laws (Surface Mining Control and Reclamation Act) frequently resulted in dumping of coal cleaning refuse into large piles. Many surface coal mine sites were simply abandoned without adequate reclamation of iron sulfide-containing materials, the source of much of the acid mine drainage. Reclamation of abandoned coal mine lands is a worldwide environmental concern because these lands surface water and groundwater quality, revegetation, and aesthetics [1]. In Ohio, USA, more than 14,000

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hectares of highly degraded abandoned coal mine lands have not yet been reclaimed [2].

When compared to native soils, new mine soils often have large quantities of coarse fragments, lowered nutrient status, poor water holding capacity [3], decreased organic matter content [4,5], low pH, and increased Fe oxides [6], as well as low microbial activity [7,8] and microbial biomass C [9,10,5,11]. The properties of disturbed mined soils make them a poor medium for plant growth, and natural recolonization by plants on these soils is slow. Some refuse or abandoned mine sites can produce copious amounts of acid that eventually drain into many streams and rivers. Acid production in soils can make them unsuitable for production of crops or for use as pasture lands or woodlands.

Applying topsoil and limestone to restore coal mined land is a well-established technology with many sites in the USA remaining in sound plant cover condition for 20 years or more after treatment [4,12,9]. Current reclamation laws require the spreading of stockpiled topsoil on mine spoil to facilitate revegetation. However, topsoil was generally not conserved when sites were surface mined for coal prior to the reclamation laws. Thus, soil must be borrowed from adjacent land thereby creating another disturbed area. The cost of reclamation becomes prohibitive if a sufficient amount of borrowed soil is not available adjacent to the mine site. Moreover, in mine land soil 20 years after reclamation using topsoil, total microbial biomass, microbial biomass carbon, and soil organic matter were only 20%, 44% and 36% of values found in adjacent undisturbed soils [9].

The Clean Air Act, as amended in 1992, confirmed the need to develop and implement processes to remove SO_2 from flue gases produced by burning. Some flue gas desulfurization (FGD) processes generate by-product materials consisting of various amounts of excess sorbent, reaction products containing SO_4^{2-}/SO_3^{2-} and fly ash. Because of the unspent sorbent component, these FGD products are usually alkaline and have significant neutralization potential. Several studies have shown that this property enables FGD products to be used as alkaline amendments for agricultural and mine land soils [13–16].

Composts are rich in organic C and plant macronutrients and also contain a balanced level of micronutrients [17], which often does not exist in a highly degraded coal mine land situation. Incorporation of organic matter can improve the physical and chemical properties of mine wastes and is known to improve fertility and bind trace elements, thereby facilitating reclamation efforts [3]. Microorganisms in soils play important roles in organic matter decomposition and nutrient cycling. Soil microbial communities impact plant reestablishment and the development of ecosystems in the mine soil. Microbial recovery is important to sustainable coal mine land reclamation. Application of organic wastes may increase microbial number and activity in mine soils [18,7].

The objectives of this study were to determine the effects of FGD product, compost and topsoil on (1) plant growth, (2) concentrations of plant essential and environmental concern elements in plant tissues, and (3) soil bacterial populations and diversity, and microbial biomass C to assess their potential capacities to achieve long-term reclamation success.

2. Materials and methods

2.1. Site description

The study site (Fig. 1), the Fleming abandoned mine land (AML) site, is located in Franklin Township, Tuscarawas County, Ohio, USA (40°33′19″ north latitude and 81°31′13″ west longitude). Prior to reclamation, the Fleming AML site consisted of approximately 10 ha of exposed, highly erodible underclay (a stratum of clay lying beneath a coal bed) bordered on two sides by 18 ha of spoil and 2 ha of coal refuse. Acid mine drainage was a significant problem with surface water pH ranging from 2.4 to 3.9 and electrical conductivity ranging from 0.7 to 3.0 dS m^{-1}. Oxidation of pyrite (FeS_2) associated with the Middle and Upper Kittanning coal beds was a major cause of the acidity. The spoil was derived from Pennsylvanian age rocks of the Allegheny Formation, which consist of sandstones and shales interbedded with coal, clay, and limestone [19]. The spoil at the site were extremely acidic (Table 1), and the ability of these materials to support plant growth was severely limited (Fig. 2). The entire Fleming AML site was classified as

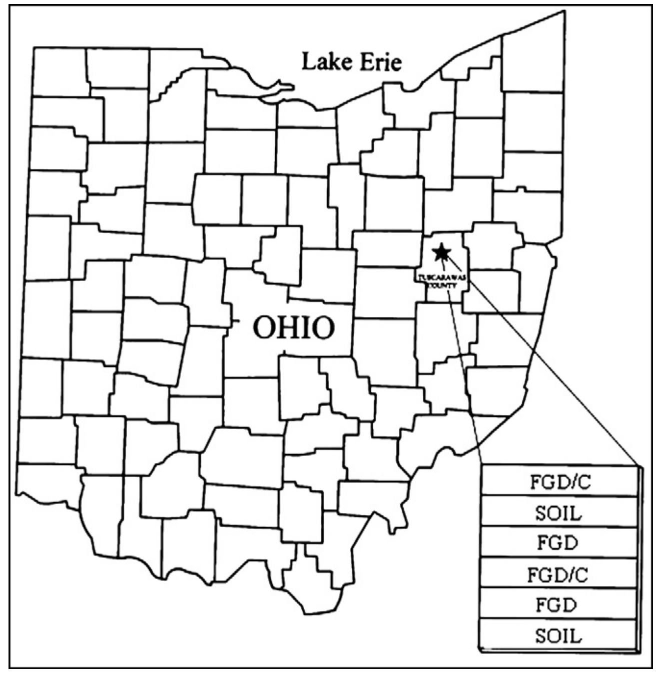

Fig. 1. Location of the Fleming abandoned surface coal mined land site in Ohio, USA.

Table 1
Selected chemical characteristics of Fleming abandoned mine land (AML) spoil and amendments.

Parameters	Spoil	FGD product	Compost	Borrow topsoil
pH (1:1 water)	3.1	12.4	7.4	4.3
Macronutrients (g kg^{-1})				
N	ND[a]	ND	8.4	ND
P	0.7	0.3	1.5	0.4
K	23.6	3.6	5.6	23.5
Ca	0.4	261	16.9	0.7
Mg	5.0	36.5	3.5	5.3
S	10.2	123	ND	0.6
Micronutrients (mg kg^{-1})				
B	ND	418	39.1	ND
Cu	26.8	49.5	69.0	62.8
Fe	55700	59000	17700	39600
Mo	14.0	22.4	27.8	<0.2
Ni	28.5	78.8	383	44.8
Zn	<0.3	112	108	138
RCRA[b]-regulated elements (mg kg^{-1})				
As	46.3	71.5	11.5	5.5
Ba	701	204	ND	503
Cd	0.8	1.5	<0.2	3.3
Cr	94.4	42.2	284	95.6
Pb	78.0	17.4	26.0	15.9
Se	4.5	8.6	0.3	<0.7

[a] Not determined.
[b] Resource Conservation and Recovery Act.