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Short Communication

Preliminary Study of Coal Fly Ash (FA) Phytoremediation by Selected Cereal Crops

Jerzy Bilski[1], Donna Jacob[2], Kyle Mclean[1], Erin McLean[1], and Mardee Lander[1]
[1]Valley City State University, Valley City, ND 58072, USA
[2]North Dakota State University, Fargo, ND 58105, USA
Corresponding author: Jerzy Bilski; E-mail: jerzy.bilski@vcsu.edu

ABSTRACT
This study focuses on the environmentally friendly utilization of coal combustion residue, fly ash (FA) containing significant amounts of heavy metals. Knowledge about the potential use of FA as a component of growth media for plants is fragmentary. Preliminary experiments tested the possibility to grow cereal crops on media composed exclusively of FA. The analysis of seven different FA from lignite and semi-bituminous coal from North Dakota and Montana sources using inductively coupled plasma emission spectrophotometry showed high concentrations of heavy metals in coal (up to, in mg/kg): As:65, Cd:3.9, Co:38, Cr:77, Li:109, Mn:1547, Pb:106, Ni:41, V:306. Seedlings of rye, wheat, oats, barley, triticale, and regreen (hybrid between wheat and ryegrass) were planted in Petri dishes (10 cm in diameter) in growth media containing FA from lignite coal, FA from semi-bituminous coal, bottom ash, and Fargo clay soil as the control. Each treatment was performed in 3 replications, and each experiment was repeated 3 times. Germination rates, plant growth analysis, and dry matter yield were determined 2-3 weeks after planting. Germination rates and dry matter yield of oats, winterwheat and regreen were greater (10-20% above controls) in media composed of coal ash, but rye, barley, and wheat seedlings were affected by FA in media. These results show the potential for the utilization of FA as a growth media for cereal crops. Therefore, these plants might be used as green cover preventing wind erosion over the coal ash piles. However, this issue requires additional in depth investigation, including a thorough chemical analysis of plant material.

INTRODUCTION

It is widely known that FA particles emitted from coal-fired plants contain several toxic trace metals [1]. On the other hand, due to the availability of large quantity of FA and the presence of high concentrations of Ca and Mg in most FA sources, FA appears to be a suitable soil amendment for liming purposes and to enhance Ca and Mg contents in the soil [2, 3] FA utilization as a soil amendment indicates the necessity to take precautions against the excessive accumulation of heavy metals by plants grown on a media with FA.

The diversity of chemical properties among FA suggests that every use of FA as a soil amendment should follow its detailed chemical analysis because it has been established that leachate from places with high concentration of FA may affect water supply. Pollutants associated with FA include several elements (Ti, Mn, Cu, Cr, Zn, As, Se, Co, Cd, Hg) whose excessive presence in the environment may become toxic [1, 4, 5, 6, 7, 8].

A vegetative cover is a remedial technique utilized on FA landfills for soil stabilization and for the physical and chemical immobilization of contaminants [4, 9, 10,11]. Many herbaceous plants, primarily grasses, which exhibit rapid growth, are moderately resistant to environmental stress, and are therefore often used as cover crops in environmental restoration and remediation projects [9, 12].

To date, knowledge about the potential use of FA as a component of growth media for plants is fragmentary. Furthermore, the environmental impact of FA utilization in providing a plant cover over the coal fly ash landfills and the importance of the unsolved problem of its disposal had attracted relatively little attention. To date, knowledge about the potential use of FA as a component of growth media for plants is fragmentary. Furthermore, the environmental impact of FA utilization in providing a plant cover over the coal fly ash landfills and the importance of the unsolved problem of its disposal had attracted relatively little attention.

We tested the overall hypothesis that North Dakota coal FA can be safely used as a component of growing media for plants, without compromising environmental health. The objective of this experiment was to determine the effects of the presence of FA in growth media on the germination and seedlings weight of selected plants.

MATERIALS AND METHODS

- Seven different coal ashes (from lignite and semi-bituminous coal), collected from diverse locations in North Dakota, Minnesota and Montana have been tested for heavy metals concentration by using inductively coupled plasma (ICP) specrtophotometry.
- Two selected coal ashes, from semi-bituminous coal from Montana and from North Dakota lignite have been used as plant growth media.
- In the preliminary experiment, experimental treatments consisted of following growth media:
    1. Soil (Fargo Clay) as a control
    2. FA from semi-bituminous coal from Montana
    3. Bottom ash from the same semi-bituminous coal from Montana
    4. FA from North Dakota lignite coal
- Five plant species have been tested: barley (*Hordeumvulgare*), oats (*Avenasativa*), rye (*Secalecereale*), wheat (*Triticumaestivum*), and perennial ryegrass (*Loliummultiflorum*).
- The experiment has been conducted in three replications, and replied three times.
- On every petri dished, 30 seeds were planted and covered with thin layer of growth media, and watered to approximate field capacity of growth media.
- The percentage of seeds germinated was determined.
- Plants were grown for 14-21 days (depending on the time of seedlings development), harvested, dried and weighted.
- The concentration of heavy metals in FA was determined by using ICP.

RESULTS

Chemical analysis of coal FA from North Dakota lignite coal and Montana semi-bituminous coal (Table 1) showed significant concentrations of heavy metals (up to, in mg/kg): As:65, Cd:3.9, Co:38, Cr:77, Li:109, Mn:1547, Pb:106, Ni:41, V:306. These concentrations, though, didn't create any risk from environmental health perspective [12].
Sample number: 1. Antilope Valley Station (Bismarck) - fly ash-lignite (AVS-FA); 2. Coal Creek Station (Headwaters Resources) - fly ash-lignite (CCS-FA); 3.Coalstrip Montana (Rosebud Mine; from NDSU) -fly ash-semi-bituminous (CM-FA); 4. Coalstrip Montana (Rosebud Mine; from NDSU) - bottom ash-semi-bituminous (CM-BA); 5. Hoot Lake Plant (Otter Tail Power Company-Fergus Falls) - fly ash - semi-bituminous (HLP-FA); 6. Stanton Station (Great River Energy) - fly ash-lignite (SS-FA); 7. Washburn Station (from Valley City) - fly ash-lignite (WS-FA).
Chemical analysis of coal fly ashes from North Dakota lignite coal and Montana semi-bituminous coal (Table 1) showed significant concentrations of heavy metals (up to, in mg/kg), particulary: As:65, Cd:3.9, Co:38, Cr:77, Pb:106, V:306. These concentrations, though, didn't create any risk from environmental health perspective [13].
Germination rates and dry matter yield (Fig. 1) of oats, winter wheat and regreen were even greater in media composed of coal FA, as compared to the germination and dry matter yield on the soil used as a control treatment, but rye, barley, and wheat seedlings were affected by FA in media. Overall, all tested plants showed at least some level of adaptability to grow on FA ash based growth media.

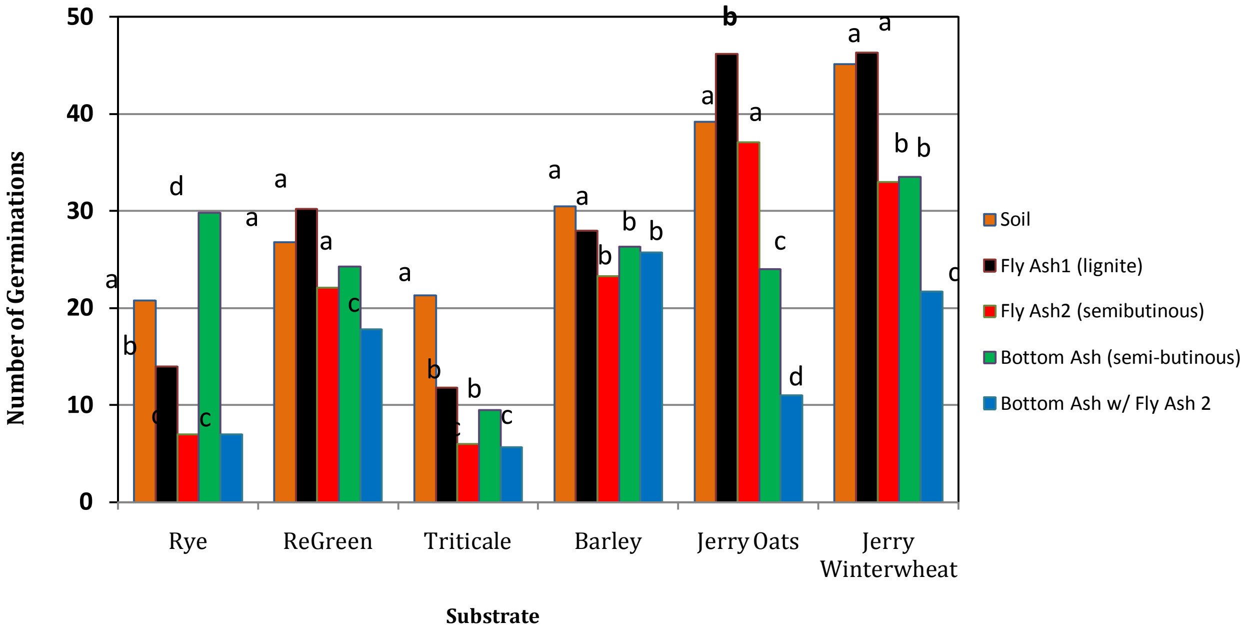
CONCLUSIONS AND FUTURE EXPERIMENTS

1. Preliminary study of the germination and seedlings growth of six cereal crops and on FAgrowth media indicate the potential of successful growth of these plants on FA residue piles.
2. Cereal crops: rye, winter wheat, barley, oats, Triticale, and Regreen might be used as plants helping to establish a green cover over coal FA piles and for wind erosion prevention.
3. Future research should determine heavy metal concentration in all plant species grown on FA media, and investigate a potential leaching from FA and soil/FA composed plant growth media.

Table 1. Concentration of selected elements in FA samples obtained from several sources.

Sample No	Sample type	Ag	Al	As	B	Ba	Be	Ca	Cd	Ce	Co	Cr	Cu	Fe	K	Li	Mg
		mg kg^{-1}	%	mg kg^{-1}	mg kg^{-1}	%	mg kg^{-1}	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	%	%	mg kg^{-1}	%
1	AVS-FA	2.56	4.62	43.84	715.96	0.31	2.56	15.34	2.18	19.08	10.89	42.91	33.94	3.13	0.37	24.98	2.60
2	CCS-FA	2.58	3.26	83.75	854.86	0.25	3.87	8.33	2.18	23.92	9.66	76.66	26.41	2.97	0.22	10.95	1.84
3	CM-FA	2.21	7.11	43.84	1030.90	0.35	3.90	14.85	2.18	73.97	14.95	39.65	61.75	1.28	0.35	109.85	2.75
4	CM-BA	3.94	6.28	43.84	540.24	0.26	2.63	10.29	2.18	52.01	9.86	13.80	26.95	4.33	0.20	90.04	1.48
5	HLP-FA	5.19	10.77	49.35	801.30	1.17	3.90	16.74	3.90	77.36	38.31	73.38	243.51	3.20	0.53	86.36	4.73
6	SS-FA	3.89	8.84	59.68	522.85	0.39	3.89	17.94	2.18	64.74	29.19	55.14	125.20	3.03	0.53	60.33	2.25
7	WS-FA	1.29	4.06	64.68	966.27	0.36	3.88	11.09	2.59	32.64	12.29	73.08	32.99	3.80	0.31	14.88	2.27

Sample No	Sample type	Mn	Mo	Na	Ni	P	Pb	S	Sb	Sn	Sr	Ti	Tl	V	Zn	Zr	Se
		mg kg^{-1}	mg kg^{-1}	%	mg kg^{-1}	%	mg kg^{-1}	%	mg kg^{-1}	mg kg^{-1}	%	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
1	AVS-FA	445.71	11.05	1.74	16.01	0.10	41.14	3.80	28.04	22.89	0.28	0.16	30.31	62.12	32.66	69.80	2.42
2	CCS-FA	302.78	14.17	0.19	23.84	0.05	41.14	0.30	28.04	22.89	0.19	0.10	30.31	98.56	40.58	68.93	3.73
3	CM-FA	1547.00	11.05	0.26	17.55	0.24	60.92	1.20	28.04	22.89	0.44	0.32	30.31	83.85	2.90	157.95	0.00
4	CM-BA	945.10	11.05	0.14	9.10	0.17	41.14	0.01	28.04	22.89	0.28	0.15	30.31	40.09	2.90	112.39	0.00
5	HLP-FA	442.86	11.05	2.70	43.51	0.21	106.31	0.01	28.04	25.97	0.77	0.81	30.31	305.84	65.58	216.23	29.70
6	SS-FA	334.73	11.68	4.36	40.87	0.13	50.42	3.58	28.04	23.35	0.49	0.54	30.31	193.96	69.41	182.29	8.94
7	WS-FA	435.92	11.05	0.40	31.69	0.06	41.14	0.96	28.04	22.89	0.24	0.14	30.31	98.96	51.09	87.31	0.00



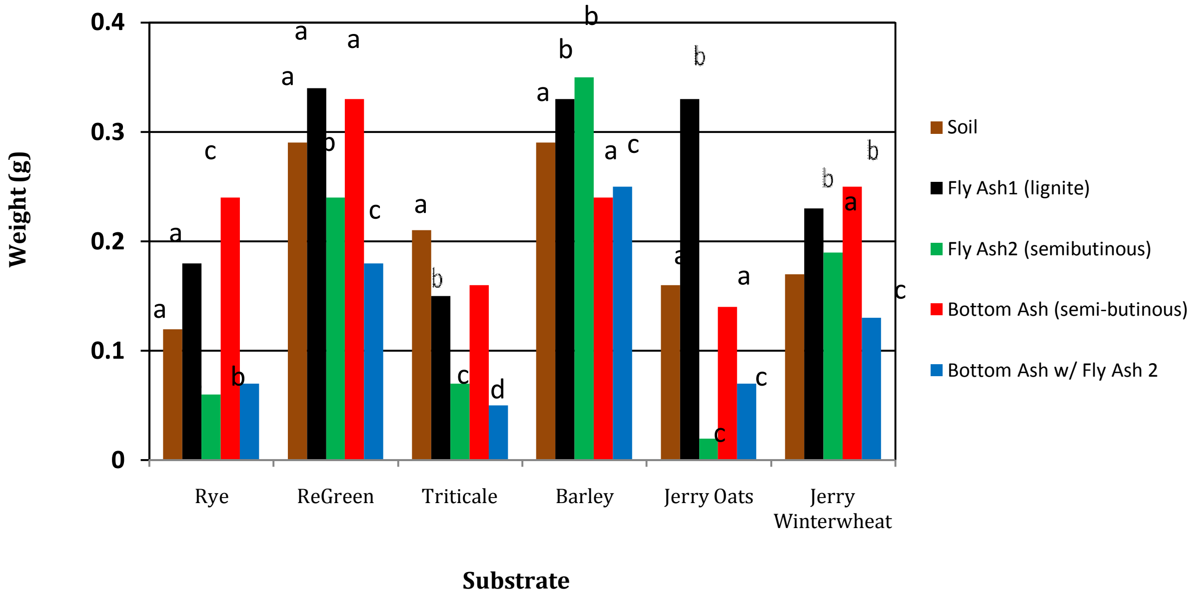


Fig.1. Effects of different growth media containing coal FA or soil (served as a control) on mean number of germination (top panel) and seedlings weight (bottom panel) of several plants. [a,b,c,d]P<0.05 values (means ± SEM) differ for a specific plant.

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