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Use of Fluidized-Bed Combustion Ash in Agricultural Applications - Technical Progress Report

**Quarterly Report
July 1 - September 30, 1996**

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Project Quarterly Report

Project # DE-AI21-94MC31205

From: R. Korcak (10/8/96)

Tasks 3 & 4

Background Analytical Data

Analysis of the FBC material and dairy manure used in all experiments is shown in Table 1. For comparative purposes, analysis of agricultural limestone from the Watertown, NY area is also presented.

The dairy manure contained higher amounts of P, K, and Zn than the FBC material while Ca and S were higher in the FBC material. Both material contained about equal amounts of Mg, Mn, and Cu.

Boron was about ten times higher in the FBC material than in the agricultural limestone used by farmers in the Watertown, NY area. The calcium carbonate equivalence of the FBC material was about one-third that of the agricultural limestone (Table 1).

Field Blackberry Experiment

The field experimental site was located on a well drained Beltsville silt loam soil. Field soil samples were obtained prior to treatment initiation from each of the 12 plot areas (see Figure 1) in July 1995. Samples were obtained at two depths: 0-3" and 3-6", air-dried and then sieved through a 2 mm sieve and stored dry prior to analysis. The background soil data obtained is presented in Table 2. Generally, there was little variation within the field site from either sampling depth. After routine analysis of these samples the 12 samples were combined into three for each depth and analyzed for trace elements. Cadmium, Ni, Pb, Cr, and As averaged (in ppm) <1, 8, 13, 20, and 13.0, respectively for the 0-3" samples and <1, 9, 46, 21, and 11.1, respectively, for the 3-6" samples.

'Chester' blackberry plants were planted in June 1995. In August 1995, foliar samples from the field planted blackberry plants were obtained prior to soil treatment applications. Average leaf fresh and dry weights were recorded as well as elemental analysis data (Table 3). The values presented in Table 3 indicate that there was little background variation due to location of plants in the replicated field plots. The only significant difference was evident in foliar B concentrations (Table 3), however, these differences were physiologically small.

At the end of August, 1995, the treatments designated in Figure 1 were applied. A swing-trellis was erected along the two rows of the experimental areas (see Figure 1) during the winter of 1995/96.

Post-treatment foliar samples were obtained on July 25, 1996 from all plots. Primocane and florican leaves were sampled separately; five leaves per plant for each of seven plants. Leaf weights are presented in Table 4. There were no significant differences among treatments for leaf fresh or dry weights for either the florican or primocane leaves.

Leaves were washed, forced air-dried at 70C for 48 hours and then re-weighed and ground to pass a 30 mesh seive. Analytical results are shown in Table 5.

Blackberry fruit samples were obtained from each plant; five fruits per plant for each of seven plants. Fruits were gently rinsed, dried, weighed and then frozen at -70C prior to freeze drying. The freeze dried samples were pounded to a fine powder prior to analysis. The average fresh and freeze-dried weights for each treatment are shown in Table 6. There were no significant differences among treatments for either fresh or freeze-dried weights.

Soil Columns

Twenty four columns, each 2.5' high, were constructed from 6" (ID) PVC pipe. A slotted drain was secured to the bottom of each drain on which a sheet of Whatman #3 filter paper was placed. For enhanced drainage, 250 g of acid-washed pea gravel was placed over the filter paper and then 3,500 g of soil were placed in each column with an additional 250 g of pea gravel on top to prevent soil ponding

The soil was a Cordorus silt loam which had an aqueous pH of 6.3 with high Mg (216 lbs/A), very low P (56 lbs P_2O_5 /A), low K (262 lbs K_2O /A), medium Ca (1144 lbs/A), and low S-SO₄ (28.4 lbs/A) contents. Trace element contents were: (in lbs/A) B (0.57), Zn (2.9), Cu (1.8), and Mn (96) and (in ppm) Cd (<1), and As (3.5).

Four replicates of each of the following column treatments were used:

Control	soil alone
5 FBC	5 ton per acre surface application (9.1 g FBC per column)
5 Manure	5 ton per acre surface application (9.1 g dairy manure per column)
5 FBC + 5 Manure	(combination of above two treatments)
10 FBC	10 ton per acre surface application (18.2 g FBC)
10 FBC + 10 Manure	above plus 18.2 g dairy manure

All columns were pre-wetted and allow to drain before treatments were surfaced applied and the washed pea gravel added. The equivalent of 1" of rainfall (200 ml

distilled water) was applied weekly for 16 weeks. The day after rainfall additions, leachates were collected, filtered and analyzed immediately for pH and electrical conductivity (EC). The remaining sample volumes were frozen (-70C) until the completion of the study and then analyzed for elemental content.

After the 16 leaching events each column was subdivided into four 4" subsections (0-4", 4-8", 8-12", and 12-16"). All soils were air-dried prior to analysis.

Column Analytical Results - Soil Subsections

Soil pH was significantly increased in the surface 4" from all treatments except the 5 ton dairy manure compared to the control (Table A). This effect diminished with depth for all treatments. Soluble salts were similarly higher in the surface 4" from all treatments, however, the 10 ton FBC and 10 ton FBC + 10 ton manure significantly increased soluble salts in the 8" and 12" sections.

Extractable soil Mg was not effected by any of the treatments which is a reflection of the high initial Mg level in this soil. Extractable P was significantly elevated by the manure treatments only in the surface soil section as compared to the control and FBC treatments. The manure contained about 0.8% P (Table 1) and this P remained immobilized in the surface soil.

The high level of K contained in the dairy manure and its ready mobility in the soil is reflected in the significantly increased levels throughout the columns (Table A). The 10 ton FBC + 10 ton manure treatment increased extractable K in the bottom section compared to all other treatments. Soil Ca was significantly increased by FBC additions and this effect was apparent even at the 12-16" depth sample.

Extractable B varied among treatment additions and B was not significantly increased by FBC additions although the FBC contained 113.7 ppm B. There was a tendency for manure addition to decrease soil B levels (Table B).

Extractable Cu only exhibited slight differences among treatments (Table B). Generally, with the higher pH of the FBC treatments especially at 10 tons, Cu extractability tended to decrease compared to the control soil. Extractable Zn was not significantly effected by treatments at any of the depth monitored even though both FBC and dairy manure added Zn (Table 1) to the media.

Nitrate-nitrogen was also effected in the surface 4" due to treatments (Table B). The differences among treatments were small. However, sulfate-sulfur was significantly increased, as expected, by all of the FBC treatments compared to control soil and manure only addition (Table B). This reaction was apparent in the 0-4", 4-8" and 8-12" sections. At the bottom of the columns, there were no significant differences among treatments in sulfate-sulfur content.

Only one replicate of the 0-4" and 4-8" sections from each treatment were analyzed for extractable Cd, As, and Se. All samples contained <1 ppm Cd regardless of surface applied treatment. Likewise, Se did not vary among treatments; over all treatments, Se varied between 0.35-0.46 ppm 0.33-0.46 ppm for the 0-4" and 4-8" sections, respectively. The concentration of As did not vary consistently for either depth for any of the treatments. Concentrations ranged from 8.32-10.22 ppm As and 7.48-10.06 ppm As from the 0-4" and 4-8" sections, respectively.

Overall, the surface applied treatments resulted in expected increases and decreases in nutrients and trace elements. The immobility of extractable P in the surface soil and the enhanced movement of Ca and K through the columns are of most practical interest. Trace elements concentrations were also within acceptable limits for agricultural soils.

Column Analytical Results - Leachates

Leachate pH and electrical conductivity at 25C (EC_{25}) were measured the day after each of the 16-1" rainfall events. The weekly leachate pH values and EC_{25} are shown in Table C. Generally, pH tended to increase with time for all treatments. This was particularly true between the first {Julian Day (JD) 269} and the second (JD 276) leaching events. The differences between treatments for the first (JD 269) and last (JD 016) leaching events for pH are shown in Figure 2 and for EC_{25} in Figure 3. Leachate EC_{25} decreased with time but the 10 ton FBC + 10 ton manure treatment still produced numerically higher EC_{25} from the last leaching event (Figure 3).

The frozen leachate samples were thawed prior to analysis for Ca, Mg, P, Cu, B, Mn, Mo, Cd, Fe, and Ni by Inductively Coupled Plasma Emission (Perkin-Elmer 40 Emission Spectrometer Model P40 ICP). Twenty-three ml of thawed sample was pipetted into 30 ml acid washed plastic bottles to which 1 ml of concentrated HNO_3 and 1 ml of cobalt reference solution (an internal standard) was added. Potassium and Zn were determined using atomic absorption (Varian Spectr AA-400) on the samples that were used for ICP analysis. Sulfate-sulfur was measured using a Dionex 2000i/sp analyzer (2.5 ml of thawed sample plus 2.5 ml demineralized water added to Dionex tubes).

Leachate elemental concentrations were at or below detection limits for B, Mo, Cu, Ni, Cd, and Mn from all 16 rainfall events.

Total amounts of Fe, P, Mg, Ca, Zn and K were calculated by multiplying the amount of leachate (in ml) times the elemental concentrations determined from each rainfall event. The average total amounts of Fe, P, Mg, Ca, Zn, K, Cl⁻, and SO_4 -S from each leaching event are shown in Figures 4-11).

Accumulative total Fe, P and Zn leachate through the columns were not significantly effected by treatment (Table D). Total Ca and Mg were significantly higher from the 10 ton per acre FBC plus manure treatment compared to all other treatments. The control and 5 ton per acre manure treatments were not significantly different.

Table 1. Total analysis of the fluidized bed combustion (FBC) residue and dairy manure used in the study. The agricultural limestone results are for comparative purposes and reflect the limestone normally used by farmers in Watertown, NY.

Parameter	FBC	Agricultural Limestone	Dairy Manure
Phosphorous (%)	0.07	0.05	0.80
Potassium (%)	0.33	0.01	3.38
Sulfur (%)	3.74	0.04	0.43
Magnesium (%)	0.43	10.75	0.40
Manganese (mg/kg)	206	237	245
Copper (mg/kg)	31.7	3.5	24.5
Zinc (mg/kg)	47.7	104	94.5
Cadmium (mg/kg)	ND*	ND	---
Nickel (mg/kg)	40.3	ND	---
Lead (mg/kg)	9.3	ND	---
Arsenic (mg/kg)	31	ND	---
Selenium (mg/kg)	4.94	ND	---
Calcium Carbonate Equivalence (%)	31.77	101.56	---
Boron (mg/kg)	113.7	12.50	---
Cobalt (mg/kg)	26.7	10.0	---
Nitrogen (%)	---	---	1.42
% Moisture	---	---	38.2
Ca (%)	19.33	19.10	0.76
NH ₄ -N (%)	---	---	0.030
NO ₃ -N/NO ₂ -N (%)	---	---	0.040
Al (%)	---	---	0.30
Fe (%)	---	---	0.42
Na (%)	---	---	0.32

*ND = not detected, below detection limits.

Table 2. Background soil data from the blackberry field plots sampled prior to treatment additions. Plots were sampled at two depths: 0-3" and 3-6".

DEPTH 0 - 3"

Treatment	pH	Mg (lbs/A)	P ₂ O ₅ (lbs/A)	K ₂ O (lbs/A)	Ca (lbs/A)
Control	6.3	300	137	215	2305
FBC	6.2	300	106	208	2230
FBC + Manure	6.3	300	139	194	2220

Treatment	Cu (ppm)	Mn (ppm)	Zn (ppm)	SO ₄ -S (ppm)	Soluble Salt (ppm)
Control	6.2	28	41	3.0	146
FBC	6.2	27	34	8.3	136
FBC + Manure	7.3	27	31	8.7	120

Table 2. (continued)

DEPTH 3 - 6"

Treatment	pH	Mg (lbs/A)	P ₂ O ₅ (lbs/A)	K ₂ O (lbs/A)	Ca (lbs/A)
Control	6.5	300	110	101	1890
FBC	6.5	300	87	95	1607
FBC + Manure	6.5	300	110	88	1566

Treatment	Cu (ppm)	Mn (ppm)	Zn (ppm)	SO ₄ -S (ppm)	Soluble Salt (ppm)
Control	11	16	25	5	72
FBC	10	22	15	6	72
FBC + Manure	11	15	20	12	72

Table 3. Average foliar analysis data from the blackberry plants grown in the replicated field plots. The values indicate plant differences before treatment application.

Designated Treatment	Leaf Fresh Weight (g per 28 leaves)	Leaf Dry Weight (g per 28 leaves)	N (%)	P (%)	K (%)
Control	42	16	2.53	0.20	1.01
FBC	42	16	2.43	0.20	0.96
FBC + Manure	32	12	2.42	0.20	0.87
	Ca (%)	Mg (%)	Mn (ppm)	Fe (ppm)	Cu (ppm)
Control	1.05	0.58	61	56	9
FBC	1.04	0.58	59	58	9
FBC + Manure	1.04	0.59	54	61	8
	B (ppm)	Al (ppm)	Zn (ppm)	Na (ppm)	Sr (ppm)
Control	44 a*	23	45	48	16
FBC	42 ab	24	43	46	17
FBC + Manure	40 b	40	37	45	18
	Cd (ppm)	Pb (ppm)	Mo (ppm)	Ni (ppm)	Co (ppm)
Control	0.02	0.12	1.06	0.39	0.02
FBC	0.02	0.12	1.00	0.44	0.02
FBC + Manure	0.02	0.12	0.98	0.22	0.02

*Values within elemental columns not followed by the same lower case letter are significantly different at the 5% level. Absence of lower case letters indicates no differences among means.

Table 4. Average florican and primocane leaf data from the blackberry plants grown in the replicated field plots. The values indicate plant differences after treatment.

Designated Treatment	Florican		Primocane	
	Leaf Fresh Weight (g per 25 leaves)	Leaf Dry Weight (g per 25 leaves)	Leaf Fresh Weight (g per 25 leaves)	Leaf Dry Weight (g per 25 leaves)
Control	43	18	80	32
FBC	50	21	78	32
FBC & Manure	45	19	79	33

Table A. Average soil pH, soluble salts and extractable Mg, P₂O₅, K₂O and Ca from the soil column sections sampled after 16 rainfall events.

DEPTH 0 - 4"

Treatment	pH	Soluble Salts (ppm)	Mg (lb/A)	P ₂ O ₅ (lb/A)	K ₂ O (lb/A)	Ca (lb/A)
Control	6.4 b*	102 d	300	211 c	54 c	1671 b
Fluidized Bed Ash 5T/A	6.9 a	576 b	300	225 bc	55 c	3000 a
Dairy Manure 5T/A	6.6 b	146 d	300	239 ab	252 b	1747 b
Fluidized Bed Ash 5T/A & Dairy Manure 5T/A	6.9 a	409 c	300	238 ab	232 b	3000 a
Fluidized Bed Ash 10T/A	7.0 a	700 a	300	222 c	58 c	3000 a
Fluidized Bed Ash 10T/A & Dairy Manure 10T/A	7.1 a	756 a	300	247 a	432 a	3000 a

*Values within columns not followed by the same lower case letter are significantly different at the 5% level. Absence of lower case letters indicates no differences among means.

Table A. (continued)

DEPTH 4 - 8"

Treatment	pH	Soluble Salts (ppm)	Mg (lb/A)	P ₂ O ₅ (lb/A)	K ₂ O (lb/A)	Ca (lb/A)
Control	6.6 b*	102	300	208	53 c	1659 b
Fluidized Bed Ash 5T/A	6.7 ab	102	300	215	56 c	1850 ab
Dairy Manure 5T/A	6.8 ab	102	300	210	93 b	1730 b
Fluidized Bed Ash 5T/A & Dairy Manure 5T/A	6.8 ab	102	300	208	98 b	1908 ab
Fluidized Bed Ash 10T/A	6.9 a	116	300	221	53 c	2136 a
Fluidized Bed Ash 10T/A & Dairy Manure 10T/A	6.9 a	103	300	223	197 a	2179 a

*Values within columns not followed by the same lower case letter are significantly different at the 5% level. Absence of lower case letters indicates no differences among means.

Table A. (continued)

DEPTH 8 - 12"

Treatment	pH	Soluble Salts (ppm)	Mg (lb/A)	P ₂ O ₅ (lb/A)	K ₂ O (lb/A)	Ca (lb/A)
Control	6.7	102 c*	300	206	52 c	1644 c
Fluidized Bed Ash 5T/A	6.7	102 c	300	210	53 c	1715 bc
Dairy Manure 5T/A	6.8	102 c	300	217	64 bc	1895 abc
Fluidized Bed Ash 5T/A & Dairy Manure 5T/A	6.8	102 c	300	218	66 b	1968 ab
Fluidized Bed Ash 10T/A	6.8	102 b	300	218	55 bc	2014 ab
Fluidized Bed Ash 10T/A & Dairy Manure 10T/A	6.8	103 a	300	223	97 a	2064 a

*Values within columns not followed by the same lower case letter are significantly different at the 5% level. Absence of lower case letters indicates no differences among means.

Table A. (continued)

DEPTH 12 - 16"

Treatment	pH	Soluble Salts (ppm)	Mg (lb/A)	P ₂ O ₅ (lb/A)	K ₂ O (lb/A)	Ca (lb/A)
Control	6.6 b*	102 c	300	177	51 b	1752 b
Fluidized Bed Ash 5T/A	6.6 ab	106 c	300	198	53 b	1801 b
Dairy Manure 5T/A	6.7 ab	102 c	300	183	54 b	1789 b
Fluidized Bed Ash 5T/A & Dairy Manure 5T/A	6.6 ab	112 bc	300	204	56 b	1931 ab
Fluidized Bed Ash 10T/A	6.7 a	150 b	300	202	57 b	2034 ab
Fluidized Bed Ash 10T/A & Dairy Manure 10T/A	6.6 ab	200 a	300	204	72 a	2120 a

*Values within columns not followed by the same lower case letter are significantly different at the 5% level. Absence of lower case letters indicates no differences among means.

Table B. Average soil extractable B, Cu, Mn, Zn, NO₃-N, and SO₄-S from the soil column sections sampled after 16 rainfall events.

DEPTH 0 - 4"

Treatment	B (lb/A)	Cu (lb/A)	Mn (lb/A)	Zn (lb/A)	NO ₃ (lb/A)	SO ₄ - S (lb/A)
Control	0.74 a*	12.1 a	20 a	15.2	61.4 ab	3.2 c
Fluidized Bed Ash 5T/A	0.57 ab	12.9 a	14 b	20.5	62.6 ab	88.5 b
Dairy Manure 5T/A	0.50 b	10.3 b	12 b	16.6	70.0 a	4.2 c
Fluidized Bed Ash 5T/A & Dairy Manure 5T/A	0.76 a	9.7 b	12 b	20.9	51.4 b	257.4 a
Fluidized Bed Ash 10T/A	0.58 ab	9.8 b	16 ab	16.3	52.4 b	253.2 a
Fluidized Bed Ash 10T/A & Dairy Manure 10T/A	0.76 a	10.0 b	20 a	15.0	60.0 ab	242.2 a

*Values within columns not followed by the same lower case letter are significantly different at the 5% level. Absence of lower case letters indicates no differences among means.

Table B. (continued)

DEPTH 4 - 8"

Treatment	B (lb/A)	Cu (lb/A)	Mn (lb/A)	Zn (lb/A)	NO ₃ (lb/A)	SO ₄ - S (lb/A)
Control	0.69 a*	11.6 a	16 a	20.8	28.6	3.5 c
Fluidized Bed Ash 5T/A	0.68 b	12.0 a	15 ab	28.0	27.0	3.3 c
Dairy Manure 5T/A	0.51 b	10.4 b	9.8 b	15.6	28.8	4.4 c
Fluidized Bed Ash 5T/A & Dairy Manure 5T/A	0.92 a	9.6 b	9.2 b	20.0	24.2	14.8 bc
Fluidized Bed Ash 10T/A	0.74 ab	9.8 b	12.5 ab	17.0	27.0	37.7 ab
Fluidized Bed Ash 10T/A & Dairy Manure 10T/A	0.74 ab	9.4 b	13.5 ab	12.8	27.2	46.2 a

*Values within columns not followed by the same lower case letter are significantly different at the 5% level. Absence of lower case letters indicates no differences among means.

Table B. (continued)

DEPTH 8 - 12"

Treatment	B (lb/A)	Cu (lb/A)	Mn (lb/A)	Zn (lb/A)	NO ₃ (lb/A)	SO ₄ - S (lb/A)
Control	0.74 a*	12.1 a	20 a	14.2	24.2	2.4 b
Fluidized Bed Ash 5T/A	0.57 ab	12.9 a	14 b	23.4	27.2	1.6 b
Dairy Manure 5T/A	0.50 b	10.3 b	12 b	15.8	25.4	4.4 b
Fluidized Bed Ash 5T/A & Dairy Manure 5T/A	0.76 a	9.7 b	12 b	22.4	21.3	8.7 b
Fluidized Bed Ash 10T/A	0.58 ab	9.8 b	16 ab	16.9	26.3	15.7 ab
Fluidized Bed Ash 10T/A & Dairy Manure 10T/A	0.76 a	10.0 b	20 a	14.0	26.4	30.0 a

*Values within columns not followed by the same lower case letter are significantly different at the 5% level. Absence of lower case letters indicates no differences among means.

Table B. (continued)

DEPTH 12 - 16"

Treatment	B (lb/A)	Cu (lb/A)	Mn (lb/A)	Zn (lb/A)	NO ₃ (lb/A)	SO ₄ - S (lb/A)
Control	0.82 ab*	15.8 a	33 a	14.8	37.8	55.6
Fluidized Bed Ash 5T/A	0.82 ab	14.1 a	19 b	20.8	32.7	58.4
Dairy Manure 5T/A	0.54 b	13.9 a	22 ab	16.2	39.8	6.8
Fluidized Bed Ash 5T/A & Dairy Manure 5T/A	0.94 a	11.6 ab	18 b	22.2	34.5	40.2
Fluidized Bed Ash 10T/A	0.62 b	9.1 b	28 ab	17.0	37.6	45.9
Fluidized Bed Ash 10T/A & Dairy Manure 10T/A	0.80 ab	12.8 ab	32 a	15.2	44.8	111.5

*Values within columns not followed by the same lower case letter are significantly different at the 5% level. Absence of lower case letters indicates no differences among means.

Table C. Average pH and electrical conductivity (EC₂₅) for the column leachate for each rain event. Rain events are indicated by julian dates (JD).

	JD = 269		JD = 276		JD = 284		JD = 290	
Treatment	pH	EC ₂₅	pH	EC ₂₅	pH	EC ₂₅	pH	EC ₂₅
Control	6.73	3.20	7.65	1.83	8.04	1.29	7.70	1.09
5 Ton FBC	6.75	3.75	7.51	1.94	7.74	1.35	7.44	1.27
5 Ton Man.	6.73	3.37	7.55	1.58	7.89	1.22	7.64	1.10
5 Ton FBC & Man	6.56	3.39	7.31	1.94	7.72	1.55	7.41	1.49
10 Ton FBC	6.54	4.07	7.39	2.52	7.72	1.80	7.48	1.56
10 Ton FBC & Man	6.47	5.56	7.28	2.79	7.92	1.87	7.69	1.93

	JD = 297		JD = 301		JD = 311		JD = 318	
Treatment	pH	EC ₂₅	pH	EC ₂₅	pH	EC ₂₅	pH	EC ₂₅
Control	8.08	0.83	8.13	0.67	8.37	0.51	8.50	0.50
5 Ton FBC	7.75	1.10	7.77	1.05	8.05	0.97	8.16	0.95
5 Ton Man.	8.06	0.85	8.08	0.72	8.36	0.65	8.42	0.66
5 Ton FBC & Man	7.87	1.22	7.84	1.10	8.17	1.02	8.34	0.96
10 Ton FBC	8.00	1.31	8.02	1.15	8.32	1.05	8.38	0.96
10 Ton FBC & Man	8.07	1.54	8.08	1.50	8.32	1.42	8.38	1.35

Table C. (continued)

	JD = 325		JD = 332		JD = 339		JD = 346	
Treatment	pH	EC ₂₅	pH	EC ₂₅	pH	EC ₂₅	pH	EC ₂₅
Control	8.30	0.48	8.48	0.51	8.63	0.53	8.64	0.51
5 Ton FBC	8.02	0.86	8.18	0.85	8.38	0.80	8.40	0.80
5 Ton Man.	8.26	0.66	8.41	0.66	8.59	0.64	8.60	0.59
5 Ton FBC & Man	8.14	0.91	8.28	0.92	8.45	0.92	8.46	0.94
10 Ton FBC	8.16	0.93	8.37	0.96	8.52	0.96	8.48	0.96
10 Ton FBC & Man	8.15	1.26	8.35	1.27	8.49	1.24	8.52	1.19
	JD = 353		JD = 360		JD = 003		JD = 16	
Treatment	pH	EC ₂₅	pH	EC ₂₅	pH	EC ₂₅	pH	EC ₂₅
Control	8.64	0.48	8.56	0.44	8.63	0.45	8.53	0.43
5 Ton FBC	8.37	0.75	8.38	0.72	8.44	0.71	8.40	0.65
5 Ton Man.	8.62	0.55	8.54	0.50	8.61	0.47	8.47	0.44
5 Ton FBC & Man	8.45	0.92	8.39	0.86	8.48	0.82	8.46	0.71
10 Ton FBC	8.49	0.92	8.47	0.86	8.53	0.82	8.38	0.71
10 Ton FBC & Man	8.52	1.12	8.45	1.07	8.56	1.02	8.48	0.90

Table D. Cumulative amounts of Fe, P, Ca, Mg, Zn and SO₄ - S leached from the columns after 16 rainfall events.

Treatment	Total Fe (μ g)	Total P (μ g)	Total Ca (mg)	Total Mg (mg)	Total Zn (μ g)	Total SO ₄ -S (mg)	Total Cl ⁻ (mg)
Control	86	38	14.5 d	8.8 d	1.6	2.7 d	6.2 c
Fluidized Bed Ash 5T/A	100	44	21.2 bc	12.5 bc	4.2	13.7 c	6.8 c
Dairy Manure 5T/A	88	47	15.6 cd	9.5 cd	2.8	3.8 d	9.9 b
Fluidized Bed Ash 5T/A & Dairy Manure 5T/A	90	47	21.0 bc	12.6 bc	2.3	18.2 b	9.8 b
Fluidized Bed Ash 10T/A	100	53	22.2 b	13.3 b	3.4	18.6 b	8.2 bc
Fluidized bed Ash 10T/A & Dairy Manure 10T/A	130	71	28.8 a	17.4 a	2.7	26.7 a	17.4 a

*Values within columns not followed by the same lower case letter are significantly different at the 5% level. Absence of lower case letters indicates no differences among means.

Figure 1. Layout of the replicate field plots for 'Chester' blackberry production on swing-trellis. Each plot contains 7 plants spaced 3.5' within row and each row is 3' wide producing a 73.5 sq ft area for treatment. FBM was surface applied at rates equivalent to 10 tons per acre (actual application was 33.75 lbs of dry FBC per plot) and dairy manure (MAN) was surface applied at rates equivalent to 5 tons per acre (actual application was 17 lbs of wet dairy manure per plot). Treatments were applied August 29, 1995. Control (CON) plots received no amendments.

Figure 2. Leachate pH from the treated soil columns after each of the 16 rainfall events.

Figure 3. Leachate EC from the treated soil columns after each of the 16 rainfall events.

Figure 4. Leachate Fe from the soil columns after each of the 16 rainfall events.

Figure 5. Leachate P from the soil columns after each of the 16 rainfall events.

Figure 6. Leachate Mg from the soil columns after each of the 16 rainfall events.

Figure 7. Leachate Ca from the soil columns after each of the 16 rainfall events.

Figure 8. Leachate Zn from the soil columns after each of the 16 rainfall events.

Figure 9. Leachate K from the soil columns after each of the 16 rainfall events.

Figure 10. Leachate Cl from the soil columns after each of the 16 rainfall events.

Figure 11. Leachate SO₄ from the soil columns after each of the 16 rainfall events.