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Effectiveness of Fluidized Bed Material as a Calcium Source for Apples[1]

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Abstract. **Fluidized bed material (FBM), a dry, high Ca, alkaline waste product which results from combining coal and limestone, was used as the sole source of Ca for 'York Imperial' apples (*Malus domestica* Borkh.) grown in outdoor sand cultures over 3 growing seasons. FBM treatments were compared to gypsum, applied at similar rates based on apple tree Ca requirements, and to a no Ca amended control. Over 3 years, leaf Ca was significantly enhanced by increasing levels of FBM. FBM was a better Ca source compared to gypsum applied at similar rates only during the third year. Fruit flesh Ca and the incidence of cork spot were not significantly or consistently affected by treatments. There were no visual or nutrient deficiencies or toxicities noted from the FBM nor were yields and average fruit size affected.**

With the current increased utilization of coal as an energy source, there is a need to reduce SO_2 emissions from coal-fired plants. One of the newer, economical methods of reducing SO_2 emission from such plants is the utilization of the fluidized-bed combustion boiler design. This process involves mixing fine grain coal and limestone (or dolomitic limestone) in a furnace with a "fluid bed" achieved by injecting air. The limestone reacts with S from the coal during combustion. Unlike the waste sludge produced by conventional scrubber facilities, the fluidized bed material (FBM) is dry and easily transported. Ruth (7) estimated that a 1000 MW fluidized-bed power plant without regeneration of the bed material would produce about 1800 metric tons of FBM per day.

Terman et al. (11) utilized FBM both as a nutrient source for peanuts and corn and as a pH amendment for acid soils and coal mine spoils. They found that the material was satisfactory for both purposes. Since FBM contains about 30% Ca and since low Ca has been associated with many fruit disorders (8), FBM may also be beneficial as a Ca source or lime substitute for apples. Previous work (5) has shown that FBM, when applied at or near the lime requirement of a range of soils, increased apple seedling growth and Ca status in the greenhouse. This

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report presents results of the effect of a single application of FBM on the Ca status (as well as other elements) of 'York Imperial' apple leaf and fruit grown in outdoor sand cultures over 3 growing seasons. The first year's results from this study have been reported previously (4).

Materials and Methods

The FBM used was obtained from the Pope, Robbins, and Evans 0.5 MW pilot steam generator in Alexandria, Va. The bed materials used (Sewickley steam coal and Greer limestone) produced FBM containing about 52.4% $CaSO_4$, 33.1% CaO, and 0.6% $CaSO_3$. Trace element concentrations were 2.9% Al, 1.02% Fe, 36 ppm Cu, 112 ppm B, 220 ppm Mn, and 80 ppm Zn. Based on analyses in other laboratories (2), similar FBM samples contained Sr ranging between 160–745 ppm and Pb between 1 and 85 ppm. Average particle size distribution was: 1 mm, 31.7%; 1–2 mm, 60.7%; 2–4 mm, 6.1%; and 4 mm, 1.4%. The material has an aqueous pH (1:1 by weight) of 12.5.

Twelve-year-old 'York Imperial'/Malling (M) 26 apple trees established in outdoor sand cultures were used to test the Ca-supplying ability of applied FBM during 3 growing seasons (1977 through 1979). These trees were used in previous nutritional studies (9). The sand cultures contained about 200 liters of quartz sand in sunken, well-drained drums. The FBM treatments were based on a previously determined Ca requirement of 115 g per tree during a single growing season. FBM (28% Ca) was applied at 1/2, 1, 2, 4, 8, and 16 times this required Ca level. This required 0.20, 0.41, 0.82, 1.64, 3.28, and 6.56 kg FBM/tree, respectively, applied in early spring, 1977. Two additional split FBM treatments were applied, pre- and post-bloom, during the first year. Since, over the 3-year growing period, the split treatments were similar to the 1 × and 2 × FBM treatments, as previously reported for the first growing season (4), they are not included here. Two gypsum ($CaSO_4\ 2H_2O$) treatments, at 1 × and 2 × FBM rates of Ca and a control (no Ca added) treatment were used for comparison. Seven replications of each of the 9 treatments were assigned in a completely randomized design to the field sand cultures.

All trees received a complete (minus Ca) nutrient solution 3 times every 2 weeks during the growing seasons. The nutrient solution was 3 mM $NaNO_3$, 1 mM KNO_3, 0.5 mM KH_2PO_4, 2 mM $Mg(NO_3)_2 \cdot 6\ H_2O$, 0.5 ppm B, 0.25 ppm Cu, 0.5 ppm Zn, 0.5 ppm Mo, 0.5 ppm Mn, and 6 ppm Fe.

Yearly, midshoot leaf samples, 20 leaves per tree, were taken during midsummer, dried at 70°C for 48 hr, and ground to pass a 20-mesh sieve. Total fruit was harvested yearly and 10 apples per tree were selected for examination for cork spot and flesh mineral analyses. A composite flesh sample from the 10 apples was freeze-dried and stored for analysis. Leaf and fruit flesh samples were analyzed for Ca, Mg, K, P, Cu, Fe, B, Zn, and Mn in 1977 by emission spectroscopy for S by a leco induction furnace equipped with an automatic titrator, and for N by the Kjeldahl method. In 1978 and 1979, the preceding elements plus Pb and Sr were analyzed by emission spectroscopy (1).

Sand samples, 0–15 cm, were taken yearly after harvest and analyzed for pH on a 1:1 (sand:water) sample. Additionally, sand conductivity, measured on a 1:1 (sand:water) sample, and 1 N NH_4OAc, pH 7.0, extractable sand Ca were determined in 1978 and 1979. Extractable sand Ca was determined using atomic absorption spectroscopy.

Results and Discussion

The trees showed no indications of foliar deficiency or toxicity symptoms from any treatment over the 3-year period. Leaf dry weight was significantly greater for the 4 × FBM treatment than the control or gypsum-amended trees (Table 1). Leaf dry weight, averaged over all treatments, was significantly higher in 1978 and 1979. Treatment effects were nonsignificant for total number and average weight of apples per tree averaged over the 3-year period. However, there were significantly more apples per tree in 1979 and the average weight per apple was significantly lower in 1979 than 1978 (Table 1).

Leaf Ca was significantly higher than the control for FBM rates at the 2 × or greater level and for the gypsum treatments, averaged over 3 years (Table 2). Gypsum, on the average, was a better supplier of Ca than FBM at similar rates. However, the yearly trends noted in Table 2 appear to indicate the FBM was a better (i.e., slower release) source of Ca than gypsum when applied at equivalent weights. This is probably due to the large particle size (slower breakdown) of the FBM and to the fact that the surface-sulfated calcium oxide particles contain a calcium oxide central core, which, when the particle weathers, could cause a short duration, high release of Ca (3, 7).

The leaf Ca levels reported in Table 2 were all above the deficiency level (0.7%) noted by Shear and Faust (10). The trends noted for leaf Ca were absent for fruit flesh Ca (Table 2). There were no significant differences between all treatments averaged over the 3 harvests. Overall, fruit flesh Ca was significantly higher in 1977 than in either 1978 or 1979. The incidence of cork spot (Table 2) varied greatly depending upon treatment and season and was influenced by the average total number of fruit per tree and average fruit weight (Table 1). Correlation analysis between cork spot incidence and average total number of apples or average fruit weight was highly significant ($p < 0.1\%$), yielding r values of -0.625 and 0.460, respectively.

Besides Ca, all elemental concentrations were within known sufficiency ranges (10). Leaf N and K were not significantly

Table 1. Average treatment and year means for leaf dry weight, number of apples per tree, and average weight per apple from the fluidized bed material (FBM) and gypsum treatments applied once to 'York Imperial'/EM 26 trees grown in outdoor sand cultures for 3 growing seasons.

Treatment[z]	Leaf dry wt (g/20 leaves)	No. apples/tree	Avg wt/apple (g)
Control—no Ca	5.7b[y]	72a	107 a
FBM			
(½ ×)	5.6b	74a	110a
(1 ×)	5.4b	63a	101a
(2 ×)	6.2ab	74a	106a
(4 ×)	6.8a	104a	112a
(8 ×)	6.1ab	88a	108a
(16 ×)	6.3ab	75a	108a
Gypsum			
(1 ×)	5.7b	85a	104a
(2 ×)	5.5b	64a	101a
Year mean			
1977	5.2b	71b	107ab
1978	6.2a	49b	115a
1979	6.0a	119a	99b

[z] The 1 × treament level of FBM or gypsum provided 115 g/Ca per tree.

[y] Mean separation in columns for treatments or years by Duncan's multiple range test, 5% level.

Table 2. Average leaf and fruit flesh Ca concentrations and the incidence of cork spot in 'York Imperial' apples grown in outdoor sand culture as affected by a single application of fluidized bed material (FBM) and gypsum.

	Leaf Ca (% dry matter)				Fruit flesh Ca (% dry matter)				Cork spot incidence (%)		
Treatment[z]	1977	1978	1979	Treatment mean	1977	1978	1979	Treatment mean	1977	1978	1979
Control—no Ca	1.15	1.09	0.90	1.06e[y]	0.020	0.013	0.013	0.016a	48[x]	33	42
FBM											
(½×)	1.14	1.28	1.05	1.11de	0.022	0.012	0.014	0.017a	53	16	52
(1×)	1.27	1.15	1.22	1.21de	0.023	0.011	0.016	0.017a	18	20	50
(2×)	1.35	1.27	1.29	1.30cd	0.023	0.018	0.014	0.019a	27	7	42
(4×)	1.50	1.35	1.58	1.48bc	0.026	0.012	0.013	0.017a	28	25	52
(8×)	1.61	1.39	1.62	1.54b	0.025	0.014	0.015	0.018a	37	28	41
(16×)	1.75	1.78	1.74	1.76a	0.025	0.017	0.014	0.019a	20	20	64
Gypsum											
(1×)	1.78	1.63	0.99	1.48bc	0.028	0.016	0.012	0.019a	2	16	44
(2×)	2.08	1.43	1.04	1.56ab	0.028	0.015	0.012	0.020a	26	20	65
Year mean	1.50a	1.36b	1.32b		0.024a	0.014b	0.014b		29	20	50

[z] The 1 × treatment level of FBM or gypsum provided 115 g/Ca per tree.

[y] Mean separation in columns or rows by Duncan's multiple range test, 5% level.

[x] Incidence of cork spot is based on 70 apples per treatment.

affected by treatments (data not shown). Leaf P, Mg, B, Mn, and Zn tended to be lower, with high rates of FBM application compared to the control or gypsum treatments (Table 3). Similar effects were noted for Cu and Fe, while there was little difference between treatments for leaf Pb (data not shown). Leaf S was significantly higher from the 16× FBM or gypsum treatments than the control due to the higher S inputs from these treatments. Although the FBM contained trace levels of B, Mn, and Zn, the amounts added were overshadowed by the higher pH of the media (see Table 6). There was no significant effect of treatments on leaf Al; however, leaf Al significantly increased from 1978 to 1979. This marked increase in leaf Al was not due to treatments, since there was little or no significant difference between treatments each of the 3 years (yearly data not presented).

Leaf Sr was significantly higher from the 4×, 8×, and 16× FBM treatments compared to either the control or gypsum treatments, reflecting the trace levels of Sr in the FBM. However, on the average, leaf Sr significantly decreased from 1978 to 1979. The reported Sr levels are within acceptable levels as reported for other crops (12).

Generally, fruit flesh levels of N, K, Mn, Fe, Cu, Al, Zn, and Pb were little affected by treatments (data not shown). Flesh

Table 3. Selected average leaf elemental composition from the 'York Imperial' apples in outdoor sand culture as affected by a single application of fluidized bed material (FBM) and gypsum.[z]

	Leaf element composition									
Treatment[y]	N (%)	P (%)	K (%)	Mg (%)	S (%)	B (ppm)	Mn (ppm)	Zn (ppm)	Al (ppm)	Sr (ppm)
Control—no Ca	2.51a[x]	0.19ab	0.89a	0.99a	0.14c	49ab	44b	54bc	310a	17cd
FBM										
(½×)	2.52a	0.18ab	0.94a	0.94ab	0.15c	48abc	31bc	52bc	313a	17cd
(1×)	2.52a	0.18ab	0.88a	0.91ab	0.15c	44c	27c	50bc	328a	18bcd
(2×)	2.51a	0.17bc	0.96a	0.90ab	0.15c	46bc	35bc	46c	325a	19bc
(4×)	2.43a	0.17bc	0.93a	0.95a	0.15c	42c	32bc	47bc	342a	22b
(8×)	2.52a	0.17bc	0.96a	0.86ab	0.16bc	43c	37bc	49bc	344a	22b
(16×)	2.48a	0.15c	1.00a	0.79b	0.19a	42c	42bc	49bc	322a	31a
Gypsum										
(1×)	2.54a	0.18ab	0.87a	0.91ab	0.17b	45bc	73a	59ab	331a	16cd
(2×)	2.52a	0.20a	0.93a	0.87ab	0.18ab	51a	83a	67a	324a	14d
Year										
1977	2.79a	0.20a	0.91b	0.88b	0.18a	50a	69a	91a	99c	NA
1978	2.36b	0.16b	1.08a	0.71a	0.16b	47b	34b	35b	253b	23a
1979	2.33b	0.16b	0.80c	1.13c	0.14c	38c	25c	26c	666a	18b

[z] Leaf Sr only analyzed in 1978, NA = not analyzed.

[y] The 1 × treatment level of FBM or gypsum provided 115 g/Ca per tree.

[x] Mean separation in columns for treatments or years by Duncan multiple range test, 5% level.

P levels were significantly lower from the higher FBM levels compared to either the control or gypsum treatments (Table 4), which follows the trend found with leaf P. Flesh Mg was similar in pattern to P, while the higher leaf S noted with FBM did not occur with flesh S (Table 4). The lower flesh P levels with increased FBM were also reflected in the leaf P levels. Due to the high Ca content of the FBM and thus the elevated media pH, perhaps just within localized areas around FBM particles, possible precipitation of applied P could have occurred, resulting in lower uptake. Additionally, the high applied Ca levels from the FBM resulted in lowered Mg uptake. Fruit flesh B and Sr were little affected by treatments although there was a significant decrease over harvests in the case of B.

Addition of FBM to the sand drums significantly increased sand pH, conductivity, and extractable Ca levels (Table 5). The high conductivity noted in the 16× FBM treatment was lower than values obtained in previous work (5) where no seedling growth depression occurred. The elevated sand Ca values are a reflection of the high Ca status of the FBM and indicate that, at comparable applied Ca levels, the FBM acted as a slower release source of Ca than gypsum (Table 5).

Tree growth and yields were not affected even at high FBM rates. Although FBM was shown to be an adequate supplier of Ca to the tree via leaf analysis, there was little or no influence on fruit flesh Ca levels. Over the 3 harvests, there was no consistent effect of treatments on the incidence of cork spot. The effect of high rates of FBM on tree nutrition generally followed expected trends based on waste composition: lower leaf Mg and P due to high Ca inputs, higher leaf S due to high S in FBM, and generally less pH-sensitive nutrients, such as Mn, Fe, Zn and Cu. From a trace contaminant standpoint, of the elements studied, only leaf Sr from the 16× FBM treatment was severely elevated. However, the levels reported are within known acceptable limits and were not reflected in the fruit flesh.

Table 4. Selected average fruit flesh composition from the 'York Imperial' apples as affected by a single application of fluidized bed material (FBM) and gypsum.

Treatment	Fruit element composition[z]						
	N (%)	P (%)	K (%)	Mg (%)	S (%)	B (ppm)	Sr (ppm)
Control—no Ca	0.53a	980a[y]	0.83a	370a	680a	27ab	0.3a
FBM							
(½×)	0.50a	920abc	0.81a	350ab	600ab	26ab	0.2ab
(1×)	0.54a	950ab	0.82a	350ab	670a	22b	0.2ab
(2×)	0.48a	870bc	0.81a	350ab	570b	24ab	0.2ab
(4×)	0.53a	830c	0.83a	330abc	550b	24ab	0.2ab
(8×)	0.48a	750d	0.77a	310bc	580b	24ab	0.2ab
(16×)	0.44a	650e	0.75a	300c	630ab	26ab	0.3a
Gypsum							
(1×)	0.44a	860c	0.66a	300c	580b	24ab	0.1b
(2×)	0.51a	960ab	0.76a	330abc	590ab	28a	0.1b
Year							
1977	0.58a	940a	0.89a	340a	680a	31a	NA
1978	0.50b	890b	0.80b	320a	470c	23b	0.2a
1979	0.38c	710c	0.64c	330a	640b	20c	0.2a

[z] Fruit flesh Sr only analyzed in 1978 and 1979, NA = not analyzed.
[y] The 1× treatment level of FBM or gypsum provided 115 g/Ca per tree.
[x] Mean separation in columns for treatments or years by Duncan multiple range test, 5% level.

Table 5. Average pH, electrical conductivity (EC_{25}), and 1 N NH_4OAc-extractable Ca from the field sand cultures treated 1 time with fluidized bed material (FBM) or gypsum.[z]

Treatment[y]	pH	EC_{25} (mmhos/cm)	1 N NH_4OAc, pH 7.0, extractable Ca (ppm)
Control—no Ca	6.9c[x]	0.096b	40d
FBM			
(½×)	7.4ab	0.192b	190d
(1×)	7.5ab	0.198b	230d
(2×)	7.8a	0.263b	390cd
(4×)	7.8a	0.252b	670c
(8×)	7.7a	0.298b	1420b
(16×)	7.7a	0.985a	2270a
Gypsum			
(1×)	7.1bc	0.122b	30d
(2×)	7.0bc	0.136b	40d
Year			
1977	7.1b	NA	NA
1978	7.7a	0.356a	700a
1979	7.6a	0.259a	670a

[z] Conductivity and extractable Ca determined only in 1978 and 1979, NA = not analyzed. For pH, statistical analyses performed on hydrogen ion concentrations.
[y] The 1× treatment level of FBM or gypsum provided 115 g/Ca per tree.
[x] Mean separation in columns for treatments or years by Duncan's multiple range test, 5% level.

The fluidized-bed combustion process has 2 inherent problems: a) the excessive amount of material produced; and b) the variability in the waste from an agricultural use standpoint. Depending upon the type of sorbent (limestone, dolomitic limestone, or synthetic materials), the characteristics of the boiler, the regeneration/reuse of the bed material, and the S content of the coal, the FBM produced can vary greatly, which in turn will vary the Ca and S contents, the liming potential, and the trace element concentrations (6). From experiments reported so far (4, 5), the present evidence, and preliminary evidence obtained from orchard experiments yet to be reported, the conclusion emerges that within the constraints of variability of FBM, it is a useful material for improving soil pH (5) and supplying Ca to apple trees.

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Soil Cation and Water Distribution as Affected by NH_4NO_3 Applied through a Drip Irrigation System[1]

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Abstract. **'Redglobe' peaches [*Prunus persica* (L.) Batsch] were grown under drip irrigation. Applications of NH_4NO_3 through the irrigation system were compared with broadcast applications. Soil pH, where NH_4NO_3 was applied through the irrigation system, decreased in the top 30 cm from 6.2 to 3.7 pH in the zone wetted by emitters that had been in place for 2 years, and from 6.2 to 4.5 pH in the zone where emitters had been in place for 6 months. Aluminum concentration in wetted zones increased from 0.01 to 1.45 meq/100 g of soil after 2 years and from 0.02 to 0.73 meq/100 g of soil after 6 months of NH_4NO_3 application through drip irrigation. Soil Ca and Mg concentrations were reduced in both wetted zones, but the greatest decrease occurred in the 2-year emitter site. The addition of NH_4NO_3 in the irrigation water substantially reduced root growth in the vicinity of the emitters, irrigation water application, and fruit yield, because of the high Al concentration in the wetted zone.**

Irrigation in the Southeast is rapidly becoming a management practice that enables peach growers to increase production. During the peach growing season in the Southeast, extended periods without significant rain can occur during May–October. This results in insufficient soil water for optimum tree growth and fruit development (2, 3). Supplemental irrigation of peaches increases fruit size (1, 14, 17, 18, 19) and marketable yield (1, 9, 10, 13, 14). Others (5) reported that 13 years of irrigation did not influence total yield, growth, or longevity of 'Elberta' or 'Redhaven' peach trees.

Perhaps 25% of the total area of peaches in the Southeast is drip-irrigated. Drip irrigation requires only about 20% of the water application energy used for sprinkler systems (11) and it increases fruit yield (14, 18). Drip irrigation systems can supply water-soluble nutrients economically. The recommended rates for supplying nutrients through a drip system are about one-half of those for surface broadcast applications (3, 4).

The overall objectives of this experiment were to determine the effects of drip irrigation and fumigation on peach tree short life and fruit production. This report presents the effects of supplying NH_4NO_3 through the drip system upon soil pH, extractable cations, root distribution, water use, and yield.

Materials and Methods

The complete experiment involved nematicide application, soil surface modification, and soil water regime treatments imposed in an orchard planted to Redglobe peaches on 'Lovell' rootstock. This report deals only with selected soil water regime treatments. One-half of the experimental site is classified as Faceville fine sandy loam to loamy fine sand in the Thermic Typic Paleudult subgroup, and the other half as Greenville loamy fine sandy to fine sandy loam, in the Thermic Rhodic Paleudult subgroup. The trees were planted on a 6.1 × 6.1-m grid in early March 1975. A 3.7-m strip between the rows was seeded to tall fescue (*Festuca elatior* L.) and kept mowed. Terbacil (0.9 kg/ha) and diaron (1.3 kg/ha) were applied each spring to

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