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The Effect of Pulp Mill Effluents on the Carbon Dioxide Evolution of Three East Texas Soils

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THE EFFECT OF PULP MILL EFFLUENTS ON THE

CARBON DIOXIDE EVOLUTION OF

THREE EAST TEXAS SOILS

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THE EFFECT OF PULP MILL EFFLUENTS ON THE CARBON DIOXIDE EVOLUTION OF THREE EAST TEXAS SOILS

by

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INTRODUCTION

The South boasts 98 pulp and paper mills with a daily capacity of almost 75,000 tons. This is an increase of nearly four times the production of 1946. A further twofold increase in pulp production is predicted by 1985 (Southern Forest Resource Analysis Committee, 1969). Since 8,000 to 12,000 gallons of water are required in the processing of each ton of paper (Vercher et al., 1965), the Southern paper industry must presently be able to dispose of almost one billion gallons of waste water per day (Jorgensen, 1970). This volume will be doubled over the next fifteen years.

Present waste water disposal methods depend primarily on natural stream flow to dilute and transport the waste. However, this effluent, containing cellulose, hemicellulose, lignin, and sulfates and chlorides of sodium, imparts a strong odor and dark color to natural waters and may be harmful to fish and other aquatic life.

With an increase in effluent discharge, resulting from the predicted increase in production, and the recent emphasis placed on water quality and pollution, the pulp and paper industry must find alternative disposal methods. Several possible alternatives include clarification and filtration within the mill, impoundment, and land disposal as an irrigation media (Jorgensen, 1970).

Land disposal as an irrigation media on agricultural and forest lands is a most attractive possibility. The ability of plants, particularly forest vegetation, to transpire large amounts of water along with a relatively low cost of establishment would make this an ideal method of disposal. Additional benefits would be relief from water stress during drought periods, leading to a possible increase in wood production, and partial recycling of the water through the environment.

However, the successful use of land disposal systems is highly dependent on soil conditions, particularly the ability of soil microorganisms to digest the organic components of the effluent and to clarify and purify the effluent as it percolates through the upper layers of the soil. Some of the constituents of the effluent, especially the sulfates, chlorides, and sodium are thought to be detrimental to plants and/or soil microorganisms.

The purpose of this study was to investigate the effect of pulp mill effluent on the activity of soil microorganism populations in surface soils.

REVIEW OF LITERATURE

Interest in land disposal of pulp mill effluents stems from the irrigation of land with waste materials of the food processing industry (Mather, 1953; Gellman and Blosser, 1960). The basis of such disposal systems is the ability of soil organisms to utilize the organic wastes, converting them into natural compounds (Watterston, 1971). Organic wood fiber in pulp effluents that contribute to oxygen deficiency and biological oxygen demand (BOD) in streams may be beneficial in increasing forest production by increasing friability and contributing organic matter needed by soil organisms.

A number of reports are favorable to irrigation. McCormick (1959) and Vercher _et al_. (1965) found no harmful influence on crops, cattle, or soils while irrigating sandy soils. Watterston (1971) and Jorgensen (1970) recommend against the use of effluent for irrigation until some means of decreasing the sodium ion concentration is devised. This lack of agreement stems, in part, from soil, effluent treatment, and effluent dilution differences in the various studies. Jorgensen (1970) listed high sodium hazard, salinity hazard, high concentration of bicarbonates, high pH, and high organic matter content among the factors which limit the suitability of effluent for irrigation. He also indicated that salinity and sodium hazards in black water, from the NaOH pulp bleaching process, is high enough to suggest dilution before use as an irrigant. Watterston and Smeltzer (1970) reported black water caused sodium saturation of the exchange complex, dispersion of the clay particles, and bivalent cation replacement of calcium and magnesium by sodium. Acid water, from the chlorination step of the pulp bleaching process, appeared to be less harmful to soil, although indications were that over a period of time acid water, too, would prove detrimental due to a loss of calcium and magnesium. In a small pot study using a sandy loam, Jorgensen (1970) found a 40 percent black water solution induced mortality in pot-grown slash pine seedlings. Survival was related to sodium and soluble salt accumulation, though mortality was not preceded by stunting. Treatment with a 20 percent black water solution developed the maximum sodium and salinity hazard when applied to a well drained soil.

Soil texture must be evaluated when considering irrigation with mill effluents. Plant growth in porous textured soils such as sands and sandy loams might be expected to benefit by irrigation, but there is a possibility of sub-surface water contamination by the effluent. The heavier soils, clays and clay loams, tend to disperse and prevent further percolation of the effluent into the soil. McCormick (1959) reported salt concentrations in sandy soils approaching the salt concentrations of the irrigating water. In clayey soils near the wilting point, sodium accumulation may cause salt concentrations as high as 100 times that of the irrigating water. The high sodium and organic residues in 100 percent black water induces poor soil structure in a sandy loam by breaking down the soil aggregates and causing puddling of the surface soil (Jorgensen, 1970). Watterston and Smeltzer (1970) reported sodium saturation, and the associated breakdown of soil aggregates and dispersion of clay particles plugged a Blake clay and a Woden clay loam preventing infiltration and percolation of water. This dispersion of clay particles may cause a decrease in soil permeability and aeration resulting in anaerobic conditions unfavorable for the respiration of large groups of soil microorganisms. Little effect was noted on a Eustis sand with its low content of fine soil particles.

Of the many groups of microorganisms inhabiting the soil, the most important, in terms of organic matter decomposition, include bacteria, fungi, actinomycetes, and protozoa. They are of two types: The autotrophs, whose diet consists of minerals which they synthesize into organic tissue, and the heterotrophs, which require organic materials previously synthesized by some other organism. Heterotrophs are consumers and embrace all animals, the fungi, and most bacteria. The role of microorganisms in the soil forming process is enormous, mainly because of the intensity of biological transformations of substances in the rapid sequence of generations (Volobuev, 1963). Nearly all the nitrogen and sulfur and much of the phosphorus in agricultural soils are released by microbial activity. Raw organic matter and minerals are transformed by soil microbes into humus, essential for good tilth, favorable aeration and moisture retention, and as a buffer against pH changes. Bollen (1959) contends their function is to render potential fertility available to trees and other organisms under certain environmental conditions: an optimum temperature of 28°C, a humidity of 50 percent of the soil's field capacity, and a food supply with a carbon-nitrogen ratio of 25:1. The activity of microorganisms depends especially on the forms of energy available, temperature and moisture content, aeration, which should be approximately 50 percent of the pore space of the soil, and reaction, which varies considerably but should lie near pH 7 (Volobuev, 1963). Their metabolic end products increase the size and the stability of the soil aggregates (Gellman and Blosser, 1960), affect decomposition and humus formation, and mineralize the humus fraction (Walczyna, 1962). These factors which benefit the soil also serve to increase the soil microorganism population. A common means of estimating this population involves measurement of their carbon dioxide respiration.

Carbon dioxide is usually found in higher than atmospheric concentrations in forest soils (Voigt, 1962), with concentrations varying from 0.03 to 13 percent by volume. Movement is by diffusion from high to low concentrations and is related to soil porosity (Smith and Brown, 1933). This diffusion from the high carbon dioxide concentrations in the soil to the relatively low concentrations of the atmosphere is generally termed "soil respiration." The evolved carbon dioxide is generated by the decomposition of organic matter by soil organisms and/or by root respiration (Wiant, 1967a; Reiners, 1968). While fungi and the soil fauna account for much soil respiration, most authorities agree that bacteria contribute the major source of carbon dioxide found in the soil. Many investigators have expressed the opinion that root respiration, too, accounts for a large portion of soil respiration (Wiant, 1967a).

Temperature and moisture are the major influences on soil respiration. Earlier investigators indicated soil respiration data which followed a Q_{10} factor of 2 (the rate at which a chemical reaction is doubled for each 10° C increase in temperature) between 10° and 40° C. Wiant (1967b) substantiated earlier reports by indicating a Q_{10} factor of 2 between 20° and 40° C.

The effects of moisture content on respiration are usually not as abrupt as are those of temperature (Wiant, 1967c; Reiners, 1968). While a 50 to 60 percent moisture content produces the greatest carbon dioxide production (Wiant, 1967c), moisture contents near 100 percent of field capacity, for short periods of time, reduce respiration only slightly. Moisture contents below 10 to 20 percent of field capacity produce a sharp decrease in respiration (Wiant, 1967c). Percolating water may also cause an increase in carbon dioxide evolution due to the displacement of carbon dioxide from the pore spaces (Huber, 1958).

MATERIALS AND METHODS

Three soils were selected to represent extremes of texture: a Eustis sand, a Mantachie fine sandy clay loam, and a Blake clay. After removal of the surface vegetation and litter, the top 4 inches of soil were removed and mixed. The mixed soil was placed in mason jars in a 3-inch layer on top of a 2-inch layer of gravel. Approximately 2 inches of air space was left between the top of the soil and the lid of the jar to serve as a chamber from which the sample air was drawn.

A 45 jar array was established in a greenhouse with a temperature range from 22° to 35° C. Fifteen jars (5 of each soil type) were watered with black water (the NaOH extraction water from the pulp bleaching process) diluted 50:50 with distilled water. Another 15 jars were watered with a 50:50 acid water (water from the chlorination step of the pulp bleaching process) solution, and a third set of 15 jars served as a control and was watered with distilled water. An initial complete wetting required 100 ml of effluent. Subsequent applications were 50 ml regardless of effluent type or soil texture. In no case were the soil samples waterlogged. Observations through the glass sides of the containers permitted determination of the correct amount of effluent. All soils were watered at 2-day intervals as the evaporation of moisture from the jars equalled approximately 50 ml in 2 days. Measurements of carbon dioxide evolution were made on the off-watering day.

A Beckman infrared gas analyzer (Model IR 215) coupled with a Beckman pen recorder was used to determine carbon dioxide evolution.

The gas analyzer, described by Huber (1958), can detect differences of 1 part per million in carbon dioxide concentrations. The sample air was drawn through Tygon tubing by a Neptune 4K electric air pump at a flow rate of 1 liter per minute. Moisture was removed from the air sample before entering the gas analyzer by passing through Drierite ($CaSO_4$), and the air was scrubbed of carbon dioxide after passing through the analyzer by passing through Ascarite (a sodium hydrate asbestos). Flow meters were provided on either side of the sample jar to permit detection of any leaks in the system (Figure 1). Evolution of carbon dioxide from the jar was measured by closing the jar opening securely with a 2-hole stopper mounted in a mason jar lid. Carbon dioxide-free air was introduced through one hole, and the atmosphere above the soil was sampled through the other. The input nozzle extended 1 inch deeper than the exit nozzle to provide good circulation.

Carbon dioxide measurements were taken immediately following potting and from 24 to 30 hours after each effluent addition. Temperatures varied from 23° to 28° C at the time of measurement, and all measurements were corrected to 25° C on a Q_{10} factor of 2 basis by plotting on Log 10 semi-log paper. Two supplementary studies were also conducted to substantiate the results of the initial investigation.

In the first, 100 cc of sucrose was mixed with 500 cc of the fresh Mantachie fine sandy clay loam. The soil mixture was then added to mason jars which were maintained uncapped in a constant temperature water bath at 27° C. Initially 50 ml of concentrated acid water was added to 4 jars, 50 ml of black water was added to 4 jars, and a

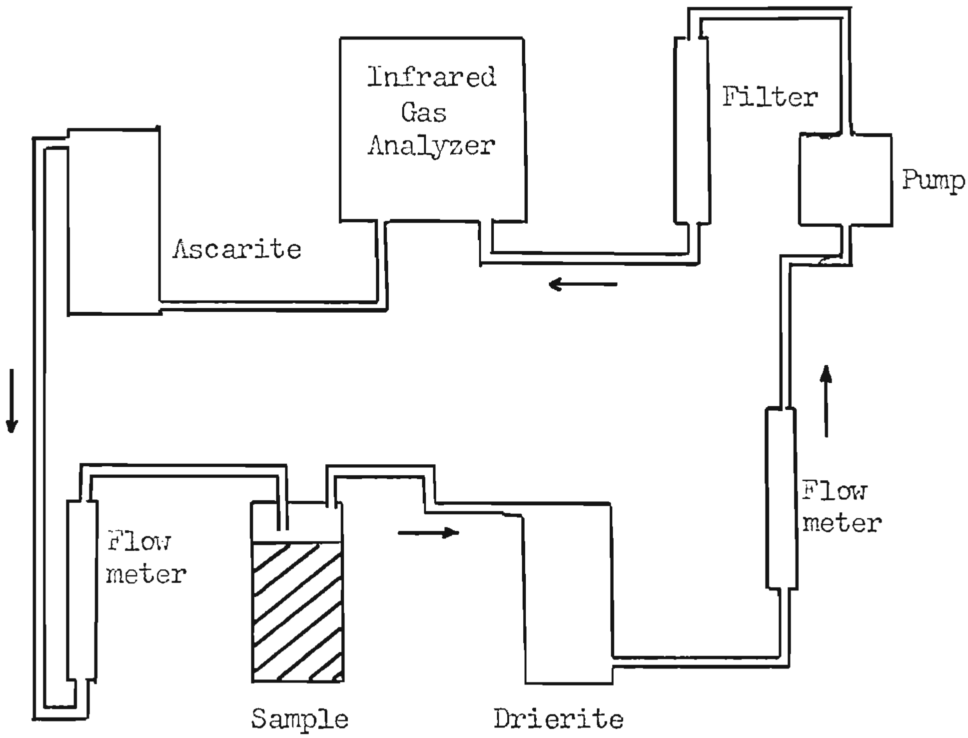

Figure 1. Diagram of the carbon dioxide measurement system.

distilled water control was added to 4 jars, followed by subsequent 25 ml of acid water, black water or control water additions at 48 hour intervals. Carbon dioxide evolution was measured 24 hours after watering. Measurements were conducted in the same manner as in the original investigation.

The second supplemental study involved measurement of growth rates in an agar media. Three sets of 3 petri dishes were poured with potato dextrose agar. The first set was hydrated with acid water instead of distilled water. A second set was poured with black water agar, and a third set was poured with distilled water following regular hydration procedures. All solutions were sterilized at 15 psig for 20 minutes in a steam autoclave before pouring into sterile petri dishes. A soil fungi, one of the *Penicillium* species, was aseptically transferred from a stock culture to all nine of the petri dishes. The petri dishes were then placed in a 20° C incubator for two weeks and compared at two day intervals for differences in rate of growth.

RESULTS AND CONCLUSIONS

All soils, regardless of treatment, displayed a general decline in carbon dioxide evolution during the course of the study. Depletion of an oxidizable substrate is believed responsible. All soils exhibited a peak in respiration midway in the experiment (Figures 2,3,4). The peak was most pronounced in the acid treatment and especially in the Blake clay. This "acid peak" may have been caused by measurement near the apex of the population cycle. The peak occurred first in the clay, followed by the loam and finally by a reduced peak in the sand (Figure 5).

The significantly lower (1% level) carbon dioxide evolution of the Blake clay (Figure 2, Appendix Tables 1, 5) may be attributed to the many wettings and intermittent dryings which tended to puddle the surface soil forming a layer which interfered with gaseous exchange. Measurements were made while the soils were moist, and the soil water also interfered with aeration. The gravel under the Blake soils always contained some excess effluent, although in no case was the soil sample inundated. The gravel beneath the loam and sand generally dried completely.

Respiration of the Eustis sand was greater than that of the Blake clay and less than that of the Mantachie fine sandy clay loam (Figure 3). Greater porosity of the sand would allow good aeration and respiration, but the low organic matter content may have limited population levels.

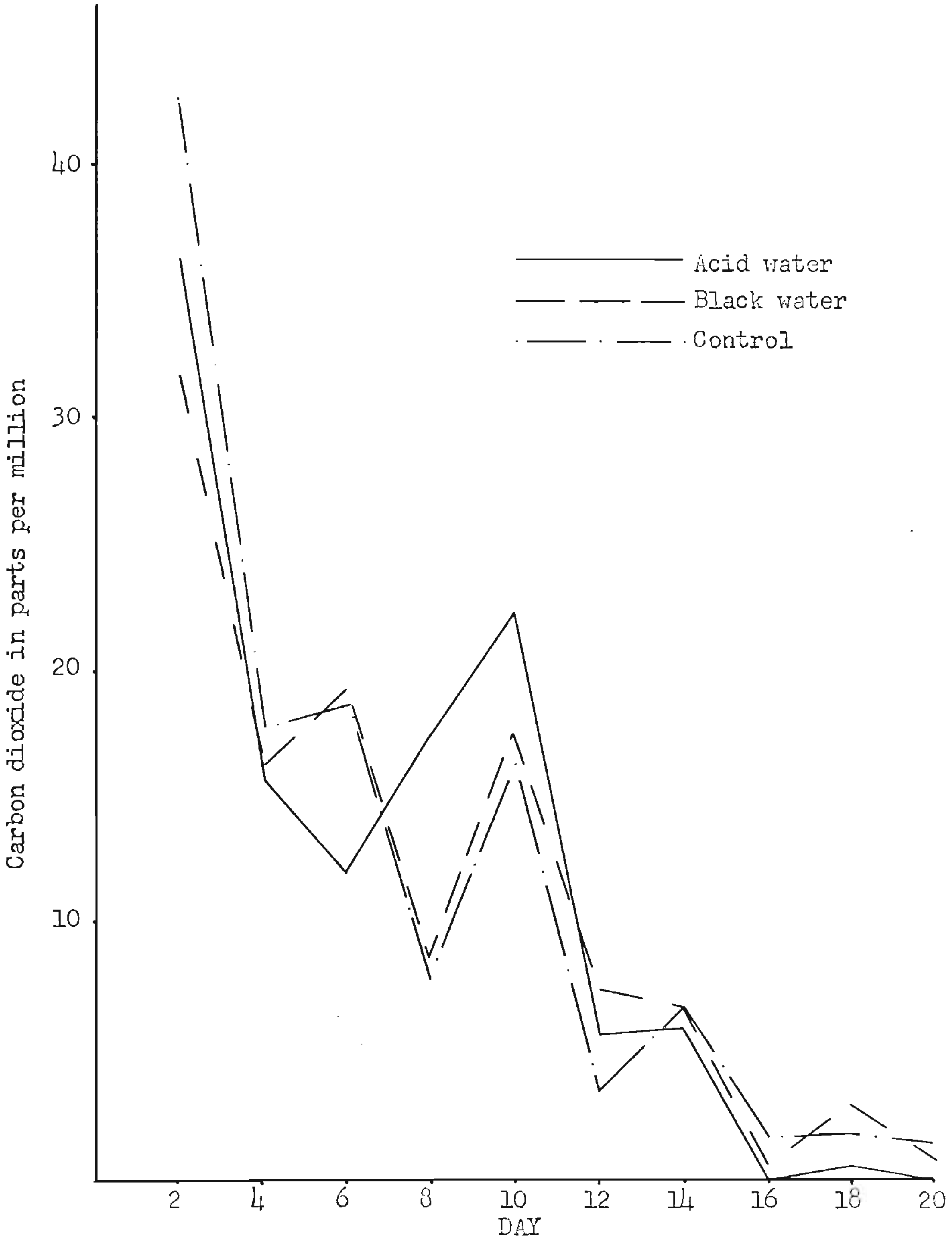

Figure 2. Average respiration of Blake clay under acid, black, and control water treatments for 10 measurements at 2-day intervals.

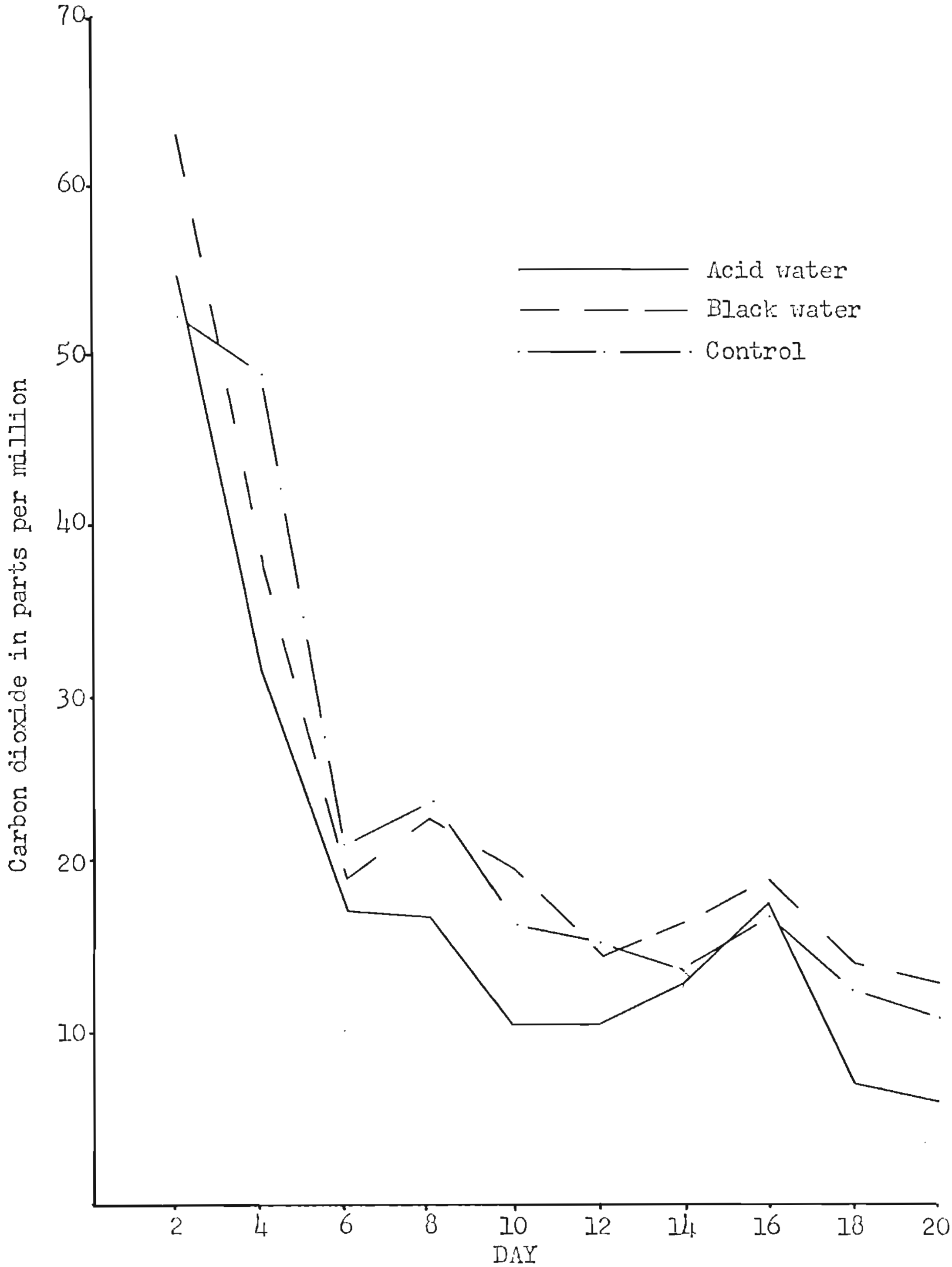

Figure 3. Average respiration of Eustis sand under acid, black, and control water treatments for 10 measurements at 2-day intervals.

The jars containing the Eustis sand dried most quickly, a result of the good aeration. A high evaporation rate coupled with deep soils and the need for additional organic matter may make sandy soils the natural choice for effluent disposal, although the possibility of sub-surface water contamination must be taken into account.

The Mantachie fine sandy clay loam, with good aeration and a high initial organic matter content, produced the greatest carbon dioxide evolution (Figure 4, Appendix Tables 3,5). Final readings were nearly ten times greater than those of the Blake clay and two times greater than those of the Eustis sand. Loam with a low clay content may also serve as a good choice for effluent disposal as the loam displayed good soil evaporation.

The acid water treatment yielded the lowest readings in all three soils, probably a result of the low pH. Respiration from the Mantachie fine sandy clay loam was highest followed by the Eustis sand and then the Blake clay (Figure 5, Appendix Table 2). Land application of the acid water alone is undesirable due to the low pH of the effluent which produces a reduced soil organism population.

Black water treatment of the three soils vied with the control for the highest respiration. Final respiration under black water treatment was highest in the Eustis sand and Mantachie fine sandy clay loam (Figure 6). This higher respiration was probably a result of the organic matter added by the effluent. While puddling of the surface layer was evident in all treatments of the Blake clay, black water caused the worst puddling. For this reason, irrigation with black water alone is undesirable.

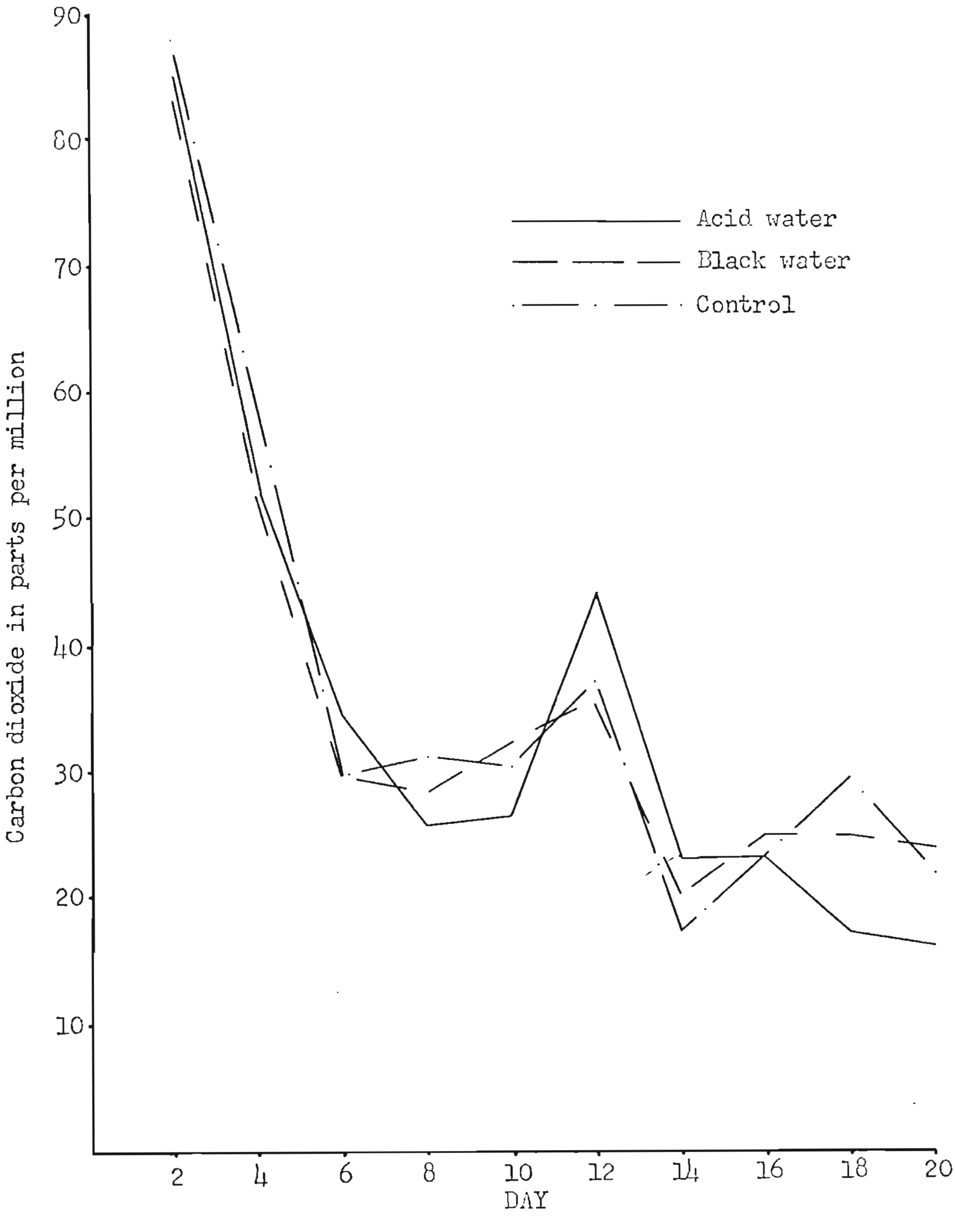

Figure 4. Average respiration of Mantachie fine sandy clay loam under acid, black, and control water treatments for 10 measurements at 2-day intervals.

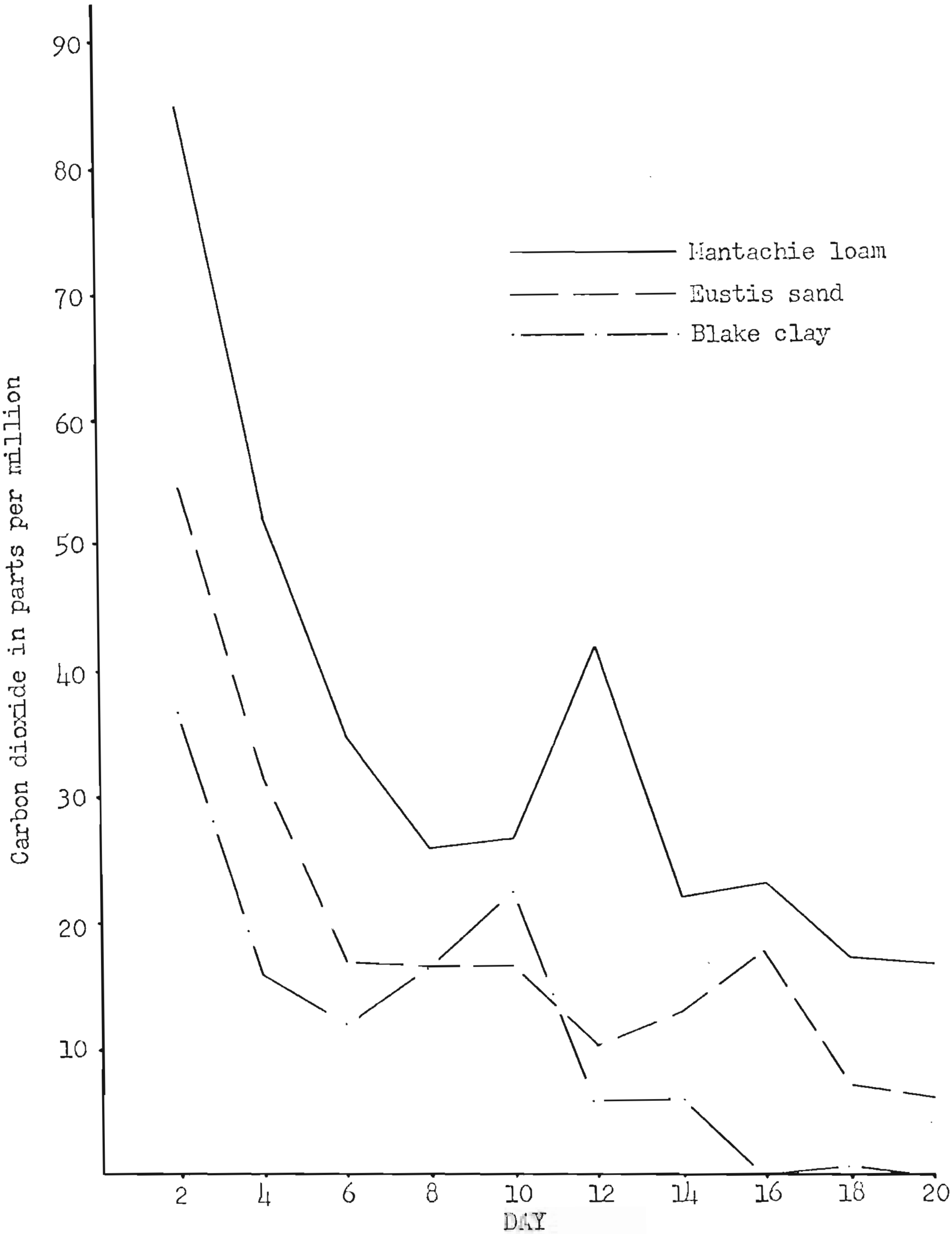

Figure 5. Average respiration of Mantachie loam, Eustis sand, and Blake clay under acid water treatment for 10 measurements at 2-day intervals.

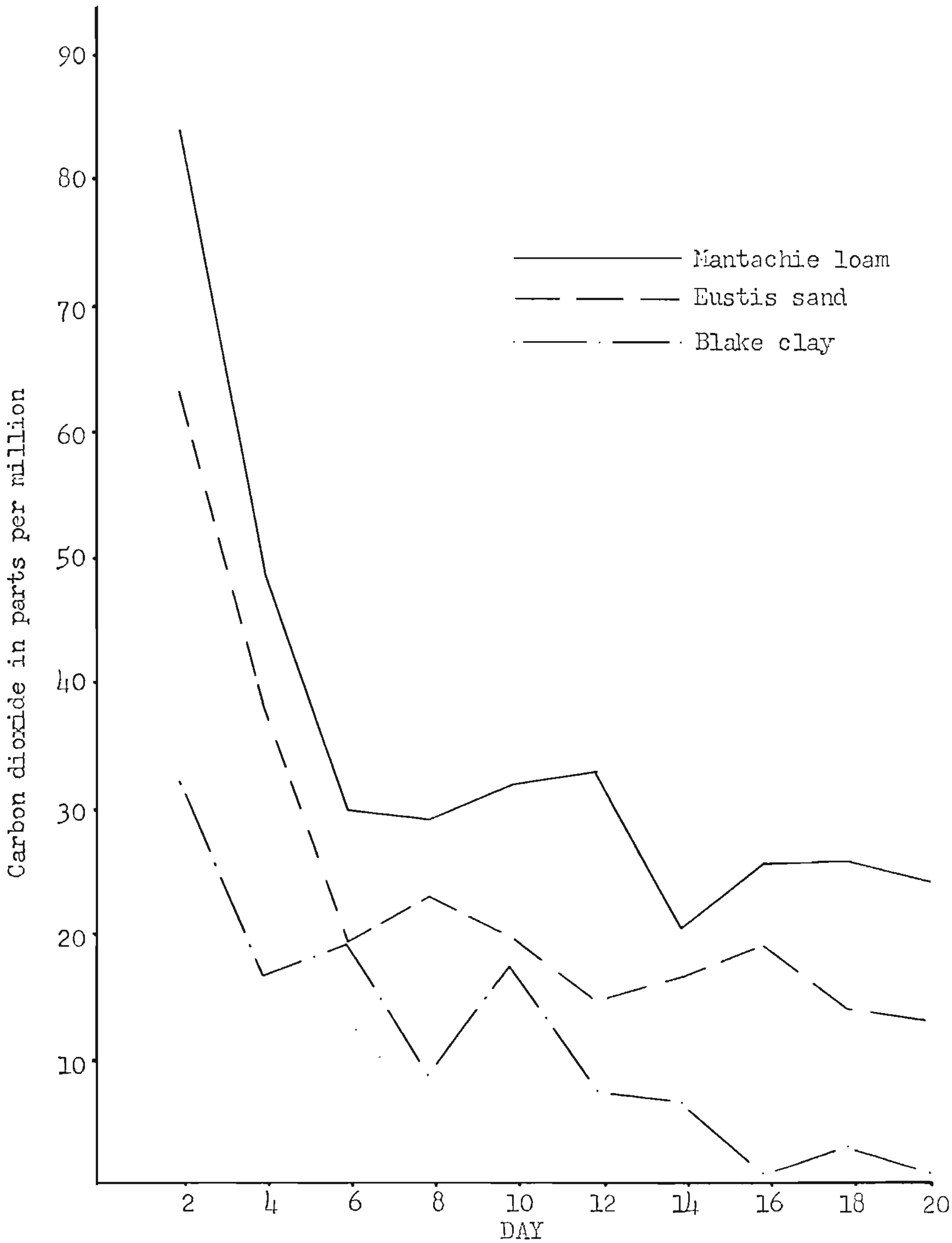

Figure 6. Average respiration of Mantachie loam, Eustis sand, and Blake clay under black water treatment for 10 measurements at 2-day intervals.

Respiration under control treatments displayed the same general decline as did the acid water and black water treatments. The final readings in two of the three soils showed the control treatment with a lower respiration than the black water treatment (Figure 7). There was no statistical significance between any of the treatments on a soil basis (Appendix Table 5).

The supplementary study involving the irrigation of jars containing a mixture of soil and dextrose showed an increase in respiration (Figure 8). Acid water, black water, and control treatments gave intermingled results until the sixth day when the control began to produce a greater carbon dioxide evolution. Results were not significant (Appendix Table 6). All treatments did display a marked increase when compared to the original study, and the addition of dextrose, as a food source, is believed responsible.

The second supplementary study involving the Penicillium sp. plated on three types of agar was also non-significant. An area grid showed growth to be almost identical and no treatment differed statistically from any other (Appendix Table 7). Growth was slow but the fungi eventually covered the entire agar disk.

The use of whole mill effluent (acid and black waters mixed) should be possible on sands or very sandy loams with little clay. The use of acid water or black water alone is not recommended nor is the application of effluents to heavy soils or loams with a high clay content.

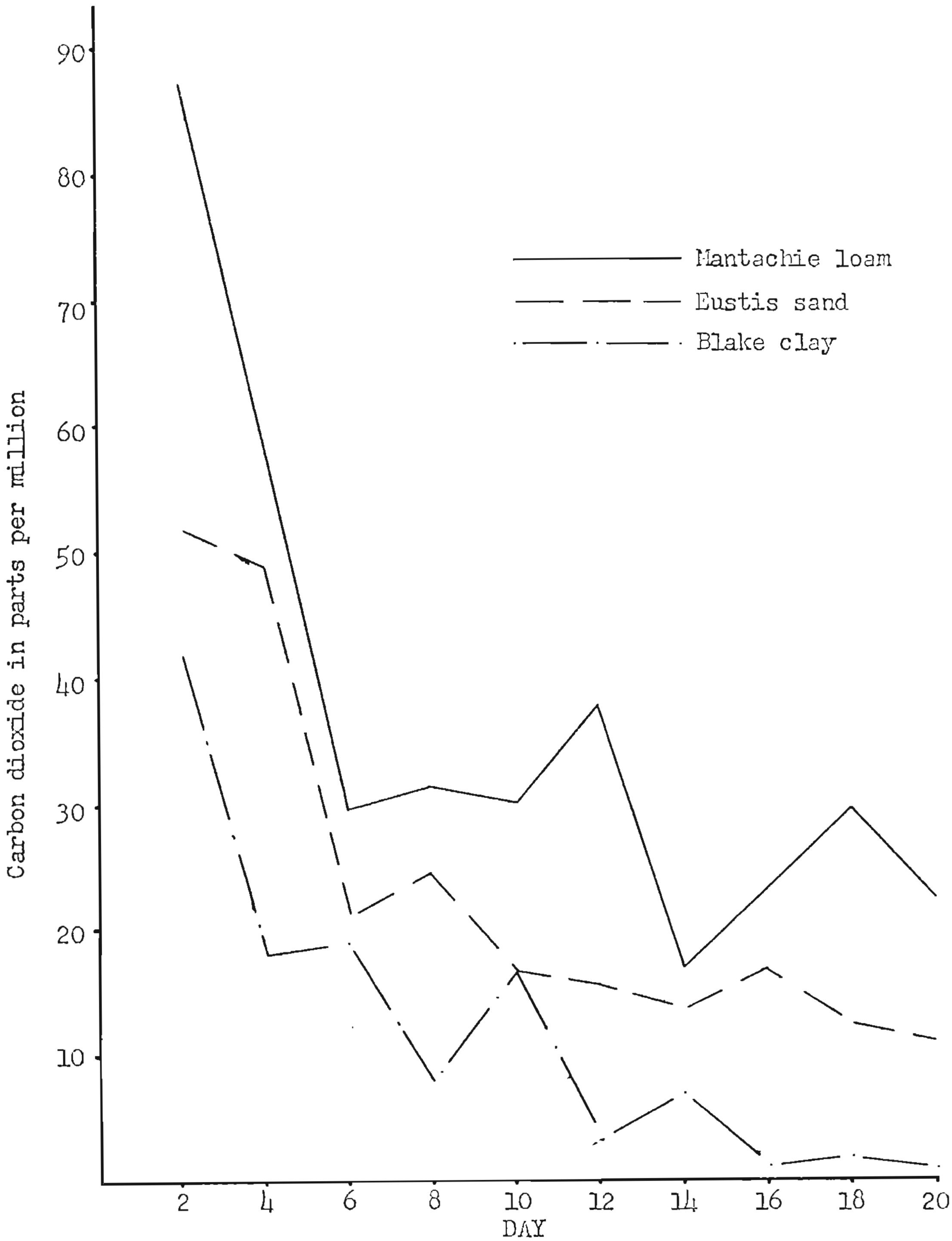

Figure 7. Average respiration of Mantachie loam, Eustis sand, and Blake clay under control water treatment for 10 measurements at 2-day intervals.

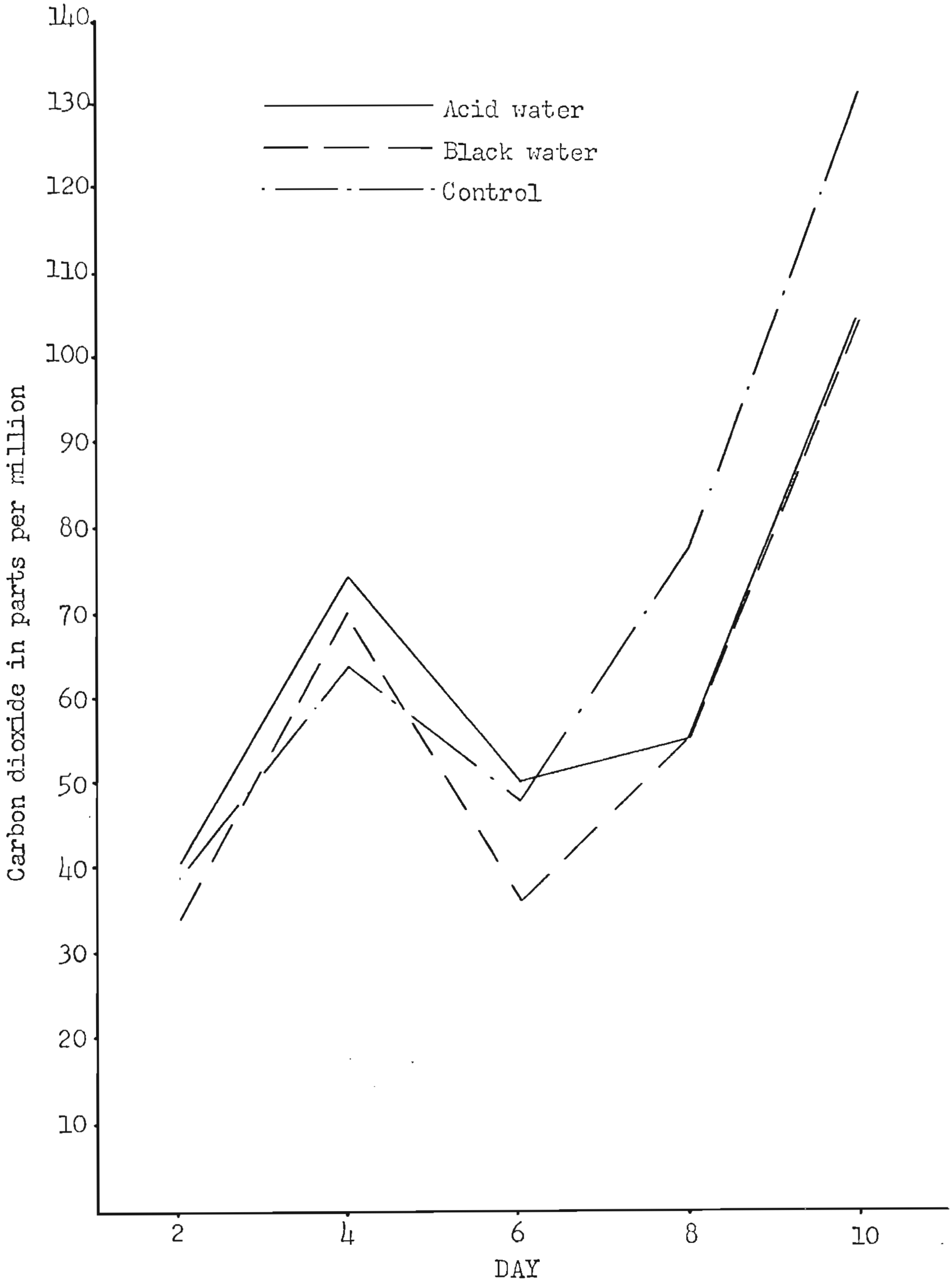

Figure 8. Average respiration of soil-sugar mixture under acid, black, and control water treatments for 5 measurements at 2-day intervals.

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APPENDIX

Appendix Table 1. Carbon dioxide evolution of Blake clay for each jar by measurement day (parts per million).

JAR NO.	DAY 2	4	6	8	10	12	14	16	18	20	$\bar{\bar{X}}$
A1	35.0	17.5	6.0	21.5	21.5	10.5	10.0	0	2.5	0	
A2	40.0	15.0	6.0	16.0	21.5	5.5	5.0	0	0	0	
A3	35.0	15.0	11.5	16.0	21.5	5.5	5.0	0	0	0	
A4	40.0	17.5	17.5	16.0	27.0	5.5	5.0	0	0	0	
A5	35.0	15.0	20.0	19.0	21.5	2.5	5.0	0	0	0	
$\bar{X}$	37.0	16.0	12.2	17.7	22.6	5.9	6.0	0	0.5	0	11.79
B1	32.5	15.0	17.5	16.0	19.0	16.0	10.0	2.5	2.5	2.5	
B2	20.0	17.5	20.0	10.5	19.0	5.5	5.0	0	2.5	0	
B3	32.5	17.5	20.0	5.5	16.0	5.5	5.0	0	2.5	0	
B4	40.0	17.5	20.0	5.5	19.0	5.5	10.0	1.0	5.0	2.5	
B5	35.0	15.0	20.0	5.5	16.0	5.5	5.0	0	2.5	0	
$\bar{X}$	32.1	16.5	19.5	8.6	17.8	7.6	7.0	0.7	3.0	1.0	11.38
C1	40.0	15.0	17.5	2.5	16.0	2.5	5.0	2.5	2.5	2.5	
C2	50.0	17.5	20.0	5.5	16.0	5.5	5.0	2.5	2.5	2.5	
C3	40.0	15.0	17.5	5.5	16.0	2.5	5.0	0	2.5	0	
C4	42.5	17.5	20.0	10.5	16.0	5.5	5.0	1.0	2.5	2.5	
C5	42.5	25.0	20.0	16.0	19.0	2.5	15.0	2.5	0	0	
$\bar{X}$	43.0	18.0	19.0	8.0	16.6	3.7	7.0	1.7	2.0	1.5	12.05

Appendix Table 2. Carbon dioxide evolution of Eustis sand for each jar by measurement day (parts per million).

JAR NO.	DAY 2	4	6	8	10	12	14	16	18	20	$\bar{\bar{X}}$
A1	57.5	26.0	15.0	14.0	17.5	14.0	13.5	25.0	5.0	5.0	
A2	55.0	35.0	17.5	18.0	15.5	14.0	13.5	17.5	10.0	5.0	
A3	50.0	29.5	17.5	14.0	15.5	4.5	11.0	15.0	5.0	5.0	
A4	57.5	37.0	20.0	18.0	17.5	9.5	15.0	15.0	5.0	5.0	
A5	55.0	29.5	15.0	19.5	17.5	9.5	11.0	15.0	10.0	10.0	
$\bar{X}$	55.0	31.4	17.0	16.7	16.7	10.3	12.8	17.5	7.0	6.0	19.04
B1	80.0	43.0	25.0	30.0	28.5	23.5	25.0	25.0	20.0	17.5	
B2	62.5	43.0	20.0	23.0	22.0	16.5	19.0	20.0	20.0	17.5	
B3	55.0	29.5	15.0	17.5	13.0	14.0	11.0	15.0	10.0	10.0	
B4	55.0	29.5	15.0	17.5	17.5	9.5	7.5	17.5	10.0	10.0	
B5	62.5	43.0	20.0	25.0	17.5	9.5	19.0	17.5	10.0	10.0	
$\bar{X}$	63.0	37.6	19.0	22.6	19.7	14.6	16.3	19.0	14.0	13.0	23.88
C1	55.0	62.0	27.5	27.0	17.5	19.0	13.5	25.0	17.5	15.0	
C2	55.0	48.0	25.0	25.0	17.5	19.0	11.0	20.0	15.0	15.0	
C3	45.0	43.0	15.0	23.0	13.0	14.0	11.0	15.0	10.0	10.0	
C4	50.0	48.0	17.5	25.0	17.5	9.5	26.5	15.0	10.0	10.0	
C5	55.0	43.0	20.0	23.0	17.5	14.0	7.5	10.0	10.0	5.0	
$\bar{X}$	52.0	48.8	21.0	24.6	16.6	15.1	13.9	17.0	12.5	11.0	23.25

Appendix Table 3. Carbon dioxide evolution of Mantachie fine sandy clay loam for each jar by measurement day (parts per million).

JAR NO.	DAY 2	4	6	8	10	12	14	16	18	20	$\bar{\bar{X}}$
A1	87.5	55.0	40.0	25.0	32.5	42.0	22.0	21.5	19.0	19.0	
A2	80.0	50.0	32.5	25.0	23.5	42.0	24.0	21.5	16.0	16.0	
A3	82.5	50.0	32.5	25.0	26.0	42.0	24.0	21.5	16.0	16.0	
A4	100.0	62.5	42.5	30.0	32.5	47.0	24.0	30.0	19.0	16.0	
A5	75.5	42.5	25.0	23.5	19.0	37.5	17.5	21.5	16.0	16.0	
$\bar{X}$	85.1	52.0	34.5	25.7	26.7	42.1	22.3	23.2	17.2	16.6	34.54
B1	80.0	50.0	32.5	28.0	32.5	37.5	17.5	22.5	27.0	21.5	
B2	80.0	50.0	25.0	30.0	32.5	37.5	24.0	21.5	21.5	21.5	
B3	82.5	50.0	32.5	30.0	32.5	32.5	22.0	27.0	27.0	27.0	
B4	87.5	57.5	32.5	30.0	32.5	39.5	24.0	35.0	30.0	30.0	
B5	87.5	50.0	25.0	25.0	26.0	32.5	15.0	21.5	21.5	21.5	
$\bar{X}$	83.5	51.5	29.5	28.6	31.2	35.9	20.5	25.3	25.4	24.3	35.57
C1	82.5	57.5	27.5	35.0	32.5	37.5	17.5	21.5	30.0	21.5	
C2	92.5	57.5	27.5	32.5	30.5	37.5	17.5	21.5	30.0	21.5	
C3	87.5	57.5	32.5	32.5	32.5	37.5	22.0	30.0	30.0	27.0	
C4	82.5	57.5	27.5	28.0	26.0	37.5	15.0	21.5	27.0	21.5	
C5	92.5	62.5	32.5	28.0	30.5	37.5	13.0	21.5	30.0	21.5	
$\bar{X}$	87.5	58.5	29.5	31.2	30.4	37.5	17.0	23.2	29.4	22.6	36.68

Appendix Table 4. Carbon dioxide evolution of Mantachie fine sandy clay loam and sucrose mixture for each jar by measurement day (parts per million).

JAR NO.	DAY 2	4	6	8	10	$\bar{\bar{X}}$
A1	43.0	84.0	20.0	20.0	175.0	
A2	55.0	87.0	105.0	85.0	195.0	
A3	28.0	57.0	20.0	20.0	35.0	
A4	36.0	70.0	57.0	96.0	110.0	
$\bar{X}$	40.5	74.5	50.5	55.3	128.8	69.9
B1	38.0	84.0	43.0	110.0	140.0	
B2	20.0	50.0	36.0	36.0	120.0	
B3	50.0	84.0	33.0	28.0	150.0	
B4	28.0	62.0	35.0	46.0	105.0	
$\bar{X}$	34.0	70.0	36.8	55.0	128.8	64.9
C1	36.0	66.0	45.0	70.0	147.0	
C2	38.0	66.0	45.0	87.0	160.0	
C3	50.0	70.0	85.0	120.0	225.0	
C4	33.0	55.0	17.0	35.0	105.0	
$\bar{X}$	39.3	64.3	48.0	78.0	159.3	77.8

Appendix Table 5. Factorial analysis of carbon dioxide evolution of three soils under three treatments.

SOIL	TREATMENT	BLOCKS 1	2	3	4	5	6	7	8	9	10	TOTAL
LOAM	Acid	85.1	52.0	34.5	25.7	26.7	42.1	22.3	23.2	17.2	16.6	345.4
	Black	83.5	51.5	29.5	28.6	31.2	35.9	20.5	25.3	25.4	24.3	355.7
	Control	87.5	58.5	29.5	31.2	30.0	37.5	17.0	23.2	29.4	22.6	366.4
SAND	Acid	55.0	31.4	17.0	16.7	16.7	10.3	12.8	17.5	7.0	6.0	190.4
	Black	63.0	37.6	19.0	22.6	19.7	14.6	16.3	19.0	14.0	13.0	238.8
	Control	52.0	48.8	21.0	24.6	16.6	15.1	13.9	17.0	12.5	11.0	232.5
CLAY	Acid	37.0	16.0	12.2	17.7	22.6	5.9	6.0	0.0	0.5	0.0	117.9
	Black	32.1	16.5	19.5	8.6	17.8	7.6	7.0	0.7	3.0	1.0	113.8
	Control	43.0	18.0	19.0	8.0	16.6	3.7	7.0	1.7	2.0	1.5	120.5
TOTAL		538.2	330.3	201.2	183.7	197.9	172.7	122.8	127.6	111.0	96.0	2081.4

Factorial analysis

C = $(2081.4)^2/90$ = 48135.84

Total ss = 77757.04 - 48135.84 = 29621.20

Treatment ss = 568777.56/10 - 48135.84 = 8741.92

Blocks ss = 594872.76/9 - 48135.84 = 17961.13

Error ss = 29621.20 - (8741.92 + 17961.13) = 2918.15

Appendix Table 5 (cont.)

Summary table A

TREATMENT	LOAM	SAND	CLAY	TOTAL
Acid	345.4	190.4	117.9	653.7
Black	355.7	238.8	113.8	708.3
Control	366.4	232.5	120.5	719.4
Total	1067.5	661.7	352.2	

Total ss = 8741.92

Soil ss = 1701447.98/30 - 48135.84 = 8579.09

Treatment ss = 1446548.94/30 - 48135.84 = 82.46

Soil ss x Treatment ss = 707431.76/10 - 48135.84 = 22607.34

Variation

	df	SS	MS	f
Total	89	77757.04	873.67	
Blocks	9	17961.13	1995.68	49.23**
Treatment		8741.91	1092.74	26.96**
Soil	2	8579.09	4289.55	105.83**
Treatment	2	82.46	41.23	1.01ns
S x T	4	22607.34	5651.84	139.44**
Error	72	2918.15	40.53	

Appendix Table 6. Factorial analysis of carbon dioxide evolution of Mantachie fine sandy clay loam and sucrose mixture under three treatments.

TREATMENT	BLOCKS 1	2	3	4	5	Total
Acid	40.5	74.5	50.5	55.3	128.8	349.6
Black	34.0	70.0	36.8	55.0	128.8	324.6
Control	39.3	64.3	48.0	78.0	159.3	388.9
Total	113.8	208.8	135.3	188.3	416.9	1063.1

Factorial analysis

C = 18071001/60 = 301183.35

Total ss = 430365.0 - 301183.35 = 129181.65

Treatment ss = 1644361.0/5 - 301183.35 = 27668.85

Blocks ss = 4516045.0/12 - 301183.35 = 75153.73

Error ss = 129181.65 - (27668.85 + 75153.73) = 26339.07

Summary table A

REPETITION	ACID	BLACK	CONTROL	TOTAL
1	342	415	364	1121
2	527	262	396	1185
3	160	345	550	1055
4	369	276	245	890
Total	1398	1298	1555	4251

Total ss = 27688.85

Treatment ss = 6057233/20 - 301183.35 = 1678.3

Repetition ss = 4565991/5 - 301183.35 = 3216.05

Repetition ss x treatment ss = 27668.85 - (1678.3 + 3216.05) = 22794.5

Appendix Table 6 (cont.)

Variation

	df	SS	MS	f
Treatments				
Treatment	2	1678.30	839.15	0.50^{ns}
Repetition	3	3216.05	1072.02	0.65^{ns}
T ss x R ss	6	22794.50	3799.08	2.31^{ns}
Error	16	26339.07	1646.19	

Appendix Table 7. Relative growth of a *Penicillium* sp. on three types of potato dextrose agar by measurement day (average of three measurements).

AGAR	DAY 2	4	6	8	10	12
Acid	2	8	39	53	171	307
Black	3	11	32	51	183	321
Control	2	13	34	60	160	298

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An Abstract of a Thesis

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by

JOHN C. NORRIS, B.S.

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ABSTRACT

Two pulp mill effluents, NaOH extraction water from the pulp bleaching process and water from the chlorination step of the pulp bleaching process, were applied to jars containing three East Texas soils. Carbon dioxide evolution was then measured with an infrared gas analyzer to determine the effect of the effluents on the respiration of soil microorganisms.

The relationship between effluent treatments was not statistically significant, though detrimental effects were observed in the heavier soil.

Irrigation of clays and clay loams with the effluent is not recommended. Irrigation of sandy soils should be possible if there is no danger of sub-surface water contamination.

VITA

John Norris was born in Rawlins, Wyoming, on August 12, 1944, the son of Maxwell and Geraldine Norris. After graduation from Rawlins High School, Rawlins, Wyoming, in 1962, he entered the U.S. Navy and served aboard the aircraft carrier USS CORAL SEA (CVA-43). Upon separation from active duty he entered Northwestern State College in Natchitoches, Louisiana, from which he received a Bachelor of Science degree in botany. In January, 1969 he entered the graduate school at Stephen F. Austin State University, where he completed the 60-hour Master of Forestry degree. He is presently employed as land manager by Bosch Development Co., in Longview, Texas. He is married to the former Charline Stamp. They have one son, Reid, and one daughter, Stacy.

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