ADDITION OF A CARBON PULSE TO STIMULATE DENITRIFICATION IN SOIL COLUMNS FLOODED WITH SEWAGE WATER

by

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INTRODUCTION

High-rate land filtration has been shown to be an effective method for renovating secondary sewage effluent (Bouwer et al., 1974; Lance et al., 1976). Most of the organic carbon, fecal coliform bacteria, and phosphate were removed by intermittently flooding the land with sewage effluent at infiltration rates of from 15 to 55 cm/day. Nitrogen removal at higher infiltration rates (> 30 cm/day) was about 30% in both laboratory and field studies (Lance and Whisler, 1972). Further laboratory study showed that nitrogen removal by denitrification could be increased to 90% by increasing the organic carbon content of secondary effluent to 150 ppm by adding dextrose (Lance and Whisler, 1975).

The 150-ppm C concentration is about six times the average N concentration of the wastewater. However, the intermittent wetting and drying cycles resulted in the concentration of most of the nitrogen in a nitrate peak that was leached from the soil during the first 3 days of the flooding period. The high organic carbon concentration was needed to provide a C:NO_3-N ratio adequate for complete denitrification of the nitrate peak. Because the high carbon concentration was needed only when the nitrate peak moved through the soil, much of the carbon passed through the soil columns.

About 80% of the nitrogen could be removed by reducing the infiltration rate to 15 cm/day or by mixing high-nitrate water collected during the first 3 days of the flooding period with secondary sewage effluent and recycling it through the columns (Lance et al., 1976). However, both of these methods require more land than does intermittent flooding at high infiltration rates.

The objective of this experiment was to determine if denitrification could be stimulated in soil columns with high infiltration rates by adding a pulse of organic carbon (dextrose) to sewage water. The carbon would be added only during the first few days of flooding so that it could move through the soil with the nitrate peak.

PROCEDURE

Soil columns were constructed by packing into polyvinyl chloride (PVC) pipe loamy sand from basins used for rapid infiltration of secondary sewage effluent. The basins are in the dry Salt River bed near Phoenix, Arizona (Bouwer et al., 1974). Each column consisted of a 2.75-m length of 10-cm (I.D.) PVC pipe filled with 6 cm of pea gravel topped with 250 cm of loamy sand. The air-dried soil containing 3% clay, 8% silt, and 89% sand was packed so that average bulk densities for each column ranged from 1.5 to 1.6 g/cc. Slight differences in packing resulted in infiltration rates that ranged from 15 to 50 cm/day. The columns were flooded with secondary sewage effluent on schedules of 9 days' flooding alternated with 5 days' drying. Dextrose was added during the first 3 days of flooding to increase the organic C concent of the sewage by either 100 or 200 ppm. The sewage effluent was applied with a Mariotte siphon to maintain a 15-cm constant water depth. The flow system has been described (Lance and Whisler, 1972). The flow rate and cumulative flow through the columns were measured by weighing the outflow daily, and the cumulative outflow was sampled periodically. The sewage water and column samples were analyzed for NO_2^-, NO_3^-, NH_4^+, and organic-N with a Technicon AutoAnalyzer, and for organic carbon with a Beckman total organic carbon analyzer.

Small columns were prepared by placing 3 cm of the same soil used in packing the long columns in 10-cm I.D. Büchner funnels. These were intermittently flooded with secondary sewage effluent with three levels of organic C: 15, 100, and 200 ppm. Dextrose was added to obtain the two higher C concentrations. The flooding schedule was 9 days' flooding alternated with 5 days' drying. After three flooding cycles, dextrose was added only during the first 2 days of flooding for three additional cycles. One-gram soil samples were taken at 3-day intervals, and total aerobic bacteria were determined by the dilution plate method using plate count agar. Denitrifiers were determined by the most probable number method using a 5-tube dilution series with nitrate broth (Focht and Joseph, 1973).

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RESULTS AND DISCUSSION

Although dextrose added during the first 3 days of the flooding period stimulated denitrification, it was not complete except at low infiltration rates. Infiltration rates of most of the columns decreased when dextrose was added to the sewage water (Table 1). Since a decrease in infiltration rate increases nitrogen removal, this made it difficult to assess the direct effect of carbon additions on denitrification. However, the infiltration rate of column E was changed only slightly when dextrose was added, and the rate for column D decreased only with the 200-ppm C addition. Thus, these two columns were used to demonstrate the effect of C additions to sewage on denitrification at different infiltrations rates (Figure 1).

Table 1. Infiltration rates in soil columns flooded with secondary sewage effluent amended with dextrose during the first 3 days of a 9-day flooding period.

Column	0 ppm C[1/]	100 ppm C	200 ppm C
		cm/day	
A	33.7	26.4	14.1
B	28.8	18.1	11.3
C	31.6	26.2	20.6
D	14.6	15.1	6.9
E	23.0	20.8	21.7

1. Refers to dextrose amendments; unamended sewage contains 15 ppm C.

Addition of 100 ppm C increased nitrogen removal about 20%, and addition of 200 ppm increased it about 31% at both high (22-23 cm/day) and low (7-15 cm/day) infiltration rates. Since nitrogen removal at each infiltration rate was increased by adding a 100-ppm C pulse and was further increased by adding a 200-ppm C pulse, a relationship between the organic C to N ratio and % N removal probably exists for each infiltration rate. Addition of C as a pulse did not result in much movement of C through the soil columns. The organic C concentration in water from the columns was less than 10 ppm for both the 100- and 200-ppm C treatments.

Previous experiments showed that increasing the organic C content of secondary effluent to 150 ppm eliminated the nitrate peak (Lance and Whisler, 1975). Failure to eliminate the nitrate peak by supplying the organic C as a pulse suggests that some factor works in combination with the organic C to NO_3-N ratio to limit denitrification. The bacterial population might have been too low to eliminate the nitrate peak during the detention time provided at the high infiltration rates. At low infiltration rates, this peak is much attenuated and the detention time is greater (Lance et al., 1976). Possibly, supplying organic carbon throughout the flooding period maintains a higher population of bacteria than supplying only a pulse during the first few days of flooding.

This hypothesis was tested by comparing bacterial populations in small columns when carbon was added continuously during the flooding cycles with populations when carbon was added only during the first 2 days of flooding cycles. Plate counts of total aerobic bacteria peaked during the flooding period and declined during the drying period with both treatments (Figure 2). Peak numbers were similar for both treatments. However, the peak population may have developed slightly faster when C was added continuously than when a pulse of C was added.

Rapid development of the bacterial population is important because oxidation-reduction potentials showed that most of the microbial activity in the long soil columns was concentrated near the soil surface (Figure 3). Denitrification would be limited if the nitrate peak moved into the lower section of the column before high denitrifier populations developed. Since denitrifiers are facultative anaerobes, the fluctuation in numbers of total aerobic bacteria indicated the changes in numbers of denitrifiers. However, since the measurement of total aerobic bacteria populations did not clearly show why adding C continuously stimulated denitrification more effectively than adding a pulse of C, denitrifier populations were measured directly. The denitrifier population in a soil flooded with secondary effluent on a 9 days' flooding and 5 days' drying schedule was 2.1×10^6 bacteria per gram of soil at the end of the drying period. Addition of a 200-ppm pulse of carbon (glucose) increased the denitrifier population to about 2.9×10^7 bacteria per 100 grams of soil within 4 days (Table 2). Thus, the denitrifier population increased substantially, but the nitrate peak could have moved through the soil before the bacterial population peaked. Further experiments on the development of denitrifier populations during intermittent flooding with sewage water enriched with carbon continuously will be conducted to clarify this point.

Table 2. Bacterial populations in a soil column flooded with secondary sewage effluent enriched with 200 ppm glucose during the first 2 days of a 9-day flooding period.[1/]

Days flooded before sampling	Bacteria/g of oven-dry soil x 10^6		
	Denitrifiers	Total aerobic	Total aerobic / Denitrifiers
0	2.1	20.2	0.10
4	28.8	72.2	0.40
9	32.3	34.0	0.94

1. Data averages from two cycles of 9 days' flooding and 5 days' drying of two soil columns.

SUMMARY AND CONCLUSIONS

A pulse of organic C added to sewage water during the first few days of flooding on a 9 days' flooding, 5 days' drying cycle increased nitrogen removal but did not eliminate the nitrate peak except at low infiltration rates. Adding a pulse of C could increase N removal percentage from a marginal to an acceptable level. Possibly, a wastewater with a high organic C concentration could be mixed with secondary sewage during the first few days of flooding to stimulate denitrification.

Some factor other than the C to NO_3-N ratio of the wastewater limited denitrification. Further study is needed on the development of denitrifier populations during intermittent flooding of soil columns with sewage water amended with dextrose.

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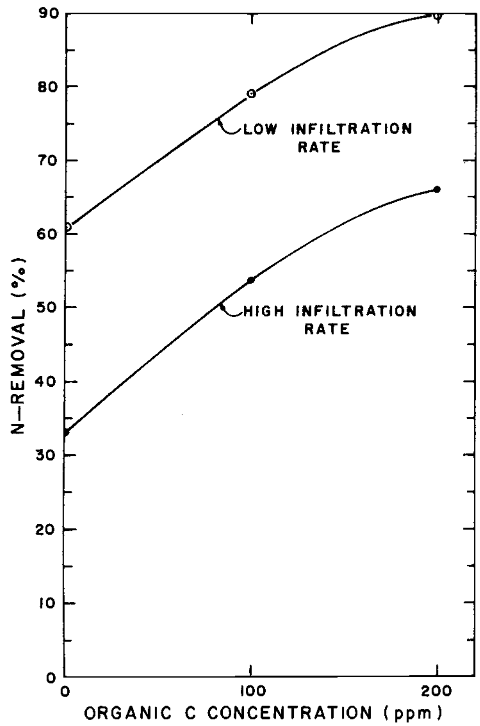

Figure 1. The effect of organic-C pulses on N removal. High and low infiltration rates were 22 to 23 and 7 to 15 cm/day, respectively. Sewage water with no added C pulse contained 15 ppm C.

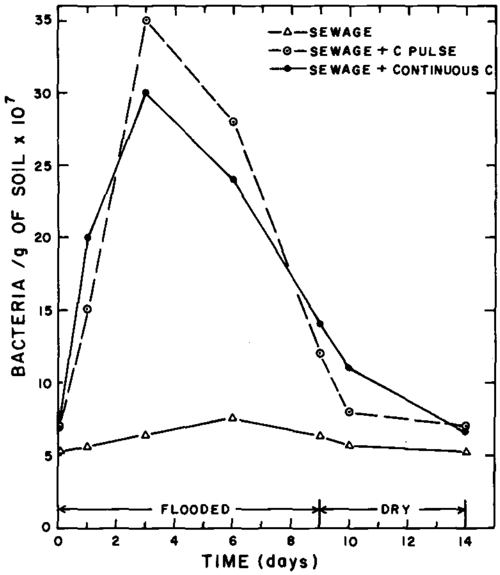

Figure 2. Aerobic bacterial populations in surface soil of columns flooded with sewage effluent with and without glucose amendments.

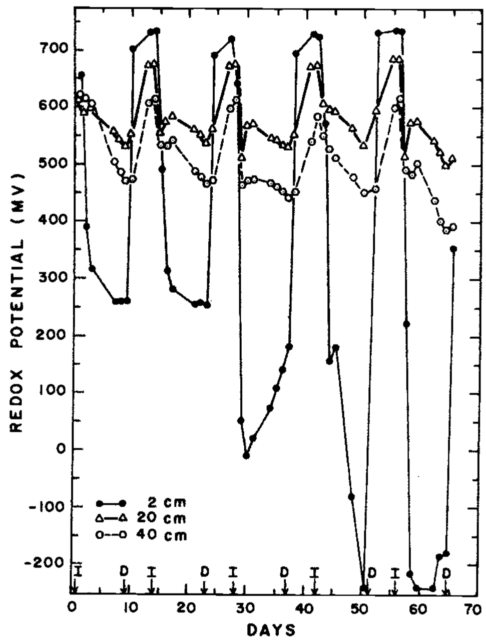

Figure 3. Redox potentials in a soil column where a pulse of carbon was added during the first 2 days of the flooding period. One hundred ppm dextrose was added at the beginning of infiltrations 3 to 5. I designates beginning of infiltration and D designates beginning of drainage.