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EFFECT OF ALGAL GROWTH AND DISSOLVED OXYGEN ON REDOX POTENTIALS IN SOIL FLOODED WITH SECONDARY SEWAGE EFFLUENT

by

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ABSTRACT

Algal growth and oxygen evolution at the soil-water interface of soil recharge basins intermittently flooded with secondary sewage effluent (SSE) produced diurnal fluxes in dissolved oxygen (DO) in the SSE and redox potentials (Eh) in the SSE and the surface soil of the basin. The maximum daily DO-% saturation in the SSE during flooding ranged from 30 to 450%, depending on the length of flooding and seasonal effects of temperature and solar radiation. Diurnal cycles of Eh in the SSE and the top 0 to 2 cm of soil indicated that oxygen production by algae and bacterial nitrifying and denitrifying reactions at the soil-water interface are occurring daily for limited periods during flooding and that these reactions might contribute to the net-N removal and renovation of SSE by soil filtration.

INTRODUCTION

Land application of wastewater has been shown to be an effective method for renovation of secondary sewage effluent (SSE) (Bouwer et al., 1974; Lance et al., 1976). The Flushing Meadows Project in the Salt River bed near Phoenix, Arizona has demonstrated that a high-quality renovated water suitable for unrestricted irrigation and recreation can be obtained with a rapid infiltration system (Bouwer et al., 1974). Soil chemical, physical and biological reactions have proven effective in removing most of the suspended solids, BOD, fecal coliform bacteria and phosphate from SSE applied at the rate of 100 m/yr. Also, management criteria were established for maximizing hydraulic loading that removed about 30 percent of the nitrogen applied in the SSE. Therefore, the feasibility of enhancing nitrogen removal by such high-rate land disposal systems is a primary factor governing their acceptance and usefulness.

Denitrification proceeds in soil only when three conditions are met: (1) NO_3-N must be produced; (2) NO_3-N must move into reduced zones; and (3) organic carbon must be present in the reduced zones as an energy source for denitrifying bacteria (Lance and Whisler, 1976). Since nitrification of the NH_4-N in the SSE must occur before denitrification can proceed, then it is essential to locate those regions in the soil-water system during flooding and drying cycles, where nitrification (aerobic process) and denitrification (anaerobic process) can occur in the system simultaneously. These biological processes have been shown to occur simultaneously at the start of each dry period in the top 15 cm of soil (Gilbert et al., 1974; Engler et al., 1976). Oxygen entered the top 15 cm of the soil profile by mass flow, as the water infiltrated through the soil to the groundwater table. Thus, nitrification proceeded immediately in the surface soil of the basin, but the high BOD and retention of water in the surface organic sediments and matrix of algae restricted oxygen diffusion into the lower soil depths. This caused reduced microsites to persist in the surface soil where conditions were favorable for denitrification. When flood periods started, not much of the NO_3-N that remained in the soil profile at the end of the dry period would be denitrified, since NO_3-N was rapidly leached into lower zones of the soil profile, where organic carbon was limiting and redox potentials (Eh) indicated NO_3-N was stable. However, during each flooding period, Eh decreased rapidly at 2 cm only and diurnal cycles of Eh occurred that were apparently caused by the growth and activity of algae which increased the dissolved oxygen concentration of the SSE in the soil basin. Therefore, since nitrifying activity may be associated with the growth and activity of algae, our objectives were to investigate the effects of algal growth on dissolved oxygen and Eh in soil basins flooded with SSE and to locate and characterize those regions in the soil-water system, during flooding periods, where microbial processes and environmental conditions were favorable for denitrification and N-removal from the SSE.

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PROCEDURE

Basin No. 1 at the Flushing Meadows Project was selected as the experimental site, because it has remained a bare soil basin throughout the operation of the system. The surface soil material in the basin consists of about 150 cm of a fine loamy sand underlain by coarse sand and gravel layers to a depth of 75 m. Flooding and drying cycles of 14 days each were used, that maximized hydraulic loading and produced N-removal rates of about 30 percent (Bouwer et al., 1974), and the water table below the soil basin rose from about 3 to 2 m deep during flooding.

When the SSE arrived at the basin area from the treatment plant, it had the following average nitrogen contents: organic-N, 1.0 mg/1; ammonium-N, 25.0 mg/1; and nitrate-N, 0.5 mg/1 (Lance and Whisler, 1972). Generally, the content of suspended solids is higher in the sewage effluent during the winter (50-75 mg/1) than during the summer (10-20 mg/1).

Redox potential (Eh) measurements were made with platinized platinum electrodes referenced to a calomel electrode in a salt bridge that was connected to a pH meter (Linebarger et al., 1975). A strip chart recorder and timing device scanned the redox electrodes once each hour. The redox electrodes were constructed from No. 22 platinum wire (Whisler et al., 1974). Duplicate electrodes were placed in the effluent water 15 cm above the soil surface, on the soil surface, and to soil depths of 2 and 15 cm. Readings of individual redox electrodes and the mean of duplicate redox readings were plotted and evaluated.

Dissolved oxygen (DO) measurements were made with an O_2-probe attached to a submersible stirrer placed in the basin during flooding. The O_2-probe, when positioned in the effluent water, was about 2.5 cm from the soil surface. DO concentrations were recorded continuously for the entire flooding period with a single channel recorder. After determining the water temperatures, the percent O_2-saturation was calculated.

Thermocouples were positioned at +60, +15, 0, and -2 cm, relative to the soil surface, to measure air, water, and soil temperatures. Thermocouples were scanned once every hour and temperatures were recorded with a multi-channel recorder.

Solar radiation data were obtained from the U. S. Weather Bureau Station located at the airport in Phoenix, Arizona.

RESULTS AND DISCUSSION

The effects of algal development and related seasonal influences of temperature and solar radiation on dissolved oxygen (DO) concentration in soil basins flooded with secondary sewage effluent (SSE) are summarized in Fig. 1. Algae developed on the soil surface during each flooding period in the highly eutrophic SSE. But during each drying period the matrix of algae on the surface dehydrated and decomposed into a thin, broken, greyish layer of residue. The soil basins were actually like shallow oxidation ponds (30 cm deep) during flooding and the suspended solids were never so high that solar radiation would not penetrate through the water to the soil surface. In the winter the water and the soil surface were heated by the solar radiation and the water temperatures were usually higher than the air temperature, especially the daily minimum temperatures. The development of algae and onset of diurnal fluxes of DO were delayed in the winter, because of lower temperatures and shorter day lengths. The primary producers in the winter were mostly benthic algae that developed a complete matrix covering the entire surface of the soil basin during each flooding period. After 5 to 7 days of flooding, the net O_2 production by these algae caused diurnal fluxes of DO with O_2-saturation peaks ranging from 98 to 182 percent.

In the summer, the primary producers were both planktonic algae in the SSE and benthic algae on the soil surface. The temperatures and solar radiation were 2 to 2.5 times greater in the summer. There was no delay in net O_2 production and large diurnal fluxes of DO saturation peaks ranged from 187 to 440 percent after the first day of flooding. The net O_2 production by the planktonic algae in the SSE exceeded the O_2 utilization of the heterotrophic consumers and decomposers during the first 5 to 6 days of flooding. During the last 7 days of flooding, the O_2-utilization of these heterotrophic organisms associated with the fully developed benthic algae and organic sediments produced diurnal fluxes of DO with saturation percentage maxima and minima ranging from 225 to 440 and 6 to 14, respectively.

It was apparent from these results (Fig. 1) that an environment suitable for nitrifying bacteria and nitrification was present daily near the soil-water interface, and within the algal matrix, especially during the summer. Previous results (Gilbert et al., 1974) have shown that nitrifying bacteria populations were highest in the surface 0 to 15 cm of soil at the end of each flood period and that the organic sediments and surface soil directly below the algal matrix became highly reduced during flooding, because of the high rates of O_2 utilization by heterotrophic decomposing organisms, mostly bacteria. Therefore, any nitrate-N and/or nitrite-N forming in the surface oxidizing zones and flowing through these lower reducing zones would be removed by heterotrophic denitrifying bacteria (Gilbert and Miller, 1978; Graetz, et al., 1973).

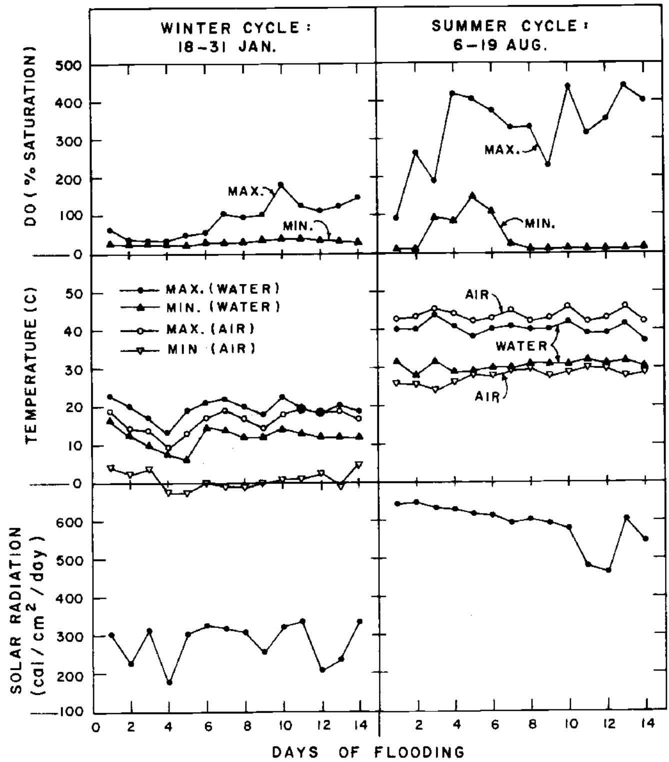

Figure 1. Effect of algal development and related seasonal (winter and summer) influences of temperature and solar radiation on dissolved oxygen concentrations in recharge soil basins flooded with secondary sewage effluent for 14 days.

In order to characterize the oxidizing and reducing zones in the soil basins flooded with SSE, redox potentials (Eh) were measured continuously and related to the diurnal fluxes of DO (Fig. 2). During flooding, infiltration rates decreased as the suspended material in the SSE was deposited on the surface of the soil basin and the algae continued to develop within and on the surface of the accumulated sediments. These circumstances altered the fixed position of the redox electrodes, relative to the biologically active soil-water interface, especially at the surface and 2-cm soil depth. Therefore, the results presented represent only the specific day during a winter (10th day) and summer (7th day) 14-day flood period that best illustrated the diurnal patterns of Eh in the system, especially at the soil surface and at the 2-cm depth.

Eh as a factor was not directly involved in nitrification or denitrification, but at least theoretically, it was the best quantitative measure for determining if the environment was favorable or unfavorable for nitrification or denitrification. The chemistry of submerged soils was reviewed (Ponnamperuma, 1972; Baas Becking, 1960) and, generally, environments with Eh >200 mV are oxidizing and <200 mV are reducing. The stratification of Eh at the soil-water interface of submerged soils was reported for irrigated agricultural soils (Patrick and DeLuane, 1972; Sheard and Leyshon, 1976), for eutrophic and oligotrophic lakes (Ruttner, 1953; Graetz et al., 1973), and for swamp-marsh soils (Engler et al., 1976). Their results showed that when aerobic soils are submerged, the surface Eh (300 to 500) differs only slightly from the flooding water. However, below the oxygenated surface layer, which is only a few millimeters thick, the Eh drops sharply and may be strongly negative.

Our results for soil basins flooded with SSE were similar and demonstrated that diurnal cycles of Eh in the SSE and to a soil profile depth of 2 cm, but not 15 cm, are associated with daily fluxes of DO in the SSE (Fig. 2). Diurnal Eh fluxes in the soil are superimposed on Eh values that are decreasing during 14 days flooding (Gilbert et al., 1974). The course, rate and magnitude of the Eh values and fluxes in the soil are dependent on the type and amount of organic matter, the nature and

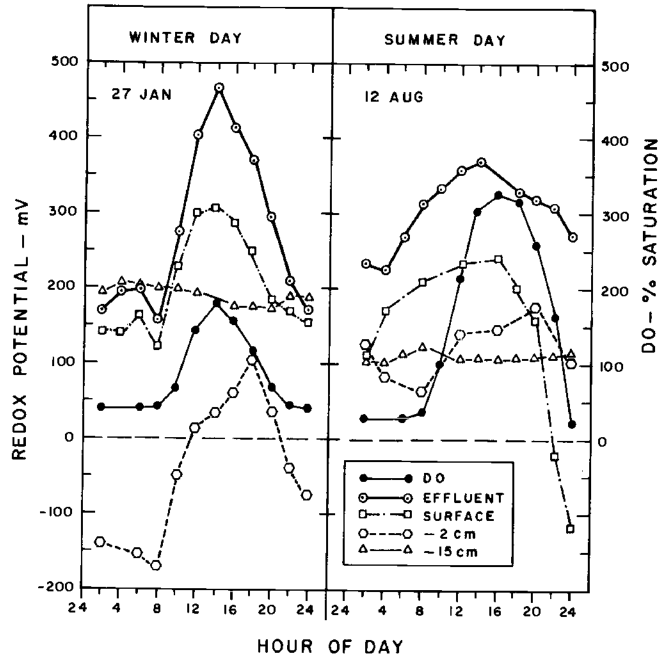

Figure 2. Diurnal fluxes of dissolved oxygen and redox potentials in soil basins flooded with secondary sewage effluent on a selected winter and summer day.

content of electron acceptors, temperature, and the duration of submergence. Since nitrate-N is known to stabilize Eh at about 200 mV in denitrifying environments (Bailey and Beauchamp, 1971; Ponnameruma, 1972), then nitrate-N or nitrite-N formed by nitrifying bacteria in the oxidizing zones associated with the benthic algal matrix was denitrified and probably caused the diurnal cycles of Eh in the surface sediments and the top 2 cm of soil. In the summer, the Eh at 2 cm was consistently higher and the nitrification-denitrification processes were greater, because of the higher temperature and greater amount of solar radiation.

SUMMARY AND CONCLUSIONS

In conclusion, our results have indicated that nitrification, which must occur before denitrification can proceed, was associated with the growth and development of algae on the surface of the soil basin during each flooding period. The daily activity of algae produced diurnal fluxes of DO and Eh that induced conditions favorable for nitrification. Subsequently, the nitrate-N and/or nitrite-N formed would be denitrified, while infiltrating through the reduced zones of the organic sediments and surface 2 cm of soil. Therefore, during flooding periods these biological processes that control N-removal are occurring in a diurnal manner, because of the daily photosynthetic activity and DO production by algae in the soil basin; and the magnitude of these diurnal biological processes was greatest during the summer, because of higher temperatures and longer photoperiods, which induced greater rates of respiration and photosynthesis.

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