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PREDICTING THE PERFORMANCE OF WASTEWATER RENOVATION CROP SYSTEMS: THE NEED FOR COMPOSITE SAMPLING

Estimates of removals in wastewater renovation projects have been based on grab samples. Even when taken each day at the same time, these are unlikely to reflect the performance of the system over any one 24-hour period.

Crops remove different kinds and amounts of nutrients during the day and night. They also respond strongly to time of day and angle of sunlight. Minor weather changes during the daylight hours also influence crop performance. Nitrogen removals are especially sensitive to the amount of sunlight. Phosphorus removals appear to be sensitive to air temperature but are otherwise diurnally continuous.

This paper presents data from a wastewater renovation crop system in south Florida. These data show changes in nutrient removals over six 8-hour, daylight sampling periods as well as net removals, as estimated by composite sampling.

The null hypothesis tested here was that grab sampling can closely estimate daily net removals in a gravel bed hydroponics system. On the basis of the results reported below, the null hypothesis must be rejected.

1. INTRODUCTION

Gravel Bed Hydroponics (GBH) and the Nutrient Film Technique (NFT) are two closely related wastewater treatment processes. In both processes wastewater is introduced into sloped channels containing plants, usually high yielding tropical grasses, which are either rooted in gravel (GBH) or are grown without a supporting material (NFT). Both processes are soilless methods of cultivating plants.

Organic load (BOD_5) is removed through the action of microorganisms attached to the gravel and/or root media. Nutrients (NO_3^-, PO_4^{-3}, NH_4^+) are removed via the photosynthetic activity associated with plant growth and, presumably, to a lesser extent by microbially mediated process.

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Some recent research into the NFT has based estimates of total system performance on analyses of grab samples [1], [2]. While grab sampling may be justified on the basis of the cost and logistics, it does not accurately reflect the GBH/NFT process, as the following shows.

HANDLEY and RAVEN [3] recently pointed out that plants are dynamic and respond quickly to fluctuations in available sunlight and relative humidity and that these factors affect nutrient uptake. Further, HANDLEY [4] demonstrated experimentally, using GBH-grown para grass, that 80% of the variation in net photosynthesis can be explained by small changes in sunlight and relative humidity. Clearly, if the plants account for a significant amount of nutrient removal, maximum removals should occur when these factors are most favourable. Since these changes occur rapidly, grab samples will not accurately estimate the potential of the GBH/NFT systems but will severely overestimate or underestimate the system's performance depending upon the condition (e.g., available sunlight) to which the system was exposed at the time of sampling. To test this idea, an experiment was designed to compare removal values as estimated by composite sampling and as estimated by grab sampling.

2. MATERIALS AND METHODS

Para grass (*Barachia mutica* = *Panicum purpurascens*) was used in each GBH channel. It is a wetland-adapted, C_4 grass which is pan-tropical and ranges into the subtropics. It grows densely, has a finely-divided root system, and attains a height of 2 m [5].

The GBH channels are 1 m wide, 12 m long, 0.2 m deep and have a 5% slope; each reactor contains a 5 cm deep layer of #15 (2-4 cm) gravel. Primary wastewater (screened and clarified) was applied continuously at a rate of 1 GPM to each channel, resulting in retention times averaging 1 hour. Composite samples were obtained using three ISCO Model #1580 refrigerated composite samplers. Samplers were positioned to obtain samples of the influent and the effluent of a randomly selected reactor. Samplers were programmed to obtain samples only during the daylight hours. Grab samples were obtained at 0800, 1100, 1400 and 1600 hours on 6 days between April and early June 1985.

The GBH Pilot Plant is located in Florida City, Florida at the extreme southern end of the Florida Pennisula. The period of the study represented a transitional season in southern Florida. April represents the end of the winter season (a mild, clear, dry period with moderate sunshine). June represents the beginning of summer, (a hot, humid rainy period with intense sunshine).

All samples were analyzed for total nitrogen, BOD_5 and orthophosphate. BOD_5 and orthophosphate were measured using Standard Methods [6]. Total nitrogen was measured using persulfate digestion [7]. Flow data were obtained

using a "V" notch weir and a Stevens Model F water level recorder. Flow data were integrated over time to obtain estimates of flow volume. Hourly air temperatures were obtained using an RTD. Hourly solar radiation data were obtained using a Weathertronics net pyro radiometer. Data for both were stored in a digital format using a Campbell Scientific micrologger.

Removal values obtained from grab samples were regressed against values obtained from composite samples.

3. RESULTS AND DISCUSSION

Table 1 summarizes the average mass removals obtained from composite samples during the six experiments. Removals of PO_4^{-3} were the greatest, while BOD_5 and TN removals averaged 33 and 34%, respectively. These removals were within the range that JEWELL et al. [1] observed using synthetic sewage and grab sampling. However, the range of values was much smaller than reported by JEWELL et al. [1]. Mass total nitrogen removals were similar to those reported by BOUZOUN and PALLAZZO [2], who also used grab samples. However, there are wide discrepancies between their grab sampled data and ours for BOD_5 and phosphorus.

Such discrepancies have been apparent throughout our research, despite the fact that the NFT/GBH systems of Cornell and CRREL are quite similar in physical and hydraulic characteristics to ours.

Table 1

Average masses applied and removed during experiments. Valus obtained from composite samples for 6 days

	Flow rate (GPM)	Mass applied (g)	Mass removed (%)	Removals range (%)
Total nitrogen	1.2	44.8	34	18–49
BOD_5	1.2	308.0	33	26–90
Total orthophosphate	1.2	17.0	54	16–41

Table 1 gave the mean values obtained from composite sampling. These represented net daily removals. Table 2 shows the contrasting results obtained on a daily basis when grab or composite sampling was used. Percent removals are given for three parameters (TN, PO_4^{-3}, and BOD_5) as estimated by grab sampling at four times a day. The same day's net removal, as estimated by composite sampling, is shown below the grab-sampled values. Of the 72 individual removals obtained by grab sampling over 6 days, only 2 values agreed with the same day's

net composite value for the same parameter. In no case, at no predictable time of day, was grab sampling a good estimator of net daily removals.

Averages of each of the grab sampled values for each day are also given in tab. 2. It can be seen that even the daily means of values obtained by grab samples poorly resemble daily net values. Only one mean (day 6, % removal of PO_4^{-3}) agreed with the some day's removal (composite sample).

Table 2

Percent removals of TN, PO_4^{-3}, and BOD_5 as evaluated by grab samples taken at four times of day and daily composite samples taken continuously over the daylight hours

	TN (%)	PO_4^{-3} (%)	BOD_5 (%)
Day 1			
Grab samples			
0800	60	45	81
1100	78	67	80
1400	−10	47	63
1600	32	11	46
Day's means	40	43	68
Composite sample	42	29	58
Day 2			
Grab samples			
0800	32	13	22
1100	23	43	47
1400	30	42	42
1600	13	28	34
Day's means	25	32	36
Composite sample	32	41	2
Day 3			
Grab samples			
0800	13	58	−2
1100	34	44	17
1400	0	27	33
1600	66	63	72
Day's means	28	48	30
Composite sample	18	21	27
Day 4			
Grab samples			
0800	18	21	84
1100	40	44	87
1400	13	42	76
1600	17	26	44
Day's means	22	33	72
Composite sample	49	35	90
Day 5			
Grab samples			
0800	−87	−34	12
1100	61	33	58
1400	30	25	53
1600	37	30	69
Day's means	10	14	48
Composite sample	29	16	64
Day 6			
Grab samples			
0800	51	22	51
1100	−131	26	66
1400	59	42	67
1600	34	58	52
Day's means	3	37	59
Composite sample	54	37	67

Nutrient removals are affected dramatically by responses of the plants to available sunlight, relative humidity and temperature [3]. It is well-known that BOD_5 removals are affected by temperature. Hence, grab sampling (and the implicit assumption that effluent water quality remains relatively uniform over the day [8]) are inappropriate for evaluating the potential of NFT/GBH systems as a treatment processes.

Table 3 lists the coefficients of determination (r^2) obtained when grab sampled removals were regressed against composite sampled removals. The coefficients of determination for all parameters at all times are less than 0.95. Only three coefficients were larger than 0.6. An r^2 value of less than 0.95 is usually considered statistically meaningless, i.e., no correlation exists.

Table 3

Coefficients of determination (r^2) resulting from regressions of removal values for TN, BOD_5 and TPO_4 determined by grab samples versus composite samples. There are no strong correlations between composite samples and grab samples, i.e., grab samples are poor estimators of daily net removals

Grab sample time	r^2 values for each parameter		
	TN	PO_4^{-3}	BOD_5
0800	0.21	0.05	0.46
1100	0.27	0.0001	0.60
1400	0.16	0.67	0.80
1600	0.34	0.01	0.00002

Of the 72 grab samples taken, 36 underestimated the net day's removal; 34 overestimated it; and two agreed with it. Nor do the values average out over time, as shown in tab. 4. BOD_5 values agree best, in this data set, being only 2% different. The mean values of TN and PO_4^{-3} disagree by 46 and 13%, respectively.

Table 4

Percent removals for grab versus composite samples. Averages for 6 days

	Parameters (%)		
	TN	PO_4^{-3}	BOD_5
Grab samples	21	34	50
Composite samples	39	30	51

4. CONCLUSIONS

The results of these regression analyses suggest that grab samples do not accurately reflect the removal capacity of NFT/GBH systems. Estimates of system performance based on grab sampling may seriouly bias the reported performance of NFT/GBH systems.

LITERATURE

[1] JEWELL W. J., MADRAS J. J., CLARKSON W. W., DELANCEY–POMPE H., KABRICK R. M., *Wastewater Treatment with Plants in Nutrient Films*, Final Report to US EPA and US DOI, 1982, p. 312.
[2] BOUZOUN J. R., PALLAZZO A. J., *Preliminary Assessment of the Nutrient Film Technique for Wastewater Treatment*, Special Report 82-4, U.S. Army Corps. of Engineers, CRREL, 1982, p. 15.
[3] HANDLEY L. L., RAVEN J. A., *Correlation of Ammonium Uptake and Transpiration as Related to Solution Concentration*, manuscript in preparation, 1985.
[4] HANDLEY L. L., *Winter Performance of Paragrass with Wastewater and Gravel Bed Hydroponics*, manuscript in preparation, 1985.
[5] HANDLEY L. L., EKERN P. C., *Effluent Irrigation of Para Grass: Water, Nitrogen, and Biomass Budgets*, Water Resources Bull., 20 (1984), 669–677.
[6] D'ELIA C. F., STEUDLER P. A., CORWIN N., *Determination of Total Nitrogen in Aqueous Samples Using Persulfate Digestion*, Limnology and Oceanography, 22 (1977), 760–762.
[7] APHA, AWWA and WPCF, *Standard Methods for the Examination of Water and Wastewater*, 1976.
[8] Anonymous, *Sampling of Sewage*, JWPCF, 33 (1961), 669–674.

PRZEWIDYWANIE ZACHOWANIA SIĘ ROŚLINNEGO SYSTEMU ODNOWY WODY ZE ŚCIEKÓW: POTRZEBA ZŁOŻONEGO POBIERANIA PRÓBEK

Stopień usuwania zanieczyszczeń podczas odnowy wody ze ścieków oceniono na podstawie wyrywkowo pobieranych próbek. Stwierdzono, że nawet wtedy gdy próbki brano codziennie o tej samej porze, nie odzwierciedlały one zachowania się badanego układu w dowolnym 24-godzinnym okresie.

Jakość i ilość składników pokarmowych pobieranych przez rośliny w dzień i w nocy jest różna. Rośliny reagują na porę dnia i kąt padania światła słonecznego, np. pobieranie azotu jest wyraźnie zależne od natężenia światła. Ilość fosforu, który w dzień pobierany jest w sposób ciągły, zależy natomiast od temperatury powietrza.

Przedstawiono dane zebrane podczas badań roślinnego systemu odnowy wody ze ścieków na południowej Florydzie. Dane te obrazują różnice w ilości substancji pokarmowych pobieranych ze ścieków w czasie sześciu 8-godzinnych okresów dziennych oraz ilość netto tych substancji usuniętych ze ścieków, oszacowaną na podstawie złożonego pobierania próbek.

Sprawdzono wyjściową hipotezę, że wyrywkowe pobieranie próbek pozwala na bliską rzeczywistości ocenę dziennej wydajności netto usuwania ze ścieków substancji pokarmowych przez rośliny hodowane hydroponicznie na podłożu żwirowym. W świetle prezentowanych dalej wyników hipotezę tę należy odrzucić.

ПРЕДВИДЕНИЕ ПОВЕДЕНИЯ РАСТИТЕЛЬНОЙ СИСТЕМЫ РЕГЕНЕРАЦИИ ВОДЫ ИЗ СТОЧНЫХ ВОД: ПОТРЕБНОСТЬ В СЛОЖНОМ ОТБОРЕ ПРОБ

Степень удаления загрязнений во время регенерации воды из сточных вод оценена на основе выборочно отбираемых проб. Отмечено, что даже тогда, когда пробы отбирались ежедневно в то же время суток, они не отображали поведения исследований системы в любой 24-часовой период.

Качество и количество питательных веществ, усваиваемых растениями днём и ночью различны. Растения реагируют на время суток и угол падения солнечного света, например, поглощение азота заметно зависит от интенсивности света. Количество фосфора, который днём поглощается непрерывно, зависит, в свою очередь, от температуры воздуха.

Представлены данные, собранные во время исследования растительной системы регенерации воды из сточных вод на южной Флориде. Эти данные отображают различия в количестве питательных веществ, усваиваемых из сточных вод во время шести 8-часовых дневных периодов, а также количество нетто этих веществ, удалённых из сточных вод, оцененное на основе сложного отбора проб.

Была проверена исходная гипотеза, что выборочный отбор проб даёт возможность близкой к действительности оценки суточной эффективности нетто удаления из сточных вод питательных веществ растениями, выращиваемыми гидропонически на гравийном основании. В свете представляемых в дальнейшем результатов эту гипотезу следует отвергнуть.