The Cultivation of Algae Using Waste Water from Feedlots

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Abstract

The cultivation of algae in waste water from a cattle feedlot is described. An average annual algal production rate of $10\ g\ m^{-2}d^{-1}$ of dried algal material was achieved, while a reduction in inorganic nitrogen and phosphorus concentrations in excess of 90% was maintained in a high rate algal pond supplied with feedlot effluent. These results indicate that the algal pond concept can be utilized efficiently under South African conditions, and research needed to optimize such a treatment/production system is discussed.

Introduction

The mass cultivation of algae has been studied extensively in the past 40 years (Goldman, 1979). Originally investigations centred on the production of single cell protein for human consumption. New applications such as the following developed with time: The treatment of waste water in which Oswald (1973) showed a reduction of BOD, coupled with the incorporation of nitrogen and phosphorus in algal biomass which reduced the intensity of eutrophication; the production of specific chemicals (Ben Amotz, 1977); the combination of algal, fish and prawn culture (Stanley and Jones, 1976; Shelef, 1976); the bioconversion of solar energy (Goldman and Ryther, 1977); and the production of health foods (Kawaguchi, 1980). Goldman (1979) concluded however, that the large scale cultivation of algae will be most successfully applied in the treatment of waste water.

In South Africa the pond concept has been applied extensively in the treatment of sewage, either as oxidation or as maturation ponds (Meiring *et al.*, 1968). The ponds are intended to fulfil a biological waste treatment requirement utilizing bacteria and algae. The treatment of waste water can be combined with the production of protein materials such as bacterial, algal and fish biomass (Pieterse *et al.*, 1981) indicating that such a combination has a significant potential for the South African situation (see also Stengel, 1970). The conclusion was drawn by Pieterse *et al.* (1981) that a large amount of basic research must be done in order to develop, apply and optimize a new technology for integrated waste treatment production systems under South African conditions.

This paper will concentrate on organic and inorganic wastes produced by animals such as cattle which, for economic and other reasons, are kept in confinement units (see Figure 1). Massive amounts of waste material consisting of urine and faeces are being produced in a concentrated point-source form in these confinement units (Table 1). The waste materials are usually removed by wash or flush water representing a major source of environmental pollution with significant health and aesthetic consequences. Although the South African Water Act prohibits the pollution of surface waters, no biological treatment process for livestock wastes has been introduced officially.

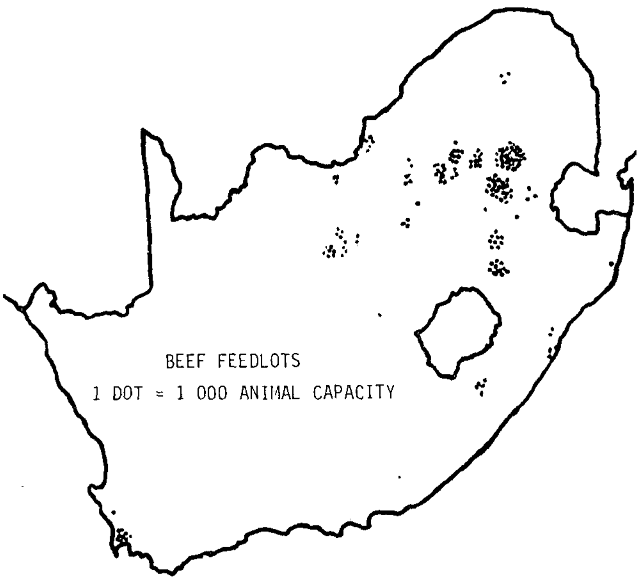

Figure 1
Location of beef feedlots in South Africa (Menné, 1980).

The intensity of the potential pollution problem can best be illustrated with the following example. The largest cattle feedlot system in South Africa contains approximately 30 000 animals producing the equivalent waste of a city of 180 000 to 300 000 people. A city of 300 000 people is required by law to treat its waste water, yet no similar requirement is expected from feedlots.

TABLE 1
NONDISPERSED ANIMAL WASTE PRODUCTION IN SOUTH AFRICA (BASED ON FIGURES FROM THE DEPARTMENT OF AGRICULTURE; MENNÉ, 1980).

	Animals in 1978	Dry Solids $t\ a^{-1}$	Urine* $m^3\ a^{-1}$
Cattle feedlots	150 000	117 000	~3000
Pig Production	921000	128 000	~7400
Poultry farming	35 700 000	142 800	—

*Based on average daily water intake: 20 ℓ per animal for cattle and 8 ℓ per animal per day for pigs.

TABLE 2
NUMBER OF CATTLE IN 26 OF THE MOST IMPORTANT FEEDLOTS IN SOUTH AFRICA (ANOMYMOUS, 1979).

Jan 1978	May 1978	Jan 1979	May 1979
67 728	85 010	90 934	124 590

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The problem of pollution could be further aggravated by the increasing number of cattle kept in confinement units (Table 2).

In ponds intended to stimulate algal growth (both for water treatment and algal production purposes) a complex system of reactions and processes, changing equilibria, and different types of organisms are found, interrelating with one another in various ways. This paper will concentrate on the cultivation of algae in a high rate algal pond receiving waste water from a cattle feedlot.

Factors controlling the rate of change of any algal population are given by the following equation (based on Uhlman, 1971):

THE RATE OF CHANGE
of and algal population
$\frac{\Delta x}{\Delta t}$
EQUALS
$\mu.x + \mathrm{Vol}.x_0 + \mathrm{Susp}.x + \mathrm{Res}.x$
MINUS
$\mathrm{Vol}.x + \mathrm{Pred}.x + \mathrm{Sed}.x + \mathrm{Dec}.x + \mathrm{Par}.x$
Where
x = algal biomass/volume
Vol = flow volume
$\mu.x$ = Growth rate
$\mathrm{Vol}.x_0$ = rate of algal biomass import
$\mathrm{Susp}.x$ = rate of suspension of algal cells
$\mathrm{Res}.x$ = rate of resuspension of algal cells
$\mathrm{Vol}.x$ = rate of algal biomass export
$\mathrm{Pred}.x$ = rate of predation
$\mathrm{Sed}.x$ = rate of sedimentation of algal cells
$\mathrm{Dec}.x$ = rate of decomposition
$\mathrm{Par}.x$ = rate of parasitization

The growth rate, inflow volume and rate of algal biomass export are the only factors that will be considered here in some detail.

Materials and Methods

The cattle feedlot-algal/bacterial/fish pond system is illustrated in Figure 2. Waste waster from the 1000 capacity confinement unit is screened with a 125 μm mesh sieve which removes ~63% of the suspended material. The screened water flows into a storage pond where the organic matter is partly stabilized by bacterial metabolism. Storage pond water is added once a day to the high rate algal pond, while the overflow from the algal pond flows into the fish pond. Water is pumped from the fish pond back to the confinement unit to be re-used as wash or flush water. Water is added to the system to replace water losses. Only part of the normal wash water volume of 500 ℓ per animal per day (500 $m^3 d^{-1}$) is being put through the pond system. The sizes of the different ponds are given in Table 3.

The high rate algal pond has a surface area of approximately 3 200 m^2 (Figure 2). Mixing is achieved by means of a paddle wheel which induces a flow of 5 cm s^{-1} in winter and 13 cm s^{-1} in summer.

Water samples for analyses were taken at positions 1, 2, 5 and 8 (Figure 2). The study period covered in this report extended from January 1979 to June 1980. Standard methods were used to quantify the different parameters.

TABLE 3
CAPACITIES AND DEPTHS OF SOETVELDE PONDS
(SEE FIGURE 2)

Pond	Depth (m)	Capacity (m^3)
Storage	~0,40	350
Algal	0,45	1 440
Fish	1,20	18 000

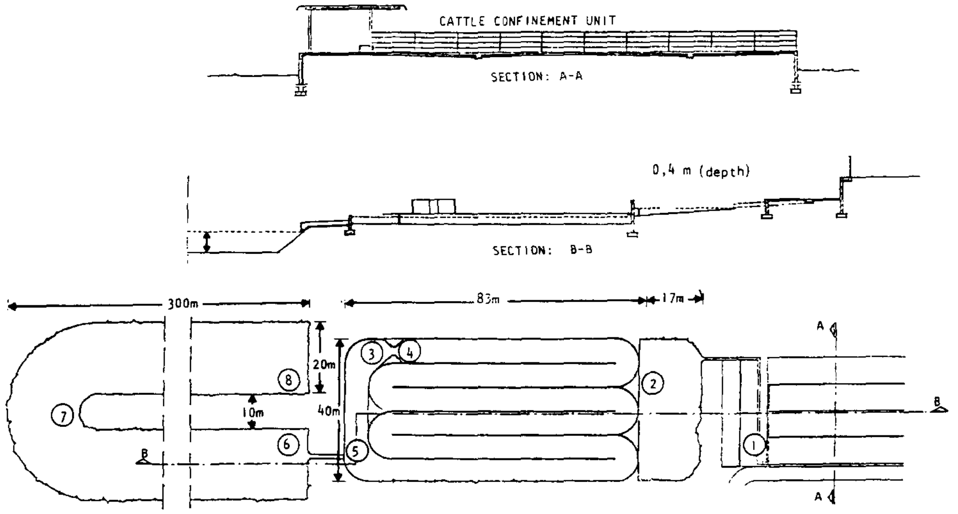

Figure 2
The Soetvelde Confinement Unit-Pond Treatment System. 1 = screen; 2 = storage pond; 3-5 = algal pond; 6-8 = fish pond.

Results and Discussion

Algal populations and algal growth

The chlorophyll *a* concentration in the algal pond varied between 140 and 18 765 µg ℓ⁻¹ (Figure 3), and was generally much higher than that of the fish pond. The algal concentration appeared to be related to the flow rate and retention time (Figures 3 and 4). High algal concentrations were maintained at a retention time of approximately 30 days (from September 1979 to March 1980).

The average chlorophyll *a* concentration between May 1979 and July 1980 amounted to ~9500 µg ℓ⁻¹. At a retention time of 41 days, the average daily production amounted to ~0,1 g Chl *a* m^{-2} d^{-1} or ~10 g dry algal mass m^{-2} d^{-1}. In his review Goldman (1979) considered a figure of 30 g m^{-2} d^{-1} as a high value and indicated that a good average lies between 15 and 20 g m^{-2} d^{-1}. De Pauw *et al.* (1978) recorded an algal growth of 10 g m^{-2} d^{-1} in diluted pig manure while Boersma *et al.* (1975) recorded a figure of 22 g m^{-2} d^{-1} also in diluted pig manure

Soeder *et al.* (1978) observed the accummulation of Pb and Cd in or on algal cells. As large amounts of algal material are produced by the algal pond, this phenomenon of accumulation as well as its possible effects should be studied in more detail.

The total average annual algal production of the system amounted to ~13 x 10³ kg dried material. At an algal/fish biomass conversion ratio of 13 : 1 (Tang and Chen, 1966) approximately 1 x 10³ kg of fish can be produced annually in such a system. It must be remembered that this figure represents only the contribution of the algae, as detrital material from the algal pond will result in additional fish biomass.

Nitrogen and phosphorus were not found to be growth-limiting under normal conditions in the algal pond, but nitrogen can be considered as potentially being the primary limiting nutrient.

Some information on the algal populations is given in Table 4. *Micractinium* sp. (possibly *M. pusillum*) was the dominant alga as for other similar waters (Shillinglaw and Pieterse, 1980; Denoyelles, 1967). In September an almost unialgal suspension was present, while a *Mellosira* sp. achieved codominance in June during periods of low algal density.

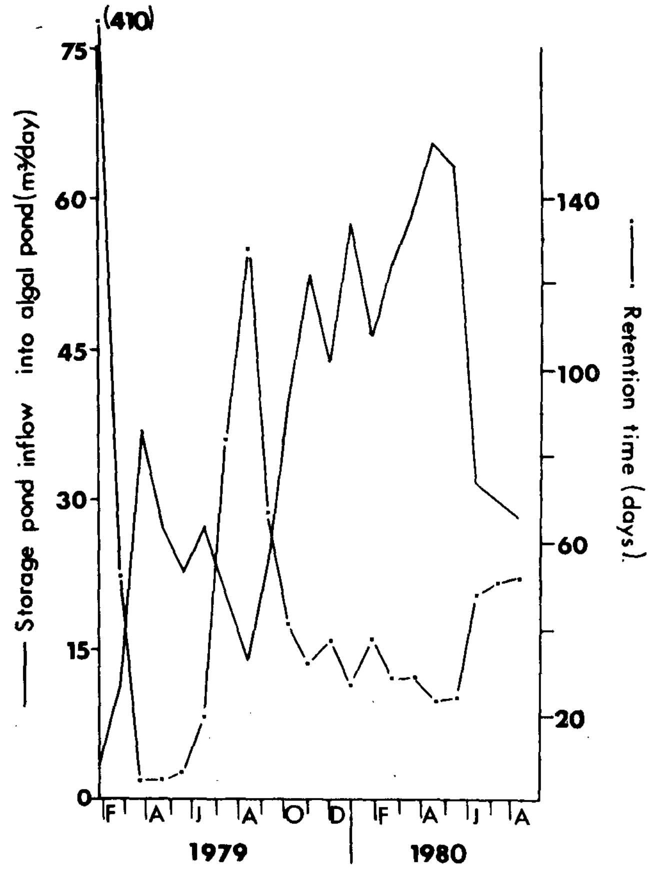

Figure 4
Monthly volume of algal pond inflow from the storage pond, and retention time of the algal pond based on total flow.

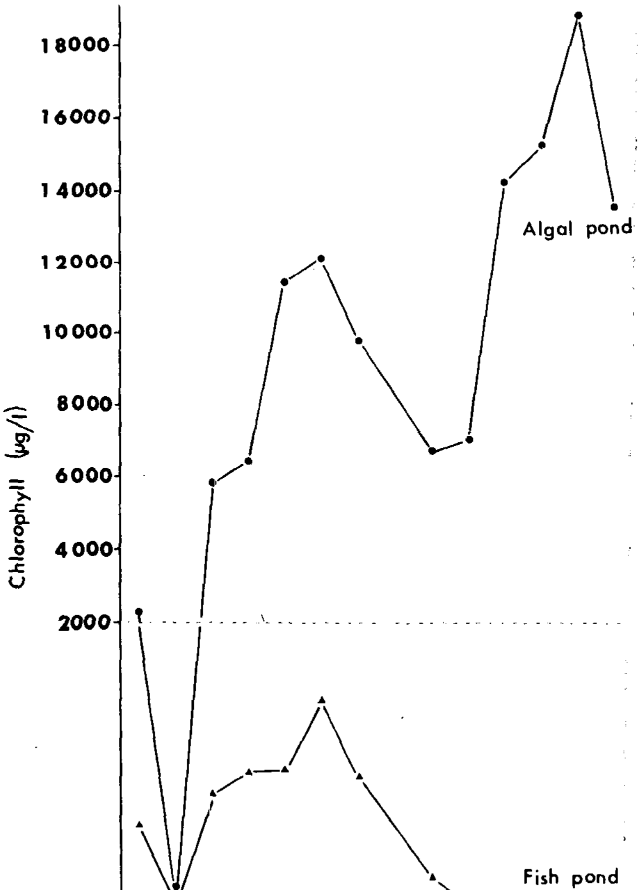

Figure 3
Monthly chlorophyll α concentrations in the algal and fish ponds.

TABLE 4
COMPARISON OF ALGAL POPULATIONS ON TWO DATES REPRESENTING LOW AND HIGH DENSITIES
(COMPARE FIGURE 4)

	June 1979		September 1979	
Chlorophyll α (µg ℓ⁻¹)	140		11 398	
Total cell number (x 10⁶ mℓ⁻¹)	0,46		6,3	
Total number of genera	12		7	
Domination*	*Micractinium*	47%	*Micractinium*	98%
	Melosira	34%	*Scenedesmus*	0,01%
	Scenedesmus	10%	*Actinastrum*	0,003%

*Based on the number of cells as a % of the total number of cells per unit volume of water.

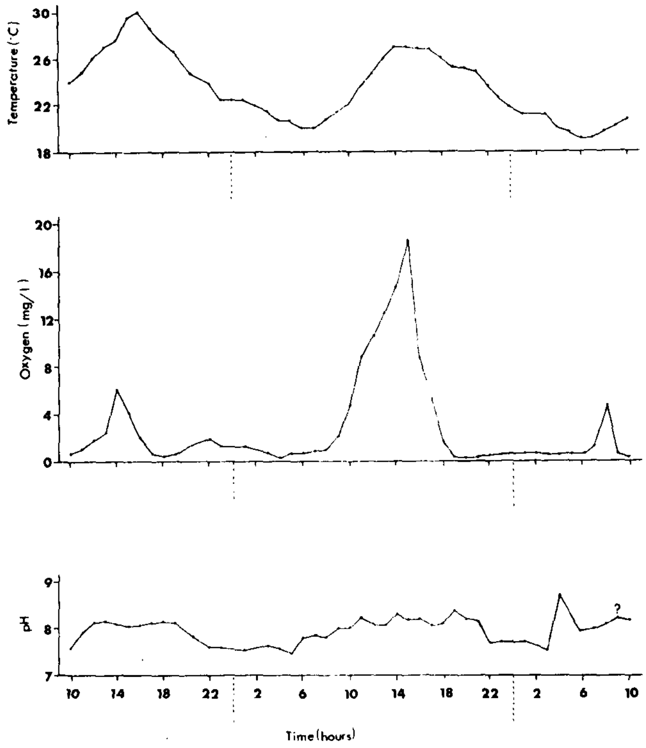

Figure 5
Hourly pH, temperature and oxygen conditions in the algal pond on 29-30 January 1980.

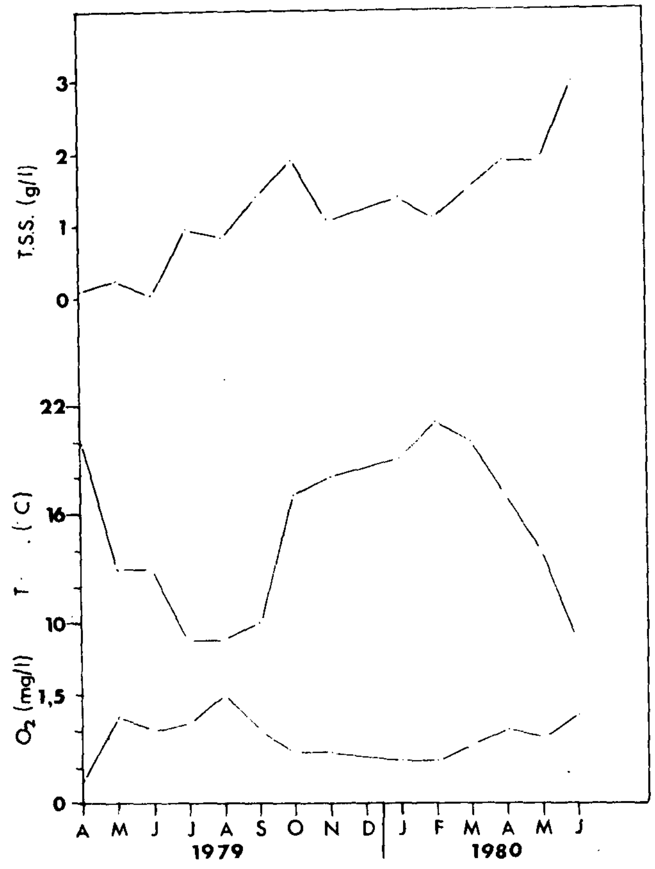

Figure 6
Monthly concentrations of total suspended solids (TSS), oxygen (O_2) and temperature (°C) in the algal pond.

Chemical conditions in the pond system

pH conditions in the algal pond ranged between 7 and 9 during the year long study period as well as during the 48 h study period (see Figure 5). In waters with high nitrogen and phosphorus levels like in the algal pond, CO_2 can become an important controlling factor in algal growth (Stengel and Soeder, 1975).

The COD values in the algal pond varied between 13,0 x 10^3 and 0,5 x 10^3 mg ℓ^{-1}, while BOD varied between 500 and 300 mg ℓ^{-1}. An average overal BOD and COD removal of ~20% and ~70% respectively occurred from the screened water to the effluent of the fish pond (Cloete, 1981).

The monthly dissolved oxygen concentration (determined between 06h00 and 07h00) for the study period and given in Figure 3, ranged between 0,4 and 1,5 mg ℓ^{-1}. The oxygen concentration was largely dependent on the time of measurement (Figure 5). During the night the concentration was reduced to almost nil while a peak of ~19 mg ℓ^{-1} was reached when no storage water was added to the algal pond. When water from the storage pond water was added, the oxygen concentration remained low becuase of oxygen consumption by the added water (Cloete *et al.*, 1982).

The concentrations of oxygen and carbon dioxide in the water are the result of gaseous exchange between the water and atmospheric phases, as well as uptake and production rates of at least the algae and bacteria. Decomposition of organic material by bacteria therefore supply CO_2 to the algae for autotrophic growth possibly indicating that complete stabilization in the storage pond could result in severe CO_2 limitation with detrimental effects on the efficiency of the system. Mixed algal/bacterial cultures provide for maximum nutrient removal (Humenik and Hanna, 1970).

Low oxygen concentrations apparently did not inhibit algal growth (Figure 5) and remained relatively low throughout the day due to oxygen consumption by decomposition reactions. Low oxygen concentrations are advantageous, however, in that they limit, together with alkaline conditions, predator numbers in algal ponds by increasing zooplankton mortality (O'Brien and Denoyelles, 1972).

The total suspended solids (TSS) increased in the algal pond during the study period (Figure 6) partly because of better algal growth and possibly partly due to an increased supply of particulate matter from the storage pond. The TSS of most outdoor cultures vary between 0 and 2 g ℓ^{-1} (Boersma *et al.*, 1975). The average TSS of the algal pond was approximately 1 g ℓ^{-1} (Figure 6). The removal of TSS by the system amounted to approximately 94%. The average amount of suspended matter finding its way into the system in the screened underflow water was approximately 70 kg d^{-1}.

High levels of ammonia N (NH_3-N) and phosphate P (PO_4-P) were found in the screened water (Figure 7). Nitrate (NO_3-N) and Nitrite (NO_2-N) concentrations were low (Pieterse *et al.*, 1981). These conditions compared well with other feedlot effluents (Miner *et al.*, 1966; Loehr, 1969; Wells *et al.*, 1970). Marked reductions in NH_3-N (99%) and PO_4-P (95%) concentrations occurred in the system, comparing well with results from the literature (De Pauw *et al.*, 1978; Shillinglaw and Pieterse, 1977). The NO_2-N and NO_3-N concentrations in the system increase to ~0,3 mg ℓ^{-1} (Pieterse *et al.*, 1981). The NO_3-N and NO_2-N concentrations of the fish pond effluent were lower than that of the Stander Water Reclamation Plant at Daspoort (e.g. Hattingh, 1977), while the average NH_3-N and PO_4-P concentrations were slightly higher.

In some maturation ponds algal growth is poor or irregular, a

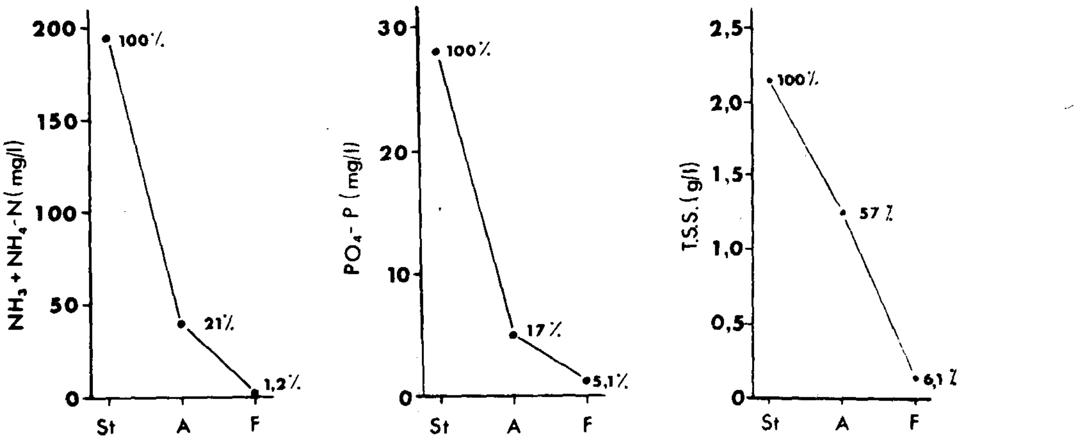

Figure 7
Average ammonia nitrogen ($NH_3 + NH_4 - N$), phosphate phosphorus ($PO_4 - P$) and total suspended solids (TSS) concentrations for the period May 1979 to June 1980. St = storage pond; A = algal pond; F = fish pond.

phenomenon possibly due to ammonia inhibition under alkaline pH conditions coupled with short retention time (Abeliovitch and Azov, 1976; Shillinglaw and Pieterse, 1977). the average NH_3-N concentration in the algal pond amounted to 40 mg ℓ^{-1} which would only inhibit algal growth significantly under low density algal conditions at pH levels of 9,0 and 9,5 (Pieterse *et al.*, 1981). As such high pH conditions are rarely reached, it does not seem as if ammonia is inhibiting algal growth in the high-rate algal pond.

During the transfer of storage pond water to the algal pond, the average NH_3-N concentration was increased instantaneously to approximately 86 mg ℓ^{-1}, giving free NH_3-N concentrations of 0,43 and 4,1 mg ℓ^{-1} at pH's of 7 and 8 respectively based on the equation given by Spotte (1970). The growth rate of low density (35 mg ℓ^{-1} inoculum) algal populations will be reduced by a factor of two at a free NH_3-N concentration of 4,2 mg ℓ^{-1} at a pH of 8 (Table 5). This would result in the washout of the population depending upon the retention time. Ammonia is, however, not considered to be inhibiting to growth during periods of high algal density (compare 70 mg ℓ^{-1} inoculum, Table 5) as was mosly the case in the algal pond. It is nevertheless interesting to note that *Scenedesmus bijugatus* appeared to be able to adapt to high NH_3 and high pH conditions (Table 5).

The pond system markedly improved the quality of the cattle feedlot effluent, yet the effluent did not comply with standards set for drinking water (SABS, 1971; see also Train, 1979).

TABLE 5
FREE AMMONIA-NITROGEN (NH_3-N) CONCENTRATION IN mg ℓ^{-1} REDUCING THE GROWTH RATE OF *SCENESDESMUS BIJUGATUS* BY HALF (GOUGH-PALMER, 1980)

pH	Inoculum 35 mg ℓ^{-1}	70 mg ℓ^{-1}
6,5	0,23	—
7,0	1,04	—
7,5	2,10	4,8
8,0	4,23	19,0
8,5	8,22	43,8
9,5	12,42	54,0

Environmental pollution and eutrophication will, however, be minimized should the fish pond effluent enter surface water supplies.

Physical conditions in the pond system

Temperatures (determined between 06h00 and 07h00) in the algal pond varied between 9°C in winter and 20°C in summer (Figure 6). In summer and on an hourly basis (Figure 5), the temperature varied between ~19°C at 06h00 and ~30°C at 16h00.

The colour of the water in the algal pond was usually brownish, turning green under high algal concentration conditions. Orange-red light penetrated the water deeper than any other, indicating that photosynthetis was primarily based on the absorption of orange-red light. Light available for photosynthesis was present only in approximately the upper 20 cm of the water column, while the photic zone was not deeper than approximately 2 cm under conditions of high algal concentration. Continuous stirring by the paddle wheel was therefore necessary to ensure continual agal growth. The light shading effect of non-living suspended matter can be eliminated by employing dialysis tubing (Dor, 1975).

The average retention time based on total monthly flow rates was 41 days for the algal pond (see Figure 4), with a minimum of 6 days occurring in May 1979 and a maximum of 113 days occurring in July 1979. Short retention periods corresponded with low algal concentrations, possibly indicating that the growth of the algae could have been inhibited by some factor. In the literature retention times recommended for pond operation vary from a day or three (McGarry and Tongkasame, 1971; Boersma *et al.*, 1975) to periods longer than 20 days (Dugan *et al.*, 1972), but a two stage system shortens the total retention time by increasing the effectiveness (Kormanik, 1972). In winter the retention times must be three times as long as in summer because of the lower temperatures and shorter days (St. Amant and Beck, 1970). The retention time of the algal pond must also be significantly longer during winter in South Africa (Figure 4). Further research needs to be done to determine the optimal retention times for winter and summer conditions. In this regard the growth rates of the algae are of extreme importance (Garrett *et al.*, 1978). Shillinglaw (1978) indicated that retention time influences the composition of algal populations in experimental maturation ponds. *Microcystis aeruginosa* became dominant when the retention time was longer than approximately 15 days.

Conclusions

Water is used, amongst others, to transport waste. In this regard urine and *faeces* produced by animals in feedlots are of paramount importance as vast amounts of waste water are produced, causing health hazards, eutrophication and aesthetic problems. As a matter of urgency consideration must be given in South Africa to the development and application of integrated livestock waste treatment-production systems in order to reduce environmental pollution and to utilize 'out-of-place' resources (i.e. the wastes).

The results presented in this paper clearly illustrate that the wastes produced by animals can be converted into usable organic matter, while significant water quality improvements occur at the same time.

The constraints imposed by economic and other considerations indicate, however, that biological recycling systems, as the one described above, must be skilfully managed in order to optimize their efficiency (see also Garrett *et al.,* 1978). The understanding of the ecology of these systems in general as well as the mechanisms involved is of fundamental concern. Further research into various aspects of the problem is therefore needed.

References

ABELIOVITCH, A. and AZOV, Y. (1976) Toxicity of ammonia to algae in sewage oxidation ponds. *Appl. Environ. Microbiol.* 31 801-806.

ANONYMOUS (1979) Cattle in Feedlots. *Vleissentraal Information Bulletin.* 11 9.

BEN AMOTZ, A. (1977) *In: European Seminar on Biological solar Energy Conversion Systems.* Hall, D.O. and Vignais, P.M. (Eds.). Grenoble-Autrans, Grenoble, France.

BOERSMA, L. BARLOW, E.W.R., MINER, J.R., PHINNEY, H.K. and OLDFIELD, J.E. (1975) Protein production rates by algae using swine manure as a substrate. Proceedings of the 7th Cornell Agricultural Waste Management Conference; Jewell, W.J. (Ed.). Arbor Science Publ., Ann Arbor, Michigan.

CLOETE, T.E. (1981) Heterotrophic aspects and algal-bacterial interactions in a pond treatment system for cattle feedlot effluent. M.Sc.-thesis, University of the Orange Free State, Bloemfontein.

CLOETE, T.E., LE ROUX, J.D., TOERIEN, D.F., PIETERSE, A.J.H. and DOWNES, M. (1982) Oxygen dynamics and heterotrophic aspects of a pond treatment system for cattle feedlot effluent. *Agric Wastes* (accepted for publication).

DENOYELLES, F. (1967) Factors affecting phytoplankton distribution in a double cell sewage lagoon. *J. Phycol.* 31 174-181.

DE PAUW, N., BRUGGEMAN, E. and PERSOONE, G. (1978) Research on the tersiary treatment of swine manure by mass culturing of algae. *Mitt. Internat. Verein. Limnol.* 21 490-506.

DOR, I. (1975) High density dialysis culture of algae in sewage. *Water Research* 9 251-254.

DUGAN, G.L., GOLUEKE, C.C. and OSWALD, W.J. (1972) Recycling system for poultry wastes. *J. Water Poll. Contr. Fed.* 44 432-440.

GARRETT, M.K., WEATHERUP, S.T.C. and ALLEN, M.D.B. (1978) Algal culture in the liquid phase of animal slurry – effect of light and temperature upon growth and phosphorus removal. *Environ. Pollut.* 15 141-154.

GOLDMAN J.C. (1979) Outdoor algal mass cultures. I. Applications. *Water Research* 13 1-19.

GOLDMAN, J.C. and RYTHER, J.H. (1977) *In: Biological Solar Energy Conversion* Mitsui, A., Miyachi, S., San Pietro, A. and Tamura, S. (Eds.). Academic Press, New York.

GOUGH-PALMER G.E. (1980) Personal communication. Address: Institute for Environmental Sciences, U.O.F.S., Bloemfontein.

HATTINGH, W.H.J. (1977) Reclaimed water: a health hazard? *Water S.A.* 3 104-112.

HUMENIK, F.J. and HANNA, G.P. (1970) Respiratory relationships of a symbiotic algal-bacterial culture for wastewater nutrient removal. *Biotech. Bioeng.* 12 541-560.

KAWAGUCHI, K. (1980). *In: Algae Biomass: Production and Use.* Shelef, G. and Soeder, C.J. (Eds.). Elsevier/North Holland Biomedical Press, Amsterdam.

KORMANIK, R.A. (1972) Design of two-stage aerated lagoons. *J. Water. Poll. Contr. Fed.* 44 451-458.

LOEHR, R.C. (1969) Animal wastes – a national problem. *J. Sanit. Engng. Div., Am. Soc. civ. Engrs, S.A.* 2(95) 189-221.

MEIRING, P.G.J., DREWS, R.J.C.C., VAN ECK, H. and STANDER, G.J. (1968) A guide to the use of pond systems in South Africa for the purification of raw and partially treated sewage. C.S.I.R. Special Report WAT 34.

MENNÉ, D. (1980) Personal communication. Address: E.L. Bateman Ltd, P.O. Box 198, Germiston.

McGARRY, M.G. and TONGKASAME, C. (1971) Water reclamation and algae harvesting. *J. Water Poll. Contr. Fed.* 43 824-835.

MINER, J.F., LIPPER, R.I., FIND, L.R. and FUNK, J.W. (1966) Cattle feedlot runoff, its nature and variation. *J. Wat. Poll. Contr. Fed.* 38 1582-1591.

O'BRIEN, W.J. and DENOYELLES, F. (1972) Photosynthetically elevated pH as a factor in zooplankton mortality in nutrient enriched ponds. *Ecology* 53 605-614.

OSWALD, W.J. (1973) Completed waste Treatment in Ponds. *In: Progr. Water Technol.*, Vol. 3 *Water Quality: Management and Pollution control Problems*, S.H. (Ed.). p. 153-163. Pergamon Press, Oxford.

PIETERSE, A.J.H., LE ROUX, J.D., CLOETE, T.E. and GOUGH-PALMER, G.E. (1981) Waste Systems. Proceedings of a Workshop on Biological Production Systems and Waste Treatment. Grobbelaar, J.U., Soeder, C.J. and Toerien, D.F. (Eds.). UOFS Series C, No. 3, University of the Orange Free State, Bloemfontein.

SABS (1971) *Specification for water for domestic supplies.* South African Bureau of Standards, Pretoria.

SHELEF, G. (1976) Combined systems for algal wastewater treatment and reclamation and protein production. Third Progress Rep., 013-565, Sherman Envir. Engrng. Res. Ctr. Technion. Israel Inst. of Technology, Haifa, Israel.

SHILLINGLAW, S.N. (1978) Personal communication. Address: Institute for Environmental Sciences, U.O.F.S., Bloemfontein.

SHILLINGLAW, S.N. and PIETERSE, A.J.H. (1977) Observations on algal populations in an experimental maturation pond system. *Water S.A.* 3 183-192.

SHILLINGLAW, S.N. and PIETERSE, A.J.H. (1980) Algal concentration and species composition in experimental maturation ponds with effects of aeration and recirculation. *Water S.A.* 6 186-195.

SOEDER, C.J., PAYER, H., RUNKEL, K., BEINE, J. and BRIELE, E. (1978) Sorption and concentration of toxic minerals by mass cultures of Chlorococcales. *Mitt. Internat. Verein. Limnol.* 21 575-584.

SPOTTE, S. (1970) *Fish and Invertebrate Culture.* Wiley-Interscience, New York.

ST. AMANT, P.O. and BECK, L.A. (1970) Methods of removing nitrates from water *J. Agr. Food. Chem.* 18 785-788.

STANLEY, J.G. and JONES, J.B. (1976) Feeding algae to Fish. *Aquaculture* 7 219-223.

STENGEL, E. (1970) Anlagentypen und Verfahren der technischen Algenmassenproduktion. *Ber. Dtsch. Bot. Ges.* 83 11 589-606.

STENGEL, E. and SOEDER, C.J. (1975) Control of photosynthetic production in aquatic ecosystems. *In: Photosynthesis and productivity in different environments.* Cooper, J.P. (Ed.). Cambridge University Press, Cambridge, p. 645-660.

TANG, Y.A. and CHEN, S.H. (1966) A survey of the algal pasture soils of milk fish ponds in Taiwan. *Proc. World sym. Warmwater Pond Fish Culture, F.A.O. Fish Rep.* 44(3) 180-198.

TRAIN, R.E. (1979) *Quality criteria for water.* Castle House Publ., Ltd., London.

UHLMAN, D. (1971) The influence of dilution, sinking and grazing rate on phytoplankton populations of hyperfertilized ponds and micro-eco-systems. *Mitt. Internat. Verein. Limnol.* 19 100-124.

WELLS, D.M., GOMB, W., ALBIN, R.C., MEENAGHAM, G.F. and COLEMAN, E. (1970) Control of water pollution from South Western cattle feedlots. Presented at the 5th International Water Pollution Research Conference, San Francisco, California.