Recycling system for poultry wastes

G. L. DUGAN, C. G. GOLUEKE, AND W. J. OSWALD

The very great problems besetting animal wastes management are well known. They have been reviewed thoroughly by Loehr in a paper that continues to be relevant to the situation as it exists today. However, one or two additional items might be mentioned simply as a reminder of the seriousness of the situation as well as its relationship to the wastewater problem.

Thus, Robbins et al. state that of the more than 1 bil tons of animal wastes produced each year, at least 400 mil tons are liquid, and of these totals about 50 percent are concentrated in animal growing areas. For an average-sized mechanized dairy operation (400 head of cattle), the daily production of solid wastes is about 14 tons, and of liquid wastes, about 4.5 tons. Solid wastes generated each day in a 10,000-head feedlot amount to 260 tons and liquid wastes, about 100 tons. A 100,000-bird poultry operation produces about 20 tons of manure each day. Aside from aesthetic nuisances, one of the major impacts of inadequate management of animal wastes is the contamination of water supplies by runoff and percolation. A principal contaminant is nitrogen, which on passage through the soil is oxidized to nitrate, the form in which nitrogen of manure origin usually is found in contaminated water. For example, Gilham et al. demonstrated an increase of 2 to 15 mg/l NO₃ concentration of groundwater [water table—8 ft (2.4 m)] as it moved beneath a barnyard they were studying.

Approaches

The relative advantages of solids handling (dry handling) of animal wastes as contrasted to wet handling (hydraulic handling) have been the subject of numerous and often heated arguments between their respective proponents.

Solids handling is the traditional method of manure handling. Basic mechanisms range from the manure fork to mechanized scrapers. Wet handling is mostly in the experimental or demonstration stage as yet. The development of lagoon technology and of the oxidation ditch principles has led to the conversion of some phases of manure handling to hydraulic means. For example, a slotted floor over an oxidation ditch makes it possible for hogs to drop their wastes directly into the ditch. Other examples of wet handling are the experimental setups developed by Gilham et al., Pratt et al., and Wirty et al. As yet, none of these systems has completely overcome the objectionable odor problem.

The closest approach to a complete hydraulic system is the integrated sanitation waste materials recycling system developed at the University of California. The University of California system was designed not only to treat wastes and conserve water, but also to reclaim directly the nutrients in the wastes. A description of it and a discussion of some of the results obtained in studying a pilot-plant application of the system constitute the subject matter for this paper.

Materials and Methods

Description of the system. In general, the University of California system is largely an enclosed hydraulic one involving an aerobic phase, in which oxygenation can be accomplished either by the photosynthetic activity of algae or by mechanical aeration, and an anaerobic phase. When photosynthetic oxygenation is utilized, algae production is practiced. The algal product can either be recycled in the system as a proc diet or dive feedstuff for poultry, the design of the animal rectly to the other types:

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tem as a protein supplement in the animals’
diet or diverted from the system for use as
feedstuff for other animals.

Although the detailed description that
follows deals with an operation involving
poultry, the principles involved and the
design of most of the components outside
the animal enclosure can be applied di-
rectly to the handling of the wastes of
other types of animals.

A generalized flow chart of the system
as embodied in the pilot plant at the Uni-
versity’s Richmond Field Station is shown
in Figure 1. The interrelation between
the aerobic and anaerobic phases together
with the operation of the system are il-
ustrated by Figure 1. A brief description
of the flow chart is as follows: The chick-
en’s excreta are flushed down manure
troughs into a sedimentation tank. The
supernatant in the sedimentation tank is
pumped directly to an algal (or aerated)
pond, while the settleable solids are
measured and discharged into a digester.
Supernatant from the digester is dis-
charged into the algae pond. Stabilized
digester sludge is wasted periodically to
the environment. Pond effluent, or super-
natant from the algae separation process, is
pumped to the manure troughs for use as
flushing water, thus completing the cycle.
Dried algae may be fed back as a supple-
ment to the chicken’s diet. Among the
variations tried during the course of the
study were the bypassing of the anaerobic
phase and the use of mechanical aeration
of the pond during periods of poor algal
growth. Tap water served as drinking
water for the birds. Overflow from the
drinking water troughs served as make-up
water for that lost through spillage, evap-
oration, and occasional discharge.

Pilot-plant components. A detailed
Diagrammatic sketch of the pilot plant is
given in Figure 2. The description that
follows is relatively brief because a detailed
description of the individual components
has been given in previous publications.

The birds were housed in a 14- by 14-ft
(4.2- by 4.2-m) enclosure designed to
accommodate 112 to 140 birds and to be
representative of a practical egg-production
operation. In the enclosure, 28 ele-
vated chicken batteries were suspended in
two rows of seven back-to-back batteries.
Directly beneath each of the two rows of

FIGURE 1.—Flow pattern for generalized pilot plant.
chicken batteries were fiber-glass-coated plywood troughs to catch the chicken droppings. The sloping troughs converged before entering the sedimentation tank outside the enclosure. A tipping bucket was mounted at the head of each trough. Once each hour the buckets were filled to the extent that they tipped their contents into the trough and flushed the excreta through the troughs and into the sedimentation tank. A submerged pump moved the supernatant from the settled flushings in the sedimentation tank to the algae pond. A sludge pump moved the settled chicken manure to the digester through a calibrated manure hopper.

Drinking water was provided to the birds by means of a continuous low-rate flow of tap water maintained in water troughs attached to each row of batteries. Overflow from the troughs was discharged into the upper ends of the manure troughs to keep the surface from drying.

The digester was a vertically positioned cylindrical concrete tank partially sunk in the ground. The tank was fitted with a cover plate designed to permit ready access to its interior. The digester was equipped so that its contents could be heated, mixed, and sampled at various levels. Provision also was made for measuring gas production and collecting composite samples of the gas.

The aerobic phase of the plant consisted of a high-rate algal growth pond. The pond was a shallow, fiber-glass-lined tank equipped for mixing the pond contents for a 10- to 15-min period once each hour. The full capacity of the pond-tank was 5,000 gal (18.9 cu m). The volume of the culture could be varied by varying the depth of the culture and by moving an adjustable partition in the tank.

In the study, two methods of algae removal were practiced in the operation of the algal pond, namely, settling and centrifugation. Settling was accomplished by pumping the culture from the algae pond to a settling tank. Although this method was not a very effective one so far as removal of cells was concerned (20 to 30 percent removal), a sufficient number were removed to impart a detention period to the algal population. The solids content of the settled slurry ranged from 1 to 4 percent. A solid-bowl centrifuge was used to harvest the algae by centrifugation.

Birds used in the study were egg-laying white leghorns. At the time of the start of the run, they were 20 wk old.

Analyses. Analyses were made routinely to determine the nitrogen (total, NH₃, and organic), chemical (TS) and of the mixture as it the sediment and supernatant contents solved “Methods”.

In the examinations of the algal pond culture of manure by determining, or recording, algal production by the birds, the intake can be obtained. Principal products are algal protein substitute amino acids.

FIGURE 2.—Poultry operation with an integrated sanitation-waste materials recycling system.
FIGURE 3.—Settling rate of suspended solids in chicken manure suspensions as a function of dilution.

organic), biochemical oxygen demand, chemical oxygen demand, and total solids (TS) and volatile solids (VS) concentrations of the manure input (that is, of the suspension as it was flushed down the troughs), the sedimentation tank contents (settled and supernatant), the digester content (settled and supernatant), and the pond contents [that is, of the suspended and dissolved solids (SS and VS)]. "Standard Methods" was used in making the analyses. In addition to the foregoing, determinations were made of the dissolved oxygen (DO) and algal concentration of the pond culture. The energy content of the manure and of the various outputs was determined by means of a bomb calorimeter, or obtained from the literature. A record also was made of the daily egg production and manure output by the birds, their gain in weight, and their food intake.

The study included an investigation of the nutritional characteristics of the algal product. In this phase of the study, the algal product was fed to the birds as a substitute for soybean oil meal, and an amino acid analysis was made of a composite sample of the product. In the feed tests, two of the batteries received a standard mash (16 percent protein), two received a special “control” mixture, while the remaining three received the control mixture supplemented respectively with 5 percent, 10 percent, and 15 percent dry algae. The algae substituted for an equivalent amount of soybean meal. The amino acid analysis was made with the use of an automatic amino acid analyzer.

The systems approach was used to analyze the performance of the pilot plant. A “balance” of inputs, outputs, concentration changes within the system, and Δ system changes was performed for TS, VS, total unoxidized nitrogen, and energy for the system components, chickens, sedimentation tank, digester, and algae pond.

RESULTS

The results reported herein are selected key findings presented in summary form. The work which led to the findings, as well as the findings themselves, are given in extensive detail in two annual reports.², ³

² Beckman Instruments Co., Fullerton, Calif.

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The selected findings are concerned with (a) the effect of ss concentration on the settleability characteristics of the solids in manure slurries, (b) pond and water requirements per bird, (c) gas production in the digestion of the manure solids, (d) algal yield, (e) photosynthetic efficiency of the algae pond, (f) reduction in solids brought about by the integrated process, and (g) an economic appraisal of the system.

Effect of solids concentration on settleability. Because the system involves the use of photosynthesis as an important part of its overall function, it is important that the ss in the flushings from the manure troughs be kept at as low a concentration as possible. If they were dumped into the algae pond, the ss would impart a high turbidity to the pond suspension and thereby reduce light penetration and photosynthetic activity.

Early in the study it became apparent that an important factor in the settleability of solids in manure slurries was the ss concentration of the slurries. The family of curves in Figure 3 shows the effect of dilution on the settling rate of the ss in a chicken manure slurry. As the figure shows, most of the ss settled out of suspension when the wet solids concentration of the slurry was 1 percent or less. With the concentration at 3 to 5 percent, the settling time lengthened to 30 min. Not only was the settling time prolonged as the solids concentration was increased, but the percentage of the solids remaining in suspension also increased. In keeping with this finding, the hydraulic system of the pilot plant was adjusted such that the manure concentration of the flushings from the manure troughs approximated 1 percent.

Digestor performance. At loadings ranging from 0.040 to 0.054 lb vs/day/cu ft (0.64 to 0.87 kg/day/cu m) and an average detention time of 23 days, gas production amounted to 12 cu ft/lb (0.75 cu m/kg) of volatile matter introduced. The CH₄ content of the gas ranged from 13 percent at the beginning of the study to 45 percent at the end. The trend in CO₂ concentration was quite the reverse, beginning at 67 percent and ending at 41 percent. The obvious reason for these trends in relative CH₄ – CO₂ concentrations was a buildup of the methane-forming bacteria. The overall trend was much the same, if not identical, to that encountered in establishing a conventional wastewater sludge digester. If the latter is true, then it is to be expected that had the experimental run with the digester been extended, the CH₄ content of the gas eventually would have been on the order of 60 to 70 percent.

Pond performance. In the study, the hydraulic detention time of the algae pond ranged from 9 days to infinity. Excluding the infinity, the average detention time was 22 days. The depth of the pond ranged from 7 to 12 in. (18.8 to 30.5 cm). Although eventually the pond surface area was reduced to an equivalent of 2 sq ft (0.19 sq m)/bird, the performance at the reduced area equalled that with the original area of 7 sq ft (0.65 sq m)/bird.

At the 7-ir infinity ra amount of about 8 pe a yield we 20 tons of surface (4 round ope contained 1. The ov efficiency of 0.6 to 2.8. It shoul that the d synthetic fo the alg sured in t the manu the pond: if t the ppm act as aera vertical pi the pump : fitting so horizontall into the p the aeratio with a sing the no cor. The abilit necessary : loveness of voum of

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<table>
<thead>
<tr>
<th>Amino Acid*</th>
<th>Sample 1 (g AA/16 g N)</th>
<th>Sample 2 (g AA/16 g N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lysine</td>
<td>5.52</td>
<td>5.25</td>
</tr>
<tr>
<td>Histadine</td>
<td>1.62</td>
<td>1.51</td>
</tr>
<tr>
<td>Ammonia</td>
<td>1.87</td>
<td>1.79</td>
</tr>
<tr>
<td>Arginine</td>
<td>5.34</td>
<td>5.12</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td>9.01</td>
<td>8.49</td>
</tr>
<tr>
<td>Threonine</td>
<td>4.59</td>
<td>4.37</td>
</tr>
<tr>
<td>Serine</td>
<td>4.21</td>
<td>3.97</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td>10.34</td>
<td>10.10</td>
</tr>
<tr>
<td>Proline</td>
<td>4.47</td>
<td>4.17</td>
</tr>
<tr>
<td>Glycine</td>
<td>5.63</td>
<td>5.37</td>
</tr>
<tr>
<td>Alanine</td>
<td>7.40</td>
<td>7.18</td>
</tr>
<tr>
<td>Valine</td>
<td>6.07</td>
<td>5.42</td>
</tr>
<tr>
<td>Methionine</td>
<td>(1.72)</td>
<td>(1.71)</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>8.00</td>
<td>7.88</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>3.26</td>
<td>3.10</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>4.83</td>
<td>4.47</td>
</tr>
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* Determinations were not made of the tryptophan and cystine content. The methionine value is low and cystine is not reported because a separate performic acid oxidation and hydrolysis were not carried out.

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depth and 9-day to 
finity range of detention periods, the 
amount of harvested algae solids equaled 
about 8 percent of the input solids. Such 
a yield would be the equivalent of about 
20 tons of algae (dry wt)/yr/acre of pond 
surface (45 metric tons/yr/ha) for year-
round operations. A list of amino acids 
contained in a composite sample of algae 
harvested during the run is given in Table 
I. The overall photosynthetic conversion 
efficiency of the algal culture ranged from 
0.6 to 2.8 percent. 

It should be emphasized at this point 
that the data on yield and overall photo-
synthetic efficiency are based on figures 
for the algae actually harvested and mea-
sured in the study and not on actual or 
potential yield. Because of limitations of 
manpower and equipment, only a fraction 
of the algal crop was harvested in the 

With the pond area at 2 sq ft (0.19 sq 
m)/hen, during the winter months when 
algal growth was not sufficient to supply 
the oxygenation needed to oxidize the 
chicken wastes, mechanical aeration was 
used to supply the required oxygen. No 
such aeration was needed at 7 sq ft (0.65 
sq m)/hen. To accomplish the aeration, 
three float-activated 0.33-hp (0.25-kw) 
sump pumps were pressed into service to 
act as aerators by installing a 2-ft (0.6-m) 
vertical pipe into the discharge point of 
the pump and capping the pipe with a "T" 
fitting so that the liquid was discharged 
horizontally into the air and cascaded back 
into the pond. Later it was found that 
the aeration could easily be accomplished 
with a single pump. With the one pump, 
the DO concentration remained at 6 mg/l. 
The ability of one pump to supply the 
necessary aeration was a result of the shal-
lowness of the pond and hence the small 
volume of water to be oxygenated. 

The integrated system. In arriving at 
balances concerned with the wastes 
materials, two inputs to the system as a whole 
were of significance, namely, the chicken 
manure and the tap water overflow from 
the drinking troughs. Miscellaneous in-
puts such as dust and wild bird droppings 
were negligible in amount and hence were 
not taken into consideration in making the 
balances. 

Outputs to be considered were the har-
vested algae, settled solids from the sedi-
mentation tank, grit, digester gas, and 
sump output. 

In the study and as a part of the com-
piration of the second report, data were 
compiled on the input, output, and sys-
tem changes with respect to ts, vs, unoxi-
dized nitrogen, and energy (not including 
solar energy). An analysis of the data in 
terms of the system as a whole reveals that 
biological activity in the sedimentation 
tank, digester, and pond decreased the ts 
by 60 percent; the vs by 62 percent; the 
total unoxidized nitrogen by 45 percent; 
and the energy by 56 percent. 

Nutritional study. The average daily in-
take of feed by the birds fed the standard 
mash amounted to 130 g; by the birds fed 
the "control" mash, 110 g; by the birds 
fed the 5 percent algae mixture, 102 g; by 
the birds fed the 10 percent algae mixture, 
110 g; and by the birds receiving the 15 
percent mixture, 113 g. Egg production by 
birds fed the standard mash was 71 percent; 
by those fed the control mixture, 62 per-
cent; by those fed the 5 percent algae mix-
ture, 69 percent; by those fed the 10 per-
cent algae mixture, 72 percent; and by 
those fed the 15 percent algae mixture, 61 
percent. Little or no change in weight or 
increase in morbidity or mortality could be 
attributed to the use of algae as a feed-
stuff. 

In a taste test of the eggs made with the 
use of an untrained panel, no differences 
in flavor or acceptability were noted re-
gardless of the birds' diet. However, the 
intensity of the color of the egg yolk 
increased with increase in concentration of 
the algae in the birds' diet. 

Economic analysis. Although a rigorous 
economic analysis of the system cannot be 
made at this time because of the scale of 
the plant, an analysis should lead to rea-
sonably accurate conclusions, especially if 
it is based on conservative estimates. In 
the analysis presented here, estimates were 
especially conservative inasmuch as they
TABLE II.—Estimated Costs of the Waste-Handling Facilities of a 100,000 Egg-Laying Poultry Operation Utilizing Photosynthetic Reclamation and Hydraulic Transport

<table>
<thead>
<tr>
<th>Item</th>
<th>Estimated Costs ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction and equipment:</td>
<td></td>
</tr>
<tr>
<td>Poultry enclosure additions</td>
<td>5,000</td>
</tr>
<tr>
<td>Sedimentation tank, pumps, and accessories</td>
<td>5,000</td>
</tr>
<tr>
<td>Digester(s) and appurtenances</td>
<td>50,000</td>
</tr>
<tr>
<td>Algae pond (including land, pumps, and accessories)</td>
<td>100,000</td>
</tr>
<tr>
<td>Algae removal equipment (batch centrifuge and drying facilities)</td>
<td>10,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>170,000</strong></td>
</tr>
<tr>
<td>Fixed items:</td>
<td></td>
</tr>
<tr>
<td>Depreciation (10 yr—straight line)</td>
<td>17,000</td>
</tr>
<tr>
<td>Working capital—7%</td>
<td>11,900</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>28,900</strong></td>
</tr>
<tr>
<td>Utilities and maintenance:</td>
<td></td>
</tr>
<tr>
<td>Utilities and repair of equipment</td>
<td>5,000</td>
</tr>
<tr>
<td>Additional labor</td>
<td>5,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>10,000</strong></td>
</tr>
<tr>
<td><strong>Total estimated annual cost</strong></td>
<td><strong>38,900</strong></td>
</tr>
<tr>
<td>Total estimated cost per chicken per year</td>
<td>0.39</td>
</tr>
<tr>
<td>Total estimated cost per dozen eggs</td>
<td>0.02</td>
</tr>
</tbody>
</table>

This condition applies even though the aesthetic environment may be adversely affected if the operation is conducted in a sufficiently isolated locale. The situation changes when large-scale operations are concerned. For a large-scale operation, it would be virtually economically unfeasible to provide the land area on which the manure could be spread in a concentration low enough to preclude adverse environmental effects.

References in the literature to estimates of operating expenses of large-scale industrial-type poultry operations are few and far between. One such reference is that of Linton,9 in a report on operations in two rural New York counties, he states that the average manure-handling cost in 1966 was $0.0075/dozen eggs for 6 months of manure storage and later spreading. Added to this cost is a charge of $0.35/chicken for installation costs. Using the method of calculation employed in the present study, the adjusted cost would amount to about $0.01/dozen eggs, not taking into consideration the difference between 1970 prices and 1966 prices. If Linton's estimate is typical for conventional waste-handling practice in large-scale operations, then the estimated cost of $0.02/dozen eggs (excluding algae recovery) for the system reported herein is not excessively expensive. The reason is that the $0.02/dozen figure is based on loadings much lower than capacity and on overdesigned components costing more than would be encountered in a practical operation. Moreover, the latter costs are based on 1970 prices.

Discussion

The relation between solids content of the slurry and rate and extent of settling is of particular significance in the design of a hydraulic manure-handling system inasmuch as it may be a major factor in the successful application of the design. The reasons are obvious. One important reason is that in a system designed for the separate treatment of the solid and liquid phases of the animal waste, it is essential that the two be separated as completely as possible in a system that is designed by have been ration of wastes with the livestock phase.

The large settling tank, because reported water was process, the sanitary part of the system, during the operating process, materials were mixed in the settle and nature characteristic. Although without satisfaction, especially geared to the condition of the initial stage of the system, little to system b than adequate for the required i seems to resemble a pond more stabilized quite stable.

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though the adversely conducted in the situation 3.4. The operation, technically unfeasible on which a concern adverse

estimates cale induce few and adverse is that the statements cost in the 6 months spreading.

Using the egg of the cost would not be done. If the conventional cost for algae reported herein, the major expenditure of water would be only in the start-up of the process. Moreover, the water required for the sanitation phase would be only a small part of that needed for setting up the pond phase.

During the course of the study, it was found that at the dilutions applied in operating the plant, readily putrescible materials were eluted from the solids and remained in the liquid phase. As a result, the settled solids were relatively stable in nature and lacked the objectionable characteristics of fresh manure.

Although the settled solids were digested without difficulty and gas production was satisfactory, the anaerobic phase could probably be omitted in a practical operation, especially if the operation were geared to nutrient reclamation. Elimination of the anaerobic phase would remove one of the more expensive components of the system, that is, if an enclosed, heated digester were considered. An open anaerobic pond probably would contribute little to the successful operation of the system because the aerobic pond is more than adequate for stabilizing the sludge. As for the settled solids, treatment accomplished in an anaerobic pond would resemble that accomplished in a holding pond more than it would resemble active stabilization because the solids are already quite stable.

The design criteria for the pond are those developed over the past decade for algae production ponds at the Richmond Field Station, namely, that the pond should be mixed once each day, should be shallow [9 to 12 in. (22.8 to 30.5 cm)], should have a hard surface (to prevent turbidity from suspended silt during mixing), and should have a short detention period for the algal population. Results at the time the study was ended indicated that the surface area per bird would be 2 sq ft (0.19 sq m) or less, and that the initial water investment per bird for the entire system would be about 15 gal (57 l).

The significant finding in the study was the fact that more than adequate oxygenation could be supplied by a simply constructed sump pump during those months in which algal growth was not great enough to do so. This was possible because the shallowness of the pond drastically lowered the volume of liquid to be aerated. Moreover, the shallowness obviated the need for installing the complex floating or mounting system needed when mechanical aeration is applied to a deep pond. Because of the simplicity of the pumping system, capital and operating costs would be minimal in a practical operation.

Summary and Conclusions

1. An integrated waste management system was developed in which animal enclosure sanitation was integrated with waste treatment. It was a largely closed hydraulic system involving an anaerobic phase and an aerobic phase in which oxygenation could be accomplished either by the photosynthetic activity of algae or by mechanical aeration. When photosynthetic oxygenation was used, algae were harvested.

2. The range of application of the process is from small-scale to large-scale operations. Algae reclamation would be practiced in large-scale operations and induced aeration in smaller ones.

3. An important operational feature of the system is to keep the solids content of the manure slurry to less than 3 percent, wet weight.

4. At concentrations of 3 percent or less, 70 percent or more of ss in manure slurries settle out of suspension in less than 30 min.

5. Pond depth should not exceed 12 in. (30.5 cm).

6. The indicated pond area per bird at
the time of this writing was 2 sq ft (0.19 sq m).

7. The water needed to establish the overall system is on the order of 15 gal (57 L)/hen. Amount of required maintenance water would be a function of evaporation plus spillage and minus the overflow from drinking troughs.

8. At an average detention time of 23 days, gas production in the digester was about 12 cu ft/lb (0.75 cu m/kg) vs introduced.

9. The potential algal yield from the pond was equivalent to 30 to 40 tons (dry wt) algae/yr/acre (65 to 90 metric tons/yr/ha).

10. Overall photosynthetic conversion of visible light energy to algal cellular material ranged from 0.6 to 2.8 percent.

11. Biological activity in the sedimentation tank, digester, and algal pond decreased the vs introduced into the system by 60 percent; the vs by 62 percent; the total unoxidized nitrogen by 45 percent; and the energy input (exclusive of light) by 56 percent.

12. Substituting algae for soybean meal in amounts ranging from 5 to 15 percent of the total diet of the birds was accompanied by a slight drop in the daily intake of feed (for example, 130 g/day on standard mash and 113 g/day on a 15 percent algae mixture). No noticeable effect was noted on flavor or acceptability of the eggs or on the weight, morbidity, and mortality of the birds.

13. An economic evaluation based on an integrated system of 100,000 egg layers and the application of the low-loading, high-cost, and overdesigned components used in the research indicates that the waste-handling costs of the system would be at the most $0.02/dozen eggs. If the value of the algal crop were credited to the operation, the net waste-handling cost would be about $0.01/dozen eggs.

ACKNOWLEDGMENTS

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Authors. G. L. Dugan, C. G. Golueke, and W. J. Oswald are, respectively, project engineer, Lake Tahoe Area Council Demonstration Grant, Tahoe City, Calif.; research biologist, and professor of sanitary engineering, Sanitary Engineering Research Laboratory, University of California, Richmond.

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