The Feasibility of Utilization of Solid Waste Material from the Cultivation of Shellfish as a Marketable Product

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DEL-SG-12-75

This work is the result of research sponsored by NOAA Office of Sea Grant,
Department of Commerce, under Grant No. 04-3-158-30,
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ABSTRACT

Some of the technical aspects of producing and utilizing shellfish biodeposition as a marketable product are discussed. Experiments were performed to determine the quantity and composition of solid wastes produced by shellfish. The utility of this solid material as a terrestrial plant fertilizer was demonstrated.

Introduction

It has become obvious that intensive farming with its high expenditure of fossil fuel will become increasingly difficult in a world beset by energy constraints (Clark, 1975). The problems engendered by the extensive use of synthetic fertilizers and the energy requirements necessary for the growth of feed grains to produce animal protein are now receiving widespread attention (Wade, 1975). These factors combined with projected zero discharge requirements for effluents from U.S. industries suggest a common focal point for a partial solution to these problems and a rather interesting application of current research whose goal is the intensive cultivation of shellfish. Industries -- for example, food processing industries — which yield effluents containing high concentrations of non-toxic but nevertheless undesirable nutrients and heat, should consider transferring this material to a mariculture operation rather than attempting to treat their waste independently. The shellfish mariculture operation could use the effluent from appropriate industries as a raw material and energy source to produce algae.

The algae could in turn be harvested efficiently from the waste water by the shellfish. One service and two products would result from this interaction. Industrial waste water would be treated to remove undesirable nutrients and a shellfish and shellfish waste product would be produced. The amount of solid wastes or biodeposition produced by shellfish may be considerable, so this material should be considered as an animal feed or fertilizer for land-based agriculture. Thus it may be possible to integrate portions of the operation of three apparently disparate industries -- food processing, mariculture, and agriculture -- to the mutual economic benefit of each.

A schematic of the process is illustrated in Figure I. Nutrient-rich waste water would be introduced into large well-aerated ponds and used to culture algae. The algae in these ponds would consolidate undesirable dissolved nutrients which would otherwise cause eutrophication in the natural environment into an organically bound form. This water, which contains a high concentration of micro algae, would then be circulated through tanks containing shellfish. Since shellfish use algae as a food source they could be grown in these tanks to marketable size on this food. They could also be viewed as a source of inexpensive labor, since they easily perform the ordinarily difficult task of separating the nutrient containing algae from water by first filtering the suspension, utilizing some of the material for growth and discharging their waste material as a settleable solid. The filtered water could then be safely discharged into the environment.

WASTE RECYCLE SCHEME

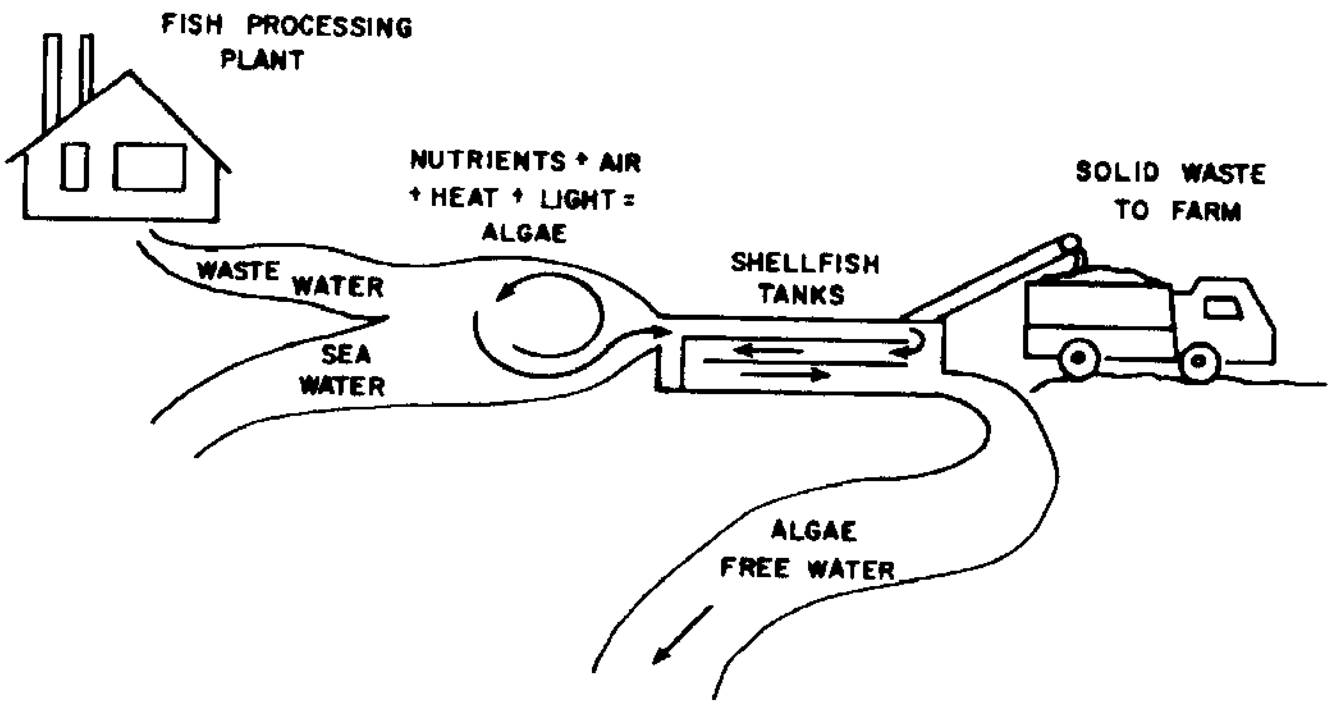

Figure 1

The solid shellfish wastes consist of digested material (feces) and algae which has been extracted from the water but which has not been digested (pseudofeces). Once separated from the growth tanks, the material could be washed and used as a fertilizer or as a livestock feed supplement so that one of the costs of producing agricultural products could be reduced.

Background

The idea of growing algae on waste nutrients and feeding the algae to shellfish is not new. Substantial efforts are underway to evaluate treated sewage effluents as a nutrient for the growth of algae which would be used to feed shellfish (Ryther, 1973). In this case, however, the large quantities of biodeposition produced by the shellfish are fed to detritus-or bottom-feeding animals which must be cultured in addition to the shellfish, so that solid shellfish wastes do not accumulate. Mimicking the natural food chain with polyculture is one way of dealing with the problem of waste accumulation but it introduces many technical difficulties, since it becomes necessary to culture intensively and reliably not just one species of organism but a whole chain of organisms, each with its own particular requirements for culture. Thus, growing algae with industrial and municipal wastes and feeding it to shellfish only partially solves the waste-disposal and waste-recycle problems, since shellfish produce considerable amounts of their own waste.

Shellfish wastes are expected to arise in quantity from another area of current research and development. Studies are underway to determine the feasibility of profitably growing shellfish (*Crassostrea virginica* and Mercenaria mercenaria) in controlled environment hardware with a high degree of water reuse (recycle). Recirculating water culturing systems have certain advantages (Epifanio et al., 1973) over flow-through water systems or simple harvesting of shellfish from the natural environment. These include: 1) less chance of predation of the cultured stock by other organisms; 2) the ability to locate seawater mariculture facilities away from coastal areas (thus reducing costs for rental or purchase of the land); 3) the possibility of controlling disease; 4) freedom from pollution of the water source; 5) a continuous supply of product; 6) faster growth in temperature-controlled environments; 7) the local cultivation of shellfish species in areas in which they are not indigenous; and 8) a uniform, high quality certifiable product. Despite these advantages, projected costs are high (Marsh et al., 1972). One of the costs involves the waste treatment necessary to recycle shellfish wastes. The recycled portion of the wastes may also cause difficulties even though from a waste treatment standpoint the digestion process has successfully reduced the level of carbon compounds in the water to a low level. Millar and Scott (1968) examined the problems of "bad water" which was causing high mortality and growth inhibition in their shellfish larvae culturing medium. They concluded that growth inhibition was not related to the dispresence of bacteria but was due to low concentrations of specific dissolved organic substances originating from the decomposition of algal metabolites or from the decomposition of the solid waste itself. King (1973) cites research suggesting that concentrations of dissolved organic materials above the parts per million range cause growth inhibition. A logical solution to these technical problems caused by the presence of decomposing wastes would be to remove the waste material from the culturing facility rather than allow it to accumulate or attempt to recycle it. However, this involves finding an economical and legal way to dispose of the material which has been removed.

This paper is a report on the results of some preliminary experiments performed to determine (1) whether the concentration or species of algae offered to the shellfish strongly influences the fraction of the total biodeposition which is feces and pseudofeces; and (2) whether the nutrient composition of the solid waste of the shellfish makes it suitable as a plant fertilizer.

The discussion has so far suggested that it may be useful to devise a strategy for utilizing waste effluents, algae, and shellfish to remove nutrients from water and produce a shellfish product and a shellfish waste by-product. It has also been suggested that a recirculating shellfish culturing process may generate a great deal of solid waste which should be removed and used as a by-product of the culture of shellfish, rather than attempt to recycle the waste material as an algal nutrient.

Three technical questions have been implicit in these discussions.

1) Can industrial wastes be utilized for algal growth?

2) What is known about shellfish biodeposition in terms of its composition and the quantity of material which would be produced?

3) Is there a potential market for this shellfish waste?

The work by Ryther's group suggests that diluted sewage is a good algal nutrient. Hartman (1974) presented data which showed that effluent from a tuna processing plant, even when highly diluted, was an excellent algal nutrient after suitable treatment.

Some information is known about the quantity and composition of solid waste produced by shellfish. Shellfish are rather inefficient in their ability to incorporate into their biomass nutrient particles removed from seawater. Langefoss (1973), using a *Phaeodoctylum tricornutum* food source at a concentration of 50,000 and 100,000 cells per mililiter, reported that 25% and 30% respectively of the total caloric content of the waste from an adult oyster was pseudofeces, algae which was not digested by the shellfish. Currie (1962) cites reports that the planktonic algae cells passing through the guts of herbivore may still be alive. Smith (1968) reports that *Mercenaria mercenaria* may eject up to 94% of an algal species which is not of a suitable size, as a stream of intact cells sheathed in a mucous coat. The mucous coat further enriches the caloric value of the biodeposition. To the extent that the composition of pseudofeces reflects the content of algae cells that go into its makeup, the pseudofeces are composed of more than 50% plant protein (Parson et al., 1961).

Finally, we must answer the question as to whether or not a market exists for shellfish wastes. The literature reveals no instance where shellfish wastes have been used as a fertilizer or terrestrial animal feed. We can, however, find a vast amount of literature on the use of species of marine algae as animal feeds and plant fertilizers. To the extent that shellfish biodeposition is not substantially different from algae, there is clearly a ready market for the material. There is presently, for example, a large worldwide algae industry whose expansion has been limited in the past by relatively inexpensive synthetic fertilizers, labor-intensive aspects of the business, and non-uniformity of the product (Woodward, 1965). Despite these considerations, a successful commercial seaweed meal production was begun in the United States as early as 1870. A liquid seaweed fertilizer was first produced commercially in the United Kingdom in 1949. The reasons for the commercial competitiveness of an industry based on a simple gathering process can be found in the remarkable properties of seaweed. As a manure, seaweed has been demonstrated to enhance the germination of seeds, increase the uptake of plant nutrients, impart a degree of frost resistance to tomatoes, vegetables and citrus fruits, and make plants better able to withstand phytopathological fungus. Two commercial field trials showed a 2-3% increase in sugar content of corn and watermelons (Booth, 1965).

As an animal feed supplement, fortified seaweed was found to replace completely artificial mineral mixtures in experiments involving identical calf twins covering a 36-lactation period time span. In most cases, the algae feed led to a considerable increase in milk production (Nebb et al., 1968). A chicken-feed diet containing up to 30% algae meal was successful but higher concentrations led to problems caused by the high iodine content of the kelp used (Hoie et al., 1955). In 1955, 5,000 tons of algae meal were sold as feed for cows and poultry. This feed helped to increase the animals' trace metal ingestion and reduce disease susceptibility (McInnes, 1955).

It is clear from the small sample of literature cited that at least the pseudofeces, which comprises 30% of the solid waste material produced by the culture of shellfish, is extremely valuable as a commercial product.

It is also possible to get a rough minimum estimate of the quantity of solid waste material involved in mariculturing shellfish from existing data (Goodrich et al., 1968). These data, obtained using oysters fed at low concentrations of algae, reflect high assimilation efficiency and minimum solid production. It shows that 500,000 eight-month-old oysters will produce 90,000 pounds of solid waste per year. This waste production figure is for less than market-size oysters and does not include algae cells which settle to the bottom of culturing tanks. This figure is more than the production of seaweed meal for the United Kingdom, United States, France, and Norway, which totaled 50,000 pounds in 1958.

To accomplish the first objective, adult oysters were placed in water containing algal species Isochrysis galbana, Cryptomonas sp., Carteria chuii, or Phaeodactylum tricornutum at concentrations ranging from 25,000 cells/ml to 250,000 cells/ml. Feces and pseudofeces produced over an eight-hour period under these conditions were separately collected and compared.

The utility of the solid waste as a fertilizer was demonstrated by placing string bean seeds in pots containing cow manure, potting soil, or oyster manure. Growth of string bean plants in these soils was compared as a method of determining the relative ability of these fertilizers to support the growth of terrestrial plants.

Materials and Methods

A. Biodeposition by Adult Oysters

Thirty adult oysters measuring approximately 6.7 ±1 cm in length and 3.4 ±1 cm in width were held in 125 liters of filtered water (0.5 pore diameter filter) for 16 hours prior to each experiment so that they could purge their guts and acclimate to the temperature (20° ± 1°C) and salinity (30± 2 ppt) of the seawater to be used in the experiment. Plywood tanks coated with Boat Armor* resin were filled with 126 liters of seawater. Algae was added to each tank so that the water contained from 10,000 cells/ml to 90,000 cells/ml. Four species of algae were investigated: *Cryptomonas* sp., *Isochrysis galbana*, *Carteria chuii*, and *Phaeodactylum tricornutum*.

One oyster was placed in each of six cups (Figure 2) designed to collect separately the feces and pseudofeces of the shellfish. These cups were then mounted in the bottom of the tanks (Figure 3) for six-hour periods. The volume of the water and duration of the experiment was such that the algal cell concentration changed by less than 10% during the course of the experiment. After the six-hour feeding period the water was drained from the tanks and filtered seawater was used to refill the tanks. The oysters

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*Boat Armor
Valspar Corporation
Rockford, Illinois

FECES-PSEUDOFECES COLLECTION CUPS

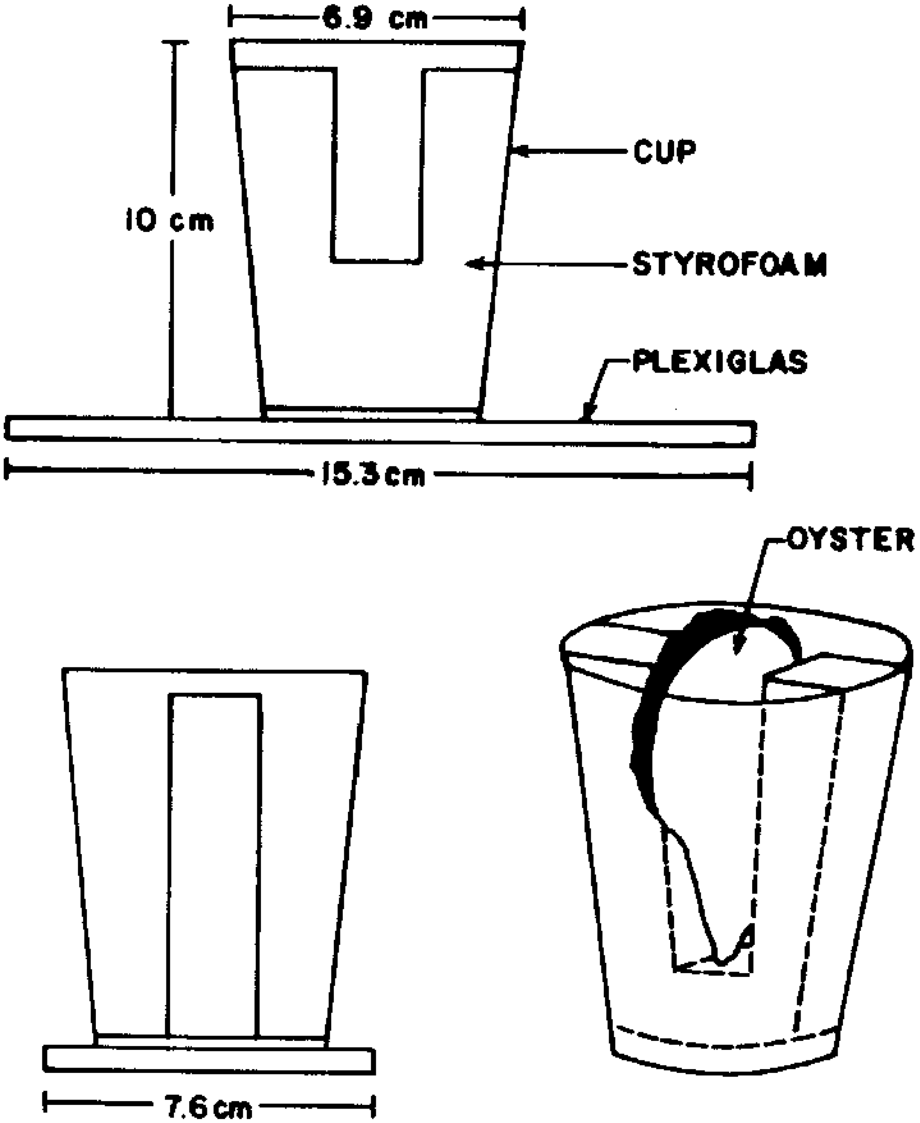

Figure 2

EXPERIMENTAL APPARATUS FOR THE COLLECTION OF BIODEPOSITION

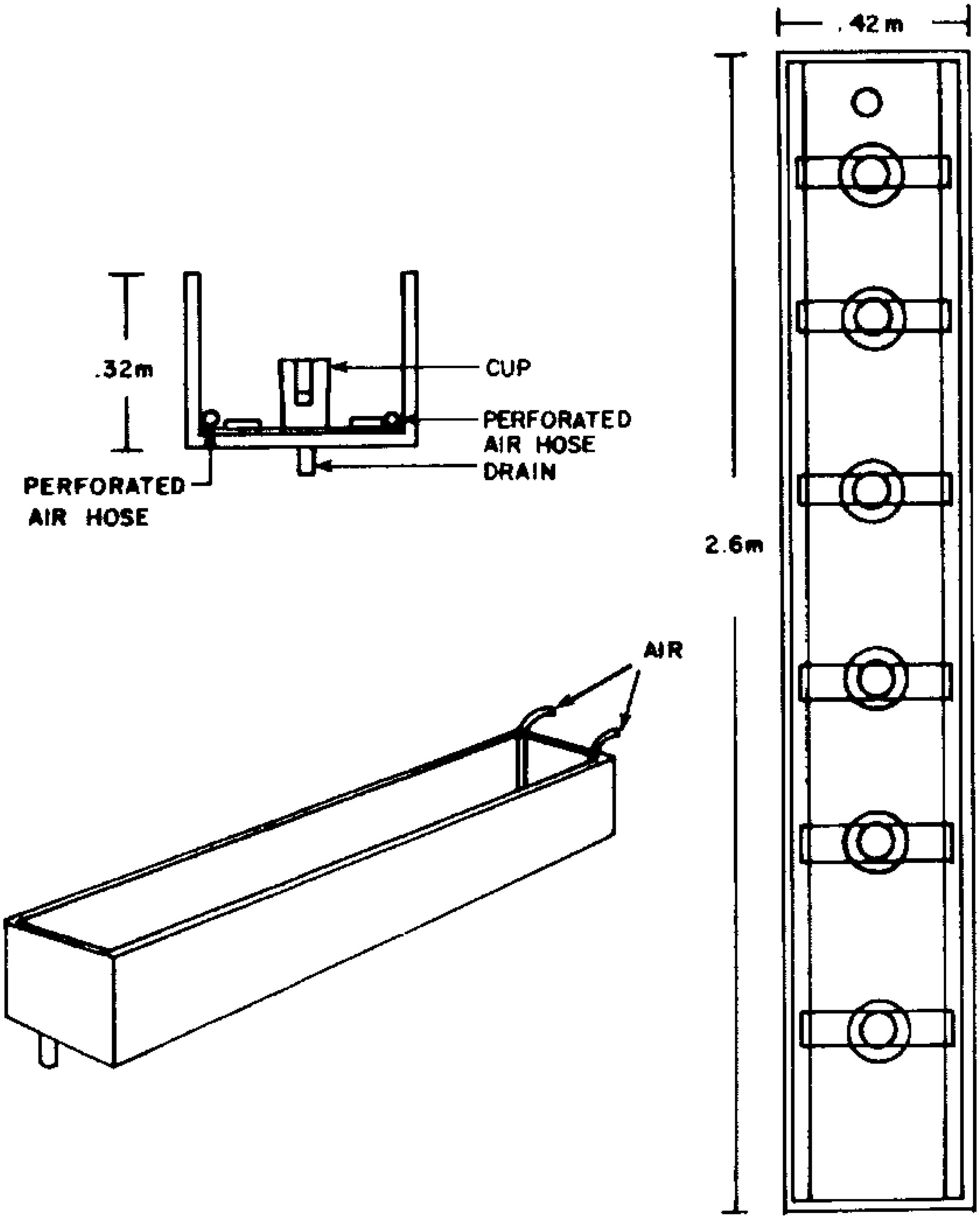

Figure 3

remained in this algae-free water for 16 hours to allow them to purge their guts. The feces and pseudofeces which were collected in the compartments of the cups were filtered onto tared glass fiber pads (47 mm Gelman) and dried in an oven for 24 hours at 65°C until a constant weight was achieved.

B. Relative Growth and Production of String Beans on Oyster Manure, Cow Manure, and Potting Soil

The experiment used 12 numbered pots each containing 35.0 grams of a 50:50 mixture of vermiculite and peat moss as an inert substrate.

The nutrients listed in Table I were also added to each pot.

The oyster biodeposition used in the experiment was produced by animals fed an equal part diet (by cell count) of the algal species, Phaeocactylum tricornutum, Isochrysis galbana, and Carteria chuii. The oyster manure was collected by filtering the solid waste from a seawater slurry with a wire mesh screen. The solid material was washed three times with distilled water.

Three nutrient types -- potting soil, cow manure, and oyster manure -- were all dried in a 100°C oven before weighing.

Two garden bush bean seeds* were placed in each clay pot and 50 ml of distilled water was added to each pot daily. Light for the plants was supplied from Gro-Lux lamps** located 60 cm above the pots. The lights were turned on for 16 hours each day. Daily observations were made of the number

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*Ferry-Morse Seed Company
Frilton, Kentucky 42041

** Sylvania Corporation
Danvers, Massachusetts

TABLE I

Pot Number	Fertilizer	Quantity
1		0.0
2	potting soil	7.2 gm
3	potting soil	21.6 gm
4	oyster manure	14.0 gm
5	cow manure	7.1 gm
6	cow manure	14.2 gm
7	cow manure	21.3 gm
8	cow manure	28.4 gm
9	oyster manure	7.0 gm
10	oyster manure	14.0 gm
11	oyster manure	21.0 gm
12	oyster manure	28.0 gm

of plants sprouted, the number of blossoms, the number of beans produced, and the height of the plants. The experiment was arbitrarily terminated after 42 days.

Results

A. Biodeposition by Oysters

Graphs 1 through 8 show the ratio of feces to pseudofeces produced and the total quantity of biodeposition produced by the oysters used in the experiments. The graphs show considerable scatter due to individual differences in the amount of material cleared by each shellfish over the time period. Errors in the weight measurements for small quantities of solid wastes were also high. However, no solid material was observed to be lost from the cups themselves due to the filtering activity of the shellfish.

8. The Use of Solid Oyster Waste as a Fertilizer

Table 2 summarizes the observations on the growth of string beans using various nutrient sources. The first pot, containing only vermiculite and peat moss, did not support growth. The potting soil produced only a margiral crop of beans, and the cow manure and oyster manure produced a nearly identical crop of beans. Pots in which both seeds did not sprout were eliminated from consideration.

In order to determine the relative nitrogen and phosphorus content of the cow manure and oyster manure, samples of each fertilizer were analyzed. The oyster manure contained 30,200 mg/kg of Kjeldahl nitrogen and 23.7 mg/kg

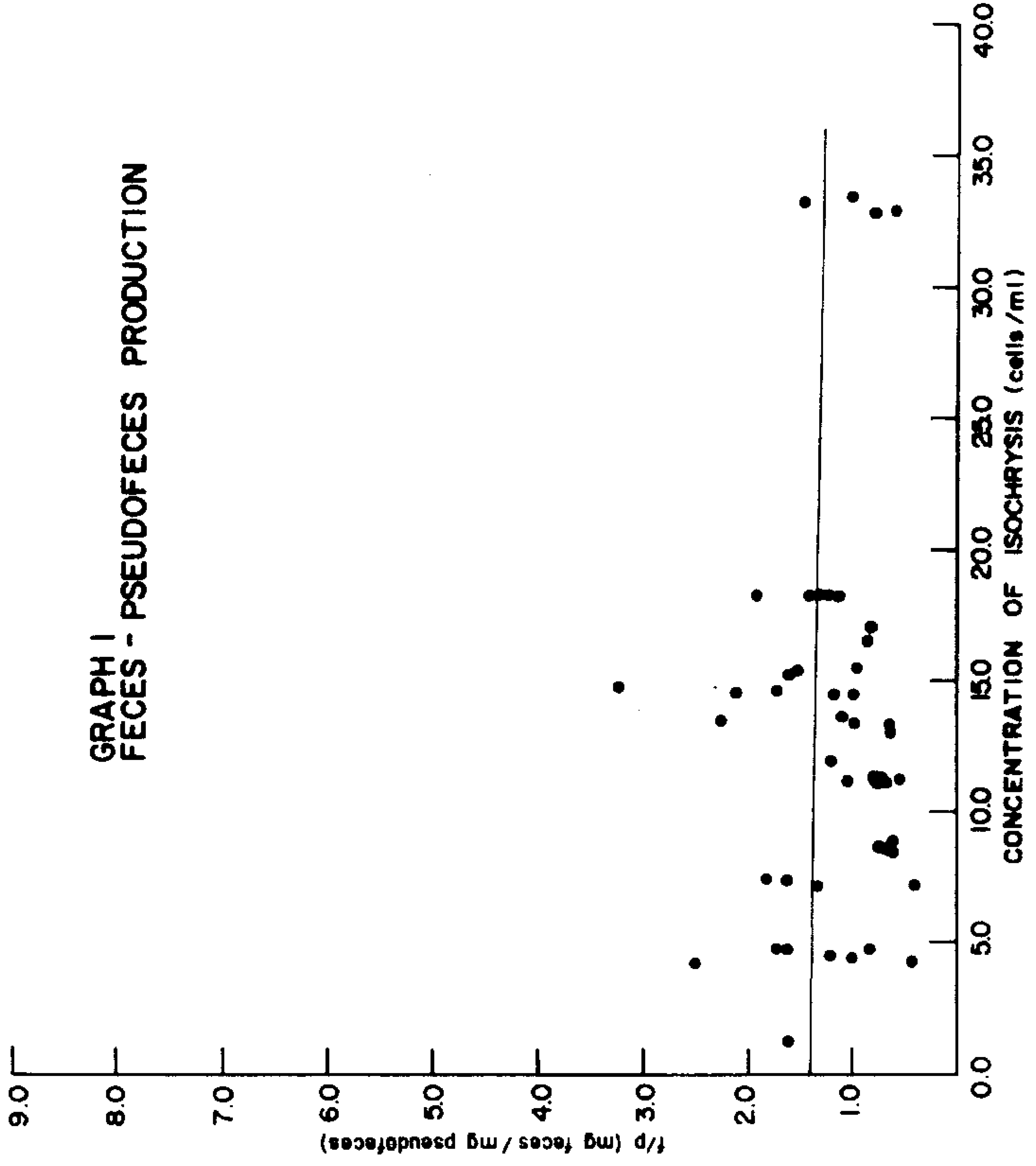
Table 2

GROWTH OF BUSH BEANS IN SOIL MIXTURES

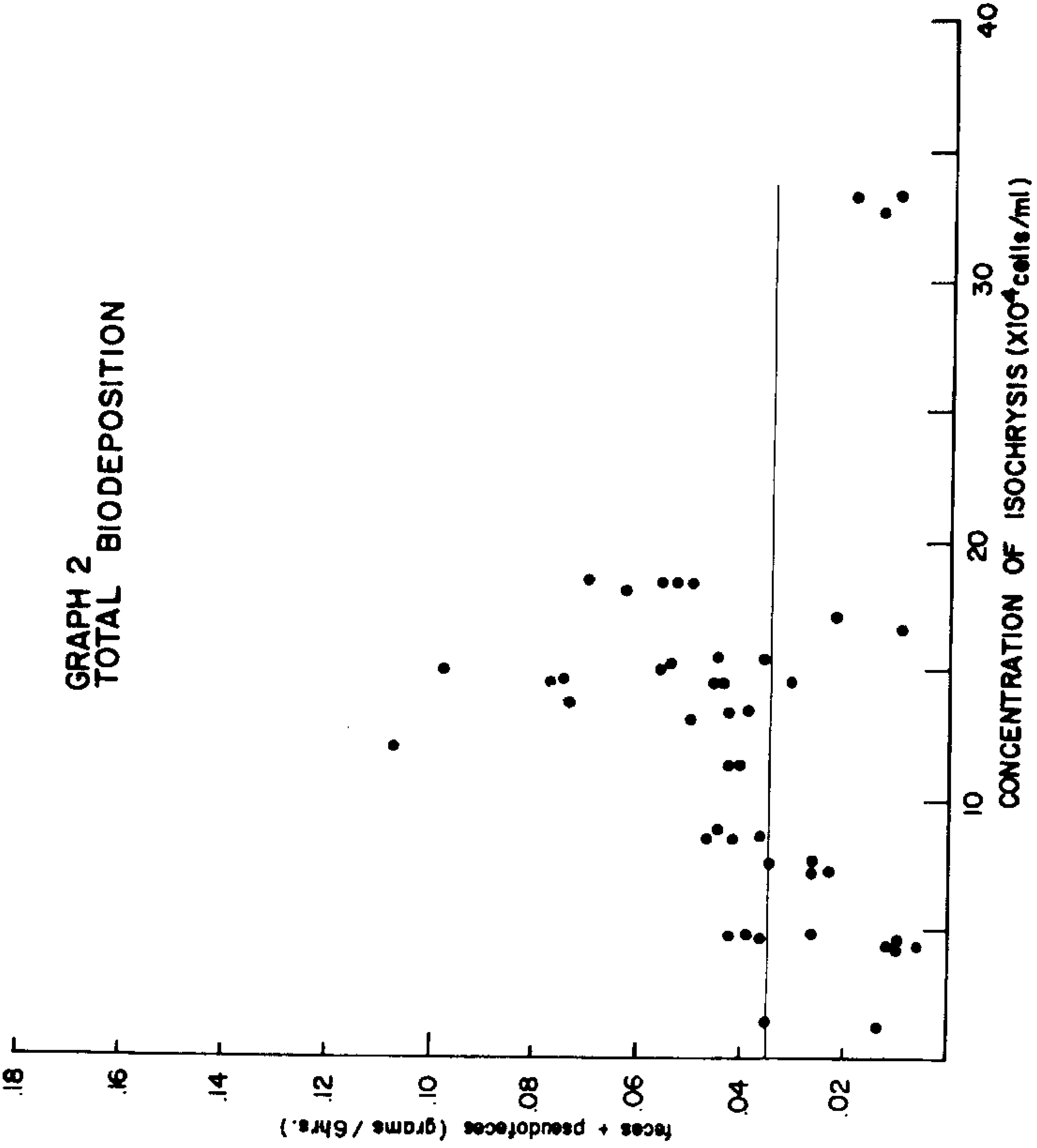
Pot Number*	Fertilizer	Observation After 42 Days of Growth		
		Combined height+	No. of blossoms	No. of beans
1	none	0	0	0
2	potting soil	76	4	0
3	potting soil	90	6	2
5	cow manure	80	5	3
6	cow manure	83	7	4
7	cow manure	80	1	6
8	cow manure	82	1	4
9	oyster manure	63	4	2
10	oyster manure	85	3	6
12	oyster manure	83	5	4

* pot no.'s 4 and 11 eliminated because only one seed sprouted.

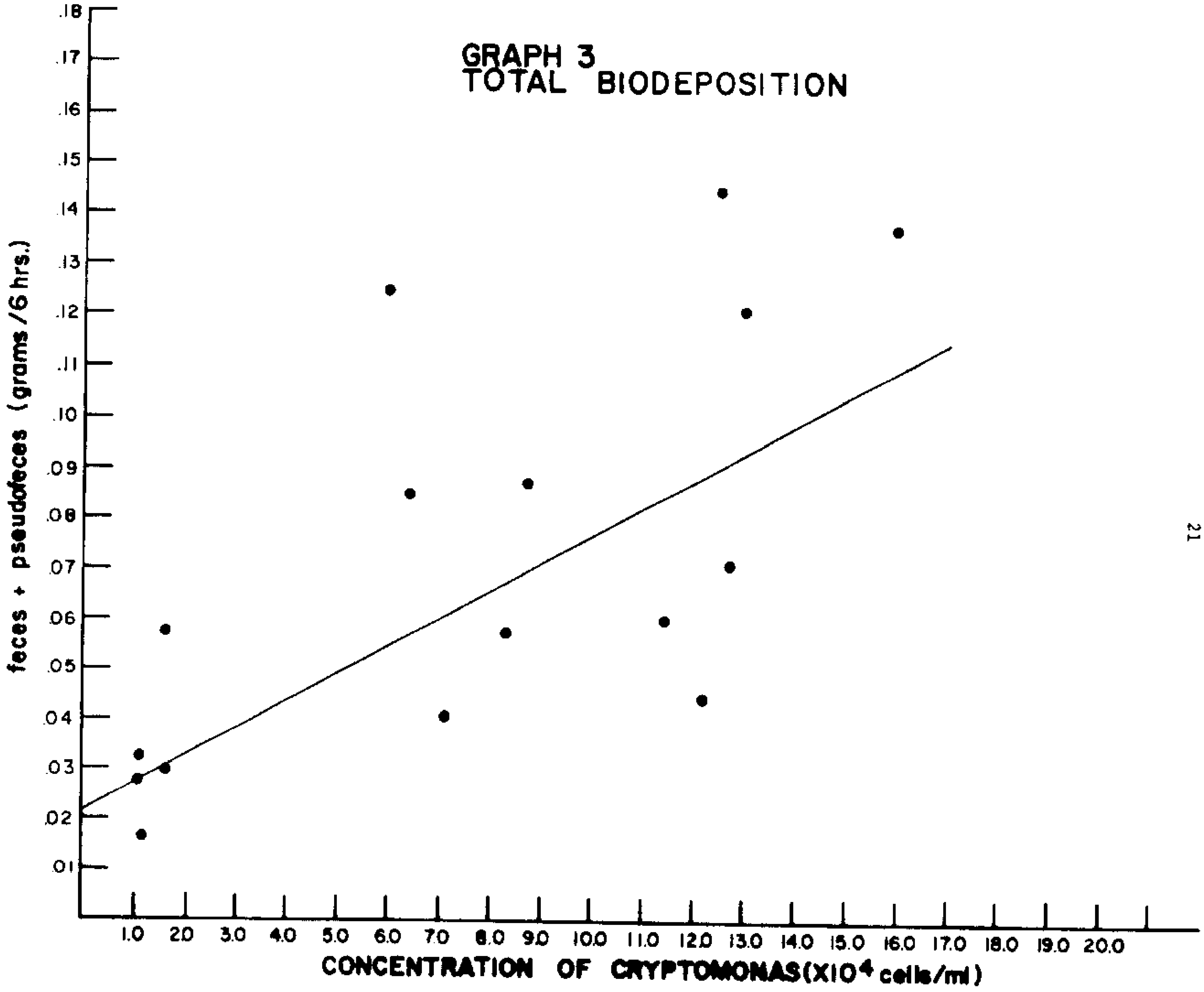
\+ height of both bean plants added together.



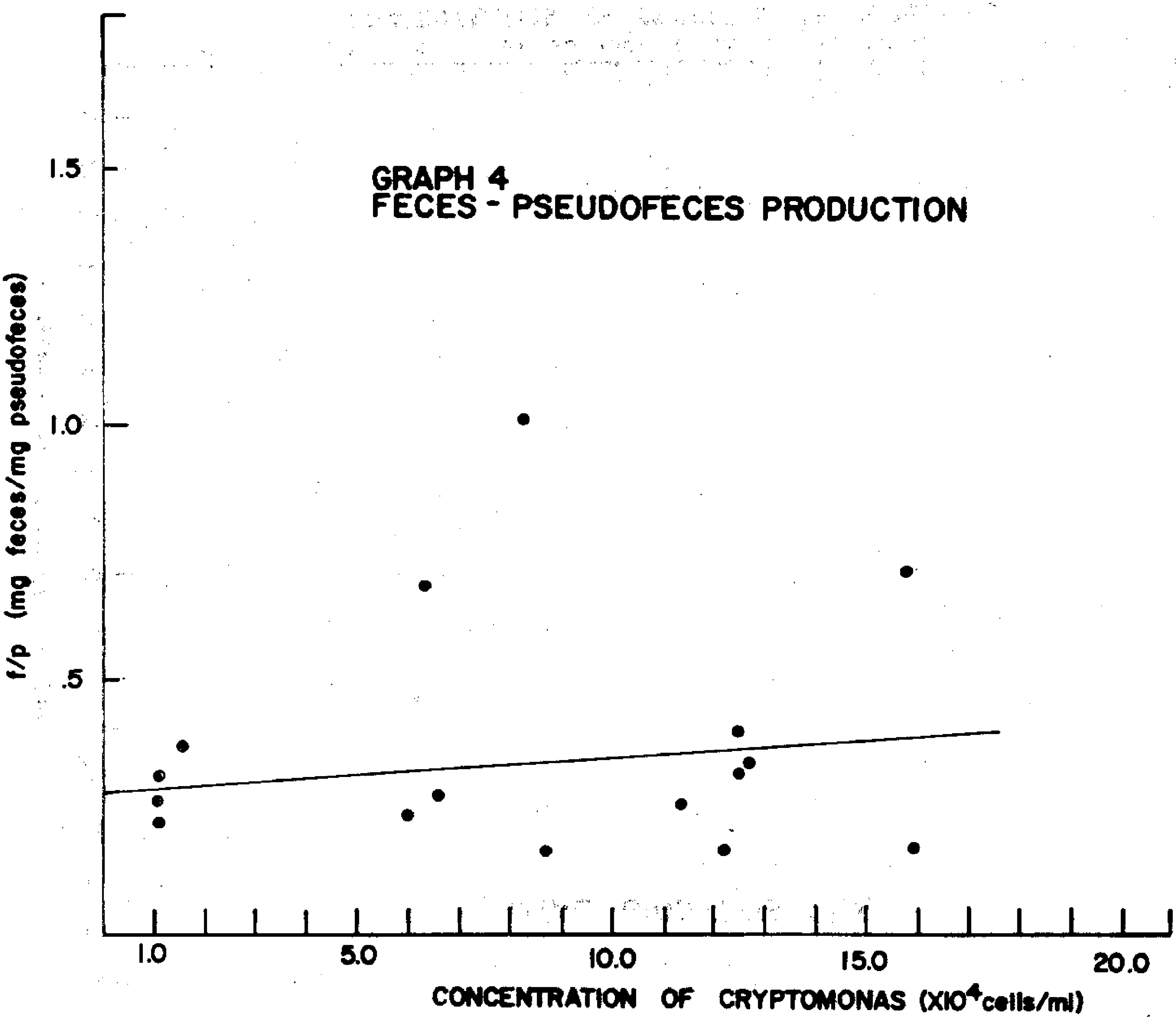
GRAPH I
FECES - PSEUDOFECES PRODUCTION



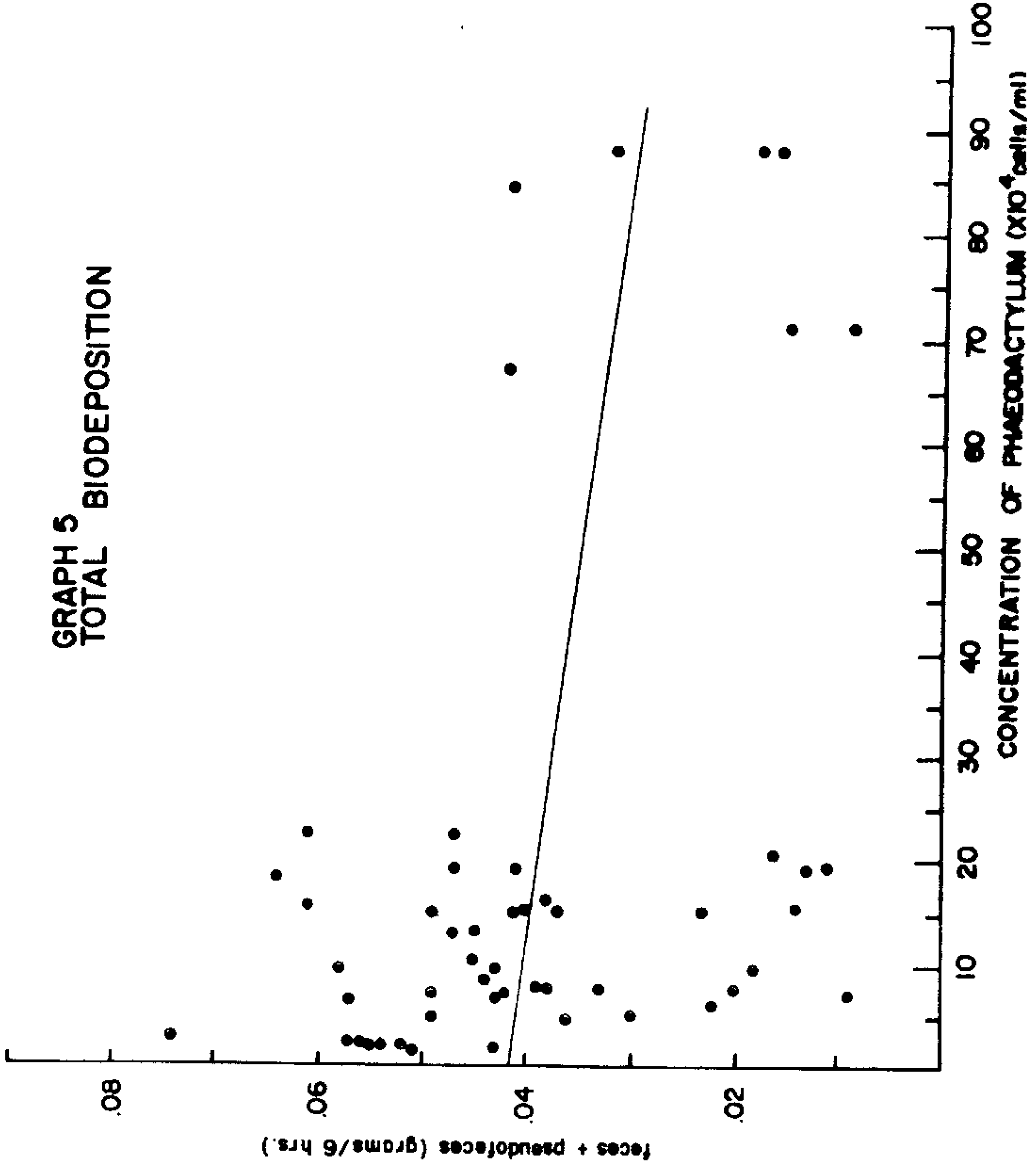
GRAPH 2
TOTAL BIODEPOSITION



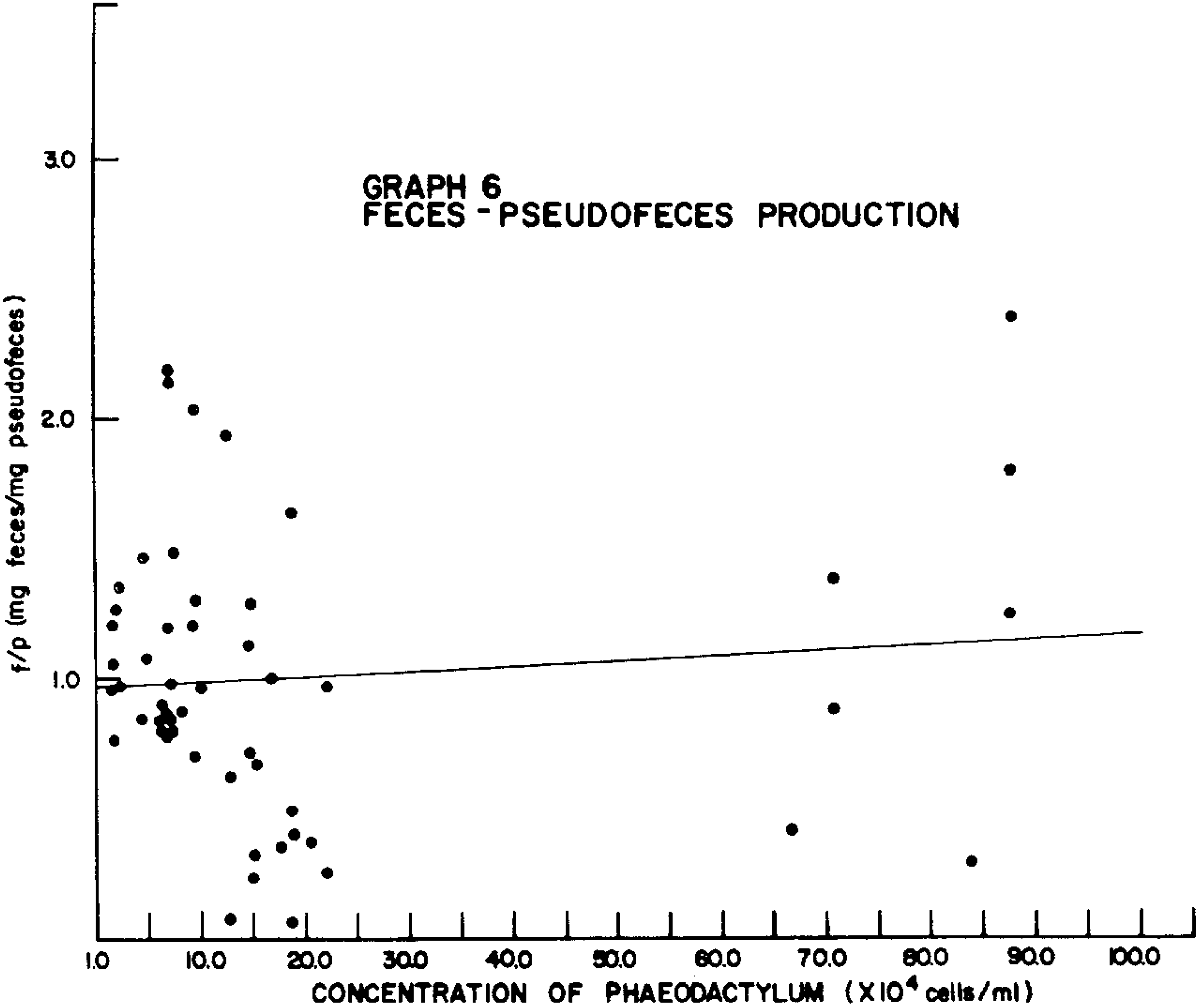
GRAPH 3
TOTAL BIODEPOSITION



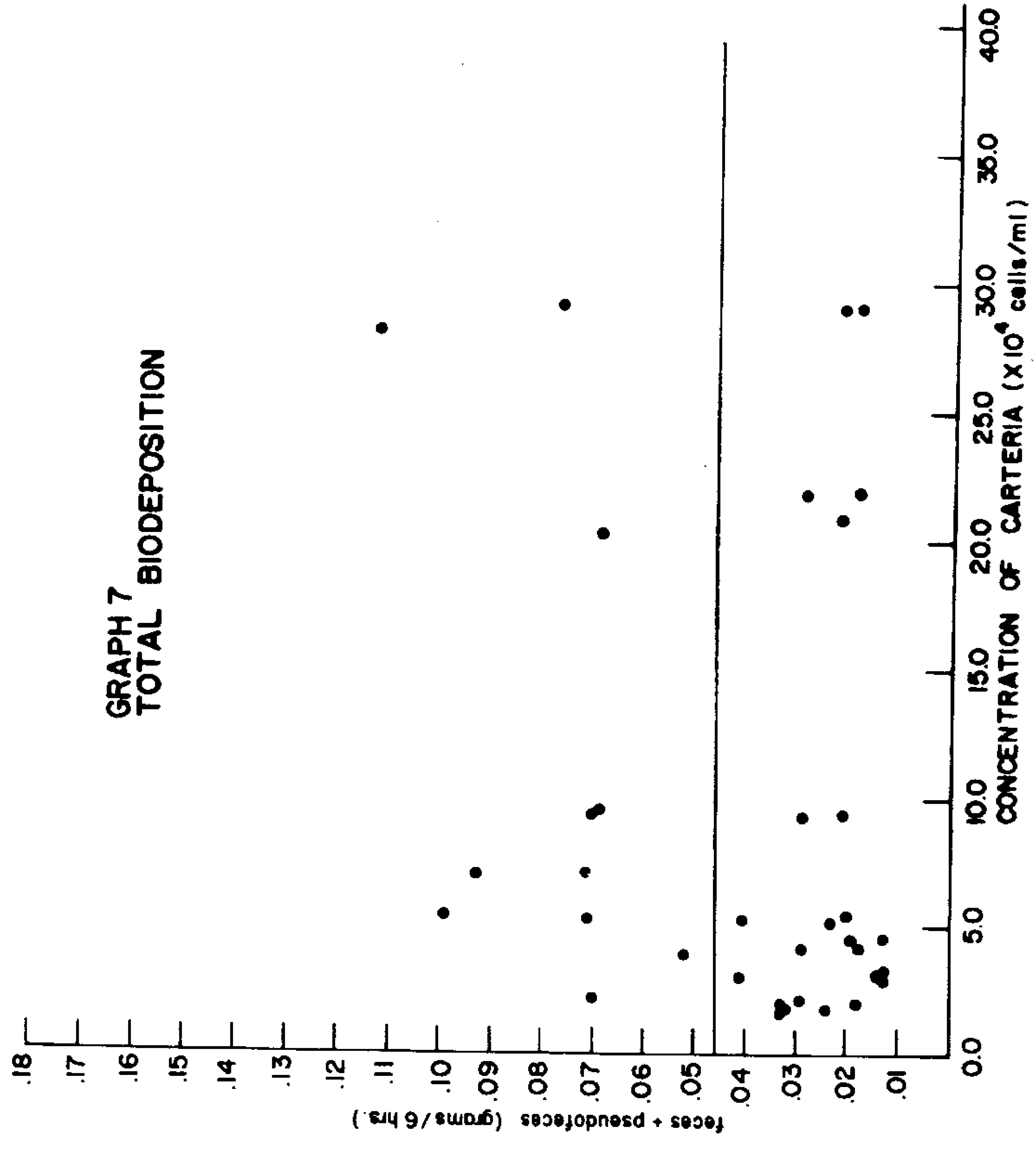
GRAPH 4
FECES - PSEUDOFECES PRODUCTION



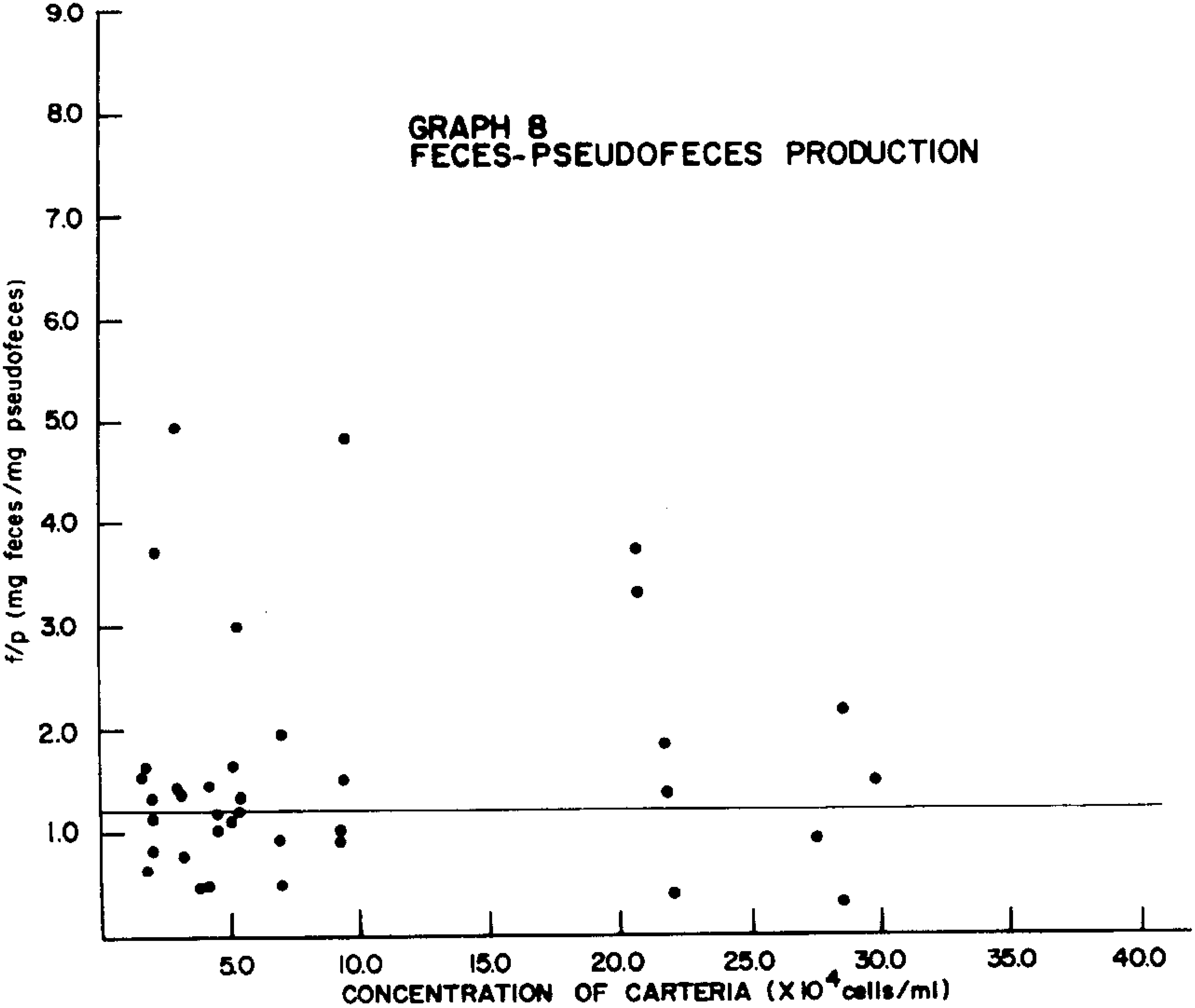
GRAPH 5
TOTAL BIODEPOSITION



GRAPH 6
FECES - PSEUDOFECES PRODUCTION



GRAPH 7
TOTAL BIODEPOSITION



GRAPH 8
FECES-PSEUDOFECES PRODUCTION

of total phosphorus; the cow manure only 16,100 mg/kg Kjeldahl nitrogen and 21.4 mg/kg total phosphorus.

Discussion

The biodeposition data shows that the feces to pseudofeces ratio for *Carteria chuii*, *Phaeodactylum tricornutum*, and *Isochrysis galbana* was about 1.0 for concentrations of algae from 10,000 to 200,000 cells/ml. Oysters fed *Cryptomonas* sp. produced more pseudofeces and had a feces to pseudofeces ratio of about 0.3 over the same algal concentration range. Total biodeposition from oysters offered all four species of algae over a very wide concentration was about .04 grams during the six-hour test period. No particular relationship between the concentration of the algae in the test water and the amount of total biodeposition could be determined. This latter result is in agreement with data reported by Pruder et al., (1974).

The plant growth experiments indicate that both cow manure and oyster manure support growth better than potting soil. There appears, however, to be little difference between cow manure and oyster manure. The reasons for this are not clear especially since oyster manure is more nutrient-rich. However, an excess of nutrients may have been used in both sets of experimental soils so that growth was not nutrient-limited. Another possibility is that the nitrogen and phosphorus in the oyster manure was unavailable for utilization by plants.

Conclusions

In this paper we have examined some of the technical aspects of a scheme to produce a marketable fertilizer or feed product from the solid wastes generated by the culturing of shellfish. This material could result from one of several possible commercial ventures involving culturing of shellfish. In one type of operation, shellfish would be fed algae which had been grown on a mixture of nutrient-rich industrial wastes or sewage effluents. The solid wastes product from the shellfish would be collected, washed,and sold as a livestock feed or as a fertilizer supplement. This process involves three separate cost-reducing components which enhance its economic viability. The producer of the nutrient-rich effluent could accomplish the difficult removal of eutrophying nutrients from a water stream by incorporating these nutrients into marine algae. The marine algae, in turn, would be efficiently filtered from the water by bivalves supplied by a company engaged in the mariculture of these organisms. The solid biodeposition from the shellfish would be collected, dried and sold to the agricultural industry. In this fashion, waste treatment costs and problems associated with the prevention of eutrophication of the natural environment would be greatly reduced. Mariculture would benefit from this cooperative effort since it would utilize space near an industry producing a waste stream for algae ponds (or lease the use of its own space for this purpose), receive a free supply of nutrients for growing algae and, depending on costs, a service fee for the use of its shellfish as labor to remove algae from water. Commercial size shellfish grown in the operation would be depurated (purified) if necessary, and sold in the seafood market. The solid wastes in turn would be sold as a fertilizer or feed supplement.

In a closed shellfish-culturing system (with recirculated water) the biodeposition constitutes a problem area from the standpoint of waste treatment costs and maintaining water quality. One solution to the problem would be to separate solid wastes from the recirculated seawater and sell these wastes as a by-product of the culturing operation.

This method of dealing with the waste problem also has advantages over the use of polyculture for converting solid shellfish wastes to a usable form, since more technological sophistication and expenses are involved in polyculture.

We also considered the shellfish solid waste by-product itself from the standpoint of its composition and utility. We found that the ratio of feces to pseudofeces is remarkably constant over a very broad range of algal cell densities. This suggests that solid waste products would be of reasonably uniform composition.

We found that solid waste produced from shellfish fed on a diet of four species of algae was a good fertilizer and that it contained nearly twice as much nitrogen and twenty percent more phosphorus than an equivalent weight of cow manure. The growth data of terrestrial plants receiving their nutrients from this source suggest a close analog between the shellfish wastes and seaweed fertilizer which are being marketed.

The use of chicken manure as a feed supplement (Evening Journal, 1974) and dairy cow manure as an important by-product (<u>Time</u>, 1974) have recently been reported. We would like to suggest that the fledgling mariculture industry and established industries beset by increasingly stringent discharge regulations should begin to consider the integration of their respective operations so that recycling of waste materials becomes a common practice in a world beset by shortages of raw materials and food.

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