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THE UTILIZATION OF BIOGAS FERMENTATION RESIDUE-SLUDGE AND EFFLUENT *

prepared by

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Through the seventies work on biogas has flourished in many Chinese villages. It is clear that biogas will continue to have an important role in the development of rural energy resources; in increasing organic manure resources; in improvement of rural hygiene and in pushing forward agricultural production. The benefits to users are manifest not only through the various applications for energy and the importance of the provision of organic manure is considered in this paper with a brief account of research and development work on the use of biogas fermented residue.

I. The Relationship of Biogas Popularization and Development of Agricultural Production

With 70% of China's large population residing in the countryside there is a high level of land utilization. With the limitations that exist upon available arable land area, raising agricultural production is a question of solving problems of crop planting and in raising soil fertility. Many tasks need to be accomplished quietly in order to raise soil fertility through increasing the soil organic matter by means of a large development in the use of organic manure. Much of the available organic matter such as hay, straw, etc. is now burnt directly to meet the fuel demands in villages. This represents a large consumption of organic matter at a low utilization efficiency, with total loss of the manure potential of the organic matter. Also these materials are used for feedstuffs and always there has been a competing demand for their use as fuel, feed or manure. With this restriction the resulting tendency has been to rely gradually upon mere application of chemical fertilizer. Reducing the recycling of organic residues to the soil, however, creates soil with diminishing fertility so that overall the potential for greater agricultural production is seriously retarded. The popularization of biogas provides a key to solution of this problem. Biogas provides means for coordinating the related demands for fuel feed and manure so that a complete recycle of materials is achieved (see Fig.1).

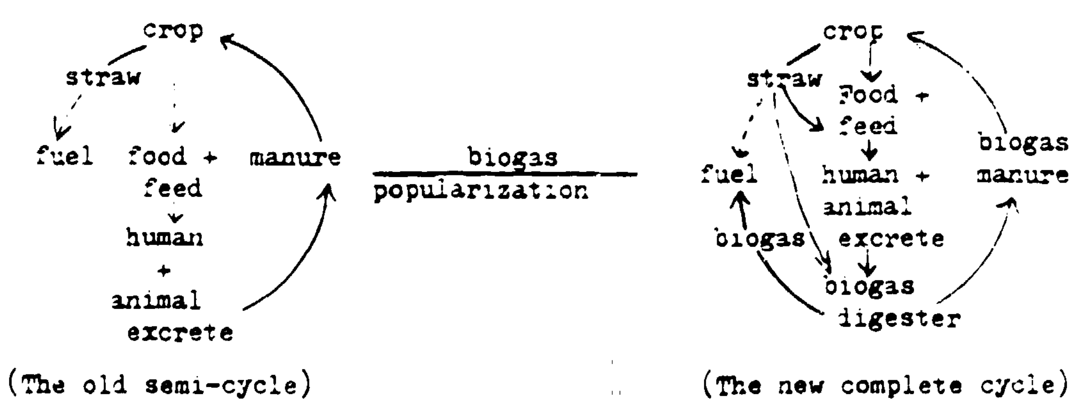

Fig.1 The relation between the cyclic usage of organic substances and the agricultural production.

From Fig.1 the importance of biogas popularization as a key link in a new system of recycling organic substance is evident. Apart from providing an alternative fuel resource it releases crop residues for use as feed or compost thereby promoting agricultural production. In China it has now been proven that the cyclic usage of organic substances in this manner is the best way to develop agricultural production.

II. Manure Efficiency and Increased Crop Yield with Biogas Fermented Residue

Biogas may be described as the by-product of the anaerobic fermentation of organic matter. When compared to traditional composting of organic matter, the manure properties of the biogas fermentation residues exhibit new properties, particularly in respect of manure efficiency.

II.1 The relationship of gas and manure production during fermentation.

The digester will produce gas and manure from such organic matter as human and animal excreta, straw, hay, etc. The following diagram (Figure 2) shows the relationship between gas and manure production.

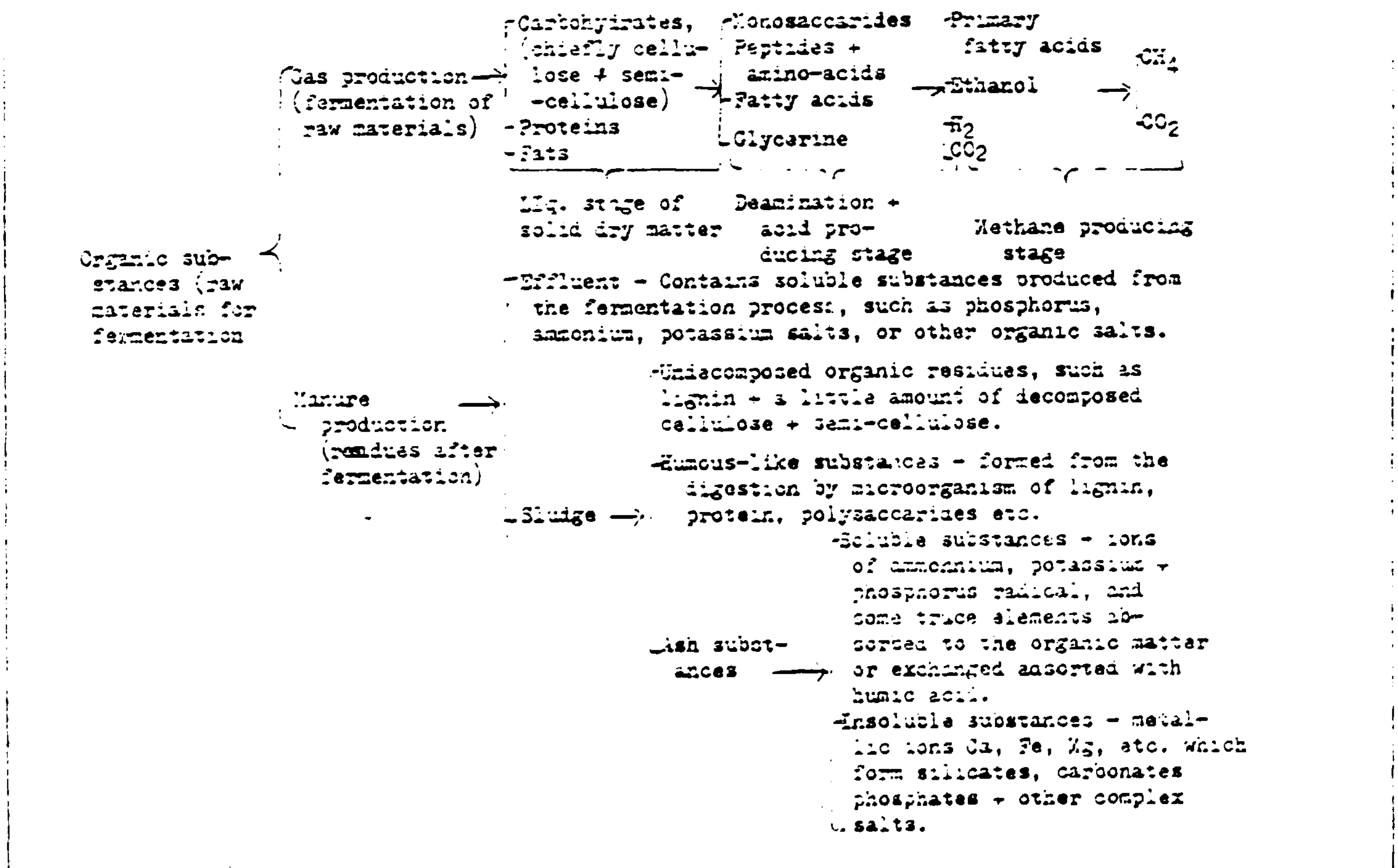

Fig.2 The relation between the biogas and manure production during biogas fermentation

The carbon, hydrogen and oxygen contained in the organic substances are gradually reduced as gaseous methane and carbon dioxide are released. The other elements in the organic substances remain in the fermentation residue, (apart from some small losses), some in solution and some in the insoluble sludge. Thus overall there is obviously no significant change in the amount of nutrient elements for manure as a result of the biogas fermentation. This is not the case with traditional composting methods.

II.2 Biogas fermentation - a good method for producing organic manure.

As well as providing an energy resource, the biogas fermentation has advantages as a means of providing organic manure througnout the rural area.

The main advantages are:

(1) It increments the organic manure supply

(a) by extending the source of material for manure (see Fig.1);

(b) through actually stimulating the production of accumulating and composting manure by making available material that would otherwise be used as fuel. Thus, more gas production results in more manure supply and this is an incentive for cadres and commune members to develop biogas;

(c) by providing a simple and low cost procedure which can be undertaken during otherwise unproductive time.

According to some production teams in Sichuan Province investigations show that the organic manure supply has increased 70% to 80% and some other active production teams have nearly doubled the manure supply.

(2) There is little dimunition in nitrogen nutrient and excellent maintenance of manure efficiency.

With the contained fermentation in an anaerobic digester, loss of available nutrients by volatilization or leaching is avoided. Thus ammonia released by the process is in fact neutralized by the organic acids produced during fermentation. The fermentation is maintained at a neutral pH. This feature of the biogas process whereby ammonia fixation occurs is an important factor.

Another feature of the biogas fermentation when compared to traditional composting methods is that the loss of organic substances is reduced. The decomposition of organic substances in anaerobic conditions is carried out by the transposition of hydrogen ions through degradation of large organic molecules into smaller molecules. This is an energy efficient process with less evolution of gaseous products than occurs in traditional manuring methods. This is illustrated by the figures below:

Method	loss (%)	
	organic matter	total N
biogas manure	30 — 50	5
open air pool of human and animal excreta	—	20
rapid composting	> 50	20 - 40

The composting method which is always adopted is a rapid process and within 2 or 3 days, the temperature in the compost rises above 70°C with pH of 8.5. For this process of rapid decomposition and mineralization much energy is required. Ammonia is not contained and it is found that there is a degradation of available phosphorus. The loss of organic matter is greater than occurs in the biogas process. When the fermentation is carried out in an open air pool the fermenting conditions are closer to the biogas process and though losses of ammonia and organic matter are higher than with the biogas process it is found that they are not so high as those which occur in composting.

Experimental results reported from sixteen districts of Sichuan Province compared the quality of equal quantities of manure processed for 30 days in digesters and in open air fermenting pools. Results are shown in table 1 below and it is seen that total nitrogen and ammoniacal nitrogen are 14% and 19.4% higher respectively for the digested manure. The effect of this higher nitrogen content was shown in trials on experimental crops of paddy, maize, cotton, wheat and rape seed. These results are given in table 2 below where it is shown that crop yields were 6.5 - 15.7% higher for crops treated with digested manure compared to the open air pool manure.

Table 1. Comparison of nitrogen changing between biogas digester and ordinary open air pool in the storing period (after 30 days)

Treatment	Total N		Ammoniacal Nitrogen	
	%	Compare	%	Compare
Digester manure	0.0454	114.0	0.0315	119.4
Open air pool manure	0.0398	100.0	0.0264	100.0

Note: The mean values of more than ten experimental results from Sichuan Province

Table 2. Fertility comparison between digester manure and open air pool manure

Crops	Yield jin/mu		Increase		Number of expt.
	effluent	check	jin/mu	%	
Rice	636.4	597.5	38.9	6.5	18
Maize	555.9	510.4	45.5	8.9	9
Wheat	450.0	390.5	59.5	15.2	29
Cotton	154.5	133.5	21.0	15.7	2
Rape	258.4	233.6	24.8	10.6	15

More results have been reported by Guangzho Energy Institute and Chekiang Provincial Biogas Office and these are given below in tables 3 and 4.

Table 3. Comparison of crops yield and loss of nitrogen between digester manure and farmyard manure

Treatment	Total N.		Ammoniacal N		Rice yield (jin/mu)	Comparison of crop yields		
	jin	%	jin	%				
Before treatment	0.950	100.0	0.168	100.0	-	-	-	-
Digester manure	0.940	98.9	0.438	260.7	1016	100.0	112.9	109.7
Open air pool manure	0.646	68.0	0.138	82.5	900	88.6	100.0	97.2
Compost	0.572	60.2	0.0301	17.8	926	91.1	102.9	100.0

NOTE: Refer to the work of Guanzhou Energy Resource Institute

Table 4. Comparison of the loss of nitrogen between biogas manure and compost

Raw materials	Method	Before fermentation			After fermentation				
		total N		available N	total N		available N		
		%	gm/jar	gm/jar	gm/jar	% of loss	gm/jar	% total N	± %
Pig dung : hay = 4:1	biogas manure	1.42	17.55	3.2	15.8	10.0	8.04	50.9	-253.6
	compost	1.42	17.55	3.2	12.3	29.6	1.50	12.1	- 52.7
Pig dung : dung (cattle) : hay = 1:1:1	biogas manure	1.95	23.71	3.4	22.7	4.35	12.3	50.3	+362.4
	compost	1.95	23.71	3.4	18.5	29.3	0.94	5.0	- 71.4
Pig dung : cattle dung : feces = 3:1:1	biogas manure	2.98	37.23	6.5	36.2	2.97	26.0	71.6	+400.0
	compost	2.98	37.23	6.5	37.3	14.7	5.32	16.7	- 18.2

NOTE: Refer to the work of Biogas Promoting Office, Zhejiang Province

The Guangzho Energy Institute results which relate to 30-50 days anaerobic fermentation show that available nitrogen content can be 2.5 to 4.0 times higher than in untreated manure. For open air pool treated manure there is a small loss of aivailable nitrogen and for compost treated manure the nitrogen loss is serious. Field experiments showed that application of biogas manure on rice increased crop production by 9.7% compared to use of compost manure and by 12.9% compared to use of open air pool manure.

The experiments described above show that biogas anaerobic fermentation is an efficient means of providing manure of high quality. Its high level of available nitrogen results in increased field yields when compared to the use of manure from traditional compost and open air pool fermentation. According to these results this method of manuring should be widely adopted.

(3) High nutrient content in effluent solution and sludge.

As has been described above, the acid producing stage of biogas fermentation avoids ammonia loss from volatilization and raises its available nitrogen content. Similarly it is found that the presence of organic acids hastens the solution of mineral substances. This raises the available nutrients in the liquid effluent part of the digester contents. The sludge from the digester contains a mixture of nutrient elements and organic matter with some nutrient in soluble form and some adsorption on the surface of the organic residues. Nutrient levels vary with various fermenting raw materials but according to analytical data from some areas in Sichuan Province the main nutrient contents of biogas manure are as listed below in table 5. Further data is given in table 6 for digester sludge samples and it is interesting to note that about 50% of the total phosphorus content of sludge is available in a soluble form.

Table 5. Approximate range of nutrient contents of digester manure

Digester manure	Organic matter (%)	Humic acid (%)	Total N (%)	Total P_2O_5 (%)	Total K_2O (%)	Properties
Effluent	-	-	0.03~0.08	0.02~0.06	0.05~0.10	rapid manure effect
Sludge	30~50	10~20	0.8~2.0	0.4~1.2	0.6~2.2	having both rapid and slow manure effect

Table 6. Nutrients content of some digester sludge samples (calculated by dry weight)

No. of samples	Organic matter (%)	Total content (%)			Available (%)	
		N	P_2O_5	K_2O	N	P_2O_5
054	30.6	0.974	0.926	2.00	0.080	0.486
055	61.0	1.363	1.093	1.04	0.228	0.695
056	47.7	1.496	0.867	1.15	0.153	0.502

NOTE: Samples were dried at 60°C available N content may be a little lower.

According to field experiments in Sichuan Province applying 3000–5000 jin/mu of effluent to crops of rice, maize and cotton provided yield increases of 9.0 - 26.4 % compared to a control. Thus each hundred jin of effluent added gave an increase of 1.38 jin of rice, 2.0 jin of maize, 0.65 jin of cotton. When sludge was applied to the same crops in quantities of 2000 - 3000 jin/mu there were yield increase of 7.9 - 9.1 %. In this case each hundred jin of sludge added gave an increase of 3.64 jin of rice, 1.66 jin of maize, 0.41 jin of cotton.

These results are given below in table 7 and it was also found that upland crop yields were similarly increased by use of effluent and sludge manures.

Table 7. Increment of various crops by application of biogas manure

Group of experiment	Crop	Amount of biogas manure applied (jin/mu)	Yield (jin/mu)		Yield increment		Jins of yield increment per each hundred jin of manure
			biogas manure	check	jin/mu	%	
Application of effluent	rice	5000	834.0	765.0	69.0	9.0	1.38
	maize	3000	584.0	324.0	60.0	18.5	2.00
	cotton	4000	159.0	133.1	25.9	26.4	0.65
Application of sludge	rice	2000	871.8	799.0	72.8	9.1	3.64
	maize	3000	667.4	617.6	49.8	8.3	1.66
	cotton	3000	166.6	154.4	12.2	7.9	0.41

NOTE: The amount of sludge applied contains 75% of water.

II.3 Increasing Crop Yield through Application Biogas Sludge Phospho-humate

In order to utilize low and middle grade phosphorite resources reasonably and effectively, a new kind of fertilizer has been developed - biogas sludge phospho-humate. This is made by mixing the sludge with phosphorite powder in the ratio 10:1 - 20:1 and composting for 1-3 months in order to improve the effect of the phosphorite. This type of fertilizer is used extensively in some areas of Sichuan Province where the soil lacks phosphorus. It has had good effect upon crop yield over a large area and has resulted in reduced production cost. In experiments on rice, sweet potato, wheat and rape it is shown that the use of phosphorite powder alone, the use of sludge alone and the use of biogas sludge phospho-humate give yield increases of 0-11%, 5.8 - 17.6% and 8.9 - 19.1% respectively. These figures are given below in table 8.

Table 8. Effect of biogas phosphohumate on some major crops

Crops			1.Check	2. Phosphorite powder 40-50 jin/mu	3. Sludge 400-1000 jin/mu	4. Phospho-humate 440-1050 jin/mu
Rice (2)	Yield (jin/mu)		581.5	620.0	634.3	653.3
	Increase	jin/mu	-	38.5	52.8	71.8
		%	-	6.6	9.1	12.3
Wheat (13)	Yield (jin/mu)		528.5	558.6	581.4	611.7
	Increase	jin/mu	-	60.0	72.8	83.1
		%	-	11.4	13.8	15.7
Sweet Potato	Yield (jin/mu)		277.2	295.9	325.0	330.2
	Increase	jin/mu	-	18.7	47.8	53.0
		%	-	6.7	17.6	19.1
Rape	Yield		246.0	246.0	260.2	268.0
	Increase	jin/mu	-	0	14.2	22.0
		%	-	-	5.8	8.9

NOTE: The number in the bracket indicates the times of experiment

In some soils lacking phosphorus, the use of phosphohumate may increase yield by 20%. In these cases the benefit of using phosphohumate compared to phosphorite or sludge applied alone are marked (see table 9 and 10).

Table 9. The chemical properties of some soils in Sichuan Province (from the experimental fields)

Soils	pH	Organic matter (%)	Total nitrogen (%)	Total P_2O_5 (%)	Available P_2O_5 (%)
Purple soil	8.1	1.29	0.096	0.148	9.4
Yellow clay	7.0	3.45	0.187	0.092	3.6
Grey alluvial soil	7.5	3.45	0.199	0.254	54.6

Table 10. Effect of biogas sludge phosphohumate on wheat growing on various soils

Soils			1.Check	2.Phosphorite powder	3. Sludge	4. Phosphohumate
Purple soil	Yield (jin/mu)		475.7	515.5	542.3	571.9
	Increase	jin/mu	-	39.8	66.6	96.2
		%	-	8.4	14.0	20.0
Yellow clay	Yield (jin/mu)		626.0	666.0	706.0	758.0
	Increase	jin/mu	-	40.0	80.0	132.0
		%	-	6.4	12.8	21.1
Grey alluvial soil	Yield (jin/mu)		703.4	699.0	728.1	744.4
	Increase	jin/mu	-	-3.8	24.7	40.0
		%	-	-	3.5	5.3

Other experimental work by Beijin Agricultural Scientific Academy on calcareous soil showed that wheat, maize, eggplant and green pepper received no distinct benefit from the application of phosphorite powder alone. However, by comparison with the application of biogas sludge phosphohumate maize and green pepper yields were remarkably increased. This increase was equally marked when compared to the effect of application of sludge alone.

These results over a wide area confirm that the application of biogas sludge phosphohumate is an effective measure to raise the efficiency of phosphorite powder and to decrease production cost. It is very important since it enables a reasonable utilization of low and middle phosphorite resources.

III. The Effect of Applying Biogas Digester Sludge for Soil Improvement

Biogas sludge is an excellent organic manure providing both long and short term benefits in crop yield. The longer term effect of promoting soil fertility has been demonstrated by Yongxing commune, Mienyang city where there is a yellow clay soil. This soil is a heavy clay, extremely infertile with phosphorous shortage and low organic matter content. Since biogas popularization in 1974 biogas manure and biogas sludge phosphohumate have been added continuously every year. The original unfertile soil has now much improved fertility with crop production greatly increased. Experimental results are reported for a period of 3.5 years with comparison against neighbouring fields. Various characteristics are compared with and without the application of 30400 jin cumulative total quantity of sludge. It has been found that the soil to which sludge was added, now contains 3-7% organic matter, 0.23% total N, 0.15% total P_2O_5, whereas the untreated soil contains 2.82% organic matter, 0.19% total N and 0.096% total P_2O_5 (see table 11). Also crop production from the sludge treated fields is greatly improved and this is illustrated in figure 3.

Table 11. Comparison of with and without the application of biogas sludge as the variation of soil nutrient (Yellow clay)

Treatment	Organic matter (%)	Total N (%)	Total P_2O_5 (%)	Total K_2O (%)	Available (P_2O_5) ppm	Available K_2O ppm
sludge	3.70	0.23	0.15	2.11	1.4	160.5
no sludge	2.37	0.19	0.096	1.95	1.9	110.3

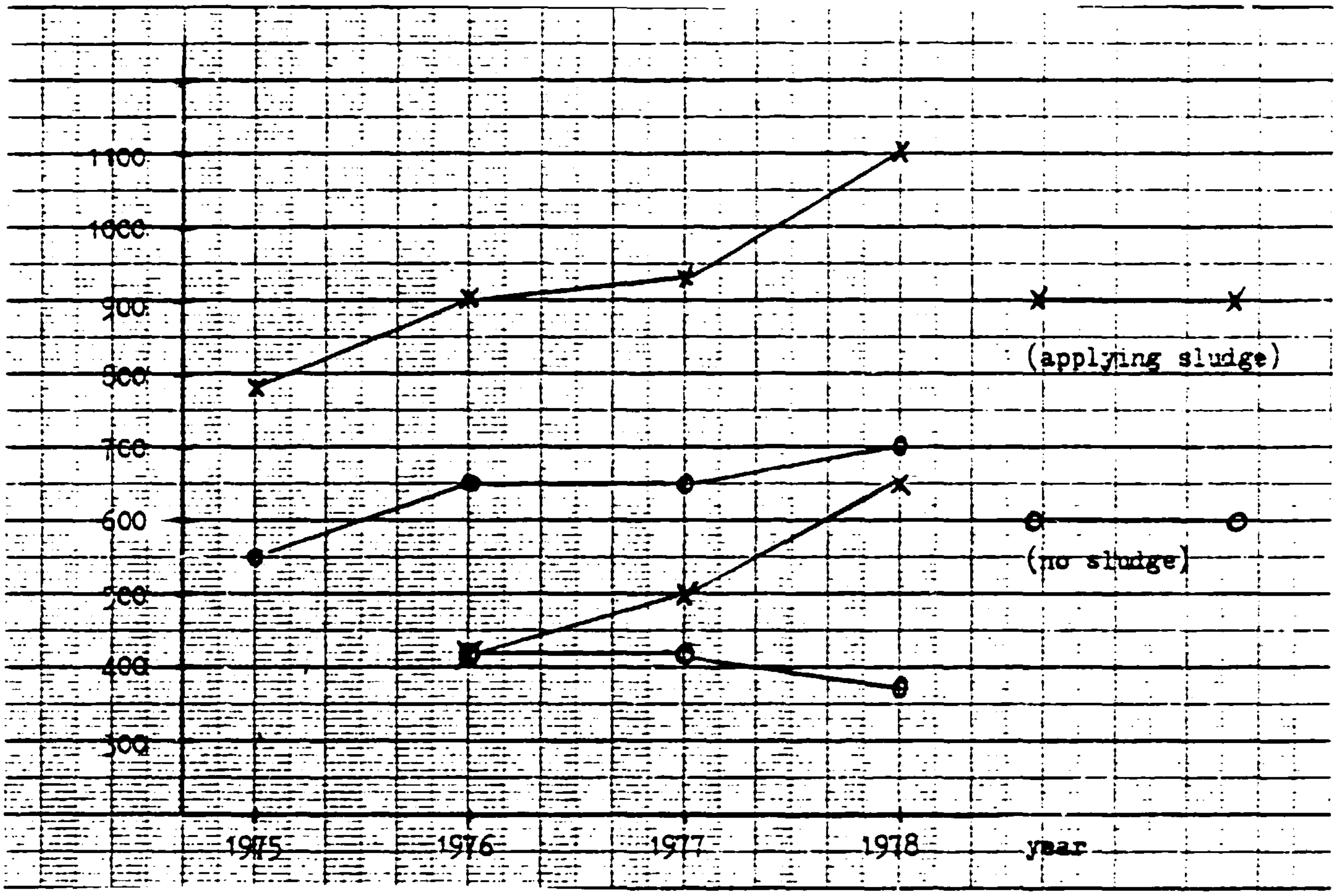

Figure 3. Comparison of crop yield with and without the application of biogas sludge.

Other experiments on non-irrigated soils took place in Chyu-Xian and Dayi (see table 12). Biogas sludge was added continuously at the rate of about 5000 jin per mu per period and the physical and chemical properties of this soil were expecially improved. Organic matter total N and P, available P and porosity increased and density decreased.

However, it was observed that the improvement process was slow in arid conditions. This is because the decomposition of organic substances is so rapid, that the process of accumulating organic matter in the soil remains a problem.

Table 12. Effect of digester sludge on physical and chemical properties of soil

Location	Time	Treatment	Organic matter (%)	Total N (%)	Total P_2O_5 (%)	Available (%)	Volume wt. gm/cm^3	Porosity (%)
Chyr-Xian	2 years	1. Check	1.04	0.064	0.096	13.2	1.44	45.66
		2. Digester sludge	1.21	0.068	0.110	14.4	1.41	46.59
	3 years	1. Check	1.31	0.0744	0.114	29.6	-	-
		2. Digester sludge	1.48	0.0892	0.127	33.7	-	-
Dayi	1 year	1. Check	1.035	0.071	0.109	16.3	1.27	52.59
		2. Digester sludge	1.286	0.101	0.11	20.4	1.26	57.09
	2 years	1. Check	1.122	0.0706	0.118	37.2	1.363	50.09
		2. Digester sludge	1.384	0.057	0.108	66.7	1.207	57.14

IV. Breeding Fish with Digester Residue

Manure is usually adopted in fish pools to promote the growth of planktons as food for the fish. Typical fish bred are grass carp, java tilapia, silver carp, big head carp, golden carp and with the exception of grass carp and bream their main food is plankton. The application of manure to the fish pools is therefore a good and economic method to promote fish growth. With the populari-zation of biogas throughout the rural area, most production teams in the commune now breed fish using digester effluent as manure. From their experience it was found that this method has advantages such as:

1) The growth and propagation of plankton is hastened.

Various water soluble nutrients are needed for growth and propagation of plankton. The effluent from biogas plants is rich in these nutrients (see table 5 and figure 2). The use of biogas effluent provides more available nutrients than does addition of compost or human or animal excreta.

According to experimental results given by Ziguong fish farm, one week after adding effluent, the concentration of plankton would be 16-20 million/litre whereas with addition of human and animal excreta it only rose to 6.7 - 15 million/litre after half a month.

2) Improved environmental water conditions.

When compost or human and animal excreta are used as manure for the fish pools much organic residue is introduced. Without further decomposition this organic matter provides little soluble nutrients. It requires bacterial action to decompose it further and this produces toxins such as H_2S and reduces the level of dissolved oxygen in the pool. Under these conditions the water environment is adverse for fish growth. Digester effluent on the other hand is a clear and transparent liquid, containing no organic residues. Thus apart from providing the necessary nutrients for plankton growth digester effluent helps maintain good water conditions for rapid, helathy, fish growth with increased food production.

3) Reduced disease and improved workers' health.

According to data provided by the Parasitic Diseases Prevention and Cure Research Institute of Sichuan Province, by treating human and animal excrement by biogas fermentation about 95% of the parasitic eggs in the digester settle in the sludge residues. These are typically blood fluke, hookworm and roundworm; other parasites such as ancyroic spirochaeta, dysenteriae bacillus, colon bacillus are completely or for the greater part killed. Thus using biogas effluent rather than untreated excrement will greatly reduce the infection rate of workers at fish ponds, leading to improved health and higher attendance rate.

Similarly common diseases observed in large fish, like bacterio enteritis, which had an occurance rate as high as 60-70% in the past have now occured in less than 5% of fish.

4) Increased fish yield, lower production cost.

According to experiments carried out by the Ziguong Fish Brigade, applying biogas effluent plus a small amount of concentrated feed to a large area in breeding fish, will yield 680 - 730 jin of silver carp per mu, a 46% - 51%

increase over the 450 - 500 jin per mu of the same fish bred with untreated effluent and concentrated feed. The experiments of the Ziguong Fish Farm further pointed out, using biogas effluent to breed fish not only greatly increase its yield, but markedly reduce the use of concentrated feed and lower the production cost. For example, using biogas effluent, for every jin of fish bred, only 0.7 jin of wheat bran is used, the feeding cost is 0.20 Yuan; whereas using untreated effluent, for every jin of fish bred, 4-5 jin of wheat bran is needed, costing 0.47 Yuan, an increase of 2.3 times. Furthermore, the biogas effluent treated silver carps reach 1,160 jin, more than doubling the yield of the untreated fish. Therefore, since 1977, the aforementioned farm has expanded its breeding of fish by applying biogas effluent, broadly increasing its fish production each year while lowering its cost (see table 12), the results were outstanding.

Results and Development of Breeding Fish with Biogas Effluent by Ziguong Fish Farm

Year	Biogas effluent pond %	Adult fish yield jin/100 mu	Adult fish value (Yuan)
1977	50	36,699	13,052
1978	80	44,333	15,370
1979	100	61,431	23,242