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EVALUATION OF THE ACTIVE SEWAGE PASTEURISATION (ASP) PROCESS FOR THE TREATMENT OF SEWAGE SLUDGES

Report to the
WATER RESEARCH COMMISSION
by the
DIVISION OF WATER TECHNOLOGY, CSIR and
DEPARTMENT OF SOIL SCIENCE AND PLANT NUTRITION
UNIVERSITY OF PRETORIA

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EVALUATION OF THE ACTIVE SEWAGE PASTEURISATION (ASP) PROCESS FOR THE TREATMENT OF SEWAGE SLUDGES

by

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EXECUTIVE SUMMARY

1. INTRODUCTION

For sewage sludge to be classified as suitable for unrestricted horticultural and agricultural usage, it must contain low levels of heavy metals and must be "further treated", i.e. either heat treated, pasteurised, irradiated, chemically treated or composted to eliminate or significantly reduce pathogen levels. Until recently these treatment methods were, apart from incineration, the only feasible options available to the sanitary engineer. The introduction of the Active Sewage Pasteurisation (ASP) process, however, not only extended the range of "further treatment" alternatives, but made possible the enrichment of two of the macro plant nutritient levels of sludge, nitrogen and phosphorus (N and P), to the extent that the end-product may correctly be called a fertilizer. These high levels of N and P will allow lower levels of application, which inturn will significantly diminish the possibility of heavy metal toxicity.

Recognizing the potential merits of the ASP process (low capital cost, small area requirements, controllability, substantially reduced risk of heavy metal toxicity and revenue generation potential), the Water Research Commission negotiated a contract with the Division of Water Technology (DWT) of the CSIR whereby the ASP process would be evaluated in terms of the degree of stabilisation and pasteurisation achieved.

2. *MODUS OPERANDI*

An experiment was conducted under the supervision of DWT staff at the pilot ASP plant situated at the Klipgat sewage works near Pretoria. Primary and anaerobically digested sludges were evaluated. Each of the 12 experimental runs lasted for at least one working day and composite samples of each run were prepared by mixing half-hourly samples taken after the process stabilised (less than 2 hours after start up). In addition, samples of untreated sludge were taken during three runs.

The results were evaluated in terms of:

* effect of type of sludge, retention time, temperature and pressure during treatment on degree of pasteurisation achieved,

* level of enrichment (nitrogen and phosphorus) obtained under different operational conditions and

* stability of the end-product as reflected by the absence or presence of nuisance conditions during land spreading and the rate of leaching of N and P relative to equivalent inorganic fertilizers.

3. RESULTS

At the rate of chemical additions tested, temperatures of 70°C appears to be the only additional requirement for achieving pathogen destruction. There were no odour nuisance conditions caused by ammonia, hydrogen sulphide and fatty acids during land spreading, but these compounds were present at low concentrations in the untreated sludge used as input to the plant. Treated sludge retained considerably more N, but also P than inorganic ammonium phosphate fertilizer upon leaching.

4. RECOMMENDATIONS

Although the ASP process appears to be an innovative process which produces a disinfected end-product, that will not give rise to nuisance conditions it is recommended that further experiments be conducted with sludges from different sewage works containing levels of odour causing compounds higher than those prevelant during this study. It is further recommended that experiments be conducted to evaluate the availability to plants and retention in soil, of the N and P in the treated sludge.

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1. INTRODUCTION

Sewage sludges, whether primary or secondary, are generally regarded as unsafe since they contain pathogens and heavy metals that may be harmful to animals and/or humans. Guidelines issued by the Department of Health and Population Development (Viviers *et al*, 1988) therefore, restrict the use of primary and secondary sludges for crop production. For a sludge to be classified as suitable for unrestricted horticultural and agricultural usage, it must contain low levels of heavy metals and must be "further treated", i.e. either heat treated, pasteurised, irradiated, chemically treated or composted to eliminate or significantly reduce pathogen levels. Until recently these treatment methods were, apart from incineration, the only feasible options available to the sanitary engineer.

The introduction of the Active Sludge Pasteurisation (ASP) process however, not only extended the range of "further treatment" alternatives, but made possible the enrichment of two of the macro plant nutrient levels of sludge (N and P) to the extent that the end-product may correctly be called a fertilizer. These high levels of nitrogen and phosphorus will allow lower levels of application, which in turn will significantly diminish the possibility of heavy metal toxicity.

Only limited tests have been done so far to qualify the pasteurisation effect of the ASP process. Recognizing the potential merits of the ASP process (low capital costs, small area requirements, controllability, substantially reduced risk of heavy metal toxicity and revenue generation potential), the Water Research Commission negotiated a contract with the Division of Water Technology (DWT) of the CSIR whereby the DWT would perform a more extensive evaluation of the ASP process in terms of:

- the effect of type of sludge, retention time, temperature, pH and pressure during treatment on composition of end-product and degree of pasteurisation achieved,

- level of enrichment of nitrogen and phosphorus (N and P) obtained under different operational conditions and

- stability of the end-product as reflected by the absence or presence of nuisance conditions during land spreading and the rate of leaching of N and P relative to equivalent inorganic fertilizers.

This report deals with the results of the evaluation carried out by the DWT.

2. DESCRIPTION OF THE ASP PROCESS

Primary or digested sewage sludge is dewatered by means of conventional methods. The dewatered sludge then enters a pipe reactor (stainless steel) with a variable retention time depending on flow rate (Fig. 1). A retention time of 10 minutes is however, normally used. At the point of entrance anhydrous ammonia gas is injected into the sludge at a pressure anywhere between 100 and 300 kPa, although 200 kPa is typical.

Due to the exothermic reaction between ammonia and sludge, the temperature rises to between 40 and 50°C depending on inlet temperature, pressure, quantity of ammonia injected and flow rate. pH normally is 11,6. Just before leaving the pipe reactor concentrated phosphoric acid is pumped into the ammoniated sludge at a rate sufficient to reduce the pH of the mixture to 7,0. Depending on residual temperature and ammonia concentration, a further temperature rise to between 65 and 75°C is obtained. The treated sludge then enters a heat exchanger where heat is transferred to the incoming untreated sludge and/or ammonia. Pasteurisation is achieved by a combination of pressure, temperature, pH and ammonia toxicity.

Pressure in the pipe reactor is controlled by throttling the outflow, while retention time is determined by the throughput rate. Final pH depends on the ratio ammonia to phosphoric acid pumped into the system. Temperature control is less straight forward, since it is dependent on both the total mass of ammonia injected and the ratio ammonia to phosphoric acid.

The end-product is a syrupy, grey to black liquid with a slight ammonia smell. The intensity of the latter is obviously dependent on pH, the concentration of free ammonia and the ratio between the ammonium phosphate species present. As more phosphoric acid enters the system the ratio di- to mono-ammonium phosphate decreases with a concomitant decrease in free ammonia, pH and ammonium phosphate solubility.

3. METHODS

3.1 *Modus Operandi*

The experiment was conducted, under the supervision of DWT staff, at the pilot ASP plant situated at the Klipgat sewage works near Pretoria (Fig. 2). The working programme and analyses performed were to a large extent determined by the available budget. Consequently only 13 experimental runs were planned as shown in Table 1. Only the first 12 of these were completed due to a lack of reliable thickening apparatus.

Primary and anaerobically digested sludges were evaluated. Each run lasted for at least one working day and composite samples of each run was prepared by mixing half-hourly samples taken after the process stabilised (less than 2 hours after start-up). In addition, samples of untreated sludge were taken during runs A5, A6 and B1.

Samples were cooled to 4°C before being air-freighted in insulated cooler bags to the Bellville laboratory of the DWT for analysis and evaluation. In addition to the process evaluation, untreated primary sludge from run B1 was used to assess the degree of stability.

At this stage it is necessary to define exactly what is meant by a "stable sludge". It should be evident that the definition depends on a knowledge of what the ultimate disposal of the sludge will involve. Since ASP-treated sludges will eventually be disposed of by spreading on land (with or without ploughing in) or subsurface injection, it was concluded that the stability requirements for these sludges should be determined in terms of hazards presented to the soil and plant, risk of damage to the environment, and the nuisance potential it could present to humans.

Using the guidelines of Vesilind *et al* (1986), the following parameters for the determination of the relative degree of stability of ASP-treated sludges were selected:

- odour generation potential (NH_3 and H_2S),
- pathogen levels,
- rate of leaching of N and P from treated sludge mixed with soil
- volatile acids concentration
- oxygen uptake rates

Investigations of the first three parameters have been completed, while the latter two were postponed for economic reasons.

3.2 Odour Generation Potential

To determine odour generation potential, separate aliquots of untreated and treated sludges from run B1 were disposed of by leaving in an open container, spreading on top of an aeolian sand (pH = 7,0), and mixing with the latter soil type to a depth of 10 cm. Cylindrical pots of 10cm diameter and 12 cm depth were used, while sludge was applied to the soil at a rate of 2 t of dry solids (equivalent to approximately

300 kg of N) per hectare. Ammonia and hydrogen sulphide concentrations were measured in the sludge and sludge/soil mixtures at the start of the experiment and after 1, 3 and 5 days.

Hydrogen sulphide and volatile fatty acid concentrations were present in very low concentrations in the untreated sludge and could therefore not be used for determinations of odour generation potential as originally intended.

3.3 Leaching Study

To test the hypothesis that N and P present in the treated sewage sludge is less prone to leaching from soil than equivalent inorganic products, a leaching experiment in the laboratory was conducted by the Department of Soil Science and Plant Nutrition at the University of Pretoria. Unfortunately, due to financial constraints, only a preliminary investigation could be carried out.

The *Total Kjeldahl Nitrogen* (TKN) content of the sludge was used as basis of comparison with mono ammonium phosphate ($NH_4H_2PO_4$). Two middle-textured soils, a sandy loam and a clayey loam were used in the investigation.

Duplicate treatments consisted of a control (soil only), treated sewage sludge from run B1 at 10 g/50 g soil (considered very high, but necessary to make determinations possible) and the N equivalent as $NH_4H_2PO_4$. The soil, in glass jars with loose-fitting lids was kept at 50% of saturation (approximately field capacity) at 25°C for 8 weeks, to ensure adequate reaction time.

Thereafter two leaching intensities were used to displace soluble N and P; a low level, consisting of two consecutive additions of the saturation volume for each soil and a high level, consisting of ten times these volumes, on Buchner funnels with suction applied.

3.4 Analytical and Microbiological Methods

Chemical analyses as well as faecal coliform and *Salmonellae* determinations on sludge samples were performed according to the techniques published in Standard Methods (APHA *et al*, 1985). The double-layer-agar method of Grabow *et al* (1984), was used for coliphage determinations while viable *Ascaris lumbricoides* ova were isolated and counted according to the latest DWT method (Franck, 1988). The procedure of Du Toit (1989) was used to measure odour generation potential. TKN and phosphorus on soil samples were determined according to the methods of Jackson (1958).

4. RESULTS AND DISCUSSION

4.1 Process Evaluation

The analytical and microbiological results of the 12 completed experimental runs are shown in Tables 2 and 3 respectively, while Tables 4 and 5 give the results of odour and leaching studies respectively.

4.1.1 Effect of temperature

Total solids, TKN, and total phosphorus concentrations increased with increasing temperature as shown in Figs. 3 to 5. Since both the quantities of ammonia and phosphoric acid injected must be increased to raise the temperature, the result is not unexpected.

4.1.2 Effect of retention time

Fig. 4 shows that there is an inverse relationship between TKN concentration and retention time. The opposite is true for the relationship between total phosphorus concentration and retention time (Fig. 5), while total solids concentration increases with higher retention times at 50 and 60°C but decreases at 70 and 90°C (Fig 3).

4.1.3 Effect of pressure

As shown in Fig. 6 the higher pressure tested (200 kPa) resulted in higher total solids, TKN and total phosphorus concentrations.

4.1.4 Effect of pH

Increasing the pH from 6 to 7 increased the total solids and TKN levels but lowered the phosphorus level slightly (Fig. 7). This result is not unexpected since the ratio ammonia nitrogen to phosphorus must be reduced to obtain higher pH values.

4.1.5 Pathogen elimination

Fig. 8 shows that both faecal coliforms and viable *Ascaris* ova were completely destroyed at 70°C while maintaining a constant pressure, retention time and pH of 200 kPa, 5 min and 7,0 respectively. Although not reported here, further tests have shown that variations in pressure (100 and 200 kPa), retention time (5 and 10 min), and pH (6 and 7) did not change the results as given in Fig 8.

Unfortunately run B1 (undigested primary sludge) ran at a higher pH than planned (9,2 instead of 7,0). Although a comparison of the effect of different sludge types (all other variables the same) is, therefore, difficult, it should be noted that some coliphage survived during this run in spite of a temperature of 70°C being maintained.

4.2 Nutrient Levels

The primary purpose of the ASP process is the treatment of raw, digested and waste activated sludges to render it pathogen- and odour-free for unrestricted agricultural application. The accompanying increase in nitrogen and phosphorus levels may be regarded as of secondary importance, albeit of significant agricultural consequence. From paragraph 4.1.5 it is apparent that indicator pathogen elimination requires a temperature of higher than 60°C. In addition a pH of 7 is highly desirable (at a too high or too low pH, ammonia odour and precipitation problems can be expected respectively).

The quantity of phosphoric acid required is determined by the desired pH and initial quantity of ammonia injected. To reach a temperature of 70°C, but still maintaining a pH of 7, 0, it is, therefore, important to inject the correct quantity of ammonia at the inlet to the pipe reactor. The results of run A3 (see Table 2) show that approximately 3,8 percent of ammonia equivalent to 3,2 percent nitrogen) and 16 percent phosphoric acid (equivalent to 3,3 percent phosphorus) are required to achieve this condition at a retention time of 5 minutes and a pressure of 200 kPa. Obviously higher nitrogen and phosphorus levels, at the correct ratio to ensure a pH of 7,0 are possible. The final levels chosen are, therefore, a matter of economic consideration.

The levels of nitrogen in sludge treated by the ASP method may be more than ten times higher than the levels in the untreated sludge. In the case of phosphorus, this concentration factor may even by higher than 30 (see Table 2). In practice this means that the treated sludge will be applied at a rate not exceeding one-tenth of that used for untreated sludges in order to satisfy the nitrogen requirements of crops. Obviously such low rates of application will significantly reduce the risk of heavy metal toxicity and lengthen the maximum cumulative period of sludge application on land at least tenfold (See Fig. 9).

4.3 Degree of Stabilization

The primary and digested sludges used as input into the ASP plant contained relatively low concentrations of heavy metals and indicator pathogens (see Tables 2 and 3). During the odour generation potential studies, it was noted that the sludges also contained low quantities of sulphur (less than the detection limit of

0,02 mg per litre). Volatile fatty acids concentrations (unreported) were also low, i.e. less than 400 mg per litre. Typical sludge odours could nevertheless be detected in all the untreated samples. The ASP treated sludges, however, emitted only a slight ammonia odour. Because of the low levels of odour causing compounds, it was decided to repeat the experiment using a sludge containing higher levels of contaminants. Unfortunately, this could not be done in time for this report, since it involves the transport of sludge from a distant source to the Klipgat plant.

Ammonia nitrogen concentrations in sand mixed with untreated and treated primary sludges are shown in Fig 10. As expected, NH_3-N concentrations were approximately 34 times higher in soil mixed with treated sludge than in soil mixed with untreated sludge immediately after mixing. After one day NH_3-N concentrations have decreased significantly in both experimental soils, but more so in the case of soil mixed with untreated sludge (71% for treated sludge and 97% for untreated sludge). Very little NH_3 release took place in both cases after the first day.

It should be kept in mind however, that in practice the quantities of sludge added to the soil will be based on the nitrogen requirements of the crop and not on a solids per hectare basis as done during this experiment. This means that the quantity of ammonia-nitrogen put into the soil will not be higher than in the case of untreated sludge. Since treated sludge releases a smaller fraction of ammonia-nitrogen into the air (Fig. 10) the potential for ammonia odours is in fact reduced after ASP treatment.

As in the case of heavy metals (Fig. 9) ASP treatment will also reduce the quantities of odour causing components such as sulphur and volatile fatty acids applied to the soil.

4.4 Leaching Study

The amounts of N and P leached were expressed as a percentage of that applied. The results are graphically presented in Figs. 11 and 12.

High leaching intensities removed more N (and P) than the low leaching intensities from both types of soil. The sewage sludge treatments retained considerably more N, and to a lesser extent P, than was found with $NH_4H_2PO_4$.

All the N supplied as $NH_4H_2PO_4$ was leached out at the high leaching intensity, as opposed to only 44% of that in sewage sludge.

5. CONCLUSIONS

5.1 At the rate of chemical additions applied during the study, a temperature of 70°C is required for achieving pathogen destruction.

5.2 Within the range of pressures (100 and 200 kPa), retention times (5 and 10 minutes) and pH (6 and 7) tested, these parameters had no discernable effect on disfection.

5.3 Total solids, nitrogen and phosphorus concentrations increased with an increase in temperature and pressure. Increased pH, however, resulted in higher total solids and TKN levels, but reduced total phosphorus levels slightly.

5.4 A longer retention time (10 minutes) resulted in lower nitrogen concentrations but higher phosphorus levels than obtained with a shorter retention time (5 minutes).

5.5 Maintaining a pH of 7 and a temperature of 70°C as required for adequate disinfection, will result in an end-product containing approximately 3,2 percent nitrogen and 3,3 percent phosphorus. Such high nitrogen and phosphorus levels will result in lower sludge application rates to the soil, which in turn will reduce heavy metal loading to the soil significantly.

5.6 At the levels of odour nuisance causing compounds tested, the ASP process resulted in an end-product with no danger of ammonia, hydrogen sulphide or volatile fatty acid odours developing during land spreading, provided that a pH of 7,0 or lower is maintained.

5.7 Active sludge pasteurisation (ASP) is an innovative process which produces a disinfected liquid end-product which will not give rise to nuisance conditions.

6. RECOMMENDATIONS

It is recommended that:

6.1 Experiments be done with sludges from different sewage works containing levels of sulphur and volatile fatty acids higher than those prevalent during this study.

6.2 Experiments be conducted to evaluate the availability to plants, and retention in soil of the N and P in the treated sewage sludge.

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TABLE 1 : DETAILS OF THIRTEEN EXPERIMENTAL RUNS

Run No	Type of Sludge	Retention time (minutes)	Pressure (Bar)	pH	Temp (ºC)
A1	Digested	5	2	7	50
2	"	5	2	7	60
3	"	5	2	7	70
4	"	5	2	7	90
5	"	5	2	7	110
6	"	5	2	6	70
7	"	5	1	7	70
8	"	10	2	7	50
9	"	10	2	7	60
10	"	10	2	7	70
11	"	10	2	7	90
B1	Primary	5	2	7	70
C1	Thickened primary	5	2	7	70

TABLE 2 : ANALYTICAL RESULTS OF 12 EXPERIMENTAL RUNS

Run No	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	B1	A5 Untreated	A6 Untreated	A7 Untreated
pH	6,9	6,7	6,9	6,9	9,3	5,8	6,7	6,5	6,5	6,5	6,7	9,2	6,3	5,8	5,9
Tot. Solids g/1	62,7	68,6	195,9	215,6	91,0	95,8	137,4	128,6	116,9	169,4	178,4	62,8	24,8	38,9	13,3
Vol. Solids g/1	31,9	37,9	100,7	104,2	52,5	53,1	66,6	56,7	53,6	69,4	71,1	31,4	14,7	21,0	7,5
TKN g/1	20,0	19,9	32,2	37,6	38,6	23,0	22,4	18,7	16,6	26,1	29,7	27,6	2,4	2,3	1,9
NH3-N g/1	19,0	18,4	31,0	34,2	37,2	21,4	18,7	16,4	15,0	23,1	26,5	26,5	0,7	1,4	0,9
Tot. P g/1	20,6	24,6	33,1	38,3	32,4	36,5	23,1	24,0	22,6	37,0	39,4	21,7	1,1	0,8	2,1
Tot. K mg/1	139	140	138	144	159	171	118	192	160	169	170	129	103	77	86
Cd mg/1	-	-	0,07	-	-	-	0,06	0,08	-	-	-	0,05	-	-	0,03
Cu mg/1	-	-	6,8	-	-	-	8,2	10,4	-	-	-	8,0	-	-	7,0
Ni mg/1	-	-	6,8	-	-	-	8,1	2,1	-	-	-	5,9	-	-	5,0
Pb mg/1	-	-	0,5	-	-	-	1,0	1,9	-	-	-	1,9	-	-	1,7
Zn mg/1	-	-	22	-	-	-	25	35	-	-	-	25	-	-	24
Co mg/1	-	-	0,59	-	-	-	0,54	0,71	-	-	-	0,40	-	-	0,12
Cr mg/1	-	-	4,3	-	-	-	7,5	21,8	-	-	-	13,7	-	-	12,9
Mn mg/1	-	-	35	-	-	-	30	36	-	-	-	30	-	-	17
Mo mg/1	-	-	0,3	-	-	-	0,5	0,9	-	-	-	0,6	-	-	0,6
Ca mg/1	-	-	495	-	-	-	570	840	-	-	-	697	-	-	448
Mg mg/1	-	-	2240	-	-	-	1563	1810	-	-	-	1562	-	-	312

TABLE 3: MICROIOLOGICAL RESULTS OF 12 EXPERIMENTAL RUNS

Run No	Faecal Coliforms per g (wet)	*Salmonellae* per g (wet)	Coliphage per g (wet)	Viable *Ascaris* ova per 5g (wet)
A1	$3,1 \times 10^{4}$	0	$2,0 \times 10^{3}$	0
2	$4,0 \times 10^{1}$	0	$4,5 \times 10^{2}$	2
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	$4,7 \times 10^{4}$	6
9	0	0	$1,7 \times 10^{4}$	4
10	0	0	0	0
11	0	0	0	0
B1	0	0	$2,7 \times 1,0^{1}$	0
A5 (untreated)	$6,8 \times 10^{5}$	0	$6,5 \times 10^{4}$	140
A6 (untreated)	$5,7 \times 10^{3}$	0	$4,8 \times 10^{4}$	14
B1 (untreated)	$5,0 \times 10^{3}$	0	$8,0 \times 10^{1}$	12

TABLE 4 : AMMONIA-N CONCENTRATIONS IN ASP-TREATED SLUDGE AND SOILS ON WHICH IT HAS BEEN DISPOSED

Sample No	Sludge sample	Method of disposal	Days after disposal of soil	Ammonia-N concentration		
				Sludge mg/1	Sludge/soil mixture mg/kg	Reduction %
1	Untreated by ASP	1	0	700	59	-
2	"	1	1	179		74
3	"	1	3	174		75
4	"	1	5	134		81
5	"	2	1	45,9		93
6	"	2	3	45,9		93
7	"	2	5	39,9		94
8	"	3	1	28,0	1,4	96
9	"	3	3	26,0	1,3	96
10	"	3	5	24,0	1,2	97
11	Treated by ASP	1	0	37170	1859	-
12	"	1	1	26263		29
13	"	1	3	28364		24
14	"	1	5	28434		24
15	"	2	1	3531		91
16	"	2	3	2205		94
17	"	2	5	2037		96
18	"	3	1	10640	532	71
19	"	3	3	8960	448	76
20	"	3	5	8980	434	79

Notes: (a) Method of disposal : 1. Left in open container
2. Spread on top of soil
3. Mixed with top 10 cm of soil

(b) Concentration of NH_3-N of sludge samples 8, 9, 10, 18, 19 and 20 were calculated from concentrations in respective sludge/soil mixtures

TABLE 5: PERCENTAGE OF APPLIED N AND P LEACHED FROM TWO SOILS AT TWO LEACHING INTENSITIES

Sample	Leaching Intensity	% N Leached			% P Leached		
		Soil A	Soil B	Mean	Soil A	Soil B	Mean
Sewage Sludge	Low	32,1	25,9	29,0	28,2	17,1	22,7
	High	42,9	45,1	44,0	33,9	37,0	35,5
$NH_4H_2PO_4$	Low	52,6	28,3	40,5	28,9	10,4	19,7
	High	105,0	97,8	101,4	55,4	41,0	48,2

Notes: (a) Soil A : Sandy loam

(b) Soil B : Clayey loam

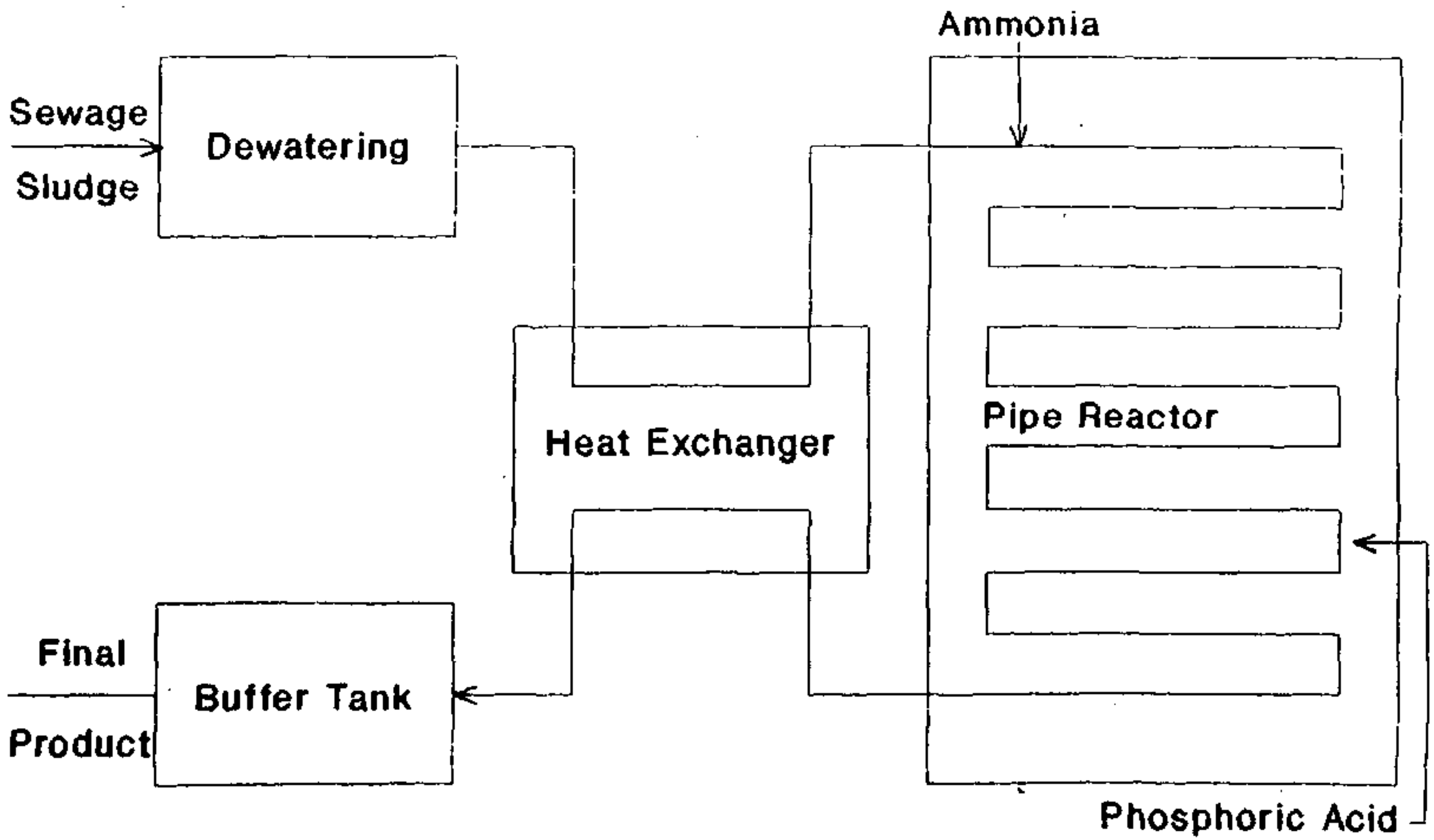

Fig.1: Schematic Diagram of the ASP Process

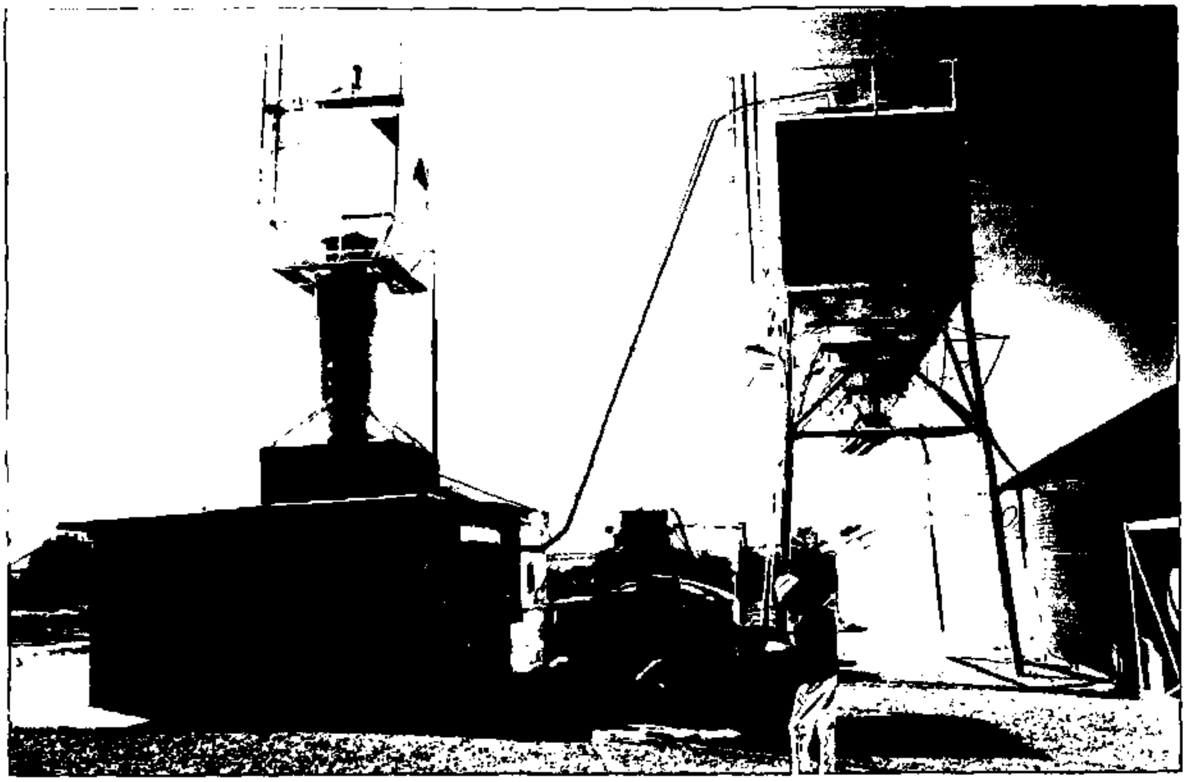

FIG 2. : THE ASP PILOT PLANT AT KLIPGAT SEWAGE WORKS

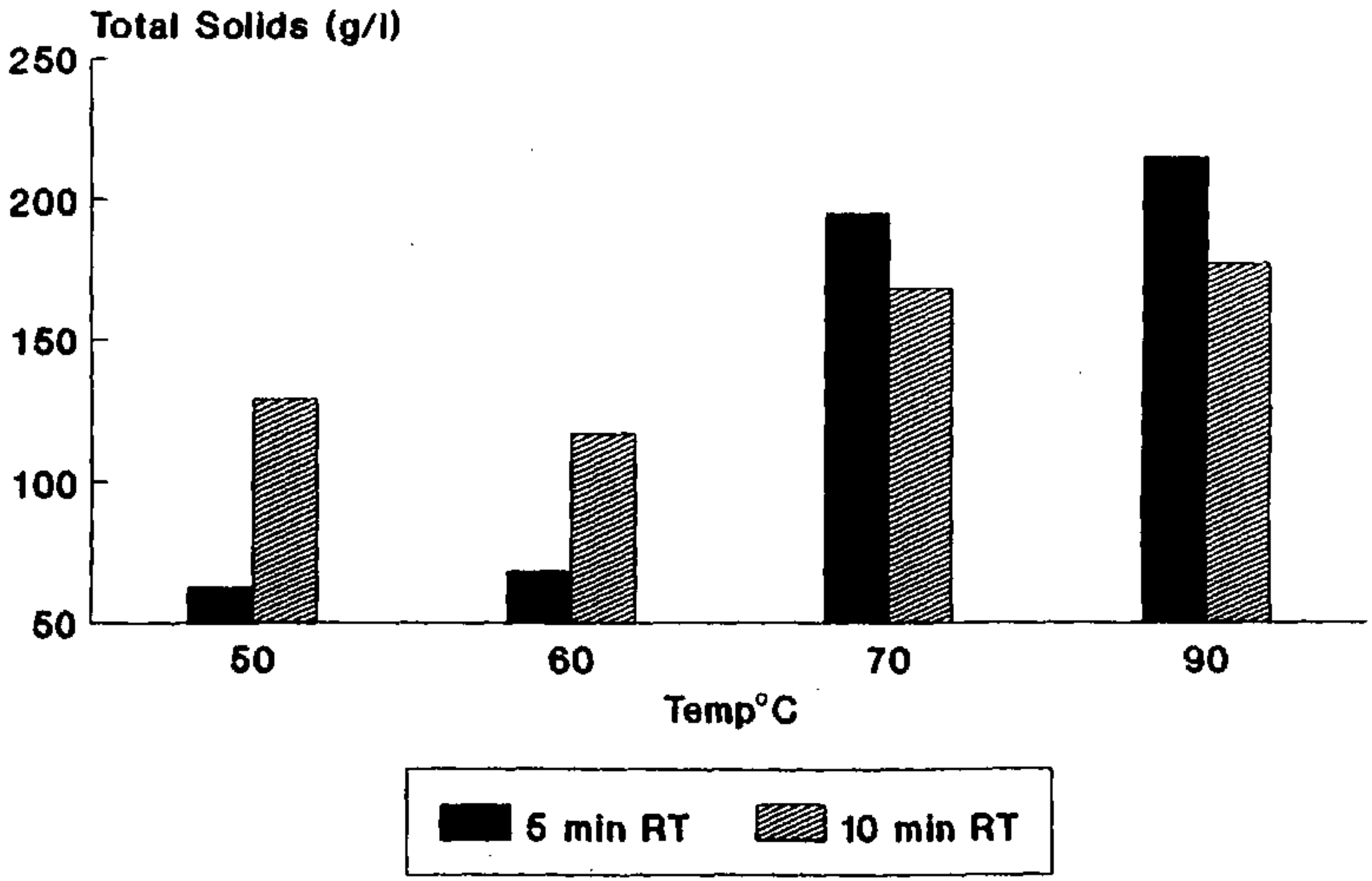

Fig.3 Effect of Temperature and Retention Time on Total Solids Concentration (Pressure=2 Bar,pH = 7,0)

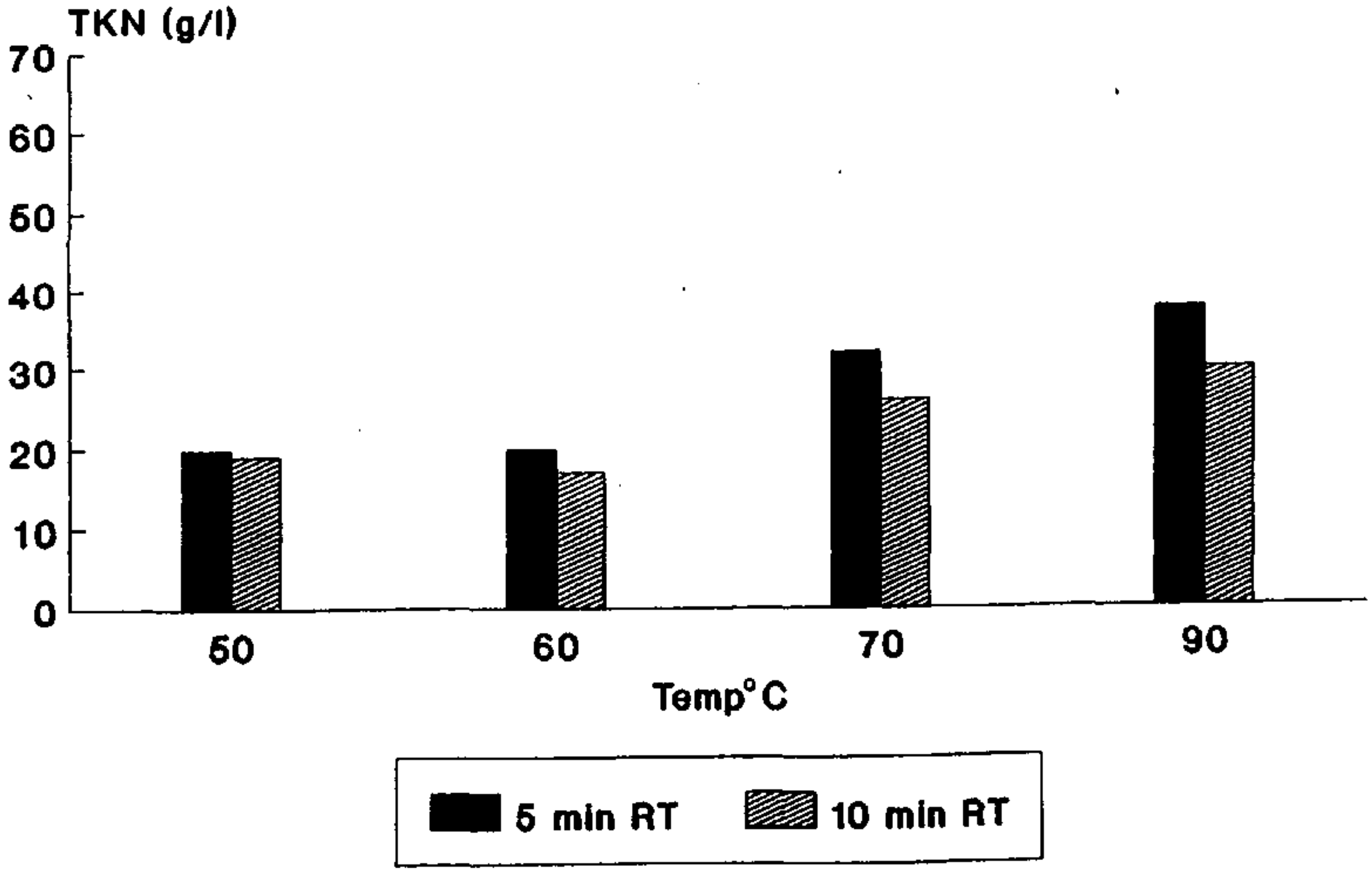

Fig. 4 Effect of Temperature and Retention Time on TKN Concentration (Pressure = 2 Bar, pH = 7,0)

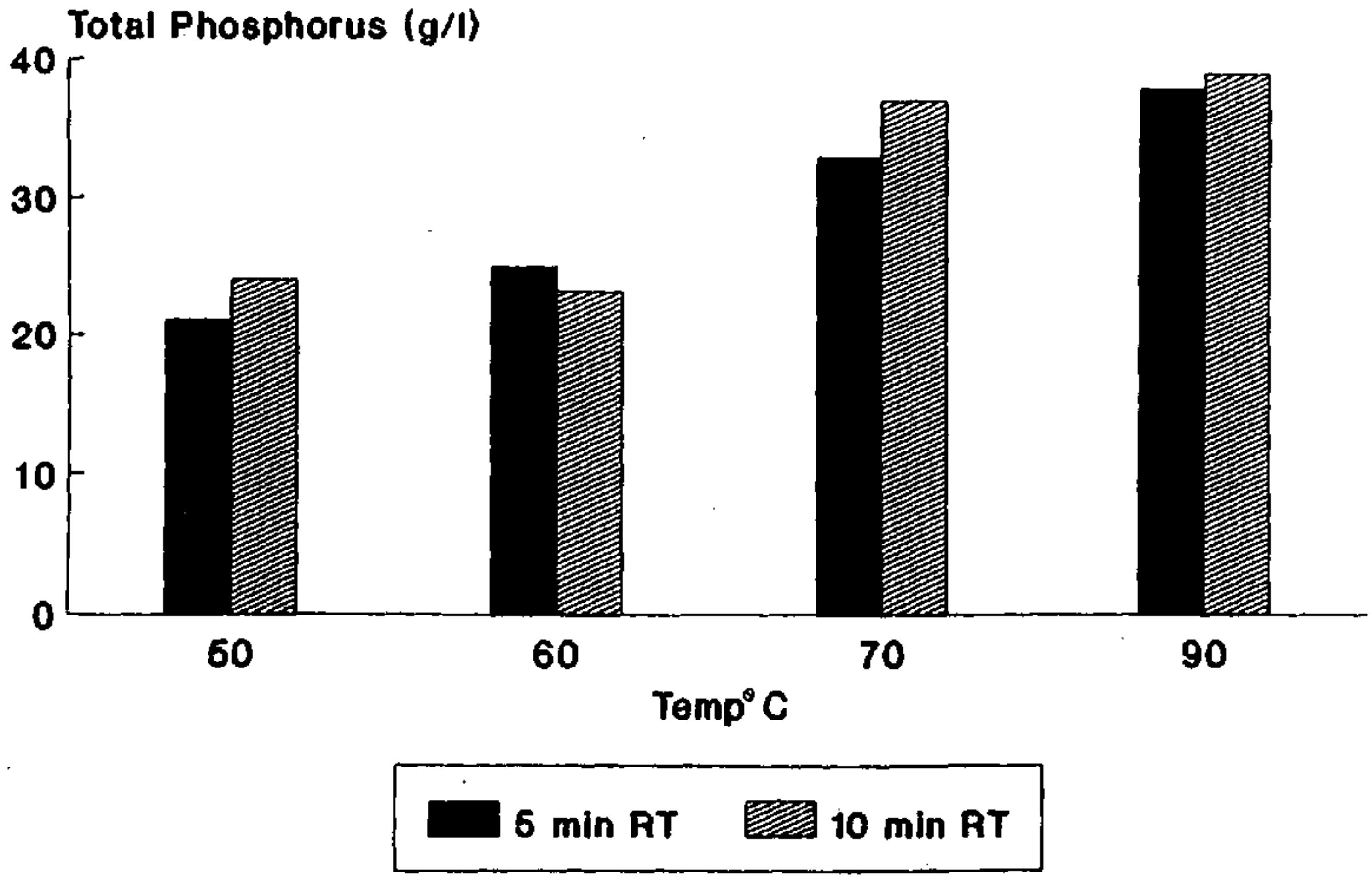

Fig. 5 Effect of Temperature and Retention Time on Total Phosphorus Concentration (Pressure=2 Bar,pH = 7,0)

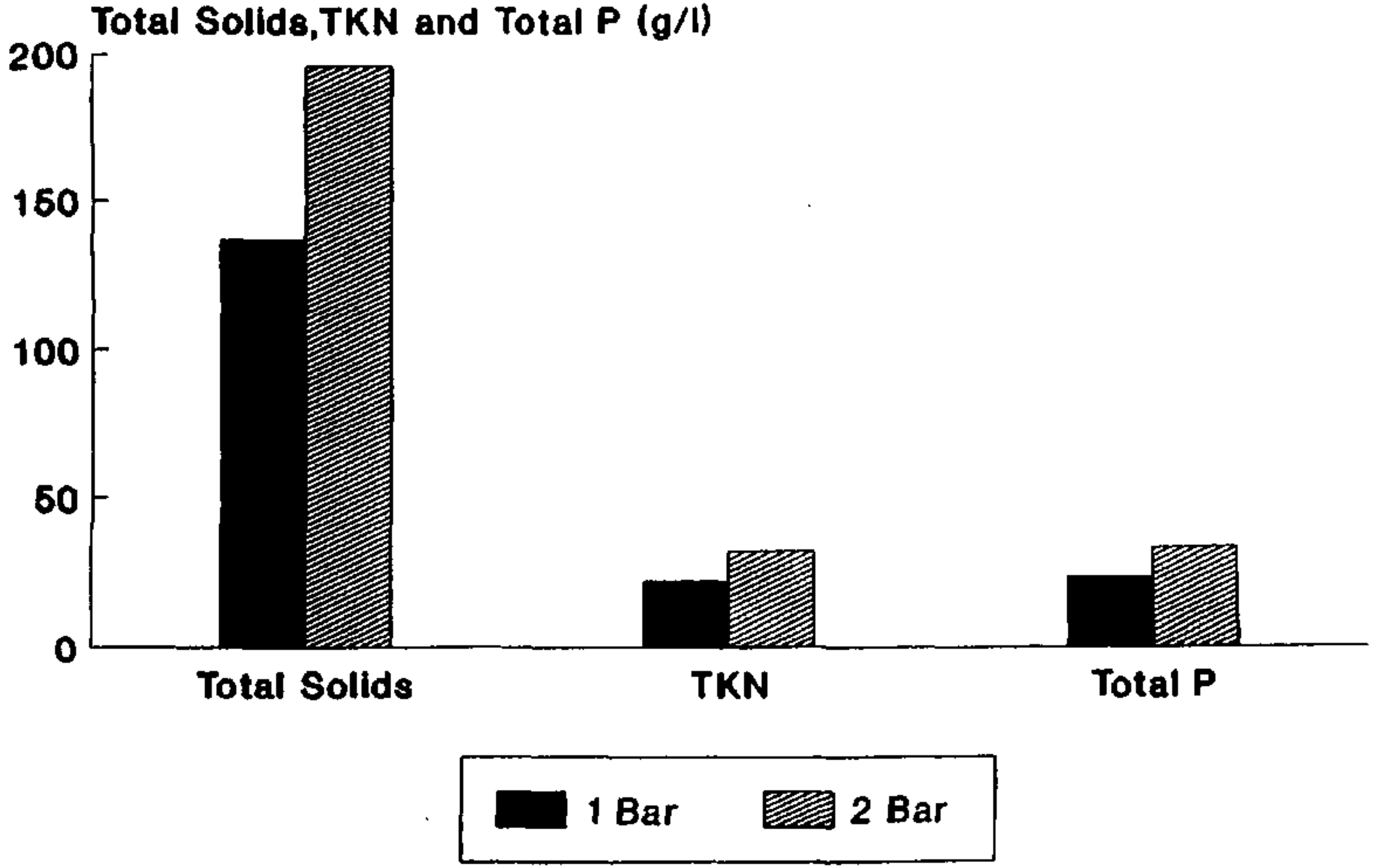

Fig.6 Effect of Pressure on Total Solids and Total Phosphorus Concentration
(Retention time=5 min; Temp=70°C, pH=7)

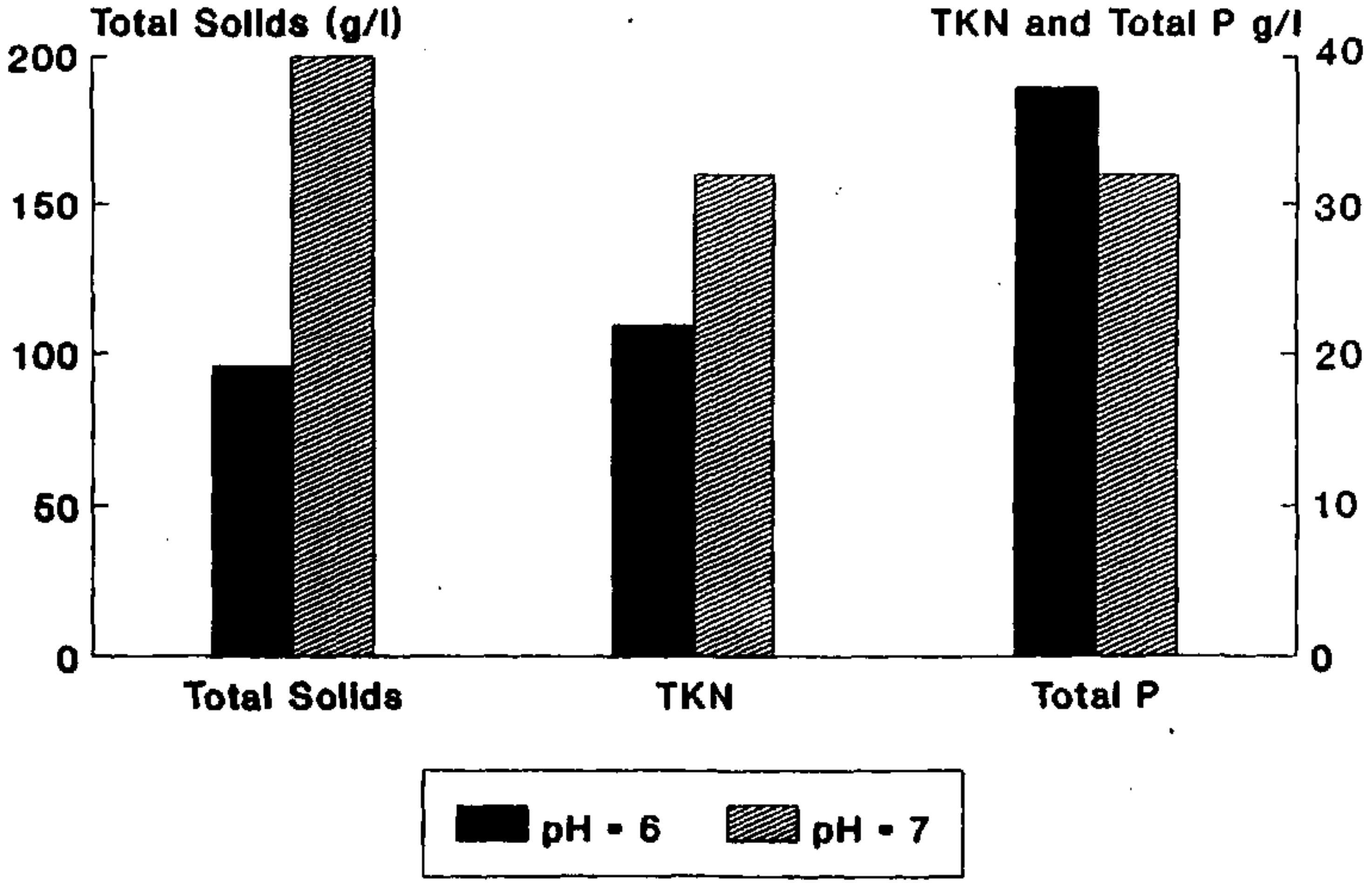

Fig.7 Effect of pH on Total Solids,TKN and Total P concentration (Pressure=2 Bar,Retention Time=5 min,Temp=70°C)

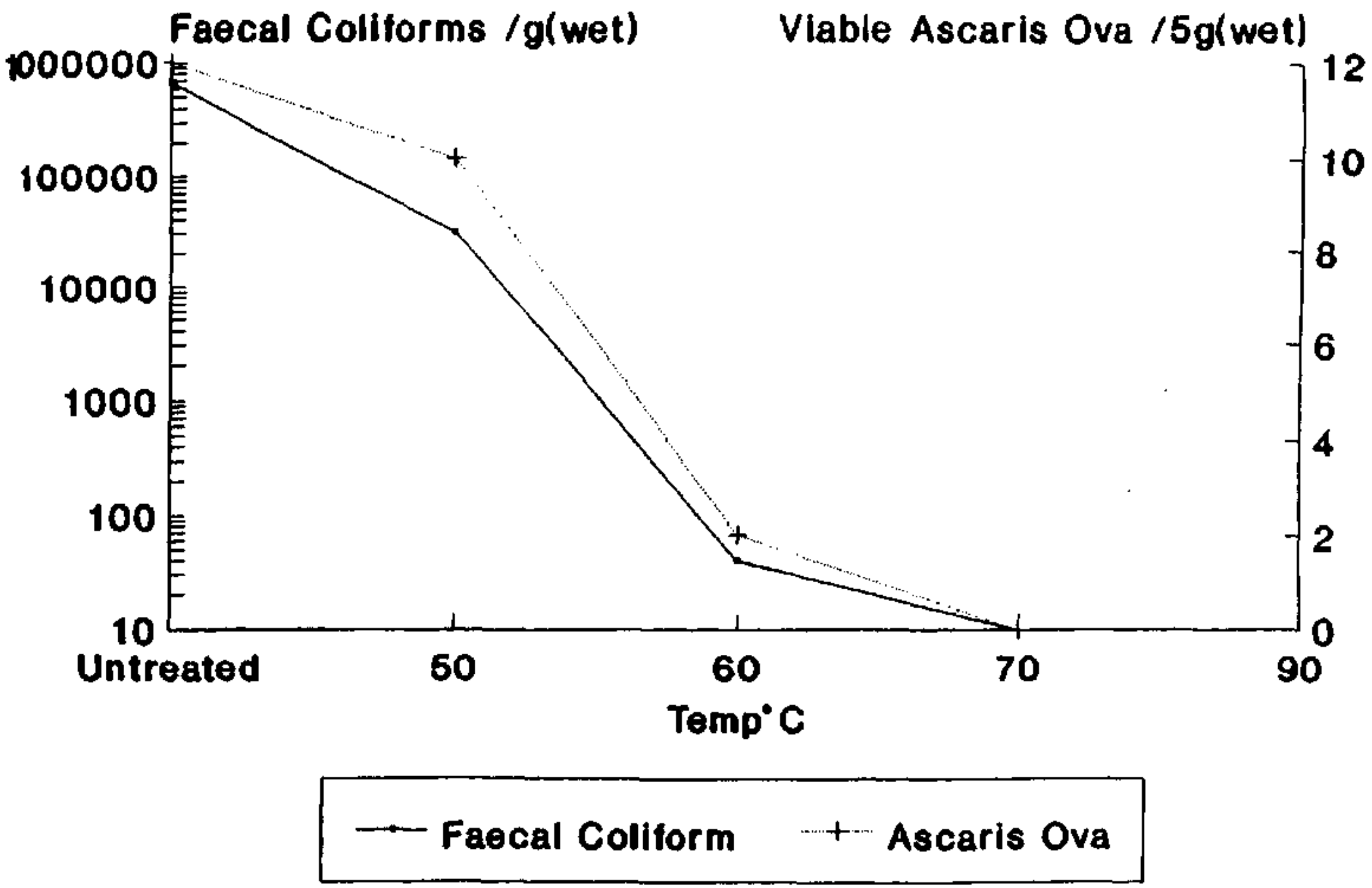

Fig.8 Effect of Temperature on Indicator pathogen Survival
(pH=7,Pressure=2 Bar,Retention time=5 m)

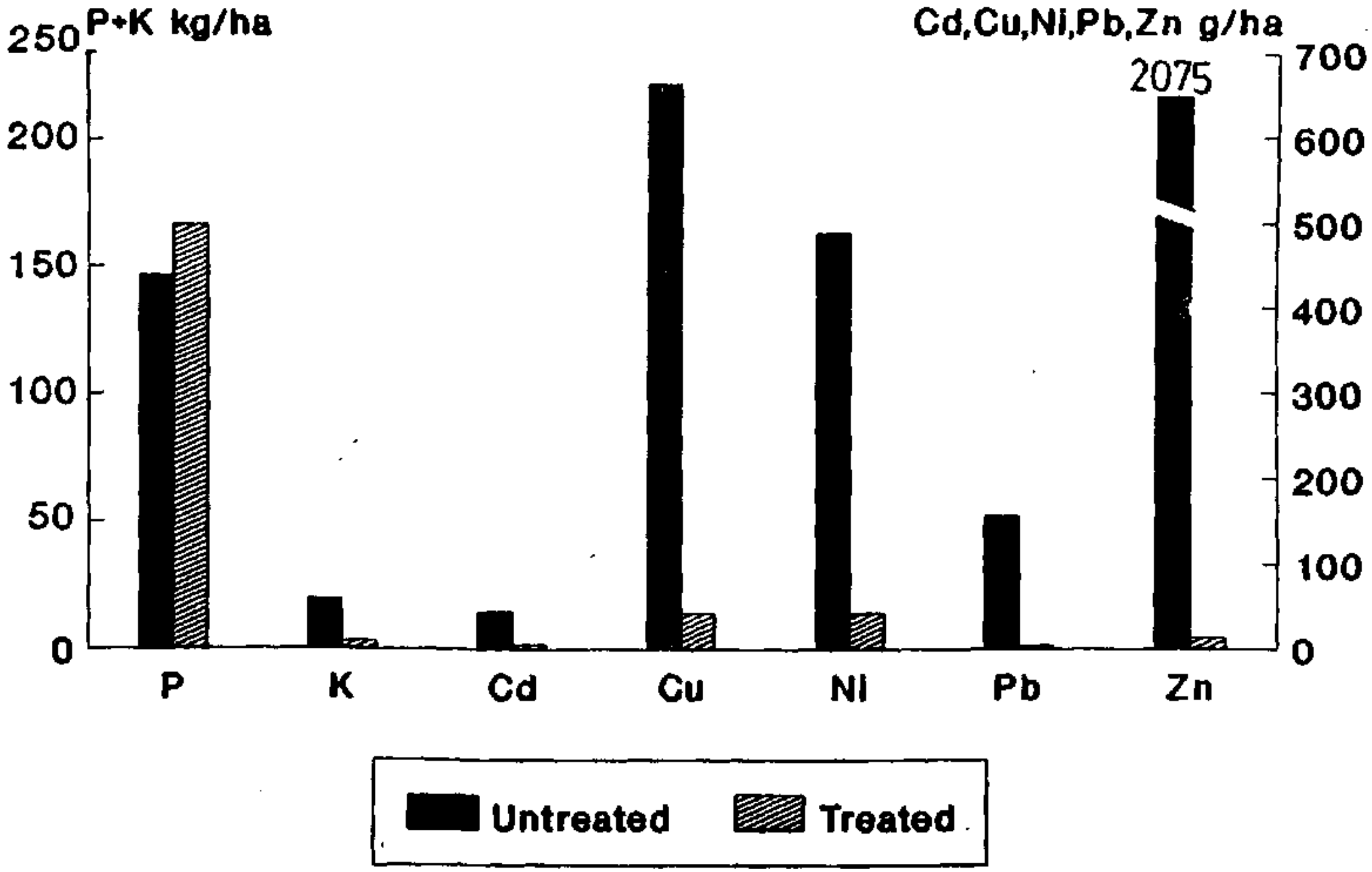

Fig.9 Quantity of P, K and Heavy Metals added to Soil at a Nitrogen Application rate of 200 kg/ha

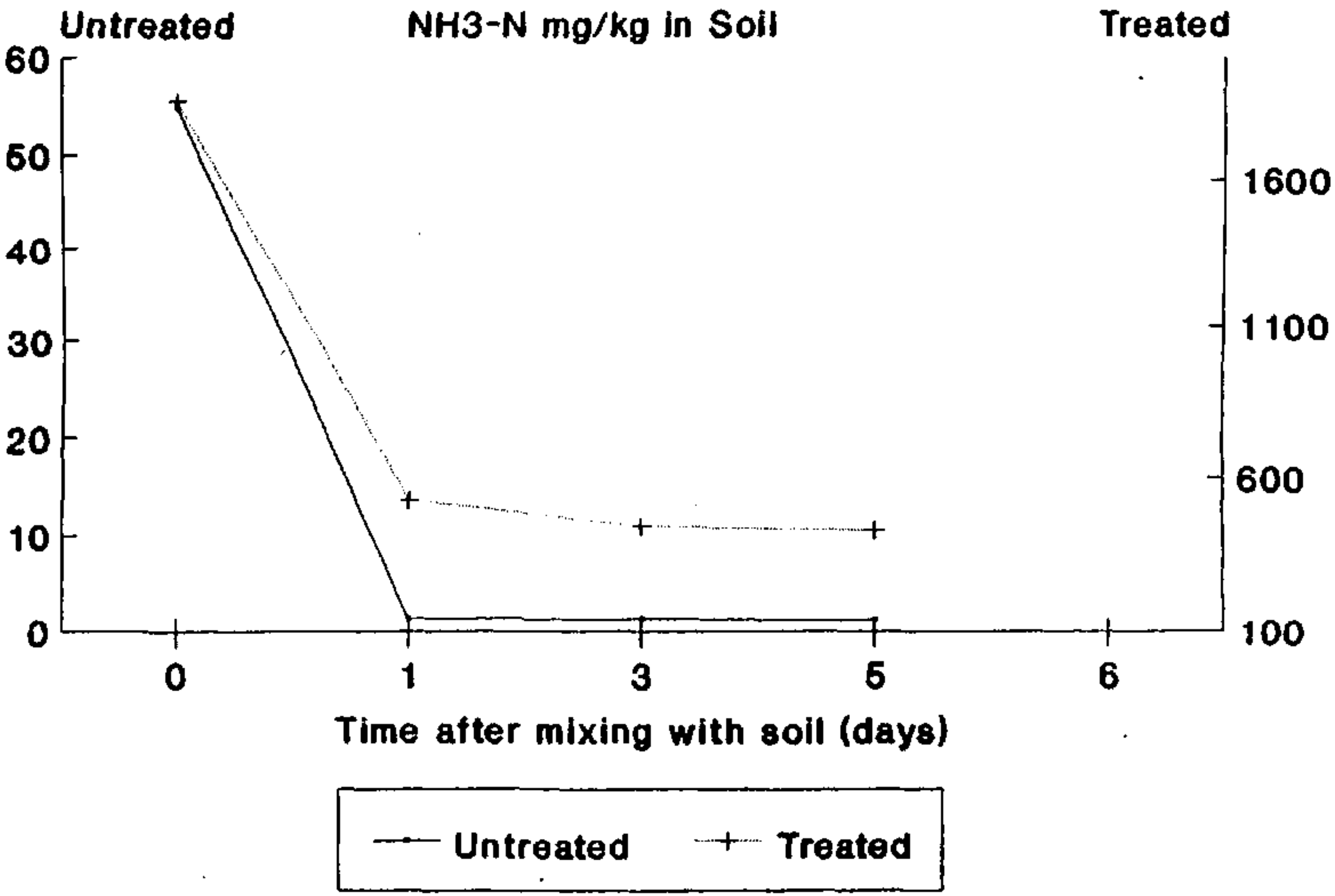

Fig.10Ammonia-N Concentration in Soil
mixed with Untreated and Treated Sludges

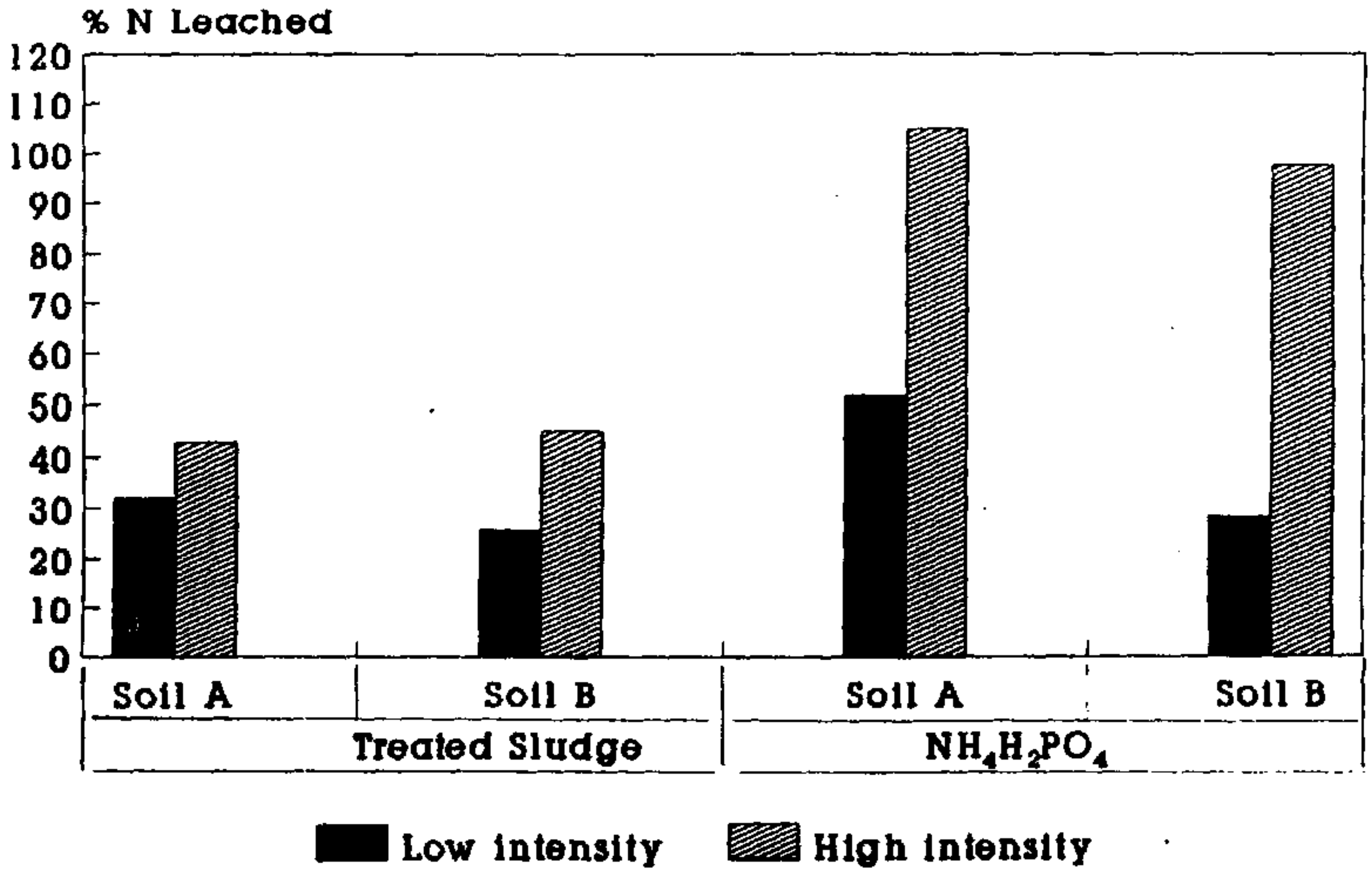

Fig. 11 Percentage of applied N leached at two leaching intensities

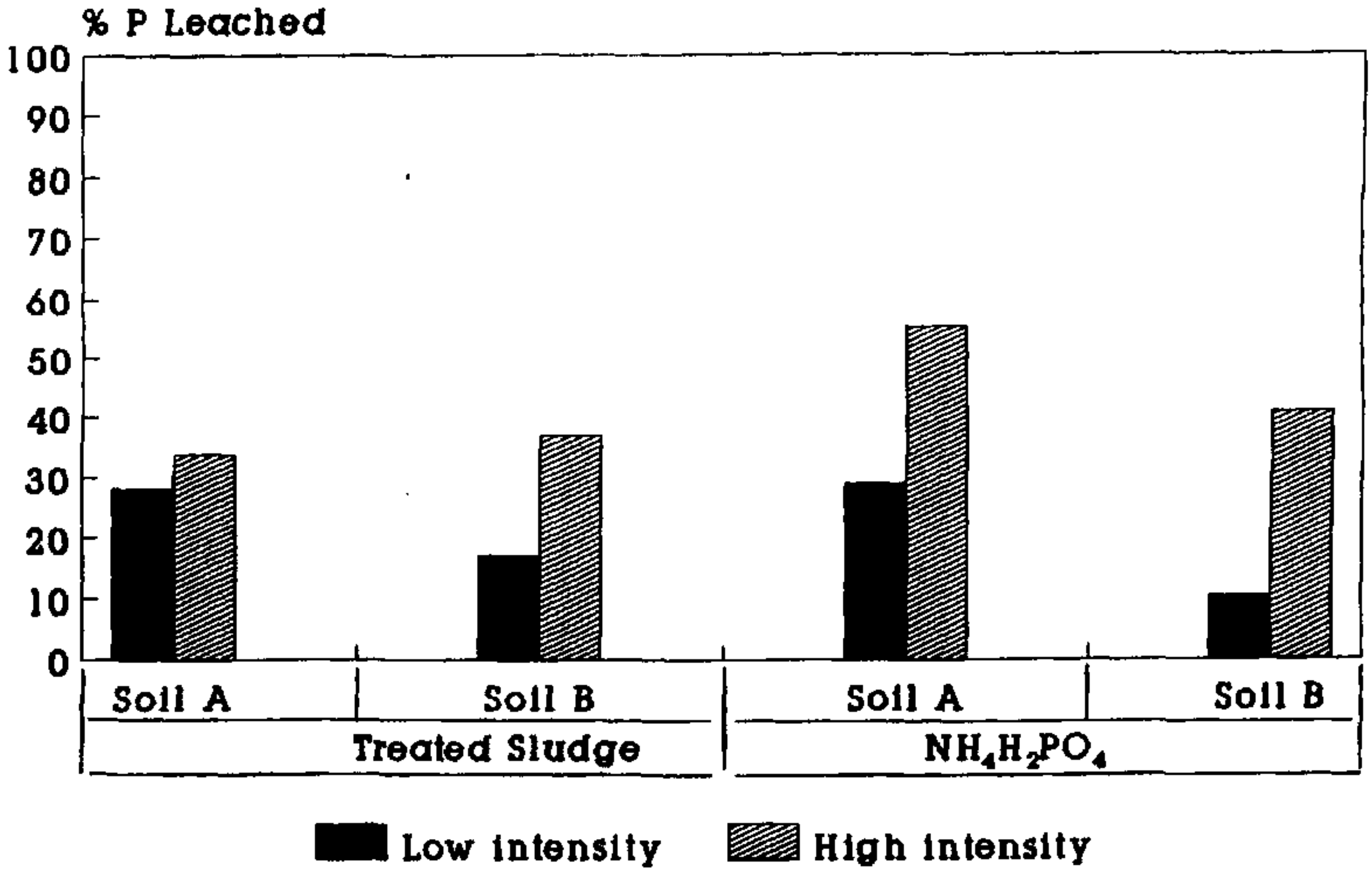

Fig. 12 Percentage of applied P leached at two leaching intensities