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Nutrient transformation of pig manure under pig-on-litter system

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ABSTRACT

A ten-month study was carried out in an experimental farm in Hong Kong to investigate the changes in the forms and content of carbon, nitrogen, phosphorus and potassium of the pig manure under a pig-on-litter (POL) system. This system, known as *in-situ* composting, utilizes a mixture of sawdust and a commercial bacterial product as the bedding material on which pigs are kept and the pig excreta are decomposed within the bedding. The effects of the commercial bacterial product recommended by the POL system (the treated group) on nutrient transformation of the pig manure were evaluated and compared with the control group (without any bacterial product).

It was found that there was no significant difference between the treated and the control groups in terms of the concentrations of organic carbon, total and extractable N, P and K of the sawdust pig manure litter samples. The patterns of how these nutrient changed with the experimental time were similar between the treated and the control groups. The concentrations of total N, NH_4^+-N, total and extractable P and K increased rapidly at the beginning of the experiment and the rate of these accumulations became slower towards the end of the study. On the other hand, total organic carbon content of the litter samples declined dramatically in the first few weeks, with C values dropped from an initial 40% to 31% at week 10. Further decrease in total carbon concentration was observed as the experiment proceeded. A very drastic drop of the C:N ratio was found within the first few days, from an initial 175:1 decreased to 40:1 within one day then further dropped to 14:1 at the end of week 1 in both treated and control groups. At the end of the experiment, the C:N ratio reached a very low value (10:1). These results suggest that (1) the commercial bacterial product did not have any significant effect on nutrient transformation of pig manure under the POL system; (2) the nutrients released from pig excreta were rapidly assimilated and immobilized by microorganisms colonized within the bedding material, with an accumulation of total nutrients (N, P and K) but a decline in C throughout the experiment; and (3) the bedding material of the POL system appeared to become more stable and mature as the study continued, the samples collected at later stage of the experiment had a more constant nutrient level and a very narrow C:N ratio.

INTRODUCTION

Intensive growth in livestock industry has resulted in the production of large quantities of livestock waste. Due to its high moisture and nutrient content, pasty consistency and unpleasant odour, livestock waste is difficult to dispose of and causes eutrophication problem in surrounding aquatic ecosystems. Surveys on Hong Kong freshwater habitats have shown that streams and rivers in the farming area have been contaminated by nutrients and organic matter released from pig waste (EPD, 1988). Research and development have been carried out by the Hong Kong Government since 1987 to treat livestock waste before disposal (EPD, 1989, 1990). A pig-on-litter (POL) system, also known as *in-situ* composting, has been developed as one of the recommended methods for pig waste disposal (EPD, 1989). The POL is a pig production method where pigs are reared on a litter bedding and pig waste (both faeces and urine) is decomposed *in-situ*. The method was first introduced to Hong Kong from Japan in 1987. It involves the mixing of sawdust with a bacterial product to make up the litter bedding. The pig excreta, once deposited, were quickly mixed with the bedding material. The nitrogenous compounds decomposed rapidly leading to the eradication of the offensive odour of ammonia. There was no unpleasant sight of the faeces and discharge of effluent was unnecessary (Tam and Vrijmoed, 1990). Initial addition of the bacterial product was expected to assist in the establishment of the initial microbial population in the litter bedding and subsequent additions would facilitate the sustenance of the large and active microbial activities for *in-situ* composting of pig waste. This enhancement effect on microbial activities is claimed by all the suppliers of the more than ten different bacterial products available on the market. On the other hand, pig manure itself contains a high density of bacteria with different functional groups and is biologically active (O'Neill and Phillips, 1991). The nutrient and organic matter of pig manure can also provide the necessary environmental conditions for continual proliferation of the bacterial population. This view is reinforced by Tam (1995) who showed that the addition of commercial bacterial product had no significant effect on the microbial population sizes and activities. Thus the significance of the commercial bacterial product is still uncertain. The present study therefore aims (1) to evaluate the effect of a commercial bacterial product on nutrient transformation of pig excreta under POL system and assess the necessity of the bacterial inoculum; and (2) to investigate the changes of organic matter and various forms of nutrients during three batches of pig rearing and the long-term performance of the *in-situ* composting process under the POL system.

MATERIALS AND METHODS

Experimental Design

A 10-month study was carried out in the experimental farm in Ta Kwu Ling Pig Breeding Centre, New Territories, Hong Kong. Eight ordinary pig pens of equal size (3.7 m^2 each, excluding the feed troughs) employing the POL system were set up. Fresh sawdust obtained from sawmills was placed on the floor at a depth of 35 cm and was used as the bedding material in each pig pen. In four pig pens labelled as "Treated Group" (four replicates), a Japan-imported bacterial product, known commercially as "Elimexal" (which the supplier claims to contain *Bacterium luwiti* at 50 million cells per g product) was added to and mixed thoroughly with the sawdust bedding at an initial inoculum size of 600 g m^{-2}. This was followed by a biweekly inoculation of 120 g m^{-2} throughout the experimental period as recommended by the supplier. Another four pig pens were used as the control, i.e. without any addition of the commercial bacterial product. After the pig pens were prepared, they were left idle for 4 days. Four piglets of similar initial weight (about 20 Kg each) were kept in each of these pig pens for 10 weeks (Batch 1). The pigs were removed and the pig pens were then left idle for 3 weeks (first idle period) before the second batch (Batch 2) of piglets were raised over another 13 weeks. The pigs were again removed and the pig pens left empty for 5 weeks (second idle period). The third batch (Batch 3) of piglets were then introduced and kept for 13 weeks. The mixing and turning of the bedding material, adjustment of moisture content, temperature changes of the air and the bedding material, and the growth and behaviour of the pigs were described by Tam (1995).

Sampling and Measurements

At each sampling, litter material (a mixture of partially degraded pig excreta and sawdust bedding) was collected at five locations (the centre and the four corners) within each pig pen and pooled together to form a composite sample for nutrient analyses. The first sample was collected immediately after the pig pens were prepared (labelled as "pre-exp" sample). The second sample was collected four days later when piglets were introduced (designated as "Day 0" sample), and on Day 1, Day 5, then weekly. The pH, moisture, conductivity, total carbon, total and inorganic nitrogen (include NH_4^+-, NO_2^-- and NO_3^--N), total and extractable P, total and extractable K were analyzed as described by Tam and Vrijmoed (1990). All nutrient data were presented on 105 °C oven dry weight basis. The mean and standard deviation of the four replicates in the treated and control group were calculated.

RESULTS

Total N, Inorganic N, Total Carbon and C:N Ratio

There was no significant difference between the control and the treated groups in all forms of nitrogen, total carbon and C:N ratios (Fig. 1). The total N content of both groups elevated significantly during the first 10 weeks (Batch 1), declined during the first idle period. The total N continuously increased to a higher level during Batch 2, dropped at idle and rose again during the third batch (Fig. 1A). The rate of increases in total N appeared to be more rapid during the first than the second batches of pig rearing, and the rate of N accumulation was slowed down at the third batch. A rapid rise of NH_4^+-N was found within the first few days, reached a peak of 6 mg g^{-1} at Week 2, and maintained at a high value till Week 10 (end of Batch 1). Similar to total N, the NH_4^+-N content also dropped during the idle periods. The rate of NH_4^+-N accumulation was also the highest during Batch 1. NO_2^--N was not detected throughout the study and the NO_3^--N was much lower than NH_4^+-N especially during the first batch (< 1 mg g^{-1} in most samples). Some accumulation of NO_3^--N was observed during the third batch and the values fluctuated between 1-3 mg g^{-1} (Fig. 1D). The pattern of changes in inorganic N throughout the study was the same as that found in NH_4^+-N. The inorganic N accounted for less than 2 % of total N (Table 1) as the nitrogenous compounds from pig waste were assimilated into microbial and organic N.

In both control and treated pig pens, there was a slight increase in total carbon from "pre-exp" to Day 0 samples due to the deposition of pig excreta. The C content then dropped rapidly from 42% to around 30% at the end of Batch 1. During the first idle period, the total C concentrations increased to 37%, probably due to the addition of fresh sawdust material for the maintenance of a constant bedding depth (Fig. 1E). Thereafter, the C level continuously declined and reached a value of around 30% at the end of the study.

In both the control and treated groups, the C:N ratios dropped dramatically within the first few days, from an initial 210:1 decreased to about 40:1 within first day and further declined to 14:1 at the end of Week 1 (Fig. 1F). After the initial drop, C:N ratio continuously dropped but at a very slow rate, reached a value of 10:1 towards the end of the study except idle periods.

pH and Conductivity

The changes in pH and conductivity value of litter material throughout the study were similar between the control and the treated pig pens (Fig. 2). There was a sharp rise in pH values within the first 1-2 days, from initial 5.2 to a peak value of 8.8, pH then decreased gradually to below 7 at the end of Batch 1. A similar pattern, an initial rapid increase followed by a gradual decline, was found in both Batches 2 and 3 (Fig. 2A). In both groups, the litter material had extremely low initial conductivity but the conductivity levels elevated sharply in the first few days. The values then increased gradually and reached a very high value towards the end of the study, above 5 mmhos cm^{-1}. A slight drop in conductivity was observed during the two idle periods as no excreta was deposited (Fig. 2B).

Total and Extractable K and P

Both the total and extractable K values increased with experimental time and there was no significant difference between the control and the treated groups (Fig. 2C & D). The accumulation of total K appeared to be more rapid during the first 10 weeks (Batch 1) than Batches 2 and 3. A slightly lower total K content was found during the idle periods. Most K was not bio-available and only less than 10% of total K was water-extractable (Table 1). The extractable K increased more rapidly during Batch 3 of pig rearing. The changes of total P during the study were similar to that of total K, again, no difference was found between the control and the treated groups. The total P concentrations increased continuously throughout the study period, with more rapid accumulation during the first than the other two batches of pig rearing. More fluctuation in extractable P content was found especially during the first batch of pig rearing. The extractable P values appeared to remain at a relatively stable level from Week 20 onwards in both control and treated groups, a pattern differed from other parameters including total P, total and extractable K.

DISCUSSION

In both the control and the treated groups, the conductivity value, content of total N, inorganic N, NH_4^+-N, total and extractable K, and total P increased continuously with experimental time except the two idle periods (Table 1). On the contrary, total carbon and C:N ratio dropped throughout the study except idle periods. These drops were very rapid during the first few weeks, indicating that active microbial respiration took place in the bedding material which oxidizes organic substrate (from both sawdust and pig waste) to carbon dioxide. The rapid microbial decomposition was also reflected by the fast accumulation of total nutrients especially total N at the beginning of the study. The speedy mineralization of organic material to atmospheric CO_2 and N-immobilization resulted a dramatic decline in C:N ratio as shown in Fig. 1 and Table 1. The continual decline of the

C:N ratios and the very narrow C:N ratio (10:1) achieved at the end of the study suggest that the litter samples might have reached maturity. Many previous studies concluded that a C:N ratio of 20:1 or 25:1 in compost could be regarded as an indication of maturity of the final product (Levi-Minzi *et al.*, 1986). The slight rise in C:N ratio during the idle periods was due to (1) addition of fresh sawdust (during first idle period) and (2) exhaustion of pig manure and the supply of nitrogenous compounds.

During idle periods, total and extractable nutrients declined while total C content and C:N ratio increased. These results suggest that no further decomposition occurred when there was no pigs kept in the pig pens, which further implies that the microbial degradation was strongly controlled by the availability of pig excreta (urine and faeces) and the process might be very rapid. Therefore degradation stopped when there was no pigs and no waste deposited onto the bedding material. Tam (1995) reported that when no pigs were kept in the pig pens during idle periods, microbiological parameters including bacterial count and biomass declined significantly.

Ammonium nitrogen levels increased rapidly in the first few weeks due to the increased microbial degradation of nitrogen-containing compounds. The release of ammonium nitrogen from N-mineralization was also reflected by the rapid increase in pH value (a peak of around 9). These results are similar to those reported by Mahimairaja *et al.* (1994). The rising temperature (around 50 °C) and pH in at the beginning of the study led to increased volatilization of ammonia and a decrease in nitrogen content (Fig. 1). This is consistent with the findings of Schwab *et al.* (1994). The decline in NH_4^+-N concentration was also due to the temporary immobilization of NH_4^+-N by microorganisms as the litter samples were rich in carbon and having a wide initial C:N ratio. Nitrates were in relatively low levels during Batch 1 and the values were more fluctuated than other nutrients. This might be related to the fact that the concentrations of nitrates were influenced by the rate of nitrification and denitrification. Denitrification is possible in aerobic composting as anaerobic pockets could be existed within the bedding material due to its high moisture contents and high biological oxygen demand (Tam and Vrijmoed, 1990). When the concentrations of total nutrients were compared with their respective extractable forms, very small proportions of total nutrients were extractable. For instance, the inorganic N in litter samples comprises less than 3% of total N (Table 1), a value similar to that reported by previous researchers (Castellanos and Pratt, 1981). Golueke (1972) also suggested that the composting of agricultural waste reduces the soluble nitrogen content due to its assimilation into microbial biomass. These findings indicate that the organic compounds from pig excreta were rapidly mineralized and immobilized into microbial cells during *in-situ* composting, probably due to the large population sizes and active microorganisms present within the bedding material (Tam, 1995).

The changes in pH, carbon, nutrient and C:N ratios at the beginning of the study were more dramatic than those recorded towards the end. The slower rates of nutrient and salt accumulation during the third than the first batch of pig rearing suggest that the aged bedding of the POL system might be more stable and had larger capacity in assimilating pig waste material. Tam and Vrijmoed (1993) have reported that the bedding material of the aged pig pens was more stable and mature.

CONCLUSION

This study clearly reveals that addition of commercial bacterial product "Elimexal" did not have any significant effect on the *in-situ* decomposition of pig wastes under Pig-on-Litter system. The litter samples collected from the treated pig pens had very similar pH, nutrient and organic carbon values to those recorded in the control groups throughout the study. The changes of nutrients and organic matter were more rapid at the beginning but slowed down towards the end of the study, indicating that the litter samples became more stable and mature. These results show that the Pig-on-Litter system could be operated on a more economical basis as (1) no addition of commercial bacterial products would be required and (2) the bedding material could be utilized for a fairly long period (at least six months or three batches of pig rearing) without replacement. However, careful control and monitoring of the environmental conditions such as ambient temperature, humidity, wind speed and degree of mixing are essential to ensure the optimal bedding condition for the microorganisms to carry out efficient and effective *in-situ* composting.

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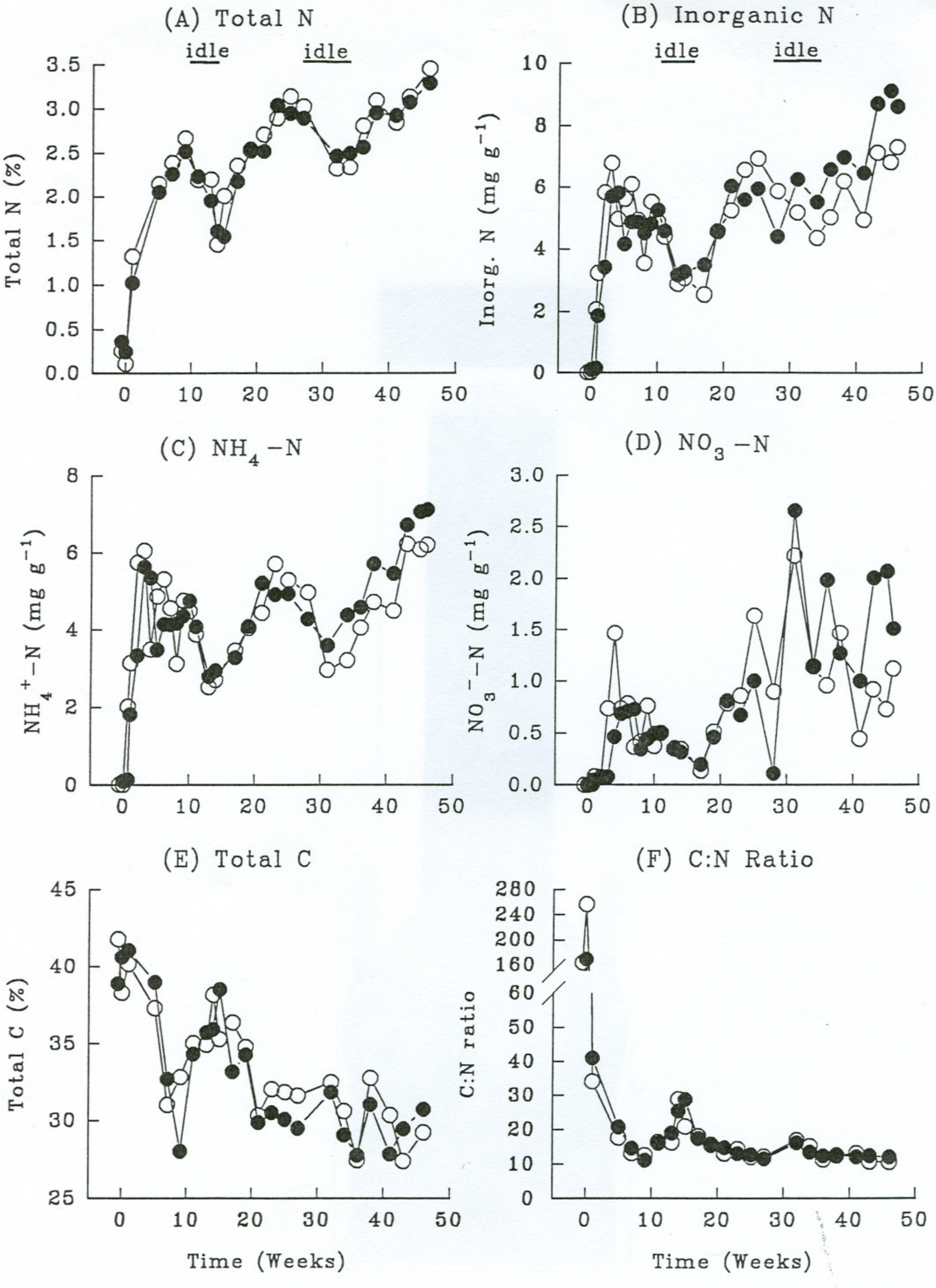

Fig. 1 Changes in total N, inorganic N, NH_4^+-N, NO_3^--N, total C and C:N ratio of litter samples during the study. (○ : control; ● : treated; the two idle periods were shown)

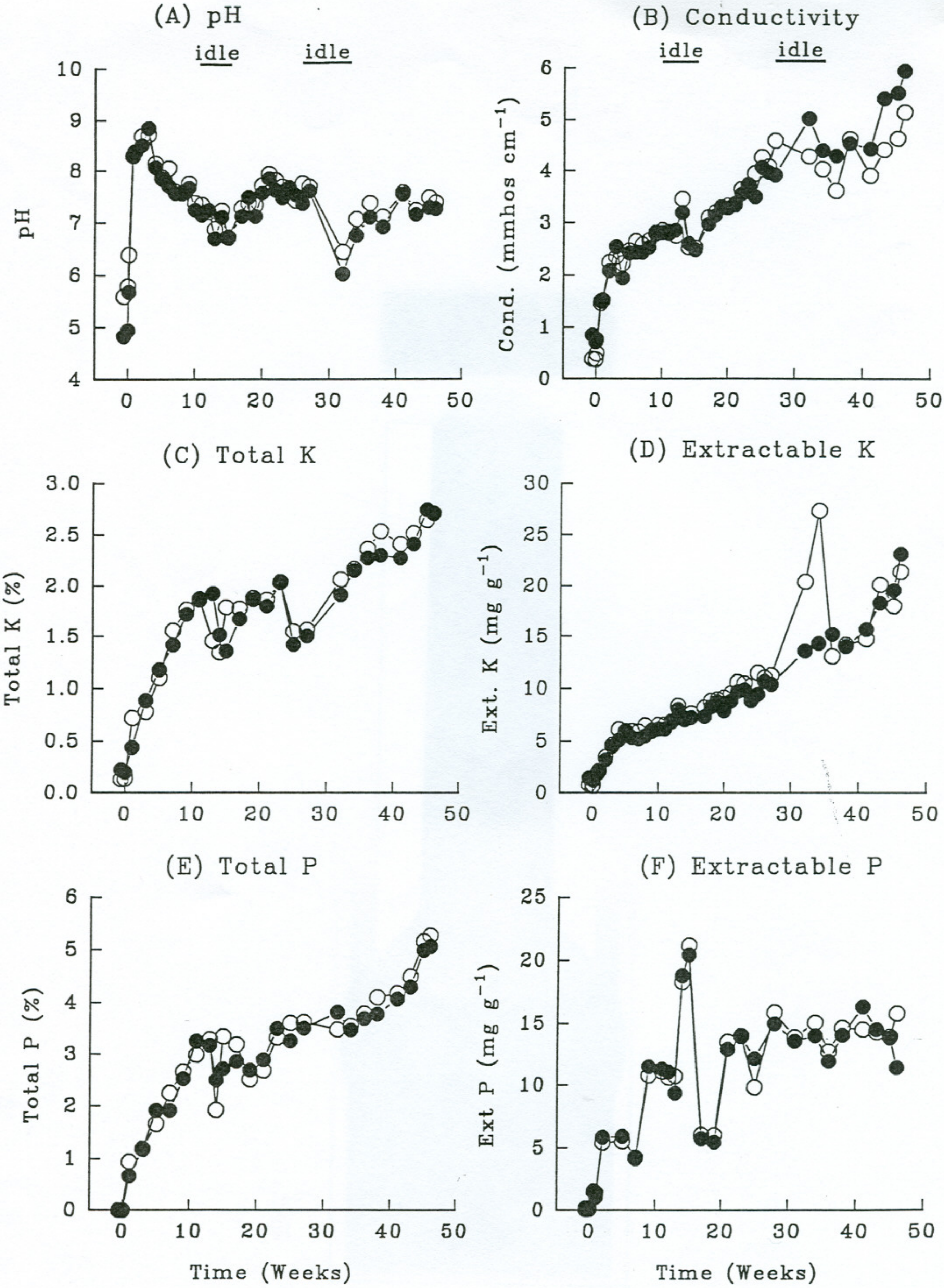

Fig. 2 Changes in pH, conductivity, total K and P, inorganic K and P of litter samples during the study. (○ : control; ● : treated; the two idle periods were shown)

Table 1 Effect of commercial bacterial product on nutrient content of litter material during *in-situ* composting.

	In-situ Composting					
	Batch 1		Batch 2		Batch 3	
	Begin	End	Begin	End	Begin	End
Parameter	Wk 0	Wk 10	Wk 14	Wk 28	Wk 33	Wk 46
pH	5.37	7.33	7.18	7.66	6.92	7.33
	(0.44)	(0.13)	(0.37)	(0.37)	(0.20)	(0.22)
Conductivity	0.55	2.84	2.56	4.25	4.22	5.54
(mmhos cm^{-1})	(0.18)	(0.37)	(0.36)	(0.95)	(0.89)	(0.93)
Total C	39.5	30.4	37.1	30.6	32.2	30.0
(%)	(2.7)	(5.9)	(1.9)	(1.9)	(4.1)	(2.2)
Total N	0.18	2.19	1.53	2.96	2.41	3.36
(%)	(0.08)	(0.28)	(0.24)	(0.20)	(0.30)	(0.25)
C:N ratio	213	11.9	27.1	11.9	14.3	11.2
	(48)	(2.8)	(4.1)	(1.3)	(1.9)	(1.6)
NH_4^+-N	0.07	4.63	3.37	4.64	3.81	6.66
(mg g^{-1})	(0.07)	(1.92)	(1.08)	(1.92)	(1.81)	(1.45)
NO_3^--N	0.002	0.44	0.17	0.51	1.14	1.31
(mg g^{-1})	(0.003)	(0.26)	(0.11)	(0.81)	(0.61)	(0.79)
Inorg. N	0.41	2.32	2.32	1.74	2.05	2.37
(% of total N)	(0.09)	(0.27)	(0.24)	(0.20)	(0.32)	(0.24)
Total P	0.004	2.59	2.21	3.56	3.51	5.17
(%)	(0.001)	(0.38)	(0.43)	(0.29)	(0.29)	(0.32)
Ext. P	0.17	11.14	18.57	15.42	14.49	13.57
(mg g^{-1})	(0.07)	(1.58)	(1.97)	(2.51)	(1.67)	(2.98)
Ext. P	42.5	4.30	8.40	4.33	4.13	2.62
(% of total P)	(0.71)	(0.32)	(0.41)	(0.25)	(0.28)	(0.32)
Total K	0.17	1.74	1.43	1.97	2.17	2.71
(%)	(0.03)	(0.20)	(0.18)	(0.27)	(0.18)	(0.16)
Ext. K	0.97	6.34	7.11	10.81	20.84	22.24
(mg g^{-1})	(0.29)	(0.67)	(0.77)	(1.83)	(9.49)	(9.15)
Ext. K	5.71	3.64	4.97	5.49	9.60	8.21
(% of total K)	(0.29)	(0.47)	(0.44)	(0.95)	(0.55)	(0.95)