ANAEROBIC DECOMPOSITION OF ORGANIC MATTER IN SUBMERGED SOILS

A Terminal Report
Submitted to the International Rice Research Institute
Los Banos, Laguna, Philippines

BY

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November 1980 - March 1983

ACKNOWLEDGEMENTS

I wish to express my profound gratitude to

- The International Rice Reserach Institute for the award of postdoctoral fellowship;
- Dr. F. N. Ponnamperuma, Principal Soil Chemist, IRRI, for his help in planning this project and for his guidance in my research work;
- Mrs. Lantin and other junior researchers, laboratory assistants, and laborers for their excellent cooperation and help;
- Mrs. Elisa M. Tabaquero and Ms. Charo Galang for undertaking the ardous task of typing this report.

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Chapter 1

RATIONALE AND DESIGN OF EXPERIMENT

Algae, azolla, straw and green manures are likely to play an important part in the future as nitrogen sources for rice in the tropics. But there is little information on the decomposition of these materials in tropical wetland rice soils. Because the rate, course and products of decomposition affect nutrient availability, and because some products may be toxic to rice, there is a need to study decomposition of organic matter in anaerobic soils. The anaerobic decomposition of organic matter in wetland rice soils depends on soil properties, kind and content of organic matter, duration of submergence, and temperature. Investigation of these factors is needed.

As reviewed in my paper (Tsutsuki, 1982, Appendix of this report) and other papers (Watanabe, 1982; Neue and Scharpensel, 1982) many works have been done to clarify the behavior of the decomposition products of organic matter in submerged soils. However, former works were rather specific to individual degradation products and few works have had synthetic view over the behaviors of many kinds of products. Added amounts of organic matter to soils in degradation studies also seems to have been higher than the practical levels.

Therefore, this study was planned to clarify the kinetics of decomposition products in 3 characteristic soils added with 3 kinds of organic materials at a practical level and incubated under submerged condition at 20°C and 35°C in the laboratory. The design of experiment and the items of analysis are described below.

Indigenous organic matter usually exist in larger amount than the added organic matter in practical case, and the decomposition of indigenous organic matter may also have important effect on the kinetics. In additional study, humus compositions of the soils for incubation experiment and the soils under different straw managements were determined.

Design of main experiment

Soils

S_1 - Pila clay loam

S_2 - Maahas clay

S_3 - Luisiana clay

Organic matter

O_1 - rice straw compost

O_2 - rice straw

O_3 - green manure

O_4 - control

Temperature

T_1 - 20°C

T_2 - 35°C

Interval of incubation

less than 10 weeks

depends on the product

Repetition - 2

Items of analysis

1. pH
2. Eh
3. Fe release
4. Ammonification
5. CO_2 formation
6. CH_4 formation
7. Volatile fatty acids
8. Phenolic acids (water soluble)
9. Phenolic acids (alkali extractable)
10. Alcohols
11. Aldehydes

Supplementary experiment

1. Humus composition of paddy soils
2. Chemical composition of organic materials.

Chapter 2

EFFECTS OF SOIL PROPERTIES, ADDED ORGANIC MATERIALS AND TEMPERATURE ON THE KINETICS OF pH, Eh, Fe^{2+}, NH_4^+, CO_2 and CH_4 IN SUBMERGED SOILS

In ferruginous Luisiana clay, kinetics of iron reduction seems to regulate the other kinetics. Formations of CO_2 and NH_4^+ may be coupled with the reduction of iron in this soil and therefore they proceeded slowly. The rates of pH and Eh changes were also slow due to the slow rate of iron reduction. Repression of decomposition at lower temperature was most marked in this soil. It may take long time until favorable condition for decomposition is attained due to the low pH of this soil.

On the other hand, high initial pH,and low active iron content of Pila clay loam caused rapid development of reduced state in this soil. Rapid decrease in Eh and rapid formation of NH_4^+ and CO_2 are all due to these characteristics of soil. Methane formation started earlier and occurred in larger amounts. Repression of ammonification, and CO_2 and CH_4 formations at low temperature were also least in this soil.

In Maahas clay, which is characterized by slightly acidic pH and medium organic matter and active iron contents, the rate of decrease in Eh was also medium among the 3 soils. However, formed amounts of NH_4^+, CO_2 and CH_4, and decomposition rates of added organic materials were least among the 3 soils.

From the composition of released CH_4 and CO_2, decomposition of organic matter in submerged soils could be separated into 3 stages.

In the first stage organic matter was decomposed to CO_2 exclusively, and the ammonification accompanied this. The second stage was featured by concurrent formation of CO_2 and CH_4, and this stage seemed to start when soil Eh became below - 0.1 V. In the third stage, organic matter is decomposed to CH_4 exclusively, and CO_2 is also used as a substrate of methanogenesis. At this stage, soil Eh was lower than - 0.2 V. Addition of rice straw and green manure to soils and increasing incubation temperature hastened the sequential change of these stages, but the high content of active iron retarded it.

INTRODUCTION

NH_4^+, CO_2, and CH_4 are stable final products of organic matter decomposition in submerged soils. Addition of organic materials and increasing temperature enhance soil reduction and change the kinetics of pH, Eh, Fe release, NH_4^+, CO_2 and CH_4. These kinetics may also differ by different soils. Many fundamental studies have been conducted on these subjects in relation to fertility and are reviewed elsewhere (1972). In view of the importance of utilizing organic materials for nitrogen source for tropical wetland rice, and in order to yield maximum benefit of organic matter amendment and to minimize its adverse effect, more information is needed for the kinetics of organic matter decomposition in submerged soils. In this paper, the kinetics of abovementioned indicies and products were studied in 3 soils applied with rice straw compost, rice straw, and green manure and incubated at 20°C and 35°C.

MATERIALS AND METHODS

The objective of this study is to clarify the kinetics of the anaerobic decomposition of 3 kinds of organic matter in 3 soils at 2 temperatures.

Three soils used here had marked difference in pH and active iron contents. Some properties of used soil samples are listed in Table 1. Pila clay loam is calcareous and slightly alkaline in pH, has higher organic matter content and lower active iron content than the other soils. Maahas clay is composed of X-ray amorphous alumino-silicates (Bajwa, 1980). It shows slightly acidic reaction and has medium organic matter and active iron contents. Luisiana clay is composed of halloysite and vermiculite (Bajwa, 1980), acidic, and has a moderate organic matter content and a high active iron content. Soils were airdried, and crushed to pass through a 2 mm sieve.

Organic materials used in this study are rice straw, rice straw-compost and green manure. Rice straw compost was made as follows. Twenty-six kg of rice straw was mixed with 830 g of $(NH_4)_2SO_4$, 600 g of calcium superphosphate, and 370 g of lime. It was piled up in a 1.5 m diameter circle, and left for 2 months in the field while being watered every 3 days. As a green manure, leaf and stem of a legume plant, <u>Gliricidia sepium</u>, was used. This plant is thoroughly naturalized in the settled areas at low and medium altitudes throughout the Philippines (Merrill, 1923). Organic materials were airdried, and ground to pass through a 2 mm sieve. Carbon, nitrogen and chemical compositions of these materials were given in Table 2.

Method of incubation for pH, NH_4^+ and gas analysis

Ten grams of soil samples and 25 mg of organic material were weighed into a 50 ml conical flask. No organic material was added for the control. After the soil and organic matter were mixed well, 20 ml of distilled water was added to the mixture, and the flask was stoppered with a silicon rubber cap. The air in the flask was replaced to argon by repeating evacuation and flushing of argon 3 times through a needle injected to the silicon stopper. The flask was further sealed by paraffin and incubated at 20°C and 35°C in an anaerobic incubator, the inner atmosphere of which was replaced to argon every week.

Gas analysis

After incubation, the flask was shaken by hand for 1 min, and the head space gas (0.1 ml or 0.5 ml) was collected through a silicon rubber cap with a gas tight syringe which had been previously washed and filled with 0.1 ml or 0.5 ml of helium. The collected head space gas was then injected to a gas chromatograph.

Gas-chromatography for Ar and CH_4

A Varian aerograph model 1868 equipped with a FID detector and a TC detector was used. A stainless steel column (6 ft x 1/4 inch O. D. x 1/6 inch I. D.) packed with Molecular Sieve 5A (30/60 mesh) was used. Helium was used as carrier gas at a flow rate of 50 ml/min. Flow rates of hydrogen and air for FID detector were 30 ml and 300 ml/min, respectively. Temperature of injector and column was 23°C, and the detector temperature was 110°C. TCD current was 120 mA. Argon was detected by TCD and CH_4 was detected by FID by switching detectors from TCD to FID. The concentration of CH_4 was estimated from the peak height ratio of CH_4 to argon.

Gas chromatography for Ar and CO_2

A stainless steel column (6 ft x 1/4 inch O. D. x 1/6 inch I. D.) packed with Porapak Q (50/80 mesh) was used. Carrier gas was helium at 50 ml/min. TC detector was used to detect argon and CO_2. The temperature of injector and column was 100°C and detector temperature was 130°C. TCD current was 80 mA. Concentration of CO_2 was estimated from the peak height ratio of CO_2 to argon.

pH

After the analysis of head space gas was finished, the silicon rubber stopper of the flask was removed, and a glass electrode and a salt bridge in a slender plastic tube, the other end of which was dipped in a saturated KCl solution with a calomel electrode, were immersed into the soil suspension immediately. The pH value was read 3 minutes after immersing electrodes.

NH_4^+

The content of the flask after pH measurement was transferred to a 100 ml plastic bottle with 80 ml of 12.5% KCl and shaken for 1 hour. After shaking, the bottles were left still overnight. Twenty-five ml of the supernatant was taken by a pipet and distilled for NH_4^+ measurement. The distillate (about 30 ml) was collected in a 50 ml conical flask containing 5 ml of 2% boric acid with BCG-MR mixed indicator and titrated with 1/200 N H_2SO_4.

Eh and Fe^{2+}

Each forty gram of soil sample (Pila, Maahas, and Luisiana) was weighed into a 125 ml Erlenmeyer flask. Besides the control treatment with no organic matter addition, each 100 mg of airdried and ground compost, rice straw or green manure was mixed with the soil in the flask. The soil sample was submerged by about 40 ml of water, put into a vacuum desiccator and deaerated under reduced pressure. After deaeration, the flask was filled with water nearly to the mouth, capped with a rubber stopper with two holes through which a bright platinum electrode and a capillary tube were inserted. The platinum wire was buried into the soil layer while the capillary tube was short enough to leak out the emerged gas. The prepared flasks were incubated at 20°C and 35°C and analyzed for Eh and Fe^{2+} periodically. Each treatment was replicated twice.

The potential of the platinum electrode was read against a saturated calomel electrode. An agar salt bridge in a slender plastic tube was used for the liquid junction to the calomel electrode.

Ferrous iron concentration in the supernatant was determined colorimetrically by o-phenanthrolin. For this purpose, 0.5 or 1.0 ml of the supernatant solution was pipetted out of the flask, and colored by 6 ml of color reagent (1 ml of 5% NH_2OH-HCl + 2 ml of 0.1% o-phenanthrolin + 3 ml of acetate buffer which contains 17.2% of sodium acetate and 0.6% acetic acid).

After measuring Eh and Fe^{2+}, the flask was filled again with water and kept in an incubator.

RESULTS AND DISCUSSION

Kinetics of pH

Kinetics of pH in 3 soils with different organic materials are shown in Figure 1.

Within 2 weeks of submergence at 35°C, the pH of Maahas clay and Luisiana clay increased and that of Pila clay loam decreased to reach a plateau between 6.8 and 7.1. The decrease in pH of Pila clay loam may be due to the shifting in carbonate equilibrium caused by the active CO_2 formation (Ponnamperuma, 1972). On the other hand, the increase in the pH of Maahas clay and Luisiana clay may be due to the consumption of H^+ ions through the reduction processes occurring in the soils.

At 20°C, pH changed more slowly than the pH at 35°C. The effect of temperature on the pH change was largest in Luisiana soil which had the lowest initial pH and highest content of active iron.

Addition of rice straw and green manure urged the change of pH in every soil especially at low temperature (20°C). Green manure was more effective in the enhancement of pH change.

Kinetics of Eh

As shown in Figure 2, Eh of submerged soils at 20°C decreased steeply within 24 hours. This decrease was most prominent in Pila clay loam which is rich in easily decomposable organic matter and poor in active Fe. The minimum Eh value in Pila clay loam reached nearly -400 mV.

The initial decrease in Eh was less drastic in Maahas and Luisiana clays especially when no organic matter was added. Addition of green manure, however, stimulated the initial decrease of Eh in these soils. In Luisiana clay, initial decrease of Eh was less than that in Maahas clay. Hydrogen and electromotive organic matter systems have been assumed to be the cause of initial decrease of Eh in the early stage of submergence (Yamane and Sato, 1968; Ponnamperuma, 1972). However, the redox system prevailing in the early stage of submergence seems to be poor in its reducing capacity because Eh returned to high level again within a few days. Manganese or iron system may determine the soil Eh at this time.

After recovering from the initial minimum after 2 or 3 days of submergence at 20°C, Eh started to decrease again. Eh of Pila clay loam was lowest and decreased most rapidly among the 3 soils. It reached lower than -200 mV within 2 weeks and decreased gradually to -250 mV by the seventh week.

In Maahas and Luisiana clay, Eh decreased more slowly. However, additions of green manure and rice straw enhanced the rate of Eh decrease (Fig. 3). This enhancement may be due to the stimulation of iron reduction. The Eh of Luisiana clay decreased more slowly than that of Maahas clay. After reaching -250 mV, the Eh of submerged soils were stable and did not decrease any more.

By increasing the incubation temperature from 20°C to 35°C, Eh of submerged soils decreased more rapidly to the lowest constant value near -250 mV. Other features were similar between 35°C and 20°C except that initial steep decrease of Eh was not observed at 35°C.

The hydrogen redox system or organic redox system, which caused the initial steep decrease of Eh at 20°C, may be masked by the other redox systems such as manganese system and iron system with larger buffering capacity at 35°C.

Kinetics of Fe^{2+} release

Luisiana clay released largest amount of Fe^{2+} in the supernatant, and followed by Maahas clay and Pila clay loam in this order (Fig. 4). Iron reduction was enhanced by the addition of green manure and rice straw, while compost had only slight or no effect in these soils (Fig. 5). The increase in temperature from 20°C to 35°C brought about the increase in the rate and amount of Fe^{2+} release in the early period of incubation. Ferrous iron was not released to supernatant water for the first 6 days at 20°C, but large amount of Fe^{2+} was detected at 35°C.

In Maahas clay, Fe^{2+} concentration decreased after reaching the maximum level (50 ppm) after 2 weeks at 35°C and after 5 weeks at 20°C.

In Pila clay loam, Fe^{2+} release was so little that the concentration in the supernatant did not exceed 10 ppm. Neither addition of organic materials nor the increase of temperature enhanced the Fe^{2+} release in this soil.

The difference in released amount of Fe^{2+} was more than expected from the difference between the contents of active iron in Maahas clay and Luisiana clay. The iron in Luisiana clay may exist in a more easily reducible form than that in Maahas clay.

Kinetics of NH_4^+ formation

Kinetics of NH_4^+ formation at 20°C and 35°C are compared in Figure 6.

Ammonification in submerged soils could be separated into two stages when soils were incubated at 35°C. In the first stage, which lasted for the first 2 weeks, NH_4^+ concentration increased rapidly and drastically. In the second stage, which started after 2 weeks, NH_4^+ concentration increased at slower and almost constant rate. Ammonification was still going on after 8 weeks in Pila clay loam and Maahas clay, but it hit the ceiling after 8 weeks in Luisiana clay at 35°C.

Also at 20°C, bimodal pattern of NH_4^+ formation was observed in Pila clay loam at 20°C, but the formation pattern of NH_4^+ could not be separated into 2 stages in Maahas and Luisiana clays. The pattern was parabolic in Maahas clay and a lag of NH_4^+ formation was observed between 2-4 weeks in Luisiana clay. Depression of ammonification due to the decrease in temperature was most marked during the first 2 weeks of incubation in every soil.

Difference between the NH_4^+ contents of amended soils and the control soil was calculated and shown in Figure 7.

Addition of rice straw compost at 0.25% level slightly increased the ammonification by the extent of 0-15 mg N/kg soil. In Luisiana clay, the mineralization of compost nitrogen was slower but larger than in the other soils.

Addition of rice straw depressed the mineralization of nitrogen by 10-20 mg N/kg soil compared with the control. The immobilization of nitrogen due to rice straw addition occurred earlier and in larger amounts at 35°C than at 20°C. Immobilization occurred rapidly in Pila clay loam and Maahas clay, but slowly in Luisiana clay.

Contrarily to rice straw, large amount of nitrogen was mineralized from green manure. At 20°C, the increase in ammonification was largest in Pila clay loam (40 mg), and followed by Maahas clay (34 mg) and Luisiana clay (26 mg). In Pila clay loam, mineralization of nitrogen in green manure was completed within 2 weeks, however, it was continuing slowly even after 6-8 weeks of incubation in Maahas soil and Luisiana soil. At 35°C larger amount of nitrogen (50-55 mg N/kg soil at the maximum)was mineralized from green manure than at 20°C. Mineralized amounts were similar among the 3 soils, but the rate of mineralization differed by soils; it was very fast and completed within 2 weeks in Pila clay loam and Maahas clay but it reached maximum after 6 weeks in Luisiana clay.

Kinetics of CO_2

Kinetics of CO_2 in 3 soils applied with 3 organic materials are compared at 20°C and 35°C (Figure 8). Formation of CO_2 was most active in Pila clay loam, reflecting the large content of easily decomposable organic matter and the favorable condition for microbial activity due to the slightly alkaline reaction. Carbon dioxide was formed in large amount within the first 1-2 weeks, and formed at a slower rate after that period at 35°C. At 20°C, CO_2 formation in Pila clay loam was less than half of the formation at 35°C, and it was formed at much slower rate. Addition of compost caused a slight increase in CO_2 formation while the additions of rice straw and green manure caused a remarkable increase (1.3-1.6 times in the first 1 week at 35°C).

Formation of CO_2 was also large in Luisiana clay, but it was not so rapid as in Pila clay loam. Slow formation of CO_2 in Luisiana clay may be coupled with the reduction of ferric oxide in the soil. The increase in temperature and addition of rice straw and green manure also enhanced the CO_2 formation in the soil.

In Maahas clay, CO_2 formation reached maximum after 2 weeks at 35°C and after 4 weeks at 20°C. After reaching the maximum, CO_2 level decreased gradually at 35°C or remained almost constant at 20°C Formed amounts of CO_2 were lower than those in Pila and Luisiana clays, and the effects of temperature increase and organic matter application were also smaller. The reason for the poor CO_2 formation in Maahas soil may be attributed to low contents of both active iron and easily decomposable organic matter.

Asami and Takai (1970) reported a high correlation between CO_2 formation and iron reduction. A large CO_2 formation from Pila clay loam with low active iron content is contradictory to this finding. In addition to the coupling with iron reduction, CO_2 might have come from other fermentation processes in this soil.

Kinetics of CH_4

Methane concentration increased rather exponentially in submerged soils. This is shown by the almost linear increase of P_{CH_4} in Figure 9. When CH_4 concentrations after 1 week of submergence were compared, activity of CH_4 formation was higher in the order of Pila clay loam > Maahas clay > Luisiana clay. This order may reversely reflect the amounts of active iron in soils because high active iron content represses CH_4 formation.

However, after 2 weeks at 35°C or 6 weeks at 20°C when reduced state developed well in soils, CH_4 concentration in Luisiana clay exceeded that of Maahas clay. Some property of Maahas clay may be repressive for the decomposition of organic matter.

Comparison of CO_2 and CH_4 kinetics and the decomposition rates of added organic materials

Kinetics of CO_2 and CH_4 are compared in Figures 10 and 11. From the kinetics of CO_2 and CH_4, decomposition of organic matter in submerged soils may be separated into 3 stages. In the first stage, organic matter is decomposed to almost 100% CO_2. In the second stage, CO_2 formation and CH_4 formation occur concurrently. In the third stage, final decomposition product is 100% CH_4. In this stage, transformation of CO_2 to CH_4 is also assumed. The first stage also corresponds to the stage of active ammonification. Duration of each stage differed by soils, added organic materials and incubation temperatures.

At 20°C, the first stage lasted long, and CO_2 was the dominant final decomposition product. In the control and compost treatment of Maahas clay and Luisiana clay, CH_4 formation was insignificant during the whole incubation period of 8 weeks at 20°C. Addition of rice straw and green manure enchanced CH_4 formation, but CO_2 was still the dominant final product in each soil.

By increasing incubation temperature from 20°C to 35°C, both CO_2 and CH_4 formations were enhanced tremendously. In Pila soil, CH_4 and CO_2 were formed concurrently already after 1 week of incubation, CO_2 formation was almost completed within 2-4 weeks, and CH_4 formation predominated after that.

In Maahas clay, both formations of CO_2 and CH_4 were less than the other soils at 20°C and 35°C. Formation of CO_2 in Maahas clay reached maximum after 1-2 weeks of incubation at 35°C. After that time, CH_4 was the dominant decomposition product and transformation of CO_2 to CH_4 may be suggested from the decrease in CO_2 concentration.

In Luisiana clay large amounts of CO_2 and CH_4 were formed at 35°C, but it occurred in much slower rate than in Pila clay loam. All 3 stages of CO_2 and CH_4 formation were recognized in the kinetics in Luisiana clay at 35°C (Fig. 11). Addition of rice straw and green manure urged the sequential change of stages.

Comparison of the kinetics of CH_4, CO_2 and Eh suggests that the second stage corresponds to soil Eh approximately below - 0.1 V and the third stage below - 0.2 V.

In Tables 3 and 4, amounts of gasified carbon after 8 weeks of incubation are shown. As mentioned above, amounts of gasified carbon increased tremendously by adding rice straw and green manure to soils and by increasing temperature. The rate of CH_4-carbon to the total gasified carbon also increased by rice straw and green manure treatments and by increasing temperature. This rate was higher in the order of green manure treatment > rice straw treatment >> control = compost treatment in every soil at both temperature.

Methane was the major decomposition product in all the treatments of Pila clay loam and Luisiana clay and in the rice straw and green manure treatments of Maahas clay at 35°C. Carbon dioxide was the major decomposition product in all the treatments of all 3 soils at 20°C and in the control and compost treatments of Maahas clay at 35°C.

The rate of decomposition of added organic material was estimated by the ratio of the increment in total gasified carbon and the amount of carbon in added organic materials. This value is shown in Table 5. Because there may be a priming effect by added organic materials on the decomposition of indigenous soil organic matter, the real value for the decomposition rate of added organic matter will be smaller than the calculated values in Table 5. Decomposition rate of compost was very low: it was at most 18% in Pila clay loam at 35°C. Decomposition rate of rice straw was 39% in Pila clay loam but it was about 7% in Maahas clay and Luisiana clay at 20°C. Increasing temperature to 35°C caused a remarkable increase in the decomposition rate of rice straw. It was 77% and 72% in Luisiana clay and Pila clay loam, respectively. However, decomposition rate in Maahas clay (41%) was considerably lower than the rates in the other soils. Decomposition rates of green manure were slightly higher than those of rice straw and the same trend as that of rice straw was observed among the decomposition rates at different temperatures and in different soils.

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Table 1. Characteristics of soil samples.

Soil type	pH	Carbon	Total N %	Active Fe
Pila clay loam	7.2	2.48	0.204	0.32
Maahas clay	6.0	1.43	0.140	1.39
Luisiana clay	5.4	1.56	0.117	1.89

Carbon : Walkley and Black (1935)
Total N : Kjeldahl Method
Active Fe : Asami and Kumada (1959)

Table 2. Analyses of the organic materials.

Material	Carbon %	Total N	C/N
Rice straw	39.6	0.56	70.5
Rice straw compost	14.2	1.69	8.4
Green manure	45.8	3.21	14.3

Source:

Walkley and Black, I. A. 1934. An examination of the method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37: 29-38.

Asami, T. and Kumada, K. 1959. A new method for determining free iron in paddy soils. Soil Plant Food, (Tokyo) 5: 141-146.

Table 3. Amounts of gasified carbon after 8 weeks of incubation at 20°C.

Soil	Treatment	Added C mg/kg soil	CH_4-C mg/kg	CO_2-C mg/kg	Total mg/kg	$\frac{CH_4}{Total}$ (%)
Pila						
	control	0	53	229	282	19
	compost	355	31	246	277	11
	rice straw	990	278	393	671	41
	green manure	1145	344	360	704	49
Maahas						
	control	0	0.9	128	129	0.7
	compost	355	1.2	155	156	0.8
	rice straw	990	43	151	194	28
	green manure	1145	88	126	214	41
Luisiana						
	control	0	4.3	164	168	2.5
	compost	355	4.4	164	168	2.6
	rice straw	990	59	180	239	25
	green manure	1145	120	196	316	38

Table 4. Amounts of gasified carbon after 8 weeks of incubation at 35°C.

Soil	Treatment	Added C mg/kg soil	CH_4-C mg/kg	CO_2-C mg/kg	Total mg/kg	$\frac{CH_4}{Total}$ (%)
Pila						
	control	0	762	373	1135	67
	compost	355	778	420	1198	65
	rice straw	990	1399	451	1850	76
	green manure	1145	1540	451	1991	77
Maahas						
	control	0	41	112	153	27
	compost	355	47	131	178	26
	rice straw	990	420	139	559	75
	green manure	1145	513	122	635	81
Luisiana						
	control	0	280	249	529	53
	compost	355	264	311	575	46
	rice straw	990	793	498	1291	61
	green manure	1145	1057	466	1523	69

Table 5. Decomposition rate of added organic materials after 8 weeks of incubation.

Treatments	Added C mg/kg soil	At 20°C Increased gasified C mg/kg soil	At 20°C Decomposition %	At 35°C Increased gasified C mg/kg soil	At 35°C Decomposition %
Pila clay loam					
+ compost	355	- 5	-1.4	63	18
+ rice straw	990	+ 389	39	715	72
+ green manure	1145	+ 422	37	856	75
Maahas clay					
+ compost	355	+ 27	7.6	25	7.0
+ rice straw	990	+ 65	6.6	406	41
+ green manure	1145	+ 85	7.4	482	42
Luisiana clay					
+ compost	355	0	0	46	13
+ rice straw	990	+ 71	7.2	762	77
+ green manure	1145	+ 148	13	994	87

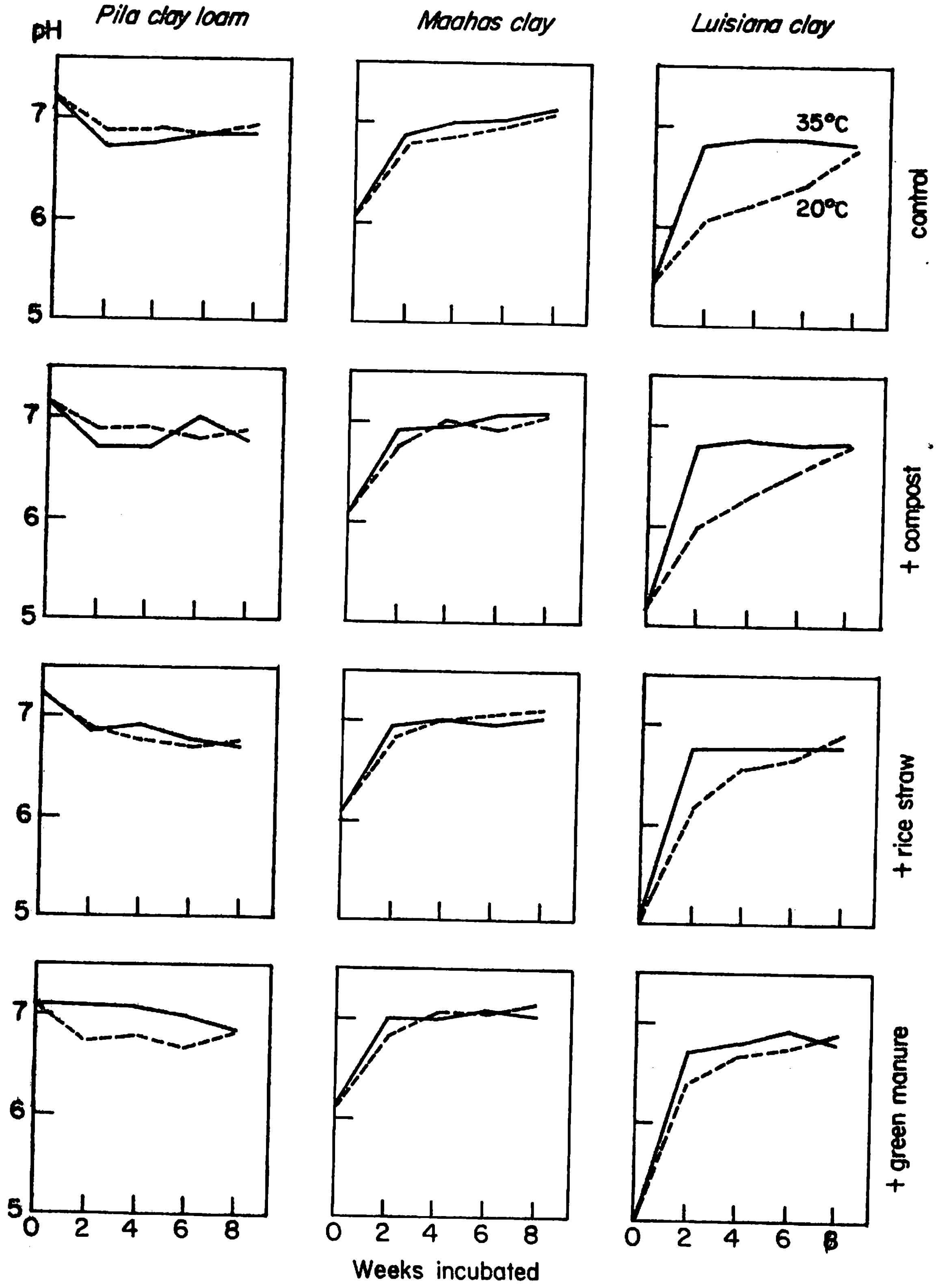

Fig. 1. Kinetics of soil pH as affected by temperature and added organic materials (soil: water = 1:2)

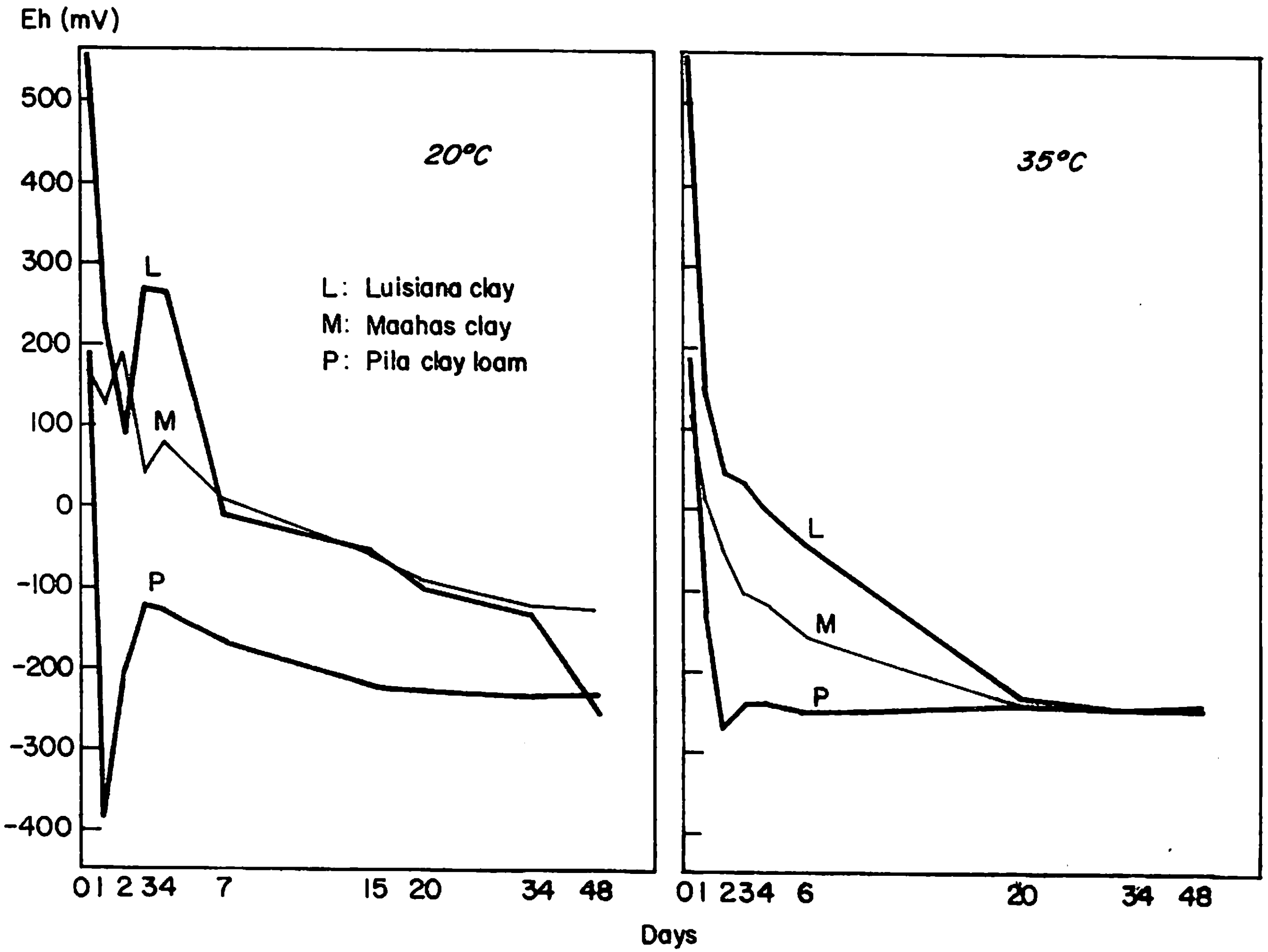

Fig. 2. Effect of temperature on the kinetics of Eh in submerged soils

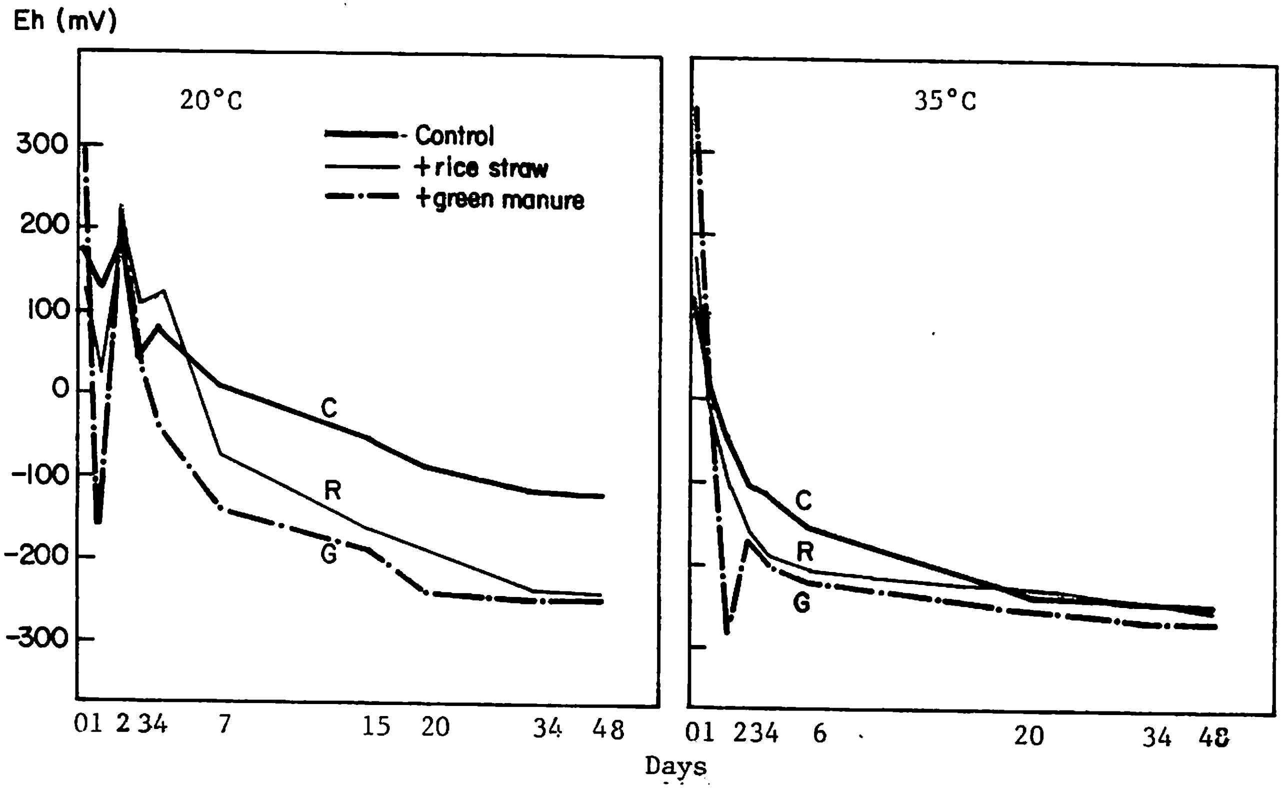

Fig. 3. Effect of organic materials (0.25%) on the kinetics of Eh in submerged Maahas clay at 20°C and 35°C

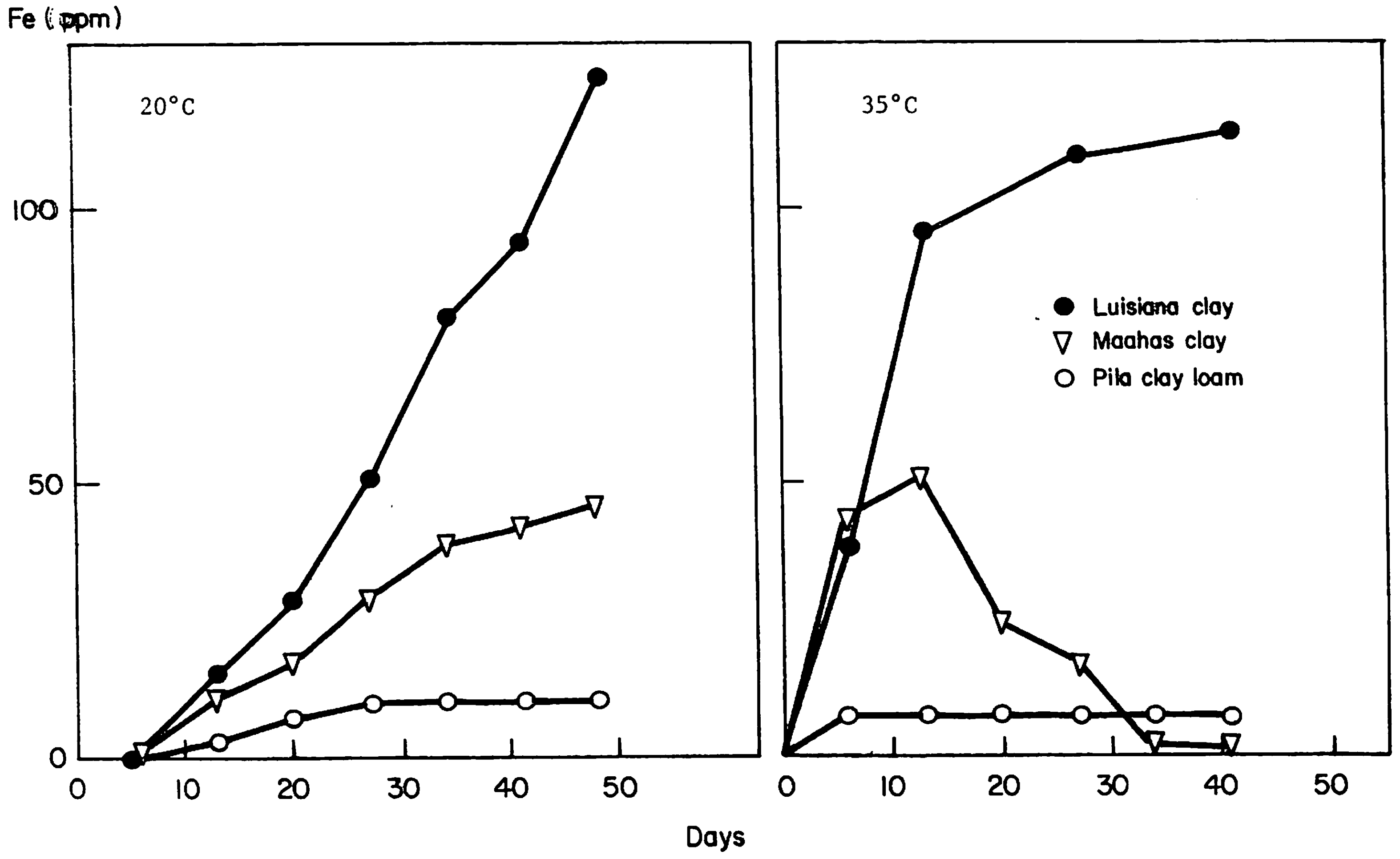

Fig. 4. Effect of temperature on the kinetics of Fe^{2+} in submerged soils applied with 0.25% rice straw

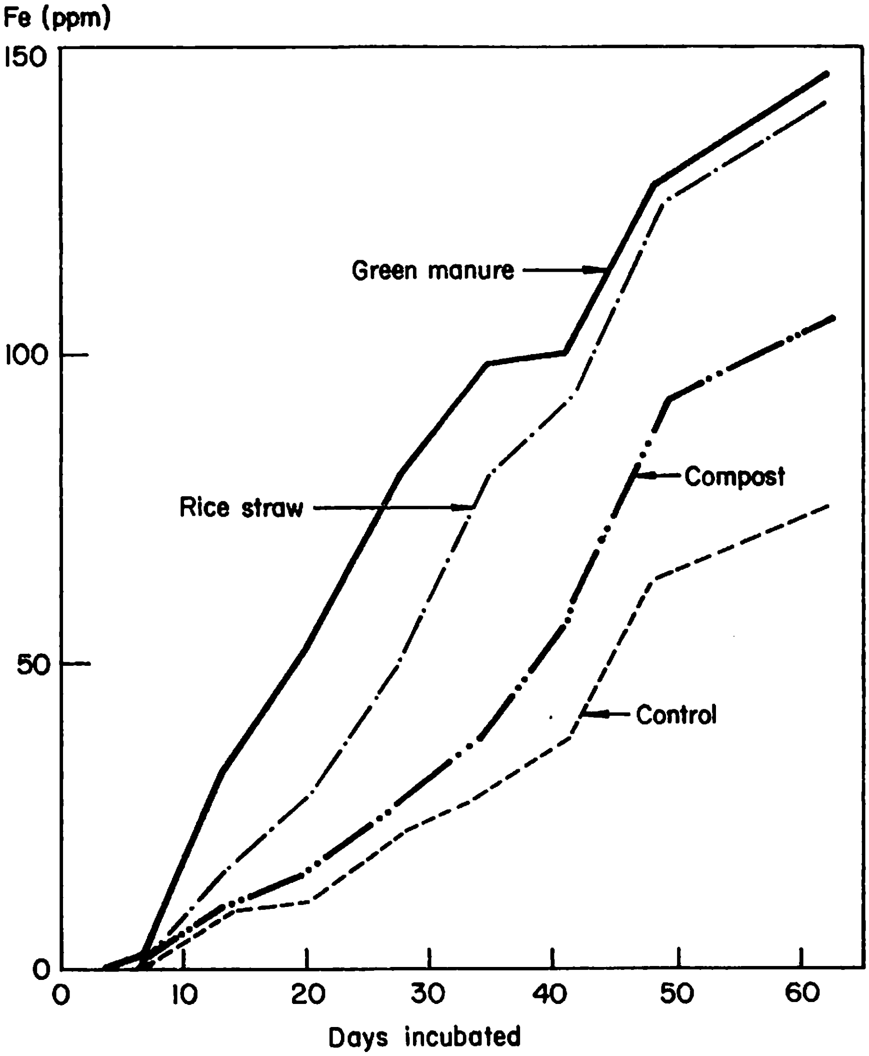

Fig. 5. Effect of organic materials (0.25%) on the kinetics of Fe^{2+} in submerged Luisiana clay at 20°C

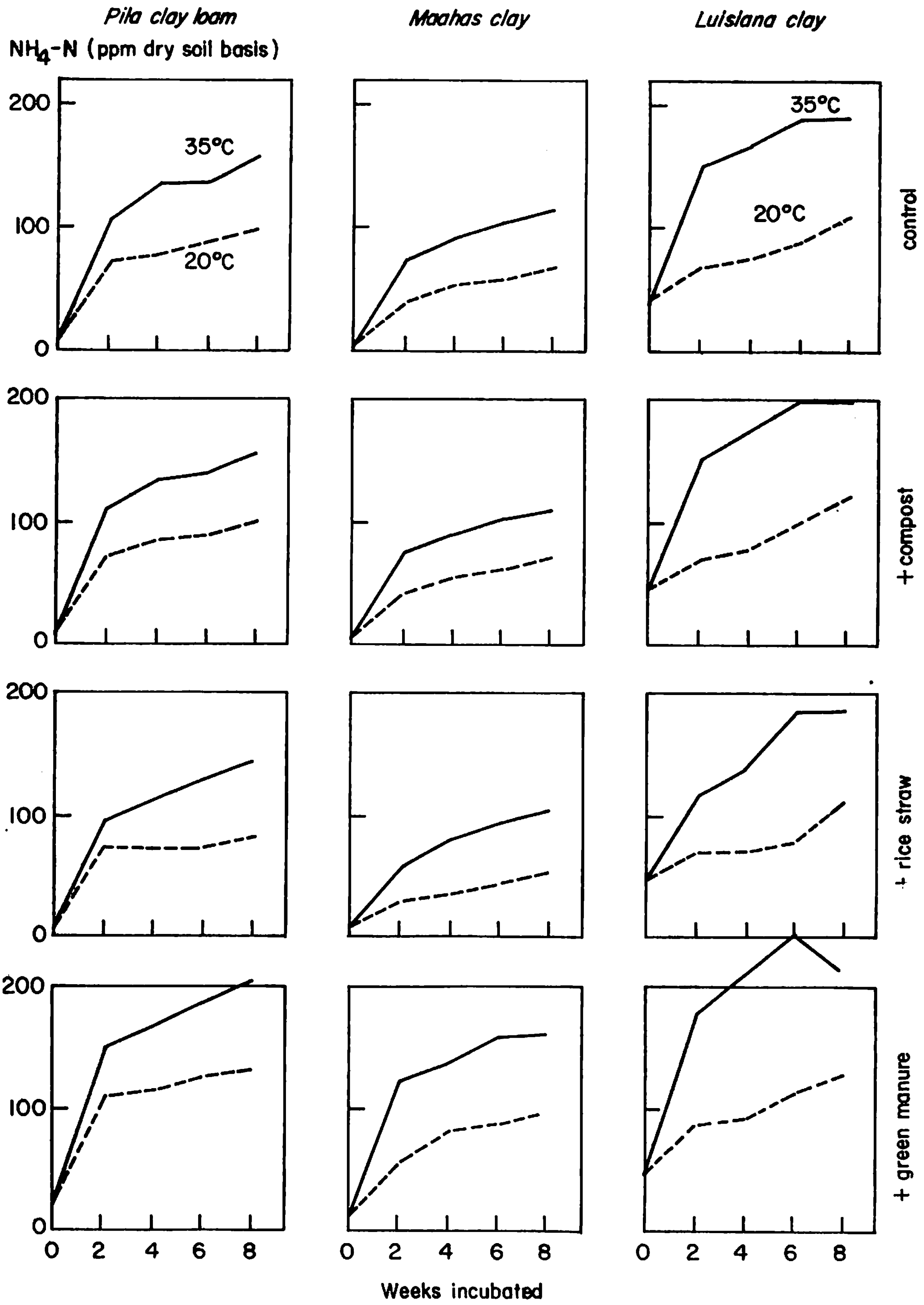

Fig. 6. Kinetics of NH_4^+ formation in submerged soils as affected by temperature and added organic materials (0.25%)

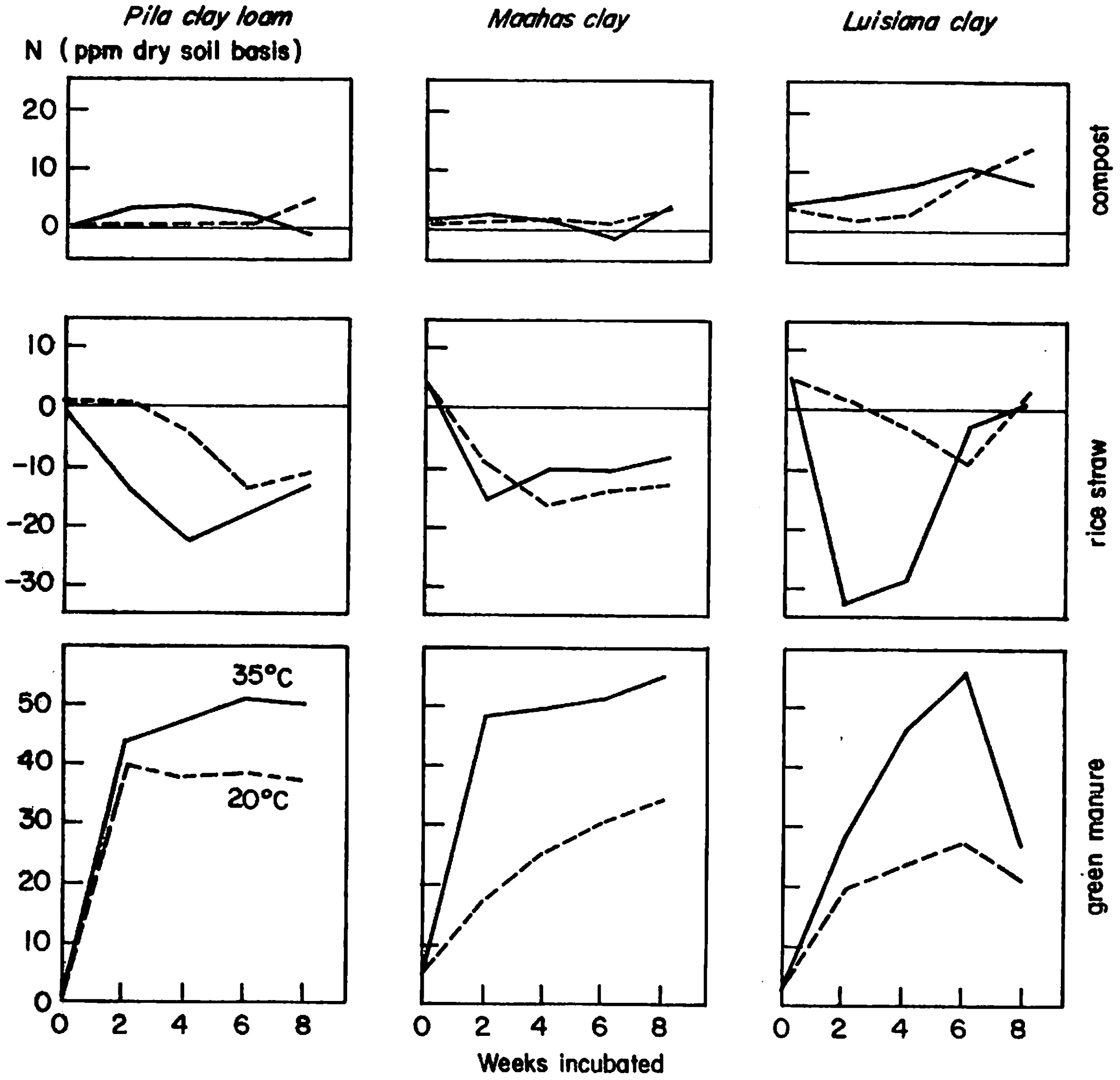

Fig. 7. Kinetics of N release and immobilization by added organic materials as affected by soil properties and temperature

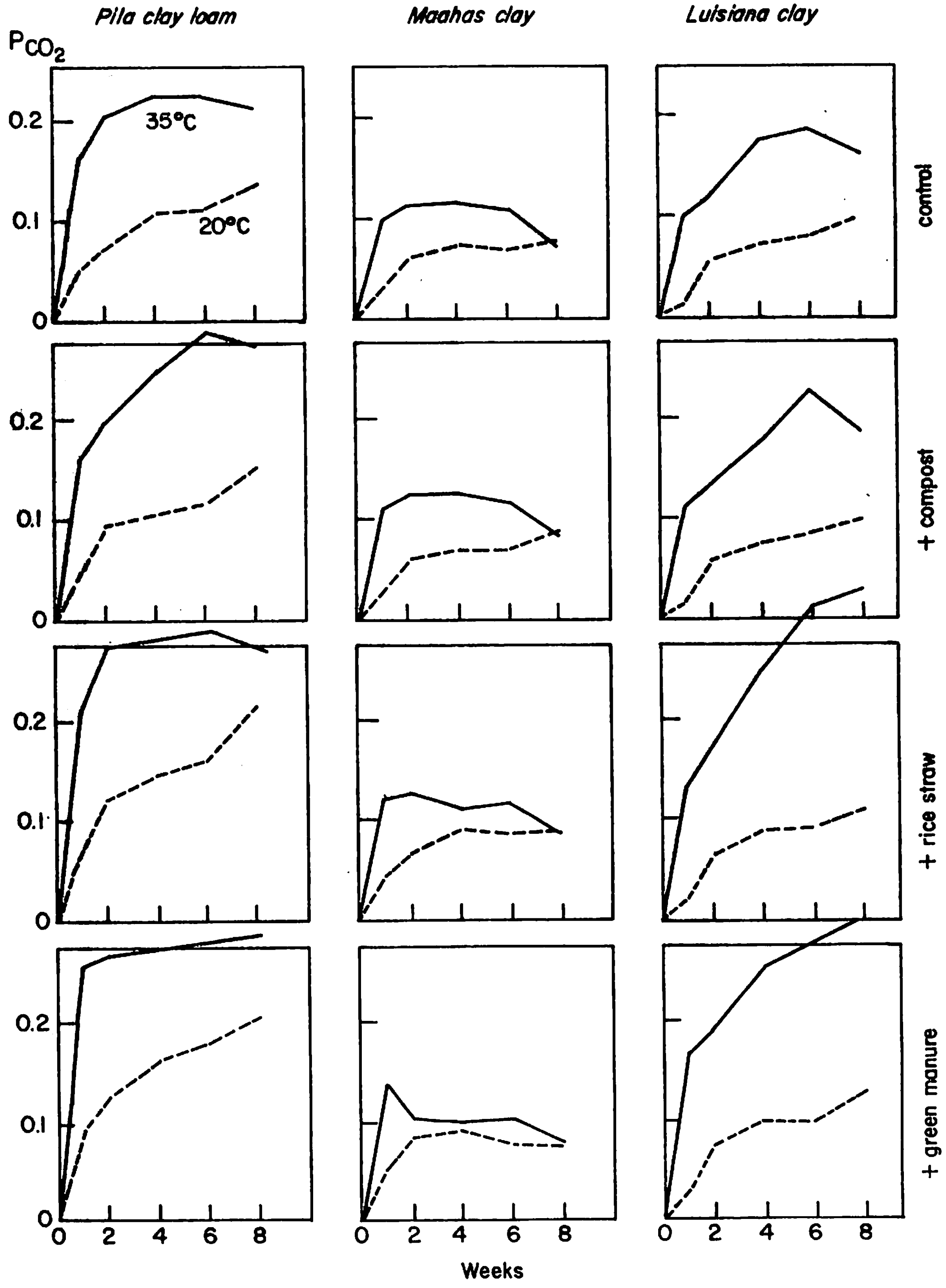

Fig. 8. Kinetics of CO_2 in submerged soils as affected by temperature and added organic materials (0.25%)

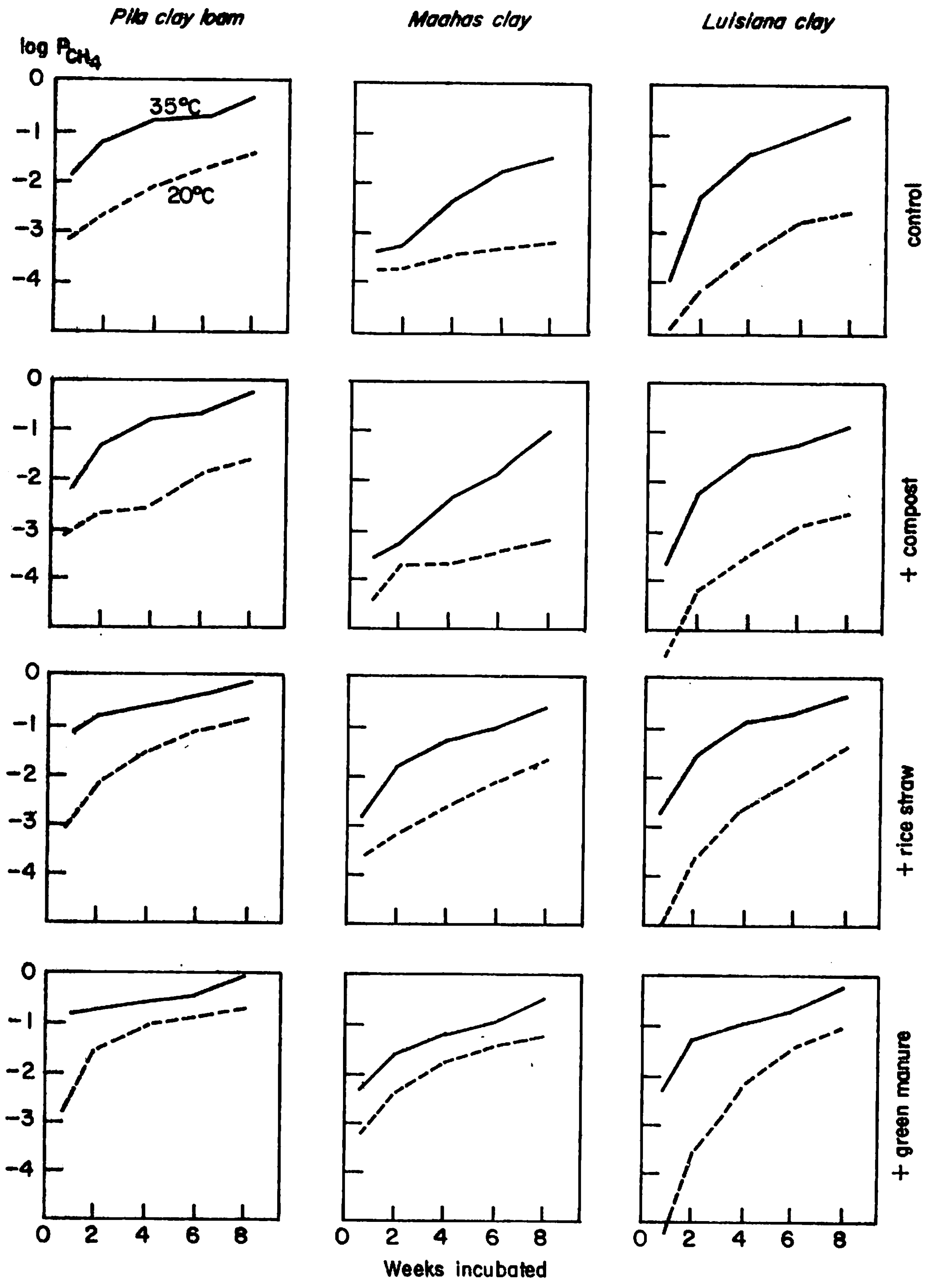

Fig. 9. Kinetics of CH_4 in submerged soils as affected by temperature and added organic materials (0.25%)

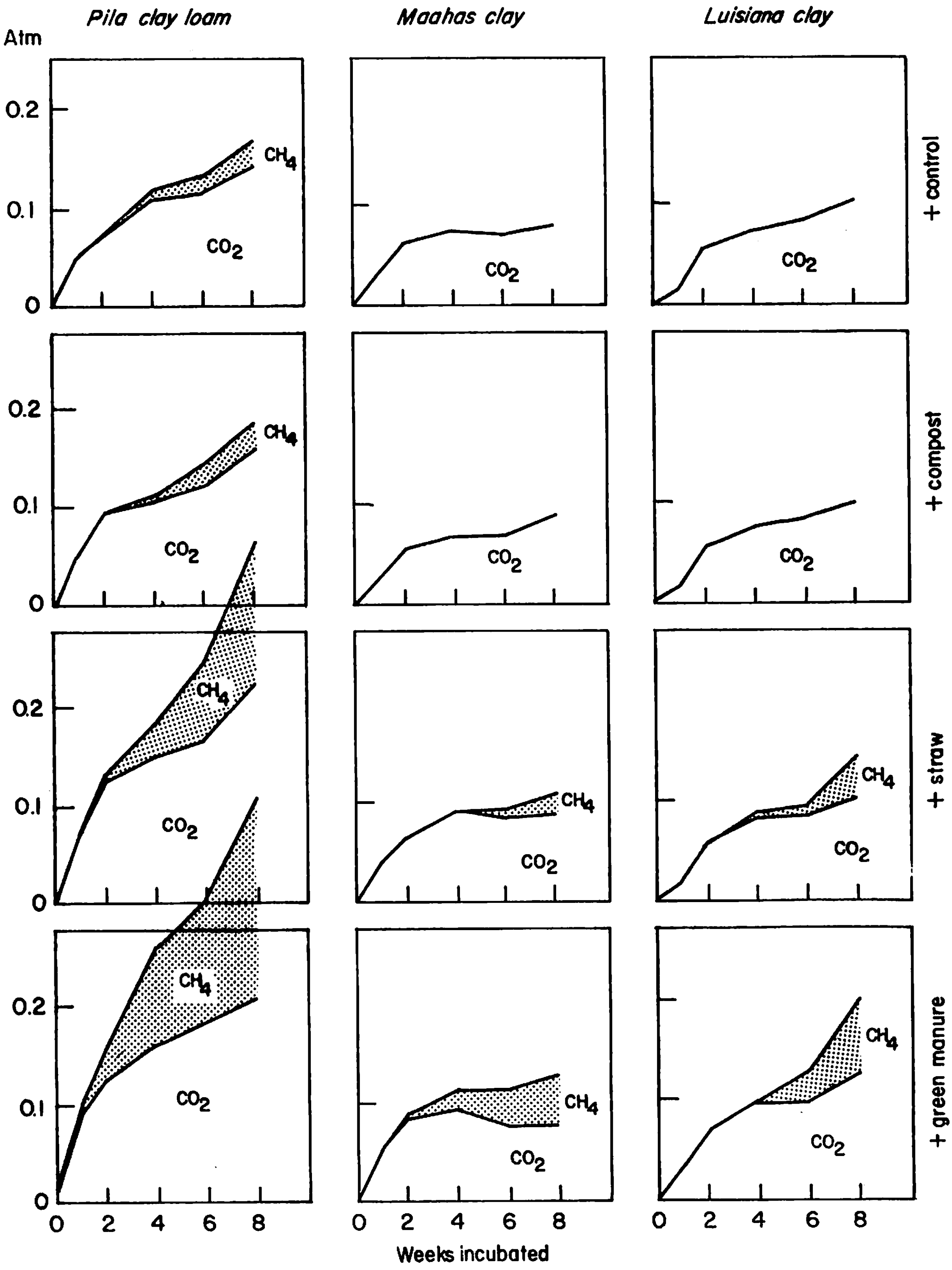

Fig. 10. Kinetics of CO2 and CH4 in submerged soils at 20°C

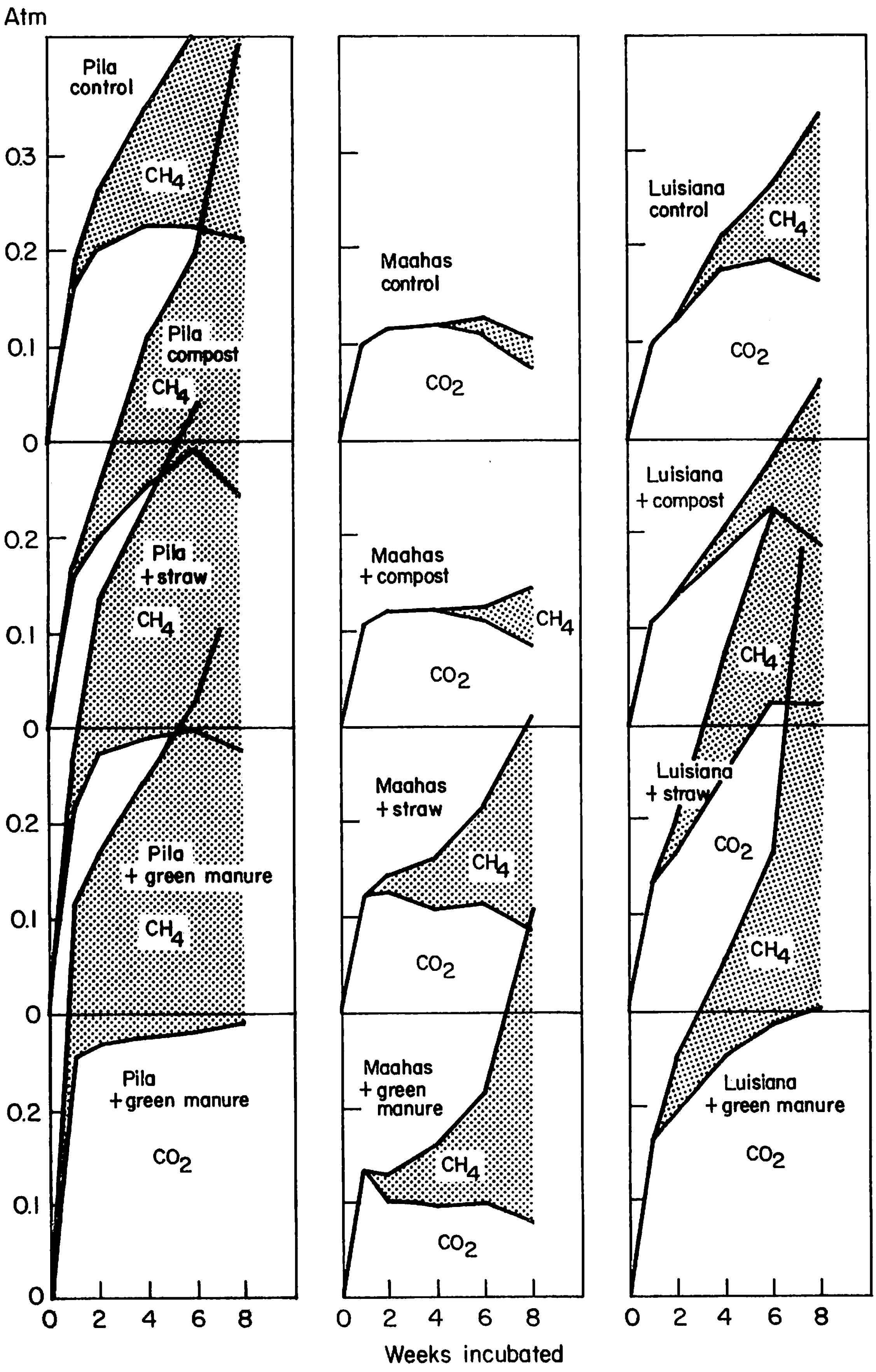

Fig. 11. Kinetics of CO_2 and CH_4 in submerged soils at 35°C