toxic substances in stubbles to elucidate the cause of poor growth of successively grown crops. His co-worker Borner (1955, 1956) detected p-hydroxybenzoic acid, p-coumaric acid, and ferulic acid in the straw and stubble of rye, wheat, and barley. The quantitative determination of phenolic acids in soils was accomplished by Whitehead (1964), who found p-hydroxybenzoic acid, vanillic acid, p-coumaric acid, and ferulic acid in 4 soils, each at a concentration lower than 0.05 mM. Phenolic acids have been assumed to be growth inhibitors for dryland crops (Wang et al 1967b), the phytotoxic substances associated with the decomposition of plant residues in anaerobic soil (Patrick 1971), and the cause of phytotoxic effects of decomposing rice residues in soil (Chou and Lin 1976).

Kuwatsuka and Shindo (1973) determined phenolic acids extractable with a methanol-0.1 N NaOH mixture from both fresh rice straw and decomposing rice straw to be p-coumaric, ferulic, p-hydroxybenzoic, and vanillic acids and trace amounts of salicylic, syringic, protocatechunic, -resorcylic, caffeic, sinapic, gallic, and gentisic acids. From the results of incubating rice straw at different temperatures under moist and flooded conditions, Shindo and Kuwatsuka (1975a) assumed that phenolic acids which initially existed in rice straw were rapidly degraded in the early stages of incubation and subsequently produced again from the lignin component. The pathways from p-coumaric acid to p-hydroxybenzoic acid and from ferulic acid to vanillic acid were deduced from the changes in amounts of these phenolic acids. To alleviate their toxic effects, p-coumaric acid and ferulic acid were also temporarily methylated by soil microbes (Shindo and Kuwatsuka 1975b) and gradually transformed to p-hydroxybenzoic acid and vanillic acid. These latter acids are further transformed via protocatechuic acid to humic substances by polymerization or to aliphatic acids by ring cleavage.

When rice straw was mixed with soil and incubated under moist and flooded conditions, phenolic acids due to rice straw decreased gradually with time. It took nearly 30 days for the amounts of p-coumaric and ferulic acids to decrease to half of their initial levels when the rate of rice straw to soil was 8% (Shindo and Kuwatsuka 1977). After 6-10 weeks of incubation, decreasing curves of p-coumaric and ferulic acids showed shoulders, indicating the formation of these acids in the soil. Phenolic acids decreased more rapidly under moist conditions than under flooded conditions.

Shindo and Kuwatsuka (1978) determined the concentrations of phenolic acids in nine rice soils in Japan as 10-26 ppm (average 21 ppm); the levels were not affected by rice straw incorporated after the preceding cropping season. It seems that phenolic acids at those levels in rice soils do not affect the growth of either the root or the whole rice plant. Shindo and Kuwatsuka (1976) ascribed the low concentration of phenolic acids in rice soils to leaching. Leaching of phenolic acids in soil profiles is also obvious in the data of Wang et al (1967b).

The kinetics of phenolic acids were investigated by Tsutsuki and Ponnamperuma (unpublished) in three submerged soils treated with 0.25% rice straw, rice straw compost, or green manure at two temperatures (20 and 35°C). The largest concentrations of phenolic acids ranged between 13.6 umol/kg soil for p-hydroxybenzoic acid and 74.2 umol/kg soil for ferulic acid when rice straw was applied. Addition of 0.25% green manure or compost affected the concentration of phenolic acids in soils only a little. Changes in the concentrations of phenolic acids in Luisiana clay after 2 and 6 weeks of submergence at 20 and 35°C are shown in Figure 4. After 2 weeks of anaerobic incubation, the concentration of each phenolic acid was always higher at 20°C. However, the difference due to the incubation temperature was small at this time. The concentration of p-hydroxybenzoic acid increased after 6 weeks of incubation at 20°C, while it decreased with time at 35°C. At 35°C, degradation of p-hydroxybenzoic acid may be faster than its formation. Concentrations of the other phenolic acids such as vanillic, p-coumaric, ferulic, and sinapic acids increased with increased period of incubation at both temperatures. In Luisiana clay, concentrations of phenolic acids were higher at 20°C than at 35°C after 2 and 6 weeks of incubation. However, in Pila clay loam and Maahas clay the concentrations of phenolic acids were higher at 35°C after 6 weeks of incubation. Higher temperature might have favored the formation of phenolic acids from rice straw.

The discussions which consider phenolic acids as plant growth inhibitors in soils are usually based upon the concentration of phenolic acids determined by alkaline extraction, and the amounts of water soluble phenolic acids are very low. The amounts of water soluble phenolic acids in the soil under permanent pasture at pH 5.8 were equivalent to concentrations in the soil solution ranging from 1.4 uM for p-hydroxybenzoic acid to <10 nM for ferulic acid (Whitehead et al 1981). Amounts up to 2000 times greater than these were extracted by 2 M NaOH. Kaminsky and Muller (1978) recommend against the use of alkaline soil extraction in the study of allelophathy, because the use of an alkaline extractant results in the chemical modification of the compound under study, and the compounds which are not solubilized by neutral extractants may not be available to plants. However, localized concentrations of phenolic acids close to fragments of decomposing plant material might be sufficiently high to have some effect. Moreover, Rice (1979) considers that some compounds may influence plant growth at concentrations at which they are completely adsorbed by soil particles and are not extractable with water.

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Table 1. Characteristics of soil samples.

Soil type	pH	C	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

Table 2. Analyses of organic materials.

Material	C	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

Table 3. Sulfur containing gases evolved from a submerged soil (Nyuzen) treated with organic materials (adapted from Minami et al 1981).

Compound	Amount (nmol/kg soil)			
	Control	Rice straw	Compost	Cystine
H_2S	0	1700	0	4720
COS	17	78	23	566
CS_2	7	4	8	71
CH_3SH	17	56	0	145
CH_3SCH_3	129	483	129	113
CH_3SSCH_3	53	54	0	74

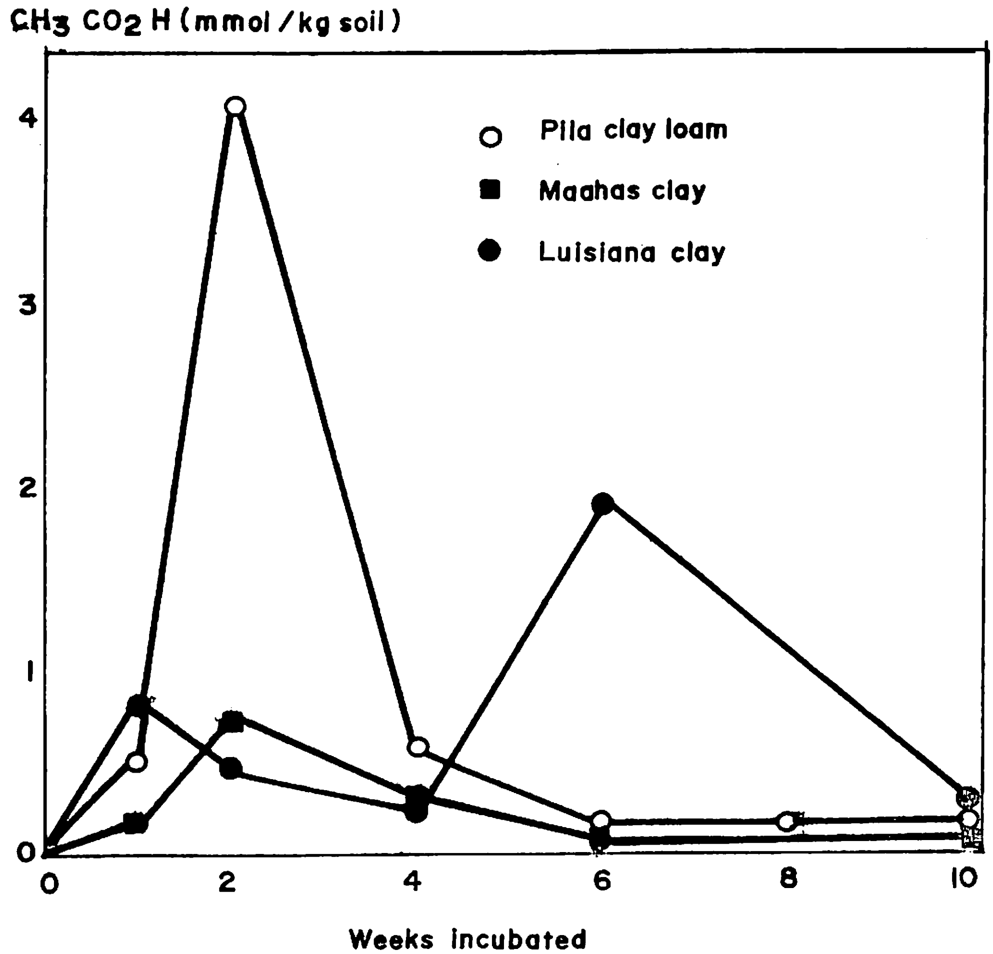

Fig. 1. Kinetics of acetic acid in 3 submerged soils treated with rice straw (0.25%) at 20°C.

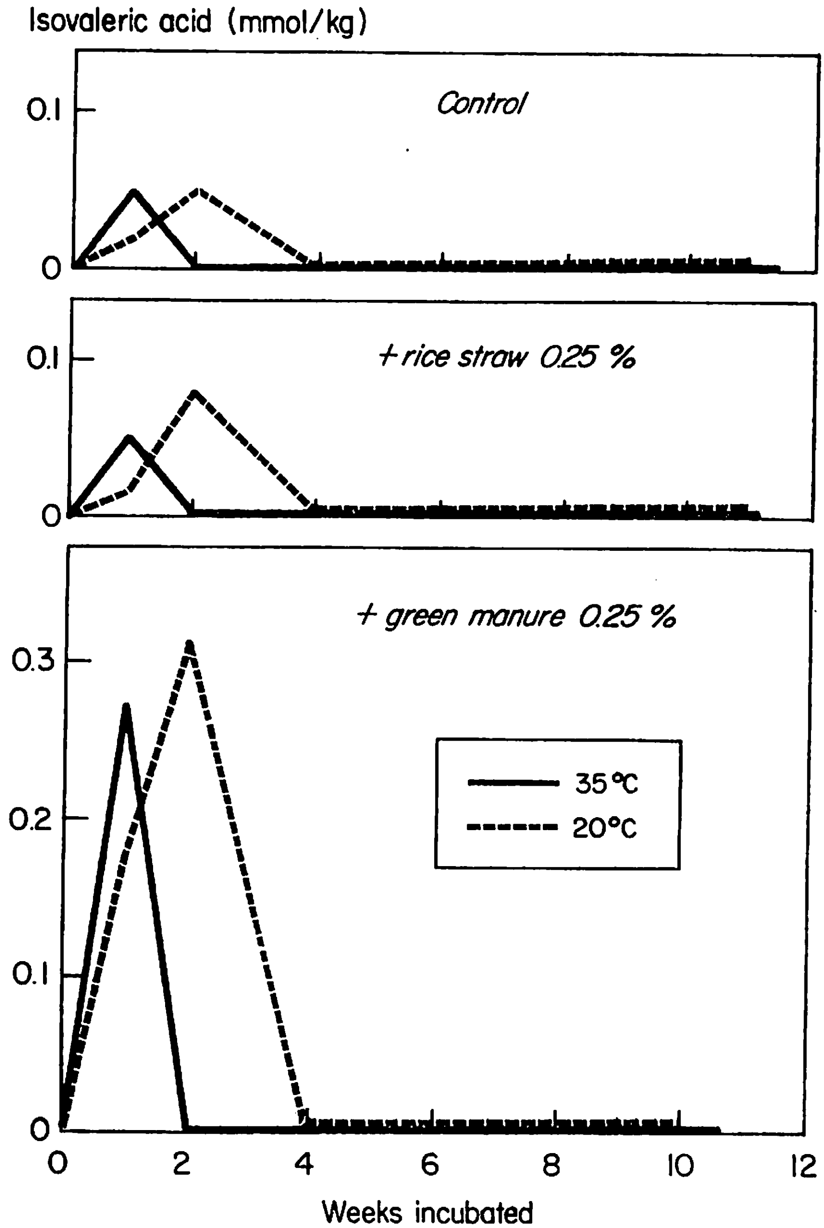

Fig. 2. Effect of organic matter on kinetics of isovaleric acid in submerged Pila clay loam at 20 and 35°C.

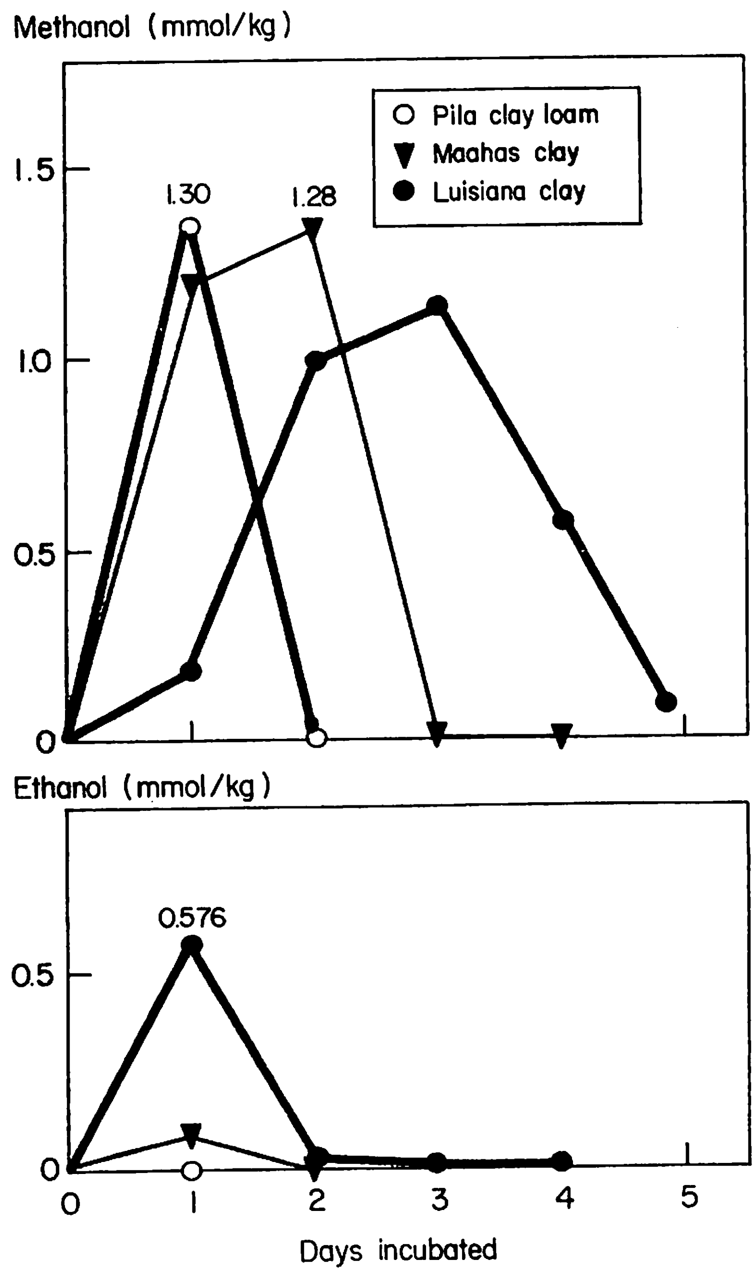

Fig. 3. Kinetics of alcohols in 3 submerged soils treated with green manure (1%) at 35°C.

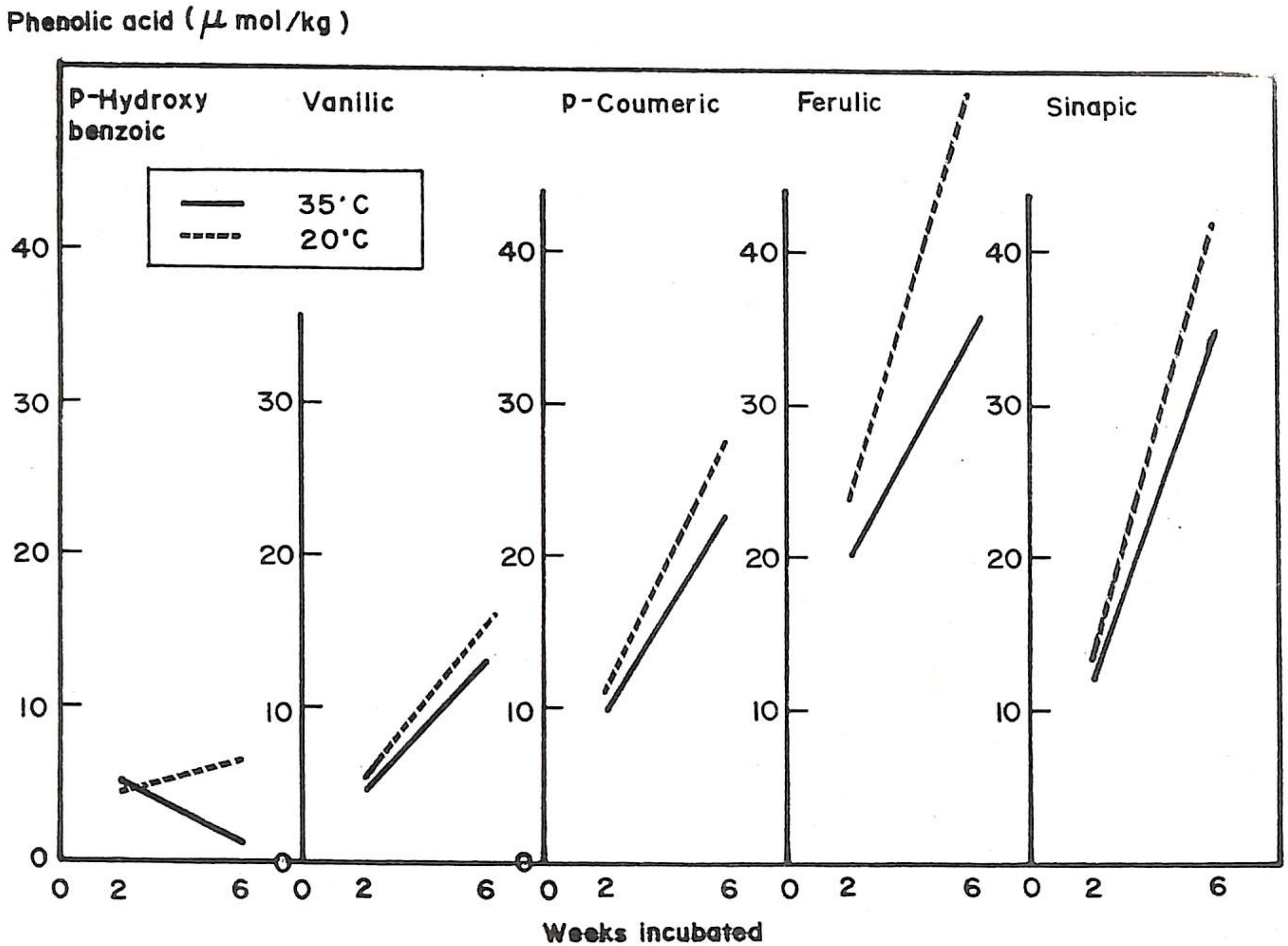

Fig. 4. Kinetics of phenolic acids in submerged Luisiana clay treated with rice straw (0.25%).