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INFLUENCE OF TEMPERATURE ON THE KINETICS OF RICE STRAW DECOMPOSITION IN SOILS

D. PAL, F. E. BROADBENT, AND D. S. MIKKELSEN
University of California, Davis [1]

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ABSTRACT

The influence of 7.2°, 22°, and 37°C temperature levels on the extent and rates of rice straw decomposition and loss of soil organic matter was investigated in two soils at 60 percent WHC using tracer techniques. About a third of straw-C was lost at 7.2°C within a 4-month incubation period. At all temperature levels, the percentage of straw-C loss after 6 days followed the path of power functions. Differential equations were deduced to describe the instantaneous rate parameter, v_i, which decreased with time in asymptotic fashion. Temperature dependence of v_i is consistent over the range 7° to 22°C but less so over the range 22° to 37°C. Soil-C loss increased with increasing temperature regardless of straw incorporation. Addition of straw always promoted native soil carbon loss at all temperature levels.

Mineralization of straw nitrogen at 7.2° and 22°C was about the same but at 37°C mineralized nitrogen appeared to be lost, possibly as gaseous nitrogen. Soil inorganic nitrogen content increased with increasing temperature, as did the native soil carbon loss.

INTRODUCTION

In soil systems, temperature influences mineralization of carbon and nitrogen at each biochemical step, since activities of enzymes as well as microorganisms are temperature dependent. Waksman and Gerretsen (1931) presented a detailed analysis concerning the influence of temperature on decomposition of oat straw constituents in a soilless culture. They found that decomposition of lignins at 37°C was fairly rapid, 50 to 60 percent having disappeared in 9 months. At 7°C the lignin decomposition was negligible. At low temperatures CO_2 arises mainly from water-soluble constituents, starches, and celluloses and not from lignins. With increasing temperature, decomposition of all constituents increased initially for up to 16 days; after that, rate was nearly independent of temperature. Bartholomew and Norman (1946) noted that at temperatures below 12°C, the peak rate of CO_2 evolution was delayed. Nommik (1962) ran experiments at 5°, 12°, and 24°C and found that the rate of straw decomposition was highest at 24°C and decreased rapidly at lower temperature. Brown and Dickey (1970) found that decomposition of straw was more rapid at Huntley, Montana than at Bozeman because air temperature at Huntley was 2.3°C warmer than at Bozeman.

N transformations, as well as C mineralization, are influenced by temperature. Kuo (1955), Nommik (1962), and Broadbent (1968) reported that the time required for maximum net immobilization of nitrogen was longer at lower temperature. Under conditions favorable for rapid decomposition, net immobilization occurs fairly rapidly in the first few days, after which it becomes negligible (Broadbent 1968). Much of the work related to temperature influence on fate of straw-C and -N has been without use of tracer techniques, and the data obtained have not been given adequate mathematical treatment. The present experiment was designed to evaluate the influence of temperature variables on the extent and rate of rice straw decomposition as distinguished from native soil organic matter. For this purpose, doubly tagged (^{13}C and ^{15}N) straw was incorporated in two fine-textured soils at a 1 percent rate and 60 percent WHC (water-holding capacity).

MATERIALS AND METHODS

The soils used in the investigation were Sacramento clay and Stockton adobe clay. The

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properties of both soils have been described in an earlier article (Pal and Broadbent 1974). The rice straw was tagged with ^{13}C and ^{15}N as described elsewhere (Pal 1973). The straw contained 39.18 percent C with 1.854 percent excess ^{13}C and 2.65 percent N with 7.332 percent excess ^{15}N.

Three temperature variables were imposed on soils treated with and without straw at 60 percent WHC. These were: 7.2°, 22°, 37° ± 0.5°C. For each treatment receiving straw, 0.25 g of the ground straw was incorporated in 25 g of each soil contained in 8-oz bottles. Corresponding controls were carried out at each temperature level. Each treatment was run in duplicate. The moisture was brought to 60 percent WHC, the bottles were stoppered after putting 3 ml of 1 *N* NaOH in 5-ml beakers attached to the stoppers. Incubation was carried out at the respective temperature levels. Procedures used for CO_2 determination and isotope analysis were essentially the same as described earlier (Pal and Broadbent 1974).

To determine the inorganic nitrogen release from straw during decomposition, 0.1 g straw was added to 10 g soil in eight replicates of each treatment. The experiment for N release at the three temperature levels was run at 60 percent WHC and moisture lost by evaporation was made up frequently by adding distilled water. The inorganic nitrogen released from straw and native organic matter during decomposition was determined using procedures described previously (Pal and Broadbent 1974).

RESULTS

Figure 1 illustrates the percentage of added straw-C lost with time at the three temperature levels imposed on the two soils under study. At 7.2°C, straw carbon loss was less than at warmer temperatures. In Sacramento clay, the proportion of straw carbon loss increased with increase in temperature at all times during 4 months' incubation. However in Stockton adobe clay, the fraction of straw carbon loss at 37°C became less than at 22°C after 4 weeks of incubation. At 7.2° and 22°C, the percentage of straw carbon loss in Sacramento clay was less than in Stockton adobe clay. This was not the case at 37°C, where the fraction of straw carbon loss in Sacramento clay was greater than in Stockton adobe clay. The equations for curves in Fig. 1 predicted the observed values reasonably well for $t > 6$ days because plots of log (straw carbon loss) vs. log (time in days) showed highly significant correlation coefficients ($.98 > r > .95$). These equations were differentiated with respect to time, t, to deduce the instantaneous rate parameter, $v_i = Amt^{(m-1)}$ at various temperature levels. The values of constants Am and (m-1), are given in Table 1. The values of Am indicate the highest level of microbial activity at 22°C and lowest at 7.2°C in both soils. The values of (m-1) were most negative at

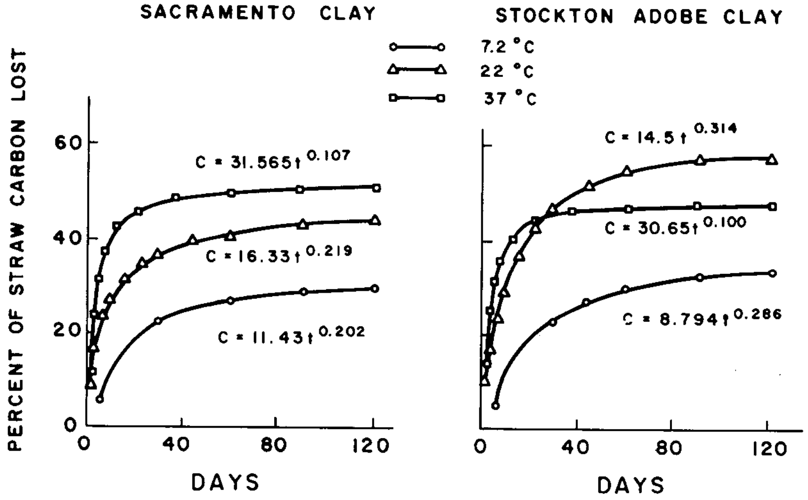

FIG. 1. Influence of temperature on the percentage of straw carbon loss during the course of 4 months of decomposition in soils. Equations with general form, $C = At^m$ where C is percentage of straw carbon loss in time, t is days, and A and m are constants, were fitted to data for incubation period $6 < t < 121$ days.

37°C, suggesting that v_i decreased more sharply at 37°C than at either 7.2° or 22°C.

In the beginning of the incubation period, v_i is strongly temperature dependent, but with an increased incubation period, temperature-dependence of v_i becomes weaker (Fig. 2). In both soils, values of v_i remained highest at 22°C. In Stockton adobe clay, values of v_i at 37°C were even less than at 7.2°C after 10 days. This confirms that the stimulatory influence of high temperature on rate of straw carbon loss was of short duration.

The influence of temperature on organic carbon balance in soils is shown in Table 2. These data reveal that (i) organic carbon balance in soils incubated alone became more negative with increasing temperature, (ii) soil carbon loss increased with increasing temperature in all treatments with and without straw incorporation, and (iii) in soil samples treated with straw, the net gain of organic carbon was highest at the lowest temperature (7.2°C) in both soils. In Sacramento clay, the net gain of carbon decreased with increasing temperature. In Stockton adobe clay, the net gain was higher at 37°C than at 22°C. The percentage of straw-C retained was highest at 7.2°C and followed a trend identical to net gain of organic carbon.

TABLE 1

Influence of temperature variables on values of constants Am and (m − 1)

Temperature variable	Sacramento clay		Stockton adobe clay	
	Am	(*m* − 1)	*Am*	(*m* − 1)
7.2	2.31	−0.798	2.52	−0.714
22	3.58	−0.781	4.55	−0.686
37	3.38	−0.893	3.07	−0.900

The native carbon loss at various temperature levels as a function of time is presented in Fig. 3. With the exception of 7.2°C in Sacramento clay soil, the addition of straw always promoted native soil carbon loss at all temperature levels. At 7.2°C in Sacramento clay soil, enhancement of soil carbon loss appeared to be negligible. Priming ratios (Pal 1973) as listed in Table 3 were ≥ 1 in all cases. The priming ratios varied very little with time but in a definite order. At 37°C, priming ratios increased with time, while at 22°C, they decreased with time on both soils. At 7.2°C priming effect was more intense in Stockton adobe clay than in Sacramento clay, while the reverse was true at 37°C. It is postulated from these results that native soil organic carbon loss is promoted by decomposing straw over a wide range of temperature (7.2° to 37°C) at 60 percent WHC.

Straw used in the present study contained nearly 2.7 percent N with a C:N ratio of 14.8:1, and, therefore, no net immobilization of nitrogen was observed. Rather, a net release of nitrogen from straw occurred up to 30 days incubation at all temperature levels (Fig. 4). In Sacramento clay, the net mineralization of straw-N was highest at 22°C throughout the incubation period. At the end of 120 days, the net mineralization of straw-N at 7.2°C reached

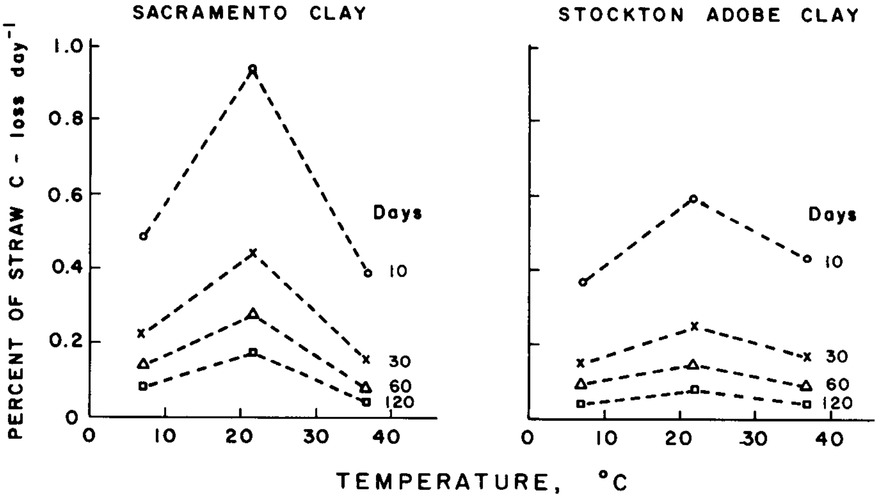

FIG. 2. Changes in straw decomposition rate, v_i, in soils with time as a function of temperature.

TABLE 2

Balance sheet of carbon in soils incubated for 4 months at various temperature levels

Soil	Temperature °C	Straw input mg C	Carbon output as CO_2 (mg C)		Net gain (+) or loss (−) mg C	Percent of added C retained	Turnover time in years
			Straw	Soil			
Sacramento clay	7.2	0	—	6.96	−6.96	—	—
		97.95	28.85	7.35	+61.75	70.01	126
	22	0	—	14.5	−14.5	—	—
		97.95	43.0	14.7	+40.3	54.95	10.7
	37	0	—	16.94	−16.94	—	—
		97.95	49.92	20.13	+27.90	48.04	131
Stockton adobe clay	7.2	0	—	9.9	−9.9	—	—
		97.95	32.76	11.93	+53.26	65.19	13.5
	22	0	—	17.00	−17.00	—	—
		97.95	56.33	19.28	+22.34	41.62	1.3
	37	0	—	18.61	−18.61	—	—
		97.95	46.84	20.87	+30.24	51.11	373

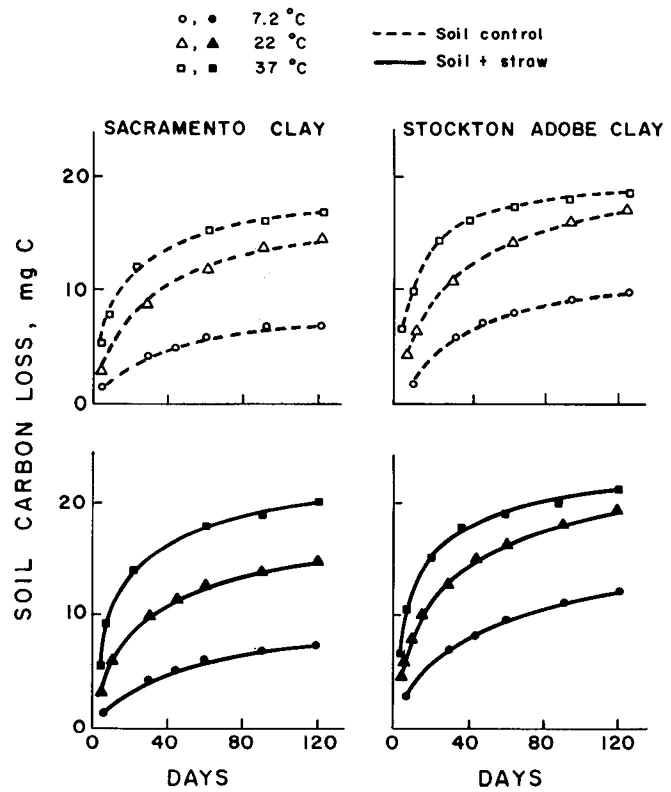

FIG. 3. Influence of temperature on the soil carbon loss during 4 months' incubation with and without straw amendment.

about the same as at 22°C. At 37°C the net mineralization of nitrogen increased with time up to 30 days, but thereafter nitrogen disappeared at a rate greater than it was produced. In Stockton adobe clay, the net mineralization of straw-N increased with time at 7.2° and 22°C for 4 months and did not differ appreciably. At 37°C, the inorganic N pool from straw increased up to 60 days and decreased afterwards up to 120 days.

It is apparent from data delineated in Fig. 5 that soil inorganic nitrogen content increased with increasing temperature. The increase was more pronounced at 10 days' incubation than at the 120-day incubation period. At 37°C, the inorganic N released from soil organic matter in soil controls was markedly higher than soil samples treated with straw on both soils. At 7.2°C and 22°C, the differences in soil N release with and without straw application were not appreciable in either soil.

DISCUSSION

Temperature influences all chemical and physical processes in the soil ecosystem including those regulated by organic catalysts and microbial activity. The temperature quotients, Q_{10}, as listed in Table 4 for different lengths of incubation period, were calculated using the relation,

$$\log Q_{10} = \frac{10}{T_2 - T_1} \log \frac{v_2}{v_1},$$

where v_1 and v_2 are the instantaneous rates of straw decomposition at temperature T_1 and T_2, respectively.

TABLE 3

Influence of temperature on priming ratios at various times of incubation

Soil	Temperature °C	Days of incubation 30	60	90	120
		Priming ratios, p_r			
Sacramento	7.2	1.00	1.02	1.04	1.06
clay	22	1.10	1.01	1.00	1.01
	37	1.16	1.16	1.18	1.19
Stockton	7.2	1.13	1.17	1.20	1.21
adobe	22	1.18	1.15	1.13	1.13
clay	37	1.07	1.10	1.11	1.11

Over the temperature range 7.2°–22°C the Q_{10} at 2 days was over 12. This was due to the prolonged lag phase at 7.2°C where negligible amounts of CO_2 were evolved during the first 2 days of incubation as compared to a short lag phase of only a few hours at 22°C. Bartholomew and Norman (1946) reported that at temperatures above 12°C, the peak rate of CO_2 evolution occurred in the first 24 hours of incubation but not so at lower temperatures. As the lag phase at 7.2°C ended, the Q_{10} values decreased to 1.4 and 1.6 in Sacramento clay and Stockton adobe clay, respectively, within 10 days' incubation period. Throughout the remainder of the incubation period in the temperature range 7.2°–22°C, the Q_{10} values were about 1.5. Thus the dependence of v_i on temperature between 7° and 22°C appears to be consistent after 10 days' incubation in both soils.

Over the temperature range 22° to 37°C, the v_i was accelerated about 1.5- to 1.6-fold per 10°C rise in temperature during the first 2 days of incubation. It seems likely from these data that the lag phase at 37°C is very brief (1 or 2 hr) and the period during which CO_2 evolution rate is maximum is also short. At 37°C, more C was lost initially than at 22°C. On both soils, within less than 10 days, Q_{10} values between 22° and 37°C fell below one. This indicates that the straw decomposition rate decreased abruptly with rise in temperature within the 22° to 37°C range after the first few days of incubation.

Decomposition processes decreased in rate with increase in temperature above optimum, like many enzyme catalyzed reactions. This is

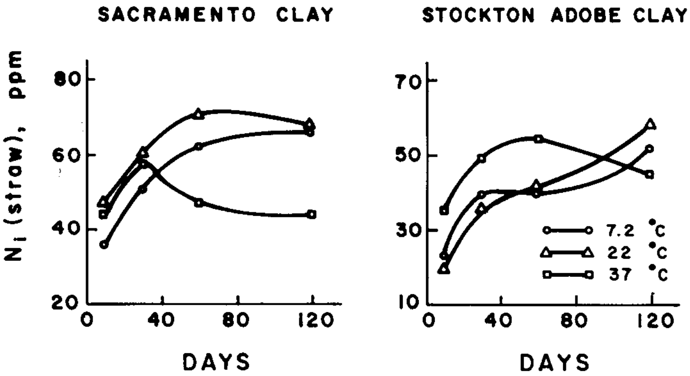

FIG. 4. Net mineralization of straw nitrogen as a function of time in soils at different temperatures.

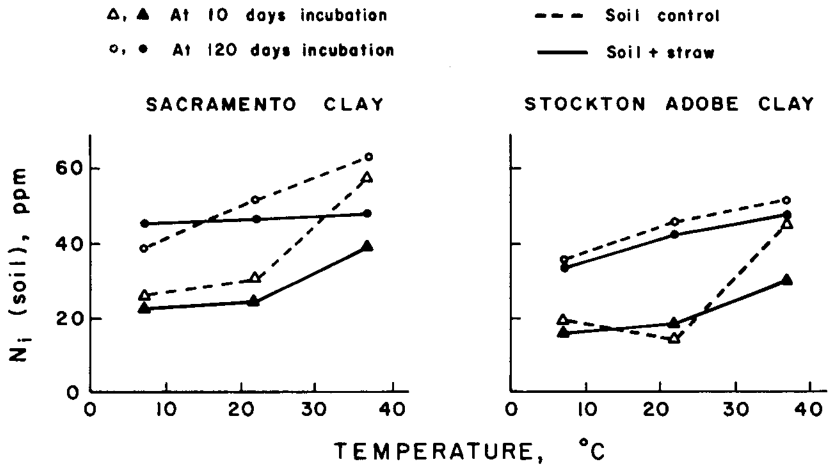

FIG. 5. Changes in soil inorganic nitrogen as a function of temperature with and without incorporation of straw in soils.

TABLE 4

Q_{10} for decomposition rate of rice straw in soils at various lengths of incubation period

Soil	Temperature range	Days of incubation			
		2	10	30	120
	°C	Q_{10} values			
Sacramento clay	7.2-22	12.7	1.38	1.40	1.45
	22-37	1.5	0.81	0.75	0.66
Stockton adobe clay	7.2-22	13.5	1.56	1.59	1.64
	22-37	1.6	0.55	0.47	0.39

usually attributed to the inactivation of enzymes at temperatures higher than optimum. The decrease in decomposition rate at 37°C was more pronounced in Stockton adobe clay than in Sacramento clay, as shown by Q_{10} values (Table 4). The phenomenon of lower heat resistance of certain enzymes from a mesophilic population than the same enzyme from thermophilic microorganisms is not fully understood (Clifton 1957). In Stockton adobe clay, the proportion of straw carbon loss during 4 months' decomposition at 37°C was less than at 22°C. This indicated that the micropopulation in this soil consisted mainly of temperature-sensitive heterotrophs with an optimum growth temperature below 37°C.

Turnover times (Pal and Broadbent 1974) calculated by extrapolation of curves presented in Fig. 1 indicated that the longest time required for complete loss of added straw-C occurred at 37°C followed by that at 7.2° and 22°C (Table 2). At 22°C, values for turnover time were 1.3 years in Stockton adobe clay and 10.7 years in Sacramento clay. This again suggests, as in our earlier article (Pal and Broadbent 1974), that higher amounts of straw-C can be turned over in Stockton adobe clay each year, during seasons with temperature close to 22°C or lower, than in Sacramento clay. Surprisingly enough, turnover time at 37°C was over 100 years in both soils. It is conclusive from these findings that the influence of temperatures higher than optimum, on the enhancement of straw decomposition processes, is temporary even when moisture conditions were held constant at 60 percent WHC. For rapid turnover of straw-C a temperature range near 22°C is desirable. Under field conditions on Sacramento clay and Stockton adobe clay this temperature is likely in the spring (March through mid-June) and right after the crop harvest in September. Any of these times would favor intense decomposition of added crop residues for rapid turnover, provided moisture is maintained near field capacity. Since burning of rice residues per se may not always benefit crop production (Williams et al. 1972) but rather creates a nuisance in air pollution and may increase probability of health and accidental hazards, it is desirable that straw be managed by soil incorporation to a greater extent than at present.

Native soil organic carbon loss was accelerated with increase in incubation temperature in all treatments with and without straw added which is in contrast to the variable influence of temperature on straw decomposition. This finding is in agreement with the idea originally proposed by Jenny (1931) that in regions of effective and comparable rainfall organic matter level decreases with increasing mean annual temperature. The influence of straw incorporation on enhancement of soil carbon loss was evident at all temperatures. Priming ratios (Pal 1973) were equal to or greater than unity at all temperature levels (Table 3). Although the influence of temperature on the extent of priming action has never been evaluated before, this appears to be the reason why many investigators, working under different temperature conditions, observed the phenomenon of positive priming action when moisture and aeration conditions usually favored intense decomposition. It is speculated that within the 7.2° and 37°C temperature range the sensitivity of microflora involved in decomposition of resistant soil humus is not appreciably altered by straw incorporation as long as moisture level is held constant.

Net gain of carbon in soils was evident even after 4 months' incubation at all temperature levels in straw-amended treatments. The straw carbon retained in Sacramento clay was highest at the lowest temperature. It is expected that the retained carbon is largely derived from the lignin fraction of straw. Also, a mixed population of microorganisms assimilate substrate carbon. For example, aerobic bacteria assimilate 5 to 10 percent, fungi 30 to 40 percent and actinomycetes 15 to 30 percent of substrate carbon (Alexander 1965). In soil controls, the net loss of organic-C was in the decreasing order as follows: 37° > 22° > 7.2°C.

Appreciable accumulation of inorganic nitrogen mineralized from straw during 4 months at various temperature levels occurred in the decreasing order: 22° ≥ 7.2° > 37°C (Fig. 4). However, the differences in the inorganic nitrogen pool at 7.2° and 22°C were small. In Stockton adobe clay the net release of straw nitrogen was highest at 37°C up to 60 days of incubation. A loss of straw inorganic nitrogen was observed after this time. The net loss of mineralized nitrogen from straw in Sacramento clay was evident even after 30 days of incubation at 37°C. The losses of nitrogen at 37°C may have been presumably by volatilization of ammonia, denitrification of nitrate nitrogen, or both. Many active denitrifiers are thermophilic as well as heterotrophic and can function well at 37°C when energy material is available to support their growth.

Changes in soil inorganic nitrogen at 7.2° and 22°C were not appreciably influenced by straw incorporation (Fig. 5). Nevertheless, at 37°C more inorganic nitrogen accumulated in the soil control than in straw-treated samples.

CONCLUSIONS

1. About a third of straw carbon was lost at 7.2°C during the course of 4 months of decomposition. Rates of straw decomposition increased with a rise in temperature only initially and the time during which CO_2 evolved at maximum rates was short at higher temperature levels. On Sacramento clay, the rates of decomposition at 37°C decreased sharply and became lower than at 22°C within less than 10 days and even less than at 7.2°C in 60 days incubation. On Stockton abode clay, decomposition rates at 37°C became lower than at 7.2°C within less than 10 days. Rates at 7.2°C always remained lower than at 22°C throughout incubation period on both soils.
2. Temperature did not seem to influence the nature of the priming effect, which was positive throughout the incubation period. Priming ratios were always greater than 1.0 at the three temperature levels under study.
3. A net gain of C in soils was apparent when straw was applied at a 1 percent loading rate at any of the temperature levels. Turnover time for straw carbon was calculated to be lowest at 22°C and highest at 37°C in both soils.
4. Net release of N from straw in 4 months was about the same at 7.2° and 22°C. At 37°C, loss of mineralized straw-N occurred after 30 days of incubation in Sacramento clay and after 60 days in Stockton adobe clay.
5. Soil inorganic nitrogen increased progressively at 7.2° and 22°C and was not appreciably influenced by straw incorporation. At 37°C, more inorganic nitrogen accumulated in soil controls than in corresponding straw-treated samples.

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