PN-ABT-346

Pergamon

0038-0717(94)E0069-C

Soil Biol. Biochem. Vol. 26, No. 10, pp. 1379–1387, 1994
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0038-0717/94 $7.00 + 0.00

CARBON AND NITROGEN MINERALIZATION FROM COWPEA PLANTS PART DECOMPOSING IN MOIST AND IN REPEATEDLY DRIED AND WETTED SOIL

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(Accepted 15 March 1994)

Summary—Knowledge of C and N mineralization kinetics during decomposition of legumes is important to optimize management practices of green manure cropping systems. Our objective was to quantify the rates of C and N mineralization of cowpea [*Vigna unguiculata* (L.) Walp.] decomposing in continuously moist soil and in soil air-dried and rewetted every 5 days. Fresh cowpea plant parts were kept at 30 C for 68 days. Evolved CO_2 and mineral N released were measured periodically. Repeated drying and wetting did not significantly reduce C mineralization of cowpea, which averaged 62% of initial plant C for the two moisture regimes at 68 days. Nitrogen mineralization from cowpea, however, was reduced significantly from 46% of initial plant N in moist soil to 29% in repeatedly dried and wetted soil at 68 days. Carbon and N mineralization from cowpea were linearly related after an initial phase of rapid C loss. With repeated drying and wetting, a greater amount of N remained in undecomposed plant material, that was retrieved periodically during incubation. Repeated drying and wetting of the soil appeared to increase the resistance of certain N compounds of the plant to microbial decomposition. Further, repeated drying and wetting of the soil severely inhibited growth and/or activity of nitrifiers. Periodic drying of the soil as occurs in the field will reduce N mineralization from legume green manures compared to the decomposition in continuously moist soil, but may contribute to long-term N fertility by increasing soil organic N content.

INTRODUCTION

Leguminous green manure is an important component in sustainable cropping systems, especially where access to external inputs such as N fertilizers is limited. Knowledge of legume decomposition and N mineralization kinetics is critical to optimize management practices, such as choice of legume, timing of green manure planting and incorporation, etc. Laboratory studies of C and N mineralization from decomposing legumes have generally used soil moisture conditions that are optimal for microbial activity. Periodic drying and rewetting of the soil, however, as it occurs under field conditions is likely to alter the dynamics of C and N mineralization from decomposing legumes.

It is well established that mineralization of C and N from soil organic matter is enhanced after air-drying (Birch, 1958; Jenkinson, 1966; Agarwal *et al.*, 1971; Sorensen, 1974; van Veen *et al.*, 1985). Air-drying soil before incubation increased C and N mineralization in 27 soils, and reduced the ratio of C-to-N mineralized (Winsor and Pollard, 1956). Mineralization of N from soil during the wet periods of alternating wet and dry conditions was *ca* double that under continuously moist conditions (De Bruin *et al.*, 1989).

Published information on the effect of repeated drying and wetting on C and N mineralization from decomposing plant material is limited and inconclusive. Birch (1964) reported that intermittent drying enhanced the amount of mineral N released from four of five grass species, with an increasing drying effect as decomposition was more advanced. Contrary to these findings, repeated drying at 35°C depressed the release of C and N from ground alfalfa (*Medicago sativa* L.) incubated in a calcareous soil (van Schreven, 1967). When a fresh grass–legume mixture was incubated in a slightly acid soil, C mineralization from the plant material was not affected, and N mineralization was slightly reduced by repeated drying at 35°C (van Schreven, 1968). Intermittent periods of air-drying and remoistening following the rapid phase of decomposition of *Medicago littoralis* leaves did not affect the amounts of $^{14}CO_2$ evolved or mineral ^{15}N released (Amato and Ladd, 1980). More research is needed to better understand the effect of air-drying and rewetting on C and N mineralization from decomposing legumes.

Cowpea [*V. unguiculata* (L.) Walp.] is widely grown as a green manure crop in semi-arid regions of South Asia and as a food and fodder crop in the drier regions of sub-Saharan Africa. It is regarded as an excellent green manure and fodder crop because of its rapid rates of N_2 fixation and dry matter accumulation. In India and the Philippines, cowpea

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accumulated 70–80 kg N ha^{-1} in the above-ground biomass during 6 weeks of growth (Singh *et al.*, 1981; Morris *et al.*, 1986).

Our objective was to quantify the rates of C and N mineralization from cowpea decomposing in continuously moist soil and in soil subjected to drying-wetting cycles.

MATERIALS AND METHODS

Cowpea plant material

Cowpeas of the indeterminate variety 'California Blackeye' were grown in a greenhouse to the onset of flowering (44 days) in a loamy sand with a pH of 6.9 (1:2, soil:water), 4 mg available N kg^{-1}, 838 g sand kg^{-1}, 50 g silt kg^{-1}, and 112 g clay kg^{-1}. Germinating cowpea seeds were inoculated with 1 ml of *Bradyrhizobium* strain 32H1 culture at seeding to obtain good nodulation.

At harvest, cowpeas were separated into leaves, stems, roots and nodules. Petioles, peduncles, and buds were included with stems. Plant parts were further separated into subgroups of similar parts in order to obtain a representative plant sample for each incubation jar. Fresh plant parts were cut into *ca* 0.5 cm pieces, subgroups of plant parts were remixed, and an amount corresponding to *ca* 0.5 g dry wt was incorporated into 100 g soil in each incubation jar. Leaves, stems, roots and nodules were incubated separately and also combined, with each plant part present in proportion to its occurrence on the plant (Table 1).

Plant tissue was analyzed for total N concentration using the salicylic acid modification of the semi-micro Kjeldahl method to include NO_3–N (Nelson and Sommers, 1973) and total C concentration using a total C analyzer (Nitrogen Analyzer 1500, Carlo Erba Strumentazione). Water soluble C and N were determined from aliquots of an extract prepared by shaking 150 mg ground (420 μm) plant material in 30 ml deionized water for 30 min at 23°C. Water soluble organic C was determined using the Walkley–Black wet oxidation method (Nelson and Sommers, 1982) after evaporation of the extract to dryness at 105°C. Water soluble N was analyzed using the salicylic acid modification of the semi-micro Kjeldahl method to include NO_3–N (Nelson and Sommers, 1973), after evaporation of the extract at 90°C (Table 1).

Soil conditions during cowpea decomposition

Plant material was incorporated into a sandy soil from East Texas (sandy, siliceous, thermic Psammentic Paleustalf). The soil had a pH of 5.5 (1:2, soil:water), 3 mg available P kg^{-1} (Bray-1), 2 g organic C kg^{-1}, 5.0 $cmol_c$ CEC kg^{-1}, 1.3 Mg m^{-3} bulk density, 920 g sand kg^{-1}, 20 g silt kg^{-1}, and 60 g clay kg^{-1}. This soil was selected due to its similar physical, chemical and mineralogical characteristics to soils typically sown to millet in Niger, Mali, and Senegal (Payne *et al.*, 1991), where cowpea has a particular potential as a green manure.

Soil in one-half of the incubation jars (465 ml glass canning jars) was kept continuously moist at a soil water content corresponding to 60% of water-filled porosity (0.24 kg kg^{-1}), which is considered optimum for microbial activity (Linn and Doran, 1984). Soil in the remaining jars was wetted to water holding capacity (0.27 kg kg^{-1}, determined after 2 h of water drainage through holes in the bottom of a plastic cup), then allowed to air-dry in five steps during 5 days. Each step consisted of an incubation for 16 h followed by drying for 8 h, during which the lids of the jars remained open. During incubation the soil was at 100, 75, 50, 25 or *ca* 4% of its water holding capacity. Soil water potentials at these soil water contents as determined with the filter paper method (Savage *et al.*, 1992) were above −0.02 MPa except for the driest soil water content, which corresponded to a water potential of −10 MPa. Soil water content at −0.1 MPa was 0.047 kg kg^{-1} as determined with a pressure plate apparatus. A drying period of 8 h followed the incubation at the driest water content, after which the soil was air-dry. Every 5 days the soil was rewetted to 100% of its water holding capacity, resulting in 13.5 wetting–drying cycles during the 68 days of the experiment. This rewetting frequency was chosen to simulate field conditions that occur during the rainy season of the West African Sahelian zone. During incubation and drying, jars were kept at a constant temperature of 30°C in the dark.

Measurement of net C and N mineralization, remaining plant dry weight and N, and substrate-induced respiration

Carbon dioxide evolution was measured daily following a 16 h incubation. After 39 days the frequency of CO_2 determination was reduced in the continuously moist treatment to every second day with an

Table 1. Dry matter distribution and total and water soluble C and N concentrations of cowpea plant parts

Plant part	Dry weight (%)	Total C (g kg^{-1})	Total N (g kg^{-1})	Total C/N	Soluble C (g kg^{-1})	Soluble N (g kg^{-1})	Soluble C/N
All parts	100.0	442	23.8	18.6	72.7	5.65	12.9
Leaves	41.3	455	29.9	15.2	75.7	4.70	16.1
Stems	22.4	442	16.8	26.3	65.8	7.97	8.26
Nodules	2.58	393	60.4	6.51	97.4	21.3	4.57
Roots	33.7	430	17.5	24.6	71.8	4.11	17.5

incubation period of 40 h. During incubation three jars per treatment were sealed air-tight. At the end of incubation periods, the concentration of CO_2 in the headspace was determined using a g.c. (GOW MAC Instrument Co., Series 550 Thermal Conductivity Detector). Percent CO_2 in the jar headspace was converted into mg CO_2 using the density of CO_2 at standard conditions adjusted to 30°C (Anderson, 1982) and an average jar volume subtracting the volume occupied by soil and water.

Nitrogen mineralized was measured at 3, 13, 23, 33, 43, 53 and 68 days after cowpea incorporation. At each sampling date the entire content of two jars from each treatment was extracted with 300 ml 2 M KCl. The extract was frozen until analyzed for NH_4–N and NO_3–N on a Technicon Autoanalyzer. For repeatedly dried and wetted jars, retrievals occurred on the third day after rewetting. Carbon and N mineralized from soil only was subtracted from that of soil with incorporated cowpea to estimate mineralization of C and N from cowpea.

Undecomposed cowpea plant parts remaining in the soil were collected on a 1 mm sieve following KCl extraction. Plant parts were washed free of adhering soil by a combination of washing under a gentle stream of water on a sieve, flotation in distilled water, and hand separation. Despite the thorough washing procedure, some clay particles may have adhered to the plant parts, but this error was expected to be insignificant due to the sandy texture of the soil. Plant parts were dried at 60°C, weighed and analyzed for total N using the semi-micro Kjeldahl method (Nelson and Sommers, 1973).

Substrate-induced respiration, suggested for determination of the active microbial biomass on plant residues (Beare *et al.*, 1991), was measured in each jar just prior to KCl extraction. Two ml of glucose solution (10 g glucose l^{-1}) were added per jar for continuously moist soil, and 10 ml of glucose solution (2 g glucose l^{-1}) for repeatedly dried and wetted soil. Differing amounts of glucose solution were added in order to adjust soil water contents in the two moisture regimes to a similar value during incubation with glucose. Carbon dioxide accumulated in the jar headspace after 2, 3, and 4 h was measured with a g.c. The C loss rate between the second and the fourth hour was calculated and expressed in mg CO_2–C g^{-1} initial plant material h^{-1}.

Statistical analysis

Differences in indices measured among moisture regimes and plant parts were analyzed using the General Linear Models (GLM) procedure of SAS (SAS Institute Inc., 1990) with a probability of 0.05 designating statistical significance. Cumulative net mineralization of C and N, and remaining dry matter and N were described with non-linear regression using the NLIN procedure of SAS. The relationship between actual net C mineralization and predicted N mineralization was described using linear regression.

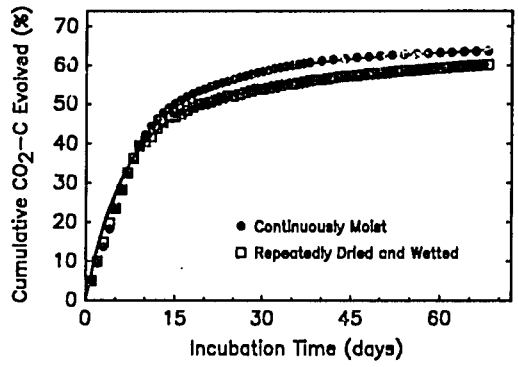

Fig. 1. Cumulative CO_2–C evolved as percentage of initial plant C during decomposition of cowpea in continuously moist and in repeatedly dried and wetted soil. Symbols represent data calculated from C loss rates and lines are non-linear regression equations with the following parameters for moist soil: $C = 52.8[1 - \exp(-0.133*day)] + 14.7[1 - \exp(-0.0208*day)]$ and for repeatedly dried and wetted soil: $C = 45.0[1 - \exp(-0.169*day)] + 20.4[1 - \exp(-0.0203*day)]$.

Net N mineralization predicted with non-linear regression equations was used in order to eliminate variability observed in net N mineralization data.

RESULTS AND DISCUSSION

Carbon evolved as CO_2

Carbon loss rates remained high for the first 7 days after incorporation, then decreased rapidly (Fig. 1). During the first 3 days evolved CO_2 was 14% of total cowpea C, and during the first 7 days 33%, when averaged across the two moisture regimes. Carbon loss during this rapid loss phase exceeded the 16% of C initially present as water soluble C (Table 1). The C-to-N ratio of the initially soluble component was 12.9 (Table 1), representing substrate C and N readily available to the microbial biomass. Berg *et al.* (1987) attributed the initial rapid release of C from clover (*Trifolium pratense* L.) roots to the almost complete decomposition of all polysaccharides. After 7 days C loss rates of cowpea started to decrease, and by *ca* 3 weeks of incubation C loss rates had reached very low levels. At the end of the 68 day incubation, cumulative C loss as CO_2 from decomposing cowpea was 64% of initial plant C in moist soil and 60% in repeatedly dried and wetted soil (Fig. 1). For individual plant parts it ranged from 50% for roots to 74% for nodules (Table 2). Carbon mineralization rates of various cowpea plant parts were within the range of those reported for other legumes (Lucken *et al.*, 1962; Till *et al.*, 1982; Kirchmann and Bergqvist, 1989).

The size of the active microbial biomass was greatest during the first 10 days after cowpea incorporation (Fig. 2), when the most rapid phase of cowpea decomposition occurred (Fig. 1). During the remaining incubation period, the size of the active microbial biomass was much smaller and corresponded to the reduced rate of cowpea decompo-

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Table 2. Carbon and N mineralized from cowpea plant parts and substrate-induced respiration in continuously moist and in repeatedly dried and wetted soil at 68 days of incubation

	Continuously moist			Dried and rewetted		
Plant part	C (%)	N (%)	SIR[1] (mg C g^{-1} h^{-1})	C (%)	N (%)	SIR (mg C g^{-1} h^{-1})
All parts	63.6[bc2]	46.1[b]	0.0765[b]	60.1[b]	29.3[b]	0.139[ab]
Leaves	65.3[b]	49.4[b]	0.0528[bc]	65.1[a]	31.5[b]	0.165[a]
Stems	60.3[c]	24.4[c]	0.0837[b]	53.2[c]	21.7[c]	0.0950[b]
Roots	52.5[d]	24.4[c]	0.122[a]	50.3[c]	16.9[c]	0.198[a]
Nodules	74.0[a]	71.8[a]	0.0286[c]	62.8[ab]	52.7[a]	0.0856[b]

[1]Substrate-induced respiration expressed in mg CO_2-C g^{-1} initial plant dry weight h^{-1}.
[2]Values followed by the same letter within a column are not significantly different at the 0.05 probability level as indicated by Duncan's Multiple Range Test.

sition. Carbon loss rate and the size of the active microbial biomass were highly correlated from day 13 until day 68 ($r = 0.995$ for both, moist and dried and rewetted soil, $n = 6$), indicating that the active microbial biomass decreased in size to adjust to the decreasing substrate availability. On day 3, however, the basal microbial respiration rate was much greater than that predicted based on the size of the active microbial biomass, which was probably the result of a very young microbial biomass and a large pool of readily-available substrate.

Fluctuating C loss rates occurred when soil was subjected to 5-day drying–wetting cycles (Fig. 3). Carbon loss rates were greatest on the second day after rewetting, but during the first 16 h after rewetting, C loss rates had already increased, indicating rapid recovery of microbial activity after drought stress. Fluctuations in C loss rates during the first 4 days after rewetting were probably caused by factors of microbial recovery and substrate availability after air-drying, rather than by changes in soil water potential, which was in a range suitable for microbial activity during this time. Rates of CO_2 evolution were very low only on the 5th day of each cycle, when soil water potential was at -10 MPa. Carbon loss rates were very low for at least 24 h at the end of each 5-day drying cycle (time of the fifth 16-h incubation and final 8-h drying period before rewetting), i.e. 20% of the incubation time. The pattern of C loss rates after rewetting was similar for stems and nodules as for all parts combined, while C loss rates of roots were consistently greatest on the first day after rewetting (data not shown). Cowpea leaves showed a changing response to rewetting with initially greatest CO_2 evolution rates on the first day after rewetting, and during later drying cycles slightly higher CO_2 evolution rates on the seond day after rewetting. This change in the response of C loss rates to rewetting may indicate that microbial biomass living on less available substrate takes longer to recover after drought stress.

Repeated drying and wetting of the soil reduced cumulative C loss from cowpea at 68 days by 5.5% when compared to C loss in continuously moist soil ($P = 0.09$). Since microbial activity was severely reduced by drought stress during at least 20% of the incubation, this small reduction in C loss indicated that during the remaining incubation time with changing but adequate moisture, microbial activity was greater than in continuously moist soil. Cumulative C loss of leaves and roots at 68 days was not significantly affected by repeated drying and wetting

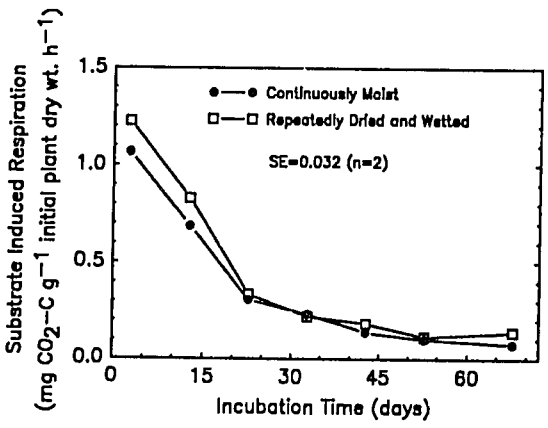

Fig. 2. Substrate-induced respiration, an estimate of active microbial biomass, during decomposition of cowpea in continuously moist and in repeatedly dried and wetted soil.

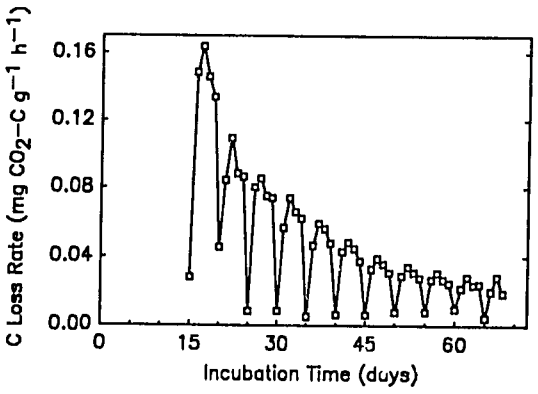

Fig. 3. Carbon loss rates of decomposing cowpea during 5-day drying-wetting cycles. (The first three cycles were omitted to show fluctuations in C loss rates on a smaller scale.) Lowest data points of each cycle were obtained during a 16 h incubation, when soil water potential was at -10 MPa, which was followed by 8 h of air-drying before rewetting.

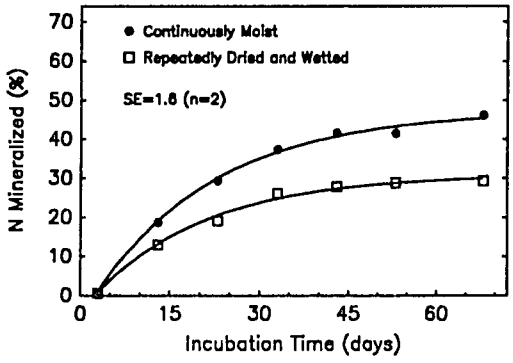

Fig. 4. Net N mineralization as percentage of initial plant N during decomposition of cowpea in continuously moist and in repeatedly dried and wetted soil. Symbols represent measured data and lines are non-linear regression equations with the following parameters for moist soil: 47.3–53.6[exp(−0.0494*day)] and for repeatedly dried and wetted soil: 30.9–35.4[exp(−0.0535*day)].

of the soil, whereas C loss from stems and nodules was reduced by 12 and 15%, respectively (Table 2). The cause of the differing effects of repeated drying and wetting on C loss among plant parts may be related to the more recalcitrant chemical structure of stem and nodular cell walls, but requires further research.

Cumulative C loss from decomposing cowpea plant parts was best described by double exponential models (Fig. 1). Under both moisture regimes, the size of the rapidly-mineralized C pool was greater than that of the slowly-mineralized C pool. Pool sizes of rapidly and slowly mineralized C of cowpea decomposing in moist soil were very similar to those for 66-day old white clover tops (Kirchmann and Bergqvist, 1989). The rate constants of the slowly-mineralized C pools of cowpea and clover were also similar, while the rate constant of the rapidly-mineralized C pool for cowpea was somewhat lower than for white clover tops.

For cowpea under moist conditions, a greater portion of the mineralizable C was in the rapidly-mineralized C pool and a smaller portion in the slowly-mineralized C pool compared to repeatedly dried and wetted conditions. Total potentially mineralizable C, however, was similar under both moisture regimes. This indicated that C was released at a slower rate when the microbial biomass was repeatedly stressed by air-dry conditions, but that C was not rendered more resistant to decomposition by frequent air-drying.

Net nitrogen mineralization

Net N mineralized from cowpea tissue at 68 days was 46% of initial N in moist soil and 29% in repeatedly dried and wetted soil (Fig. 4). Net N mineralization was highest for nodules and lowest for stems and roots under both moisture regimes (Table 2). Net N mineralization of cowpea plant parts was within the range predicted by Vigil and Kissel (1991) based on tissue N concentrations.

Cumulative net N mineralization from cowpea was negatively correlated with the size of the active microbial biomass ($r = 0.991$ for moist soil, and $r = 0.983$ for repeatedly dried and wetted soil, $n = 7$). The size of the active microbial biomass (Fig. 2) was reduced in direct proportion to the decreasing availability of mineralizable N since other factors remained constant. Very little N was released by day 3 when the size of the active microbial biomass was largest, probably due to N immobilization into newly-formed microbial biomass.

Net N mineralization of cowpea at 68 days was reduced by 36% by repeated air-drying. Significant reduction in N mineralization by repeated air-drying occurred for leaves, roots and nodules, but not for stems (Table 2). Reduction of net N mineralization by repeated drying and wetting may have been a result of chemical reactions during air-drying, which rendered N less available, a reduced size or reduced activity of the active microbial biomass, or a change in microbial species composition, such that more N was retained in the microbial biomass.

Generally, fresh plant material decomposed more readily than when dried (Read *et al.*, 1985; Henzell and Vallis, 1977; van Schreven, 1964, 1968). A retardation of N mineralization of dried alfalfa compared to fresh plant material was attributed to an increase in the C-to-N ratio of the water-soluble organic fraction by drying (van Schreven, 1964). Repeated air-drying in our study may have had a greater effect on N mineralization than air-drying only once before incubation. Goering and Van Soest (1970) concluded that artifact lignin was produced when plant material was oven dried at temperatures above 50°C through a non-enzymatic browning reaction that involved plant C and N. Moorhead *et al.* (1988) similarly found a significantly greater lignin content in water hyacinths after oven-drying at 70°C than after freeze-drying. Plant material was not oven-dried in this study, but repeated air-drying may have had a similar effect on its chemical composition as oven-drying.

The hypothesis that N in plant material was rendered more resistant to decomposition by repeated air-drying is supported by the significantly greater amount of N present in undecomposed plant material in repeatedly dried and wetted soil than in continuously moist soil after the initial 23 days of incubation (Fig. 5). The difference in the amount of N mineralized from cowpea decomposing in moist and dried and rewetted soil (Fig. 4) was very similar to the difference in the amount of N remaining in undecomposed plant material between the two moisture regimes (Fig. 5). Tissue N concentration of undecomposed cowpea pieces recovered from soil was significantly greater in repeatedly dried and wetted soil than in moist soil after the initial 23 days of incubation due to greater reduction in remaining plant dry matter than in remaining plant N. Despite the greater N

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tissue concentration of undecomposed plant material in repeatedly dried and wetted soil, N mineralization was lower, indicating that remaining plant N was in a less available form than in continuously moist soil. More research is needed to describe chemical reactions occurring in plant material during decomposition in repeatedly dried and wetted soil.

The size of the active microbial biomass in continuously moist soil and in repeatedly dried and wetted soil on the 3rd day after rewetting was not significantly different, except on day 68 (Fig. 2). Therefore the size of the active microbial biomass was not a limiting factor for N mineralization in repeatedly dried and wetted soil.

Repeated drying and wetting may have affected the species composition of the microbial biomass, and thus the amount of N in the microbial biomass. The N concentration of microbial cells is species dependent. Changes in water potential cause death of at least part of the microbial biomass (Kieft *et al.*, 1987), and would create selective pressures on the microbial population. Further, accumulation of N in less available portions of dead microbial biomass after each rewetting event could reduce net N mineralization.

Net N mineralization of cowpea was best described by single exponential models (Fig. 4). Single exponential models have been used previously to describe net N mineralization during decomposition of legumes

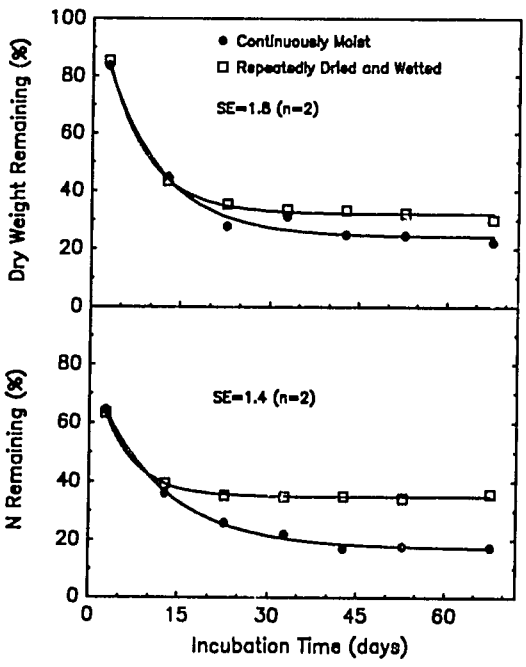

Fig. 5. Plant dry weight of and plant N remaining in undecomposed cowpea pieces in continuously moist and in repeatedly dried and wetted soil. Symbols represent measured data and lines are non-linear regression equations with the following parameters for moist soil: $DW_{rem} = 24.2 + 80.2[\exp(-0.109*day)]$ and $N_{rem} = 17.0 + 59.9[\exp(-0.087*day)]$, and for repeatedly dried and wetted soil: $DW_{rem} = 32.1 + 80.7[\exp(-0.152*day)]$ and $N_{rem} = 34.8 + 47.3[\exp(-0.184*day)]$.

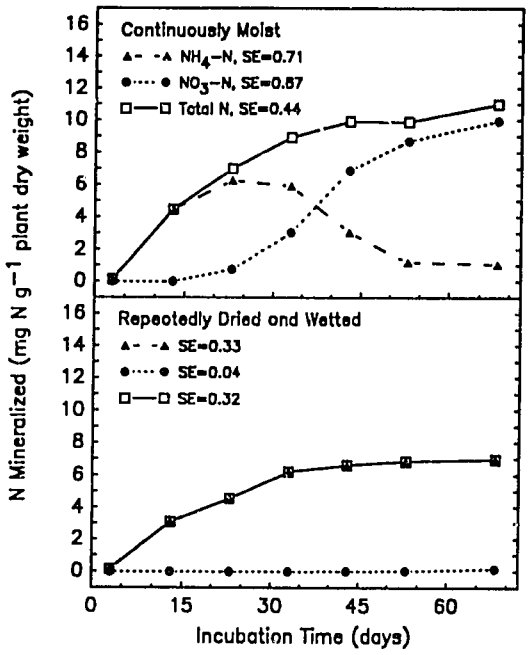

Fig. 6. Total net N mineralization during decomposition of cowpea in continuously moist and in repeatedly dried and wetted soil, and amount of mineralized N present as NH_4-N and NO_3-N.

(Frankenberger and Abdelmagid, 1985; Kirchmann and Bergqvist, 1989; Palm and Sanchez, 1990). Gale and Gilmour (1988) found a triple exponential model to best describe decomposition of alfalfa under aerobic conditions. Potentially mineralizable N predicted from non-linear regression equations, was 47% of cowpea N in moist soil and 31% in repeatedly dried and wetted soil (Fig. 4). At the end of the 68 day incubation, N mineralization had reached 95% of its predicted potential under both moisture regimes. A similar temporal pattern of N mineralization was observed for 66-day old white clover tops (Kirchmann and Bergqvist, 1989). However, for mature cowpeas only 72% of the potentially mineralizable N was released at 70 days (Frankenberger and Abdelmagid, 1985). The N release rate constant reported here for 44-day old cowpeas (0.0494 day^{-1}) was greater than that reported for mature cowpeas (0.0183 day^{-1}; Frankenberger and Abdelmagid, 1985), indicating that a greater fraction of the potentially mineralizable N is released per day in young cowpeas. These differences in the temporal pattern of N release are of importance for predicting N mineralization from legume green manures in field situations.

In continuously moist soil, mineralized N was present in the form of NH_4-N and NO_3-N (Fig. 6). Conversion of NH_4-N to NO_3-N started only between 13 and 23 days despite high NH_4-N concentrations at 13 days after cowpea incorporation. The time lag in the onset of nitrification may have been the result of an initially low nitrifier population in the soil. In repeatedly dried and wetted soil, no NO_3-N

was detected except for a trace at 68 days. Small amounts of NO_3–N were found for nodules at 43 days and for roots at 68 days (data not shown). No NO_3–N was detected at any time under dried and rewetted conditions for leaves and stems. These two plant parts also showed later onset of nitrification under continuously moist conditions compared to the other plant parts. Roots and nodules may have carried nitrifiers through contact with soil in which cowpeas were grown resulting in a greater initial nitrifier population. It appears that repeated drying of the soil inhibited growth of the nitrifier population, which due to its slow growth rate could not significantly increase during the 4 days of adequate moisture during each drying cycle. In the seasonally arid tropics and sub-tropics a lag in nitrification has been observed following the onset of the rainy season, and was attributed to death of nitrifiers under extreme drying conditions (Harris, 1980). Limited diffusion of NH_4^+ during the dry periods of each cycle would have contributed to reduced nitrification (Sabey, 1969), but would not have eliminated nitrification.

During decomposition of a whole cowpea plant, leaves contributed most (61%) to the total amount of net N mineralized at 68 days. The N contributions of stems, roots and nodules were similar (each part contributing *ca* 13% to total N release at 68 days) despite the low dry matter of nodules. A greater amount of N was released from nodules than from roots during the first month of decomposition due to their high N tissue concentration (Table 1), while thereafter cumulative net N mineralization was greater from roots than from nodules (data not shown). Averaged across moisture regimes, above-ground plant parts contributed 73% of the mineralized N at 68 days of incubation. Therefore, when above ground plant material of cowpea is removed from the field and used as animal feed, the N contribution from roots and nodules to the following crop can only be expected to be *ca* one-fourth of that when cowpea is used as green manure.

Relationship between C and N mineralization

Fractional C release from cowpea was more than double compared to fractional N release during the first 13 days after incorporation (2.6 %C:%N in moist soil and 3.5 %C:%N in dried and rewetted soil; Fig. 7). After this time, fractional release of N was greater than fractional release of C. Carbon and N release were linearly related after the first 13 days of incubation, with a slope of 0.60 %C:%N in moist soil and a slope of 0.84 %C:%N in repeatedly dried and wetted soil (Table 3). Gale and Gilmour (1988) also found a two-phase linear relationship between C and N release from decomposing alfalfa. For the first 14 days fractional C release was greater than fractional N release (5.9 %C:%N), then fractional N release was greater (0.77 %C:%N). The slope during the second phase was similar to that for cowpea.

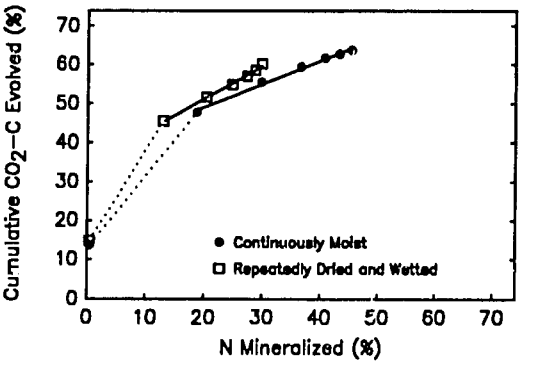

Fig. 7. Relationship between C and N mineralization during decomposition of cowpea in continuously moist and in repeatedly dried and wetted soil.

Roots had a similar two-phase relationship between C and N release as all parts combined, whereas for leaves and stems C and N release were linearly related throughout the 68-day incubation. For nodules, the relationship was linear during the first 23 days after incorporation, then C continued to be released whereas N release had become very low. Gilmour *et al.* (1985) reported a linear relationship between release of C and N from decomposing clover and alfalfa during 30 days. The slope was close to one indicating similar fractional C and N release. Similar fractional C and N release under moist conditions was found in our study for leaves, for nodules during

Table 3. Relationship between net mineralization of C and N (in percent of total and in mg C and N) during decomposition of cowpea plant parts under continuously moist and repeatedly dried and wetted conditions

Moisture regime	Plant part	Time period (days)	Intercept (% C)	Slope (% C:% N)	Intercept (mg C)	Slope (mg C:mg N)	R^2
Moist	All parts	13–68	37.04	0.599	163.8	11.1	0.994
Moist	Leaves	3–68	9.13	1.162	41.5	17.6	0.991
Moist	Stems	3–68	5.60	2.143	24.8	56.3	0.991
Moist	Nodules	3–23	7.80	0.877	31.4	5.71	0.999
Moist	Roots	13–68	27.58	1.076	118.7	26.5	0.979
Dry/wet	All parts	13–68	34.35	0.842	151.9	15.7	0.995
Dry/wet	Leaves	3–68	8.36	1.870	38.0	28.4	0.997
Dry/wet	Stems	3–68	1.03	2.458	4.55	64.6	0.990
Dry/wet	Nodules	3–23	10.15	0.825	39.9	5.37	0.999
Dry/wet	Roots	13–68	30.94	1.134	133.2	27.9	0.992

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the first 3 weeks and for roots after the first 13 days (Table 3).

The linear portion of the relationship between C and N release indicated that the C-to-N ratio of the substrate being decomposed during this time was constant. The C-to-N ratio of the substrate was 11.1 in moist soil and 15.7 in repeatedly dried and wetted soil (Table 3). The substrate, however, was comprised of changing portions of undecomposed plant material, decomposition products and dead microbial tissue. The C-to-N ratio of the material being decomposed during the linear phase of the relationship ranged from 5.4 for nodules to 64.6 for stems (Table 3). The slope of the linear portion of the relationship was significantly correlated with the initially non-soluble C-to-N ratio of the plant parts ($r = 0.95$ for moist soil, and $r = 0.92$ for repeatedly dried and wetted soil, $n = 5$), but not with the initial total C-to-N ratio of the plant parts.

Fractional C release relative to fractional N release was greater in dried and rewetted soil than in continuously moist soil for all parts except for nodules. Release of C per unit release of N appears to depend on the chemical composition of the plant material, especially its initial non-soluble C-to-N ratio, as well as on the moisture regime.

CONCLUSIONS

Kinetics of N mineralization from decomposing plant material under moist conditions may significantly overestimate N mineralization rates occurring under field conditions, where soil is subjected to drying–wetting cycles. Intermittent periods of dry soil between rainfall events or irrigations could reduce nitrate formation and nitrate losses in sandy soils with low nitrifier populations due to severely reduced nitrification in soil subjected to short drying–wetting cycles. Because of lower rates of N mineralization and lower rates of nitrification, soils subjected to frequent drying and rewetting may be more N conserving than soils that remain continuously moist.

The portion of C potentially not mineralized as CO_2 was 34%, and the portion of N potentially not mineralized was 53 and 69% for the two moisture regimes, respectively. These results indicate a possible contribution of cowpea green manure to soil organic matter formation. However, in the presence of soil animals decomposition may have proceeded further (Howard and Howard, 1974). The C-to-N ratios of plant material potentially not mineralized were 11.5 in moist soil and 9.3 in frequently dried and wetted soil, which were similar to C-to-N ratios of soil organic matter.

The relationship between C and N mineralization from cowpea decomposing in repeatedly dried and wetted soil could be used to better predict N mineralization from C loss data obtained in the field under similar soil moisture and temperature regimes than a relationship between C and N mineralization derived under continuously moist conditions. Prediction of the temporal pattern of N mineralization would allow better synchronization of N mineralization from green manure and N fertilization with crop N demand.

Acknowledgements—This research was funded by the Soil Management Collaborative Research Support Program of the U.S. Agency for International Development.

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October 18, 1994

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ATT: Referred Publications supported by Project No. 9311311, Soil Management Collaborative Research Support Program under Grant No. DAN-1311-G-00-1049-00

Enclosed are two (2) copies of two (2) technical publications from the Soil Management Collaborative Research Support Program, Project No. 9311311, under Grant No. DAN-1311-G-00-1049-00.

Sincerely,

Roger G. Hanson
Director

RGH:sm

Enclosures

cc: Dr. Charles Sloger