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Effects of pasture introduction on soil CO_2 emissions during the dry season in the state of Rondônia, Brazil

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Abstract. Soil CO_2 evolution rates, soil temperatures and moisture were measured during the dry season in two forest-to-pasture chronosequences in Rondônia, Brazil. The study included pastures ranging from 3 to 80 years-old. Mean dry-season CO_2 evolution from the forest in chronosequence I, 88.8 mg CO_2-C $m^{-2}h^{-1}$ was lower than from the pastures which ranged from 111 to 158 mg CO_2-C $m^{-2}h^{-1}$. We found that temperature was not a good predictor of CO_2 emissions from pasture but that there was a significant relationship ($r = 0.72, p < 0.05$) between soil moisture and pasture emissions. The $\delta^{13}C$ of the soil CO_2 emissions also was measured on chronosequence I; $\delta^{13}C$ of the CO_2 emitted from the C_3 forest was −29.43 ‰. Pasture $^{13}CO_2$ δ values increased from − 17.91 ‰ in the 3 year-old pasture to − 12.86 ‰ in the 80 year-old, reflecting the increasing C_4 inputs with pasture age. Even in the youngest (3 year-old) pasture, 70 percent of the CO_2 evolved originated from C_4 pasture-derived carbon.

Introduction

Tropical deforestation alters the exchange of carbon between terrestrial ecosystems and the atmosphere which is important in understanding the global carbon cycle (Bueno & Helene 1991; Houghton 1990). The Brazilian Amazon River Basin contains the world's largest tropical forest (approximately 4.6×10^6 km^2) and also has one of the highest deforestation rates (Skole et al. 1994). To understand the consequences of deforestation on soil carbon dynamics, it is important to document the differences in soil respiration among natural and managed tropical ecosystems. Indeed, little information is available on tropical soil respiration rates, a major component of ecosystem carbon dynamics (Raich & Nadelhoffer 1989; Raich & Schlesinger 1991), in either natural or agricultural systems (Raich 1983; Steudler et al. 1991).

Rondônia state, located in the Amazon Basin, is one of the most important new agricultural regions of the country. As of 1988, 29,600 km^2 or 13.9% of the original forests of Rondônia had been cut (Fearnside 1993) and by 1985 nearly 880,000 ha, that is, 30% of the total deforested area, were converted directly into pasture (Anuário estatístico do Brasil, IBGE 1992). This fact makes the region an ideal location to investigate how land use change affects soil respiration rates along a forest-to-pasture chronsequence of sites. The pasture chronosequence also represents a unique opportunity to apply stable carbon isotope dilution techniques to determine the origin of the mineralized organic material (C_3 forest or C_4 pasture) using the $\delta^{13}C$ natural abundance of the evolved CO_2 (Schönwitz et al. 1986).

Soil respiration is usually defined as the amount of CO_2 evolved from the soil surface and is primarily derived from soil organic matter (SOM) mineralized by microbiological processes and root respiration (Behera et al. 1990; Bowden et al. 1993). A major proportion of the variability in soil respiration rates can be explained by temperature and soil water content, with moisture usually the dominant controlling factor in tropical systems (Rajvanshi & Gupta 1986). Since there is only a small change in temperature throughout the year in the tropics, we made a series of measurements along forest to pasture chronosequences during the dry season, when soil respiration rates may be less variable (Kursar 1989).

The objectives of this study were to determine: 1) how the conversion of a natural forest to a chronosequence of pastures affected the dry season soil respiration rates and 2) what was the origin of the emitted CO_2 (forest or pasture derived material) using isotopic techniques.

Methods

Site description

The study was conducted at Fazenda Nova Vida, a 22,000-ha cattle ranch about 250 km south of the city of Pôrto Velho along the BR-364 road in the central region of Rondônia state, Brazil. The local climate is humid tropical, with an annual mean temperature of 25.5 °C and precipitation of 2200 mm (Bastos and Diniz 1982) including a dry season of approximately four to five months from May to September. The predominant soil at the ranch is an Ultisol (Podzólico Vermelho-Amarelo in the Brazilian soil classification) one of the dominant soil types (22%) in the basin (Moraes et al. 1995). The natural vegetation is classified as open moist tropical forest (Projeto Radambrasil 1978). According to the ranch manager's records, a slash and burn technique was used to clear the forest after selective removal of the economically important trees. Pasture grasses (*Brachiaria brizantha* and *Panicum maximum*) were sowed by airplane and weeds were controlled by fire two years after pasture establishment. Neither mechanized agricultural practices nor chemical fertilizers were used on any of the pastures.

Two forest-to-pasture chronosequences were selected on the same soil type. Chronosequence I included a forest site and pastures created directly from forest in 1989, 1987, 1983, 1979, 1972, 1951 and 1911, corresponding to pasture ages of 3, 5, 9, 13, 20, 40 and 80 years. Chronosequence II was located about 10 km away and had a forest site and pastures created in 1989, 1987 and 1972.

A detailed description of the soil characteristics of the study area has been given by Moraes et al. (1994). Total carbon stocks in the upper 30 cm ranged from 3.4 Kg m^{-2} to 2.8 Kg m^{-2} in the forests and were higher (4.0 to 3.9 Kg m^{-2}) in the 20 year-old pastures of chronosequences I and II, respectively. The 80 year-old pasture had the maximum carbon stock, 5.25 Kg m^{-2}, of all the pasture sites. Soil pH ranged between 4.6 and 4.7 in the chronosequence I and II forests and increased from 5.5 to 6.7 in the pastures of chronosequence I and from 4.9 to 6.4 in chronosequence II. Soil clay content had mean values of 27.6 percent and 21.6 percent for all sites in chronosequence I and II, respectively. Pasture bulk densities were greater than in the forests (1.44–1.41 g cm^{-3}) and increased with pasture age, reaching values of 1.53 g cm^{-3} in the 9 and 40 year-old pastures.

Field measurements

Measurements of carbon dioxide emission were made once per month at chronosequence I in early June, July and August 1992. Forest, 1987 and 1972 pastures from chronosequence II were sampled in July and August, and the 1989 pasture only in August 1992. Fluxes were measured three times during the day at 0700, 1200 and 1700 hours, corresponding approximately to the minimum, maximum and intermediate soil and ambient air temperatures. Five soil cores were taken at each site for determination of gravemetric soil moisture at 0–5 and 5–10 cm depths once per day.

Carbon dioxide emission measurements were made using a two-part chamber design (Bowden et al. 1990) with three chambers at each site. Chamber anchors were installed in June 1992, several days before flux measurements were made, and remained in place throughout the study period. In the pastures chamber anchors were located between the grass cultivars with anchors separated from each other by about six meters. Surface litter material was left in place. Initial headspace gas samples were collected using 20-ml nylon syringes (Bowden et al. 1990) at the beginning of the 30-min incubation and at 10-min intervals thereafter. Ambient air, 2, 5 and 10 cm soil temperatures were measured during each incubation. Gas samples were returned to Piracicaba and analyzed within one week. Carbon dioxide concentrations were determined using gas chromatography with a ^{63}Ni electron capture detector operated at 230 °C (Steudler et al. 1991). Two Scott certified standards of 234 and 2030 ppmv CO_2 in N_2 were used for calibration. Fluxes were calculated using the linear change in CO_2 concentration with incubation time.

$\delta^{13}CO_2$ *measurements*

During the July 1992 sampling, gases were collected from the chambers of chronosequence I pastures to determine the δ^{13}C value of the emitted CO_2. Initial and final CO_2 concentrations and corresponding δ^{13}C values were measured. Initial ambient air samples for determination of $\delta^{13}CO_2$ were taken with one-liter evacuated glass flasks (Quay et al. 1989) at the soil surface inside the chamber anchor just before the start of the flux incubation. Gas samples were collected from the chamber headspace immediately after the 30-min flux sample using a 100-ml evacuated flask. An ambient air and 30-min headspace sample was taken from each chamber at all sites. Gas samples for isotope analysis were returned to the lab in Piracicaba and analyzed within 2 weeks. Carbon dioxide from ambient air and chamber headspace gas samples was purified and the δ^{13}C values determined using a Finnigan Matt-Delta E mass spectrometer.

Calculations

The δ^{13}C value of the CO_2 emitted into the chamber was corrected for dilution by the initial ambient CO_2 values using equation 1:

$$^{13}CO_{2e} = \{[CO_{2f}] *^{13} C_f) - ([CO_{2i}] *^{13} C_i)\}/[CO_{2f}] - [CO_{2i}] \qquad (1)$$

where $^{13}CO_{2e}$ is the δ^{13}C value of the emitted CO_2 into the chamber during the incubation; $[CO_{2i}]$ and $[CO_{2f}]$ are the initial and final CO_2 concentrations, respectively and $^{13}C_i$ and $^{13}C_f$ are the initial and final δ^{13}C values of the CO_2 inside the chamber.

The amount of carbon derived from pasture (Cdp) evolved as CO_2 was calculated using the $^{13}CO_{2e}$ data in Fig. 2 and equation 2:

$$CO_2\text{–Cdp} = \{(\delta p - \delta f)/(\delta gl - \delta f)\} * \text{Total evolved C} \qquad (2)$$

where CO_2-Cdp is the amount of pasture derived carbon, δp is the $^{13}CO_{2e}$ value of a pasture site, δf the $^{13}CO_{2e}$ value of the forest (−29.43 ‰) and δgl is the ^{13}C value of −13.00 ‰ for C_4 grass litter (Cerri and Andreux 1990). The total evolved C is calculated by multiplying the mean daytime hourly CO_2 soil evolution rates by the number of hours in each of the dry season months and summing over all months.

Results

Temperature and moisture variations

Maximum and minimum ambient air temperatures during the period ranged from 29 to 16 °C in the forest sites and from 37 to 16 °C in the pastures. Soil temperatures had the smallest variation in the forest sites, where a maximum difference of 5 °C was observed at a depth of 2.5 cm (19 to 24 °C). In the pasture sites this difference increased to 19 °C (17 to 36 °C), while in the deepest soil layer (10 cm) it was about 10 °C.

Between the first sampling period on June 10 and the third sampling on August 11, there was a total rainfall of 54 mm distributed as follows: 7 mm in late June, 25 mm in July three days before sampling and 4 mm in August one week before sampling. These rainfall amounts are in the range of the longer-term (1984–1992) monthly averages of 26, 5, and 47 mm measured approximately 20 km away at Fazenda Rancho Grande. Soil moistures in the forest remained relatively constant (9–12%), generally with lower values than the pasture sites in the beginning of the dry season (Table 1). However, the pattern changed in August when the forest sites had higher soil moistures than the pastures except for chronosequence II 1989 pasture.

Soil respiration

We did not observe a consistent pattern of CO_2 evolution related to the daytime cycle of soil temperature in either the forest or pasture sites.

CO_2 evolution from forest soils

Chronosequence I and II forest soils had mean respiration rates of 88.8 ± 6.9 and 112.0 ± 7.3 mg CO_2-C $m^{-2}h^{-1}$, respectively (Table 2). Although chronosequence I and II forest sites are under the same climatic conditions and have similar vegetation, slight variations in soil composition may contribute to the differences in respiration rates. The forest soil of chronosequence II always had greater respiration rates than the forest in chronosequence I with a difference between the daily means of about 25% (Table 2). Chronosequence II forest soil had a lower bulk density and percent clay content, indicating higher soil porosity. These factors may have resulted in more favorable conditions for microbial activity and increased gas diffusion rates.

CO_2 evolution from pasture soils

Pastures of chronosequence I had greater CO_2 emissions than the forest site, except for the 9-year-old pasture in June (Table 2). All pastures had the highest

Table 1. Soil moisture meaurements (%) at 0–5 and 5–10 cm depths during the soil respiration samplings in chronsequences I and II.

Sites	June		July		August	
	depth (cm)		depth (cm)		depth (cm)	
	0–5	5–10	0–5	5–10	0–5	5–10
Chronosequence I						
Forest	11.6 ± 2.1*	12.0 ± 1.2	9.0 ± 0.9	11.8 ± 0.5	10.9 ± 1.7	12.9 ± 1.3
Pasture age						
3 year-old	15.2 ± 2.8	15.1 ± 2.3	11.3 ± 4.0	13.0 ± 1.3	9.1 ± 1.7	10.8 ± 1.0
5 year-old	17.2 ± 4.2	15.8 ± 1.3	10.3 ± 1.0	10.8 ± 0.7	7.1 ± 0.5	9.3 ± 0.5
9 year-old	12.5 ± 3.0	12.5 ± 2.2	13.3 ± 7.0	14.2 ± 8.3	4.4 ± 0.8	6.5 ± 0.4
13 year-old	12.8 ± 1.7	11.4 ± 1.0	14.5 ± 2.6	12.6 ± 2.6	6.1 ± 0.9	7.4 ± 0.7
20 year-old	18.3 ± 1.1	15.5 ± 0.9	16.5 ± 1.4	15.3 ± 0.6	11.2 ± 1.1	11.0 ± 0.7
40 year-old	13.4 ± 2.1	13.0 ± 1.0	14.8 ± 2.4	14.8 ± 1.9	8.4 ± 3.9	9.0 ± 1.6
80 year-old	16.5 ± 2.1	14.0 ± 2.3	13.5 ± 0.8	12.6 ± 1.0	5.3 ± 0.9	6.1 ± 0.6
Chronosequence II						
Forest	–**	–	10.6 ± 1.2	12.8 ± 0.6	8.7 ± 1.1	9.3 ± 0.7
Pasture Age						
3 year-old	–	–	–	–	12.0 ± 1.2	14.0 ± 2.6
5 year-old	–	–	14.5 ± 2.0	9.6 ± 2.8	5.9 ± 0.7	6.2 ± 0.4
20 year-old	–	–	14.6 ± 1.2	13.2 ± 1.7	4.9 ± 1.1	6.7 ± 0.7

* s.d. ($n = 5$)

** not measured

Table 2. Daytime mean CO_2 respiration rates (mg CO_2-C $m^{-2}h^{-1}$) in chronosequence I and II.

Sites	June	July	August
		mg CO_2-C $m^{-2}h^{-1}$	
Chronosequence I			
Forest	94.2 ± 6.3*	95.4 ± 18.5	78.0 ± 11.7
Pasture Age			
3 year-old	122.8 ± 12.5	105.0 ± 13.2	104.1 ± 24.6
5 year-old	143.1 ± 7.0	165.6 ± 1.0	112.7 ± 8.9
9 year-old	86.0 ± 2.8	151.9 ± 8.3	125.2 ± 12.1
13 year-old	114.3 ± 5.2	182.1 ± 6.2	90.9 ± 6.1
20 year-old	168.1 ± 13.6	176.2 ± 28.6	126.6 ± 19.3
40 year-old	106.1 ± 1.9	133.4 ± 5.6	94.5 ± 16.6
80 year-old	176.3 ± 8.6	173.3 ± 10.6	78.5 ± 4.8
Chronosequence II			
Forest	–**	126.0 ± 11.4	98.0 ± 14.0
Pasture Age			
3 year-old	–	–	93.8 ± 11.1
5 year-old	–	133.1 ± 2.1	66.2 ± 4.1
20 year-old	–	144.6 ± 7.4	57.3 ± 4.6

* standard error ($n = 3$ chambers)
** not measured

respiration rates during the july sampling except for the 3 and 80 year-old pastures.The lowest rates were measured in August when soil moistures were also at their minimum. Combining the data for soil moisture and CO_2 fluxes from all sampling times (Tables 1 and 2) for the pastures in chronosequence I, we found a significant correlation ($r = 0.72, p < 0.05, n = 26$) between daytime CO_2 fluxes and 0-5 cm soil moisures. However, no significant relationships were found within each month.

Mean dry season CO_2 emissions from chronosequence I pasture sites varied between 111 and 158 mg CO_2-C $m^{-2}h^{-1}$ (Fig. 1). Pasture emissions increased with age in the youngest pastures but pastures greater than 9 years-old did not show this trend suggesting that during the dry season CO_2 emissions in the older pastures may be independent of pasture age. We did not calculate the seasonal means of the chronosequence II measurements, but report the daytime means for comparison with chronosequence I (Table 2).

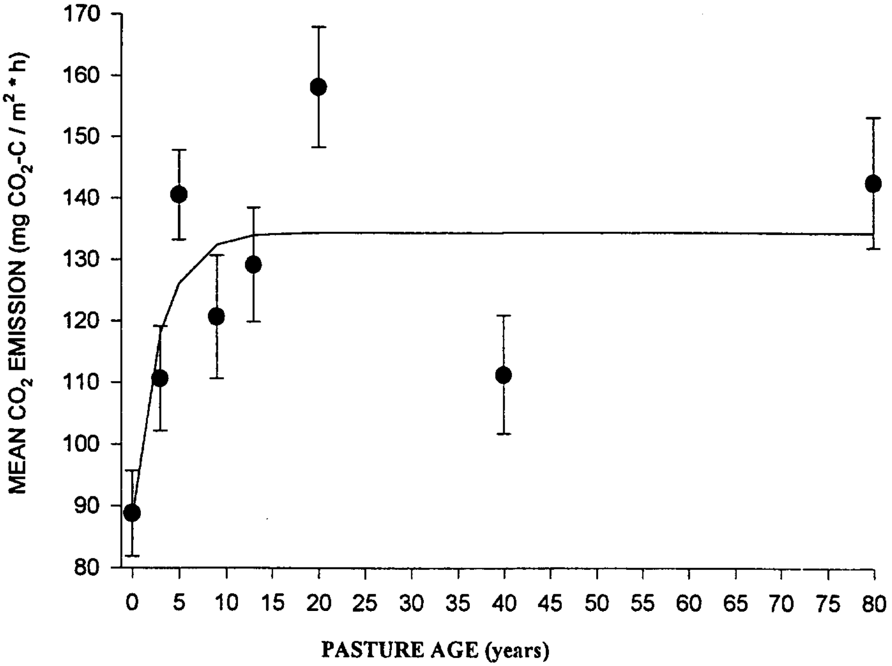

Fig. 1. Mean dry season soil CO_2 emissions and standard errors (S.E.) during the dry season from chronosequence I forest (0 age) and various aged pastures. Mean emissions were calculated by multiplying the mean daily rates by the number of hours in that month, summing over all months and dividing by the total number of hours.

Origin of the CO_2 evolved

A $\delta^{13}CO_{2e}$ value of −29.43 ‰ for the forest was determined from a survey of moist tropical forests in Rondônia during the dry season (Steudler et al. manuscript in preparation). Pasture $^{13}CO_{2e}$ δ values ranged from −17.91 ‰ in the 3-year-old pasture to −12.86 ‰ in the 80-year-old pasture reflecting the increasing C_4 carbon inputs with pasture age (Fig. 2).

Discussion

Forest CO_2 emissions

Our rates from the forest sites were higher than obtained by Medina et al. (1980) in a laterite forest, where the values ranged from 20.2 mg CO_2-C $m^{-2}h^{-1}$ during the dry season to 42.0 mg CO_2-C $m^{-2}h^{-1}$ during the wetter months, with no clear seasonal trend. The lack of a seasonal trend may be due to the continuously favorable temperature and humidity conditions in

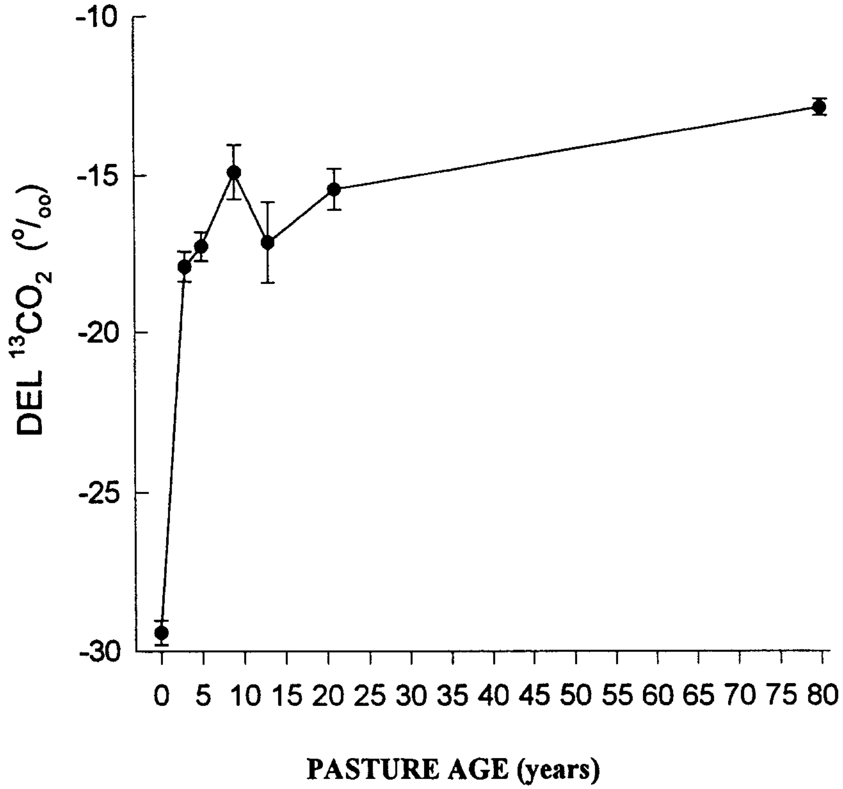

Fig. 2. Mean $\delta^{13}C$ values and standard errors (S.E.) determined for soil CO_2 emitted from chronosequence I pastures. Measurements were made in July, 1992. The forest $\delta^{13}C$ value (0 age) was determined from a survey of Rondônian moist tropical forests during the dry season.

this forest. In a monsoonal tropical forest ecosystem in India, Rajvanshi & Gupta (1986) showed that the soil respiration rate was lower during the winter months, reflecting the effect of hot dry conditions during the months of March to May, when the rates ranged between 60 and 72 mg CO_2-C $m^{-2}h^{-1}$. Kursar (1989) reported rates of 128 to 163 mg CO_2-C $m^{-2}h^{-1}$ during the early dry season for a Panamanian rain forest, comparable to 140 mg CO_2-C $m^{-2}h^{-1}$ obtained by Steudler et al. (1991) during the same period of the year in a tabonuco forest in Puerto Rico. These rates are higher than our observations, but the difference may be because these sites receive more than 100 mm of precipitation each month even during the dry season.

Pasture CO_2 emissions

Data for soil respiration rates from tropical pastures are sparse. Goreau and Mello (1985) reported mean fluxes from young pastures and a grassland were about 165 mg CO_2-C $m^{-2}h^{-1}$ from central Amazonian soils during the dry season. These sites received a mean of 50 mm precipitation/month during this time of the year. These rates are higher than the 55 mg CO_2-C $m^{-2}h^{-1}$ measured by Gupta & Singh (1981) in a tropical grassland of India, where low soil moisture became a factor limiting microbial and root metabolism during the dry part of the monsoonal summer. Our rates are at the upper range of these measurements.

The relationship $Y = 88.19 + 46.22(1-e^{-0.34x})$ gave the best fit ($r^2 = 0.53$) to the mean CO_2 forest and pasture data (Fig. 1). We found that after the nine year-old pasture there was little increase in the CO_2 fluxes from the older pastures. This may be because after grass cover is fully established and both root biomass and labile carbon inputs reach a steady state so that CO_2 releases are constant. We observed that grass stems only partly covered the soil area in the 3-year-old pasture of chronosequence I but maximum stem density was reached in the 9-year-old pasture. Bonde et al. (1991) also observed that about one third of the area in a 2-year-old pasture was covered by grass while in an 8-year-old pasture grasses covered practically the whole area. Luizão et al. (1992) found that annual fine root biomass increased from 5.1 t/ha in a tropical forest near Manaus to 8.9 t/ha an increase of 74% in a 2-year-old pasture. Kepler et al. (1990) at the same sites during the wet season measured a 127% increase in the pasture (at age 1.5 years old) CO_2 emissions compared to the forest. We measured a 33% increase in the youngest pasture CO_2 emission in August compared to the forest. The major sources of CO_2 emitted from the pasture soils are from mineralization of soil organic matter (SOM) and plant root respiration. These studies suggest that root respiration may be a major contributor to the CO_2 emitted from pastures.

Origin of the emitted CO_2

While there have been many studies that have used changes in the ^{13}C content of forest (C_3) and pasture (C_4) soil organic matter to examine soil carbon turnover (Volkoff & Cerri 1987; Martin et al. 1990; Chone et al. 1991), there are only a few reported data from field studies of $\delta^{13}C$ in the respired CO_2 from soils. Studies in temperate forest and uncultivated soils showed that the $\delta^{13}C$ of the soil-respired CO_2 ranged from −20.5 to −27.0 ‰ (Dorr & Munnich 1980; Schleser & Jayasekera 1985; Cerling et al. 1991). Quay et al. (1989) reported that the $\delta^{13}C$ results from two chamber measurements in a tropical forest soil were −24.8 and −27.4 ‰. Townsend et al. (1995) measured the $\delta^{13}C$ of the CO_2 emitted from two high elevation tropical forests in Hawaii and found values of −26.16 and −25.99 ‰. These data for C_3 systems are somewhat heavier than the −29.43 ‰. mean value we found in our tropical forest sites.

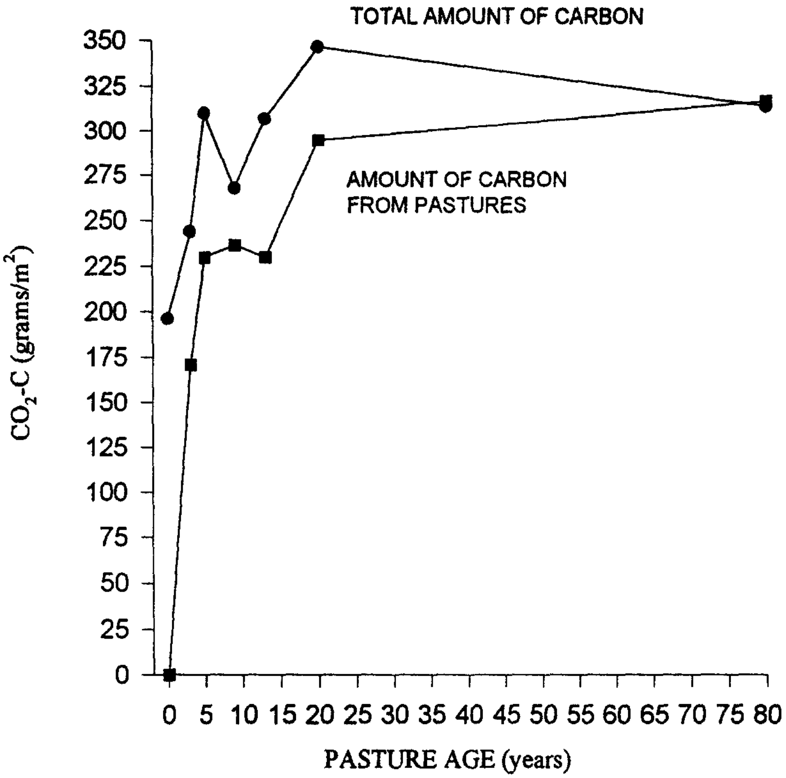

Fig. 3. Total amount of carbon emitted as CO_2 (●) during the dry season from the forest (0 age) and pastures in chronosequence I and the corresponding contribution of Cdp (■).

Our review of the literature revealed only one paper that reported the $\delta^{13}C$ of the CO_2 respired from tropical pastures. Townsend et al. (1995) found relatively constant $\delta^{13}C$ values in the respired CO_2 from pastures that were 10 to ~100 years-old. The ^{13}C values were −15.21 ‰ in the youngest pastures (10–27 years-old), −13.28 ‰ in the 40 to 50 year-old pastures and −14.65 ‰ in the oldest pasture (~100 years). We found a similar $\delta^{13}C$ value of −15.45 ‰ for our 20 year-old pasture but found a heavier value (−12.86 ‰) for the 80 year-old pasture compared to their oldest pasture (Fig. 2). We measured the greatest changes in $\delta^{13}C$ from −17.91 to −14.9‰ in the 3 to 9 year-old pastures, respectively.

We used the data in Fig. 1 to estimate the total amount of CO_2-C evolved during the dry season from chronosequence I. The amount of the CO_2-C evolved that originated from pasture derived carbon (Cdp) was calculated using the $^{13}CO_{2e}$ data in Fig. 2 and equation 2 (Fig. 3). The results showed that, in a short time, the newly introduced vegetation dominated soil CO_2 exchanges. Even in the youngest pasture (3 year-old), 70% of the CO_2 emitted from the soil system originated from Cdp (Fig. 3), and 100% of the CO_2 emitted from the oldest pasture was from a Cdp source.

Conclusions

Our analysis showed that soil moisture was a significant predictor of pasture CO_2 emissions. We found that over the dry season pastures had up to 76% greater CO_2 emissions than the forest. An exponential relationship $Y = 88.19 + 46.22(1 - e^{-0.34x})$ best described the mean CO_2 forest and pasture emissions and that in pastures older than nine-years there was little increase in flux of CO_2. This may be because the grass cover is fully established and both root biomass and labile carbon inputs have reached a steady state. Our results showed that the newly introduced vegetation dominated soil CO_2 exchanges so that even in the 3 year-old pasture, 70% of the CO_2 emitted from the soil system originated from Cdp.

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