JARQ 56 (1), 41-48 (2022) https://www.jircas.go.jp

Soil Carbon Turnover and Changes in Soil Nitrogen under the Agropastoral System in Brazilian Savannas (Cerrados)

Takuji NAKAMURA[1]*, Cesar MIRANDA[2], Tsutomu KANNO[3], Yoshinari OHWAKI[4], Osni SOUZA[1], Maria ARAUJO[1] and Manuel MACEDO[1]

[1] Hokkaido Agricultural Research Center, National Agriculture and Food Research Organization, Sapporo, Japan
[2] National Beef Cattle Research Center, Brazilian Agricultural Research Corporation, Mato Grosso do Sul State, Brazil
[3] National Institute of Livestock and Grassland Science, National Agriculture and Food Research Organization, Nasushiobara, Japan
[4] National Agricultural Research Center, National Agriculture and Food Research Organization, Tsukuba, Japan

Abstract

In the agropastoral system (pasture–soybean [PS] rotation system) initiated in 1993 in Brazilian savannas (Cerrados) in Campo Grande, Mato Grosso do Sul State, Brazil, the changes in soil carbon (C) and nitrogen (N) and the natural carbon stable isotope (^{13}C) signatures to determine the origin of soil C were examined. In this study, three primary cultivation systems were tested: 1) continuous pasture (P) (*Brachiaria decumbens*), 2) continuous soybean (S), and 3) PS rotation (4 years of soybean cultivation after 4 years of pasture). Mineralized N levels decreased after introducing soybean in the S and PS rotation fields. Using the ^{13}C natural abundance technique, 27% and 13% of soil organic C was estimated to be derived from soybean residues in the S and PS after the 8-year experiment, respectively. Thus, soybean cultivation replaced soil C by C derived from soybean residues to some extent and stimulated the degradation of soil organic matter due to the return of soybean residues with low C/N ratio and tillage system. Furthermore, larger negative N balances in the S and PS were estimated compared with the P cultivation system.

Discipline: Agricultural Environment
Additional key words: mineralized nitrogen, soybean, $\delta^{13}C$

Introduction

The Cerrados, covering an area of 204 million hectares (ha) or 23% of Brazil’s territory, is the primary ecosystem in Brazil where cultivated pastures are found. An area of approximately 50 million ha is planted with cultivated pastures, which are responsible for 50% of the country’s beef production (Macedo et al. 2001a). However, extensive pasture cultivation without fertilizer application has resulted in the degradation of over 50% grass pasture (Kanno et al. 2002, Macedo et al. 2001b). Maintaining soil fertility is an important factor for sustaining productivity in any agricultural system, particularly in these highly weathered soils. Sustainable crop–pasture rotation systems that combine soybean (i.e., agropastoral systems) have been discussed as sustainable land management systems for improving soil fertility in the tropics (Macedo 1995, Spain et al. 1996, Thomas 1995, Westerhof et al. 1999). It was reported that the growth of succeeding crops after cropping soybean in rotation systems was better than that in mono-cropping systems (Bergerou et al. 2004, Gentry et al. 2001, Kanno et al. 2002, Rao et al. 1992). Maloney et al. (1999) reported that this was due to the increase in available soil nitrogen (N) from the cultivation of soybeans.

In contrast, Heichel & Barnes (1984) reported that the removal of N contained in the soybean seeds may substantially exceed the symbiotically derived N in the

---

*Corresponding author: takuwan@affrc.go.jp

Received 12 March 2020; accepted 12 March 2021.

residue returned to the soil. Therefore, the removal of the harvested grain could actually result in a net deficit of soil N. Consequently, the effect of introducing soybean on soil N and organic matter statuses remains unclear in agropastoral systems. This research aimed to examine the effect of cultivation of soybean on soil N and the contribution of soybean-derived organic matter to the status of soil carbon (C) in the agropastoral system of Brazilian savannas (Cerrados).

Materials and methods

1. Experimental site

The experiment was conducted at the National Beef Cattle Research Center, Brazilian Agricultural Research Corporation (EMBRAPA-CNPGC), Campo Grande, Mato Grosso do Sul State, Brazil (20°27′S and 54°37′W). The rainy season is from September-October to April-May. The mean annual precipitation is 1,571 mm, 80% of which falls during the 7-month rainy season. The mean maximum and minimum temperatures are 28.8°C and 18.3°C, respectively. The soil is classified as dark red Latosol (Oxisol). The chemical characteristics of the soil before the experiment were as follows: pH, 5.7; organic matter, 2.9%; base saturation of exchangeable cations, 24%; base saturation of exchangeable calcium, 1.36; magnesium, 0.91; potassium, 0.11; and aluminum, 0.34 cmol(+) kg^{-1}; and phosphorus (Mehlich-I), 2.25 mg kg^{-1} (Kanno et al. 2002).

The experimental area before establishing the cropping systems was a degraded *Brachiaria decumbens* pasture that was seeded after the clearing of the original Cerrados forest in 1976. In 1993, at the beginning of the experiment, dolomite limestone (2,500 kg ha^{-1}) and phosphorus fertilizer (80 kg P_2O_5 ha^{-1}) were applied to the degraded pasture area as single superphosphate. The cropping systems were defined as follows (Table 1):

(1) Natural Cerrado vegetation (original Cerrado forest [FR]).

(2) Eight years of continuous pasture, for which the *B. decumbens* pasture was renewed and fertilized in 1993 (P).

(3) Eight years of continuous cropping (S), for which the area reclaimed from the degraded pasture was continuously cultivated with soybean during summers after 1993 under a farmer’s common conventional system (yearly disking), with winter fallow (disking depth, 20 cm).

(4) Four years of pasture and 4 years of cropping (PS), wherein *B. decumbens* pasture was renewed in 1993, grazed until 1997, and then substituted by a yearly crop of soybean during summer, from 1998 to 2002.

The experimental design was a randomized blocked design with four replications, except for the FR. The experimental plot for P and PS covered 0.7 ha and that for S covered 0.13 ha. On each experimental plot, the pasture was continuously grazed throughout the experimental period by two beef cattle without supplementary feed; no grass was cut, and all feces and urine were left on the pasture.

2. Chemical analysis

Soil samples from the depths of 0 cm-20 cm were collected using a metal ring. The samples were taken from eight randomized points on each plot and were mixed together. The soils were air-dried, ground, and then passed through a 2-mm mesh sieve. Total contents of soil C and N were determined using an NC analyzer (Sumigraph NC-900, Sumika Chemicals, Tokyo, Japan). Mineralized N contents in soil samples were measured according to incubation methods (Kanda et al. 2002, Matsumoto et al. 2000a, b). A 6-g aliquot of soil in a 100-mL glass bottle was moistened at 60% of maximum water-holding capacity. The soil in the bottle was incubated at 30°C for 4 weeks. After the incubation period, the inorganic N of the soil was extracted with 100 g L^{-1} KCl and determined using the indophenol method and distilled in the presence of Devarda’s alloy for ammonium and nitrate contents, respectively (JIS 1971). The content of mineralized N was determined via the difference in inorganic N content before and after the incubation.

The δ^{13}C values of soil samples, which were weighed into thin capsules containing 100-1,000 µg C per capsule, were determined via mass spectrometry (Finnigan DELTA Plus XP, Thermo Electron Co., San Jose, USA).

Table 1. Experiment detail

Treatment	93/94	94/95	95/96	96/97	97/98	98/99	99/00	00/01	Description
FR	Forest								Native vegetation (Cerrado)
P	Pasture								Continuous pasture
S	Soybean								Continuous summer soybean
PS	Pasture				Soybean				4y pasture + 4y soybean

Isotope ratios are expressed as $\delta^{13}C$ values:

$$\delta^{13}C\ (‰) = (\text{Rsample} / \text{Rstandard} - 1) \times 1{,}000$$

where R is $^{13}C/^{12}C$ and Pee Dee Belemnite was used as the standard.

The $\delta^{13}C$ values of C_3 or C_4 plants have different signatures because of larger isotopic discrimination against ^{13}C during the primary carboxylation of plants with the Calvin cycle (C_3) than that with the Hatch–Slack cycle (C_4). Common Cerrado plants or soybean are typical C_3 plants with a ^{13}C signature that ranges from −25 to −30, but the ^{13}C signature of tropical C_4 grasses, such as *B. decumbens*, ranges from −6 to −19 (Miranda et al. 1997, Smith & Epstein 1971). The litter of these plants would have a similar ^{13}C signature, and changes from C_3 to C_4 vegetation would provide an *in situ* labeling that allows identifying not only the primary C sources but also the changes occurring in the whole soil organic matter (Balesdent et al. 1987, Cadisch et al. 1996, Huggins et al. 1998, Rao et al. 1994). Thus, the proportions of C derived from Cerrado forest, grasses, and soybean were estimated according to the model of Cadisch & Giller (1996) and Cadish et al. (1996). The proportion of soil organic matter derived from C_4 grasses in a pure grass pasture after the clearing of the Cerrado rainforest can be calculated using the following formula:

$$f_{g(G)} = (\delta_{(G)} - \delta_{(RF)}) / (\delta_g - \delta_{(RF)}) \tag{1}$$

where $f_{g(G)}$ is the proportion of soil organic matter derived from C_4 grass for a pure grass pasture (G) after the clearing of the rainforest, $\delta_{(G)}$ is the $\delta^{13}C$ value of the soil under the pure grass pasture, $\delta_{(RF)}$ is the $\delta^{13}C$ value of soil under the rainforest of Cerrado (RF), and δg is the $\delta^{13}C$ value of grass plant material (g). For the model calculations, we assume that the decay of rainforest organic matter under the grass–soybean (GS) pasture is similar to the rate of decay of the rainforest organic matter under the pure grass pasture. Logically, as long as the experimental area is homogeneous at the start of the experiment, it follows that:

$$C_{rf(GS)} = C_{rf(G)} \tag{2}$$

where $C_{rf(GS)}$ is the amount of the remaining rainforest C in the GS pasture and $C_{rf(G)}$ is the amount of rainforest C in the pure grass pasture. The total amount of soil C of the GS pasture, $C_{(GS)}$, can be expressed as follows:

$$C_{(GS)} = C_{s(GS)} + C_{g(GS)} + C_{rf(G)} \tag{3}$$

where $C_{s(GS)}$ is the amount of soybean-derived C from the GS pasture and $C_{g(GS)}$ is the amount of grass-derived C from the GS pasture. Thereafter, by solving equation (3) for $C_{g(GS)}$, the equation can be shown as follows:

$$C_{g(GS)} = C_{(GS)} - C_{s(GS)} - C_{rf(G)} \tag{3'}$$

The total amount of ^{13}C in the soil under the GS pasture is as follows:

$$C_{(GS)}\,\delta_{(GS)} = C_{s(GS)}\,\delta_s + C_{g(GS)}\,\delta_g + C_{rf(G)}\,\delta_{(RF)} \tag{4}$$

where $\delta_{(GS)}$ is the $\delta^{13}C$ value of the soil under the GS pasture and δ_s is the $\delta^{13}C$ value of soybean residue. Equation (3') is substituted into equation (4) and can be expressed as follows:

$$C_{(GS)}\,\delta_{(GS)} = C_{s(G)}\,(\delta_s - \delta_g) + C_{(GS)}\,\delta_g - C_{rf(G)}\,(\delta_g - \delta_{(RF)}) \tag{4'}$$

The remaining rainforest C in the pure grass pasture can be expressed as follows:

$$C_{rf(G)} = C_{(G)}\,(1 - f_{g(G)}) \tag{5}$$

where $C_{(G)}$ is the amount of C in the pure grass pasture. Equation (5) is substituted into equation (4') and follows that:

$$C_{(GS)}\,\delta_{(GS)} = C_{s(GS)}\,(\delta_s - \delta_g) + C_{g(GS)}\,\delta_g - C_{(G)}(1 - f_{g(G)})\,(\delta_g - \delta_{(RF)}) \tag{6}$$

Equation (1) is substituted as $([1 - f_{g(G)}]\,[\delta_g - \delta_{(RF)}])$ in equation (6) and follows that:

$$(1 - fg_{(G)})\,(\delta_g - \delta_{(RF)}) = \delta_g - \delta_{(G)} \tag{7}$$

By substituting equation (7) into equation (6) and solving for $C_{s(GS)}/C_{(GS)}$, which is equal to the proportion of soybean-derived C, $f_{s(GS)}$, in the GS pasture, equation (8) is derived as follows:

$$\begin{aligned} f_{s(GS)} &= C_{s(GS)} / C_{(GS)} \\ &= 1 / (\delta_s - \delta_g)\,(\delta_{(GS)} - \delta_g + C_{(G)} / C_{(GS)}\,[\delta_s - \delta_{(G)}]) \end{aligned} \tag{8}$$

Results and discussion

The content of soil C in FR (22-27 g kg^{-1} soil) was the highest in all treatments (Fig. 1). Although the C content in the P treatment decreased once in 1997 and then increased, it slightly decreased in the P system during the 8-year experiment. The C content in the S and PS treatments did not decrease until 1997, and the C content in the S system did not differ to that in PS. The C content in the S and PS systems decreased after 1997 and was slightly lower in the S than in the PS system. The total content of soil N in the FR (1.5-2.0 g kg^{-1} soil) was the highest among all cropping treatments, and the N content in the P treatment also slightly decreased during the 8-year experiment (Fig. 1). The N content in the S and PS treatments did not change much until 1997; however, it sharply declined thereafter and was slightly lower in the S than in the PS system. Varvel (1994) reported that soil C and N contents in the continuous soybean system decreased compared with the maize–soybean rotation system. In our study, although the effects of soybeans were unlikely to appear in C and N contents during the first 4 years of the 8-year experiment, the effects were likely to be stronger during the last 4 years.

The mineralized N content in the FR was the highest among all treatments throughout the experimental period and that in the P system changed slightly during the 8 years (Fig. 2). However, for the S and PS treatments, mineralized N content decreased slightly during the first 4 years and then greatly decreased during the last 4 years. The trend of the decline of soil mineralized N content was similar to that of soil C and N contents. These data indicated that soybean cultivation would stimulate the decrease of mineralized N in soil.

There have been various studies on the estimation of organic matter turnover in soils using the C stable isotopic technique (Arrouays et al. 1995, Bonde et al. 1992, Cadisch & Giller 1996, Cadisch et al. 1996, Cerri & Andreux 1990, Neill et al. 1996, Rao et al. 1994, Yoneyama et al. 2001). After clearing the forest, the introduction of crops led to a decrease in C content, and the ratio of C derived from crop residues to soil C increased rapidly (Arrouays et al. 1995, Cerri & Andreux 1990, Neill et al. 1996). In southwest France, a rapid loss of native forest

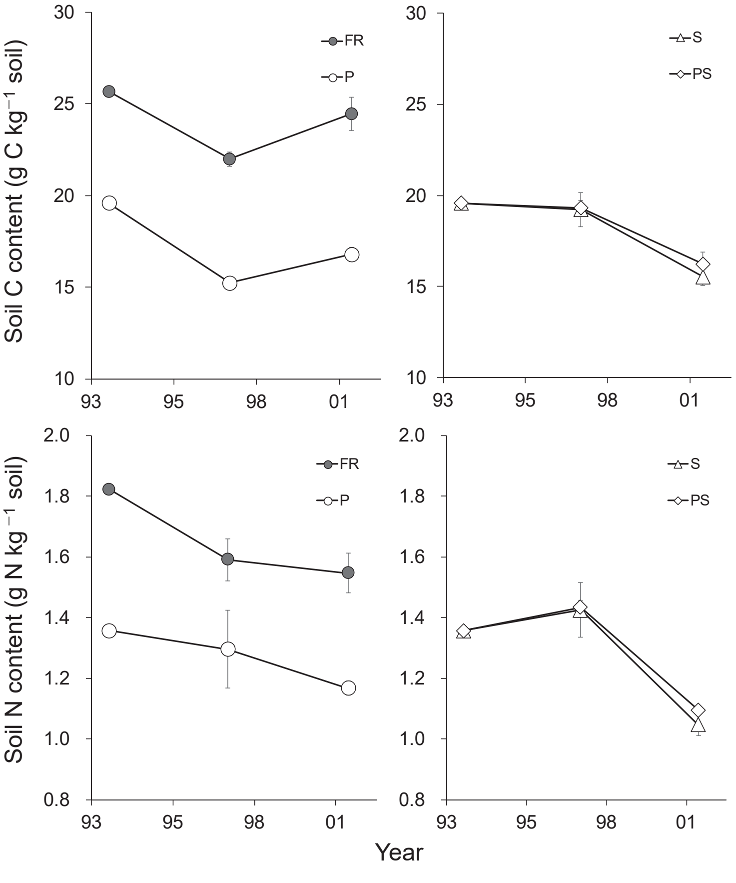

Fig. 1. C and N contents in the 0 cm-20 cm depth layers of soil under different treatments in the agropastoral experiment (left, forest and pasture; right, introducing soybean)

Soils were collected in September of 1993, 1997, and 2001.
Error bars indicate standard error.

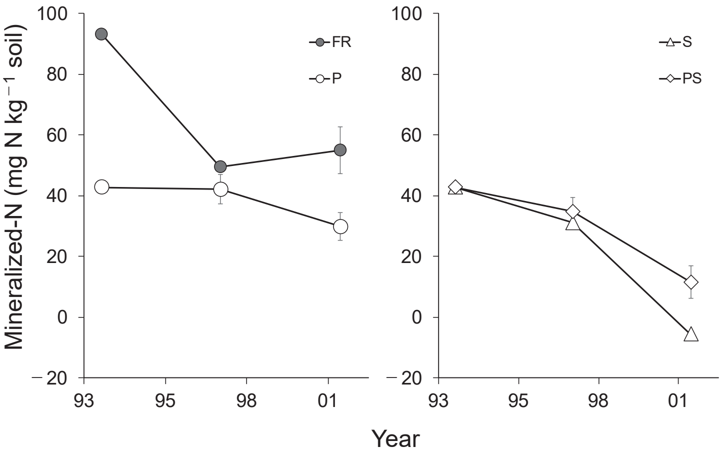

Fig. 2. Mineralized N contents in the 0 cm-20 cm depth layers of soil under different treatments in the agropastoral experiment (left, forest and pasture; right, introducing soybean)
Soils were collected in September of 1993, 1997, and 2001.
Error bars indicate standard error.

organic matter occurred, and the fraction of C coming from cultivated maize increased during the first decades of cultivation after forest clearing (Arrouays et al. 1995). In the Brazilian Amazon Basin state of Rondonia, 17% of soil C in the top 10-cm layer was derived from pastures in a 3-year-old pasture; for 5-year-old and older pastures, the ratio of C derived from pasture to soil C was higher than that derived from forests down to 30-cm depth (Neill et al. 1996). These results indicate that there was a rapid rate of increase of crop-derived C and a loss of forest-derived C in soil organic matter.

Rao et al. (1994) estimated that 29% of soil C of a grass–legume pasture was derived from legume residues in the top 0 cm-2 cm of soil of a 12-year-old tropical pasture on an Oxisol in Colombia. In our study, the FR had the lowest δ^{13}C value among all treatments during the 8-year experiment, although the FR could not be included in the multiple comparisons because of the experimental design of this study (Table 2). The δ^{13}C values for the P treatment were higher than those for other cropping systems during the experiment. For the S system, the δ^{13}C values decreased with increasing number of years. For the PS system, the values decreased after the start of crop cultivation (i.e., September 1997). Of the total soil C in the P system, 69% was derived from *B. decumbens* grass at the start of the experiment in 1993 (Fig. 3). The total soil C in the P system after the 8-year experiment contained 71% of the original C from the pasture and 29% of original C from the native forest. In the S treatment, after 8 years, soybean-originated C accounted for 27% of the total C, 39% was derived from the previous pasture period of 1978-1993, and 34% of the total C derived from the native forest. In the PS treatment, 57% of the total C originated from the pasture, 13% derived from soybean, and 30% derived from the native forest. Thus, it appeared that soybean cultivation replaced, to some extent, grass C with soybean C in the S and PS treatments.

Table 2. δ^{13}C (‰) values in the 0 cm-20 cm depth soil layer

	Sep-93	Sep-97	Sep-01
FR	− 22.6	− 19.4	− 22.8
P	− 16.5^{d}	− 16.8^{cd}	− 16.6^{d}
S	− 16.5^{d}	− 19.8^{a}	− 19.2^{ab}
PS	− 16.5^{d}	− 17.1^{cd}	− 18.2^{bc}

Multiple comparisons have been conducted in the three treatments without the FR because of the experimental design of this study.
Values with a common letter are not significantly different at $P < 0.05$ according to Tukey's HSD test.

We also estimated the N balance in the P, S, and PS treatments (Table 3). N fixation is the primary source of N input in the agropastoral system. The output of N was from soybean seeds and leaching. The N balances in the three cropping systems—P, S, and PS—were negative, and the S system induced the largest N output from the ecosystems. In addition, the PS rotation system showed a larger negative N balance than the P system. Thus, soybean cultivation in the agropastoral system induced a negative N balance because of the larger removal of

N with soybean seeds despite some N_2 fixation by soybean.

It has been indicated that in the case of the maize–soybean rotation system, the low C/N ratio in soybean residues affects N availability to the subsequent maize crop by altering the rates of soil mineralization or immobilization (Aulakh et al. 1991, Gentry et al. 2001, Green & Blackmer 1995, Kaboneka et al. 1997, Maloney et al. 1999). It was also reported that when combining sorghum and soybean, soil organic C and N decreased in the order of continuous soybean cultivation, sorghum–soybean rotation, and continuous sorghum cultivation (Havlin et al. 1990). Furthermore, in this experiment, the tillage had been done yearly after being converted to soybean cultivation from pasture. It was known that the tillage of cropping lands has led to the decline in soil organic C and soil N (Dalal & Mayer 1986a, b). It was reported that the conventional tillage system with soybean cultivation decreased soil C compared with grass pasture (Huggis et al. 2007). Al-Kaisi et al. (2005) reported that the tillage system resulted in less soil organic C and total soil N contents compared with the nontillage system. In our study, these results suggested that soybean cultivation stimulated a loss of pasture C and decreased mineralized N after 8 years in the S and PS treatments because of the low C/N ratio of soybean residues (Maloney et al. 1999)

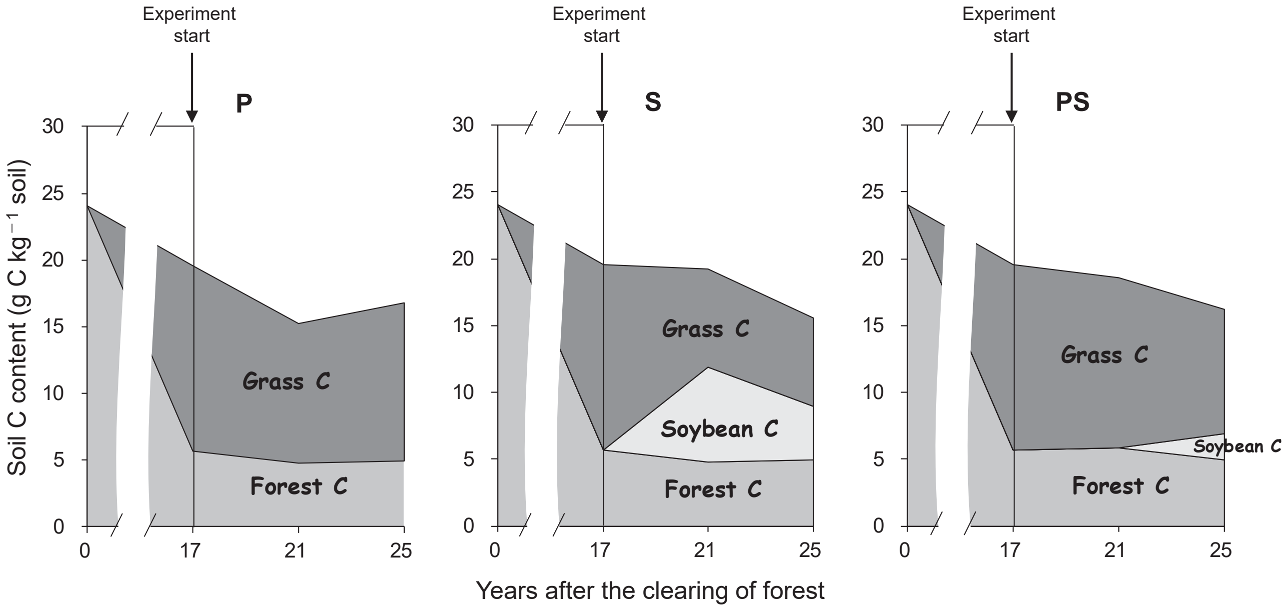

Fig. 3. Contribution of forest, grass, and soybean C with time after the clearing of the forest to soil C at 0 cm-20 cm depth in P, S, and PS cropping treatments in the agropastoral experiment

Table 3. Estimated N balance of the three cropping systems (P, S, and PS) during the 8-year experimental period

	Input			Output					
	N_2 fixation	Deposition	Total	Harvest of soybean	Liveweight gain of cattle	Leaching	Volatilization from dung and urine of cattle	Total	Balance
					(Unit: kgN ha^{-1} 8years^{-1})				
P	232	48	280		68	8	319	394	− 114
S	1,017	48	1,065	1,130		608		1,738	− 673
PS	513	48	561	441	40	384	187	1,053	− 491

Notes:

1) %DM of grain, 86%; %N in dry matter, 6.1% (Kanda et al. 2001), and the contribution of biologically fixed N in total N of grains, assumed to be 90% (Kanno et al. 2002).

2) %N in cattle was assumed to be 2.4%, and it was expected that 4.7 kg N would be lost via ammonia volatilization, when 1 kg N was taken as cattles (Cadish et al. 1994, Kanno et al. 2002).

3) Data on the grain of soybean and the liveweight gain of cattle were according to Macedo et al. (2004).

4) Data on deposition and leaching were according to Kanda et al. (2001).

5) The amount of nonsymbiotic N_2 fixation of *B. decumbens* was according to Kanda et al. (2001).

and the tillage system. Therefore, introducing soybean cultivation in the cropping system would likely cause reductions of soil C and N, accelerate the degradation of soil organic matter, and lead to the decline of mineralized N and a negative N balance in the ecosystem. In other words, soybean cultivation may cause reductions in the soil N status of this agropastoral system.

Acknowledgements

This study was conducted as part of an international collaboration between the Japan International Research Center for Agricultural Sciences (JIRCAS) and the National Beef Cattle Research Center, Brazilian Agricultural Research Corporation (EMBRAPA-CNPGC), titled "Comprehensive studies on the development of a sustainable agropastoral system in the sub-tropical zone of Brazil." We would like to thank Emeritus Prof. T. Tadano (Hokkaido Univ.), Emeritus Prof. T. Yoneyama (Univ. of Tokyo), and Dr. S. Shimada (NARC/NARO) for their critical and invaluable comments on the manuscript. Moreover, we thank Mr. M. Kouda (JIRCAS), Mr. M. M. Borges, Mr. G. M. Pitaluga, and Ms. I. M. Naka (EMBRAPA-CNPGC) for their help with the field and laboratory work.

References

Al-Kaisi et al. (2005) Soil carbon and nitrogen changes as influenced by tillage and cropping systems in some Iowa soils. *Agriculture, Ecosystems and Environment*, **105**, 635-647.

Arrouays, D. et al. (1995) Modelling organic carbon turnover in cleared temperate forest soils converted to maize cropping by using ^{13}C natural abundance measurements. *Plant Soil*, **173**, 191-196.

Aulakh, S. et al. (1991) Crop residue placement effects on denitrification and mineralization. *Soil Sci. Soc. Am. J.*, **55**, 1020-1025.

Balesdent, J. et al. (1987) Natural ^{13}C abundance as a tracer for studies of soil organic matter dynamics. *Soil Biol. Biochem.*, **19**, 25-30.

Bergerou, A. et al. (2004) Role of N_2 fixation in the soybean N credit in maize production. *Plant Soil*, **262**, 383-394.

Bonde, A. et al. (1992) Dynamics of soil organic matter as reflected by natural ^{13}C abundance in particle size fractions of forested and cultivated oxisols. *Soil Biol. Biochem.*, **24**, 275-277.

Cadisch, G. et al. (1994) Nitrogen cycling in a pure grass pasture and a grass-legume mixture on a red latosol in Brazil. *Trop. Grassl.*, **28**, 43-52.

Cadisch, G. & Giller, E. (1996) Estimating the contribution of legumes to soil organic matter build up in mixed communities of C3/C4 plants. *Soil Biol. Biochem.*, **28**, 823-825.

Cadisch, G. et al. (1996) Carbon turnover (delta-^{13}C) and nitrogen mineralization potential of particulate light soil organic matter after rainforest clearing. *Soil Biol. Biochem.*, **28**, 1555-1567.

Cerri, C. & Andreux, F. (1990) Changes in organic carbon content in oxisols cultivated with sugar cane and pasture, based on ^{13}C natural abundance measurement. *In* Transactions 14th International Congress of Soil Science, Kluwer Academic, Kyoto, Japan, pp. 98-103.

Dalal, R. & Mayer, J. (1986a) Long-term trends in fertility of soils under continuous cultivation and cereal cropping in Southern Queensland. II. Total organic carbon and its rate of loss from the soil profile. *Aust. J. Soil Res.*, **24**, 281-292.

Dalal, R. & Mayer, J. (1986b) Long-term trends in fertility of soils under continuous cultivation and cereal cropping in Southern Queensland. V. Rate of loss of total nitrogen from the soil profile and changes in carbon: Nitrogen ratios. *Aust. J. Soil Res.*, **37**, 493-504.

Gentry, E. et al. (2001) Source of the soybean N credit in maize production. *Plant Soil*, **236**, 175-184.

Green, J. & Blackmer, M. (1995) Residue decomposition effects on nitrogen availability to corn following corn or soybean. *Soil Sci. Soc. Am. J.*, **59**, 1065-1070.

Havlin, L. et al. (1990) Crop rotation and tillage effects on soil organic carbon and nitrogen. *Soil Sci. Soc. Am. J.*, **54**, 448-452.

Heichel, H. & Barnes, K. (1984) Opportunities for meeting crop nitrogen needs from symbiotic nitrogen fixation. *In* Organic farming: Current technology and its role in a sustainable agriculture, Volume 46., eds. Bezdicek, D. et al., ASA Special Publications, Madison, USA, pp. 49-59.

Huggins, D. et al. (2007) Corn-soybean sequence and tillage effects on soil carbon dynamics and storage. *Soil Sci. Soc. Am. J.*, **71**, 145-154.

Huggins, R. et al. (1998) Carbon dynamics in corn-soybean sequence as estimated from natural carbon-13 abundance. *Soil Sci. Soc. Am. J.*, **62**, 195-203.

JIS (1971) Analytical method for industrial waste water. *JIS K0102* [In Japanese].

Kaboneka, S. et al. (1997) Carbon decomposition kinetics and nitrogen mineralization from corn, soybean, and wheat residues. *Commun. Soil Sci. Plant Anal.*, **28**, 1359-1373.

Kanda, K. et al. (2001) Nitrogen flow in agropastoral systems, Brazil. *JIRCAS J.*, **9**, 23-31.

Kanda, K. et al. (2002) Carbon and nitrogen mineralization in soils under agro-pastoral systems in subtropical central Brazil. *Soil Sci. Plant Nutr.*, **48**, 179-184.

Kanno, T. et al. (2002) Dry matter productivity and forage quality of *Panicum maximum* pastures established after two different crop rotation systems. *Grassl. Sci.*, **47**, 569-577.

Macedo, M. (1995) Pastagens no ecossistema Cerrados: Pesquisa para o desenvolvimento sutentavel. *In* Proceedings of the 4th Symposium of Pasture Ecosystem in Brazil, Sao Paulo, Brazil, pp. 28-62 [In Portuguese].

Macedo, M. et al. (2001a) Preliminary results of agro-pastoral systems in the Cerrados of Mato Grosso do Sul- Brazil. *In* JIRCAS/EMBRAPA Gado de Corte International Joint Workshop on Agropastoral System in South America. JIRCAS Working Report, eds. Kanno, T. & Macedo, M.C.M., JIRCAS, Tsukuba, Japan, pp. 34-42.

Macedo, M. et al. (2004) Results of soybean yield, animal liveweight gain and soil fertility changes in agro-pastoral systems. *In* Development of sustainable agro-pastoral systems in the subtropical zone of Brazil, eds. Suenaga K. et al., JIRCAS, Tsukuba, Japan, pp. 15-18.

Macedo, M. et al. (2001b) Agropastoral systems as alternative to revert pasture degradation in the cerrados of Brazil: Preliminary results. *In* Proceedings of the 19th International Grassland Congress. International Grassland Congress, Sao Paulo, Brazil, pp. 996-967.

Maloney, S. et al. (1999) Rotational vs. nitrogen-fixing influence of soybean on corn grain and silage yield and nitrogen use. *J. Prod. Agric.*, **12**, 175-187.

Matsumoto, S. et al. (2000a) Extraction of mineralizable organic nitrogen from soils by a neutral phosphate buffer solution. *Soil Biol. Biochem.*, **32**, 1293-1299.

Matsumoto, S. et al. (2000b) The status and origin of available nitrogen in soils. *Soil Sci. Plant Nutr.*, **46**, 139-149.

Miranda, C. et al. (1997) Fluxes of carbon, water and energy over Brazilian Cerrado: An analysis using eddy covariance and stable isotopes. *Plant Cell Environ.*, **20**, 315-328.

Neill, C. et al. (1996) Forest- and pasture-derived carbon contributions to carbon stocks and microbial respiration of tropical pasture soils. *Oecologia*, **107**, 113-119.

Rao, M. et al. (1994) The use of carbon isotope ratios to evaluate legume contribution to soil enhancement in tropical pastures. *Plant Soil*, **162**, 177-182.

Rao, M. et al. (1992) Soil-plant factors and processes affecting productivity in ley farming. *In* Pastures for the tropical lowlands, ed. Hardy, B., CIAT, Cali, Colombia, pp. 145-175.

Smith, B. & Epstein, S. (1971) Two categories of $^{13}C/^{12}C$ ratios for higher plants. *Plant Physiol.*, **47**, 380-384.

Spain, M. et al. (1996) Crop pasture rotation in the Brazilian Cerrados. *In* Proceedings of the 8th Cerrado Symposium, eds. Pereira, R. C. & Nasser, L. C. B., Planaltina, Brazil, pp. 39-45.

Thomas, J. (1995) Role of legumes in providing N for sustainable tropical pasture systems. *Plant Soil*, **174**, 103-118.

Varvel, E. (1994) Rotation and nitrogen fertilization effects on changes in soil carbon and nitrogen. *Agron. J.*, **86**, 319-325.

Westerhof, L. et al. (1999) Labile N and the nitrogen management index of Oxisols in the Brazilian Cerrados. *In* Sustainable land management for the Oxisols of the Latin American Savannas, ed. Ayarza, T. R., CIAT, Cali, Columbia, pp. 133-140.

Yoneyama T. et al. (2001) $\delta^{13}C$ values of organic carbon in cropland and forest soils in Japan. *Soil Sci. Plant Nutr.*, **47**, 17-26.