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Effect of cropping systems on soil chemical characteristics, with emphasis on soil acidification*

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Abstract

The soil under intensive cultivation and low addition of crop residues is exposed to erosion and reduction of organic matter. Increases in soil organic matter, cation exchange capacity (CEC) and nutrient availability may occur in no-till systems with legumes and with large additions of organic residues. Nevertheless, some legumes may increase soil acidification through the carbon and nitrogen cycles. An experiment was carried out over 10 years, with 10 cropping systems on a Dark Red Podzolic soil (Paleudult) to evaluate the effect of no-till cropping systems on soil chemical characteristics. Legume cropping systems resulted in the greatest soil organic C gain and the highest ECEC to a depth of 17.5 cm. The increase was greatest at 0 - 2.5 cm layer. Clover systems resulted in the highest soil acidification at 2.5 - 7.5 and 7.5 - 17.5 cm depths. The rate of soil pH decrease at 2.5 - 7.5 cm depth under clover+ *Spergula*/maize system was 0.1 unit year^{-1}. Differences in soil acidification affected soil ECEC. Soil exchangeable cation data indicate that nitrate leaching increased soil acidification. Maize yields were greatest in legume systems due to increased N supply.

Introduction

The common practice of plowing the soil, associated with the lack of sufficient soil cover results in deterioration of soil physical, chemical and biological characteristics. The decline of soil organic matter content is an indicator of this process, and may affect other important soil characteristics, such as cation exchange capacity (Silva et al., 1994). The decrease of soil organic matter deserves even more attention in tropical soils, as organic matter is responsible for many soil properties (CEC, water retention, etc.). To avoid surface soil deterioration, systems with reduced soil tillage (minimum tillage), with large organic material addition, and soil cover should be used. Systems with inclusion of crops between two cropping periods is an option for improving soil surface cover, nutrient recycling, and organic material addition.

Soil organic matter accumulation in legume-based pastures may improve soil fertility resulting from increased nitrogen availability (Greenland, 1971) and cation exchange capacity (Russell, 1961). However, legume-based pastures increase soil acidification (Haynes, 1983; Loss et al., 1993; Russell, 1960; Williams, 1980; Williams and Donald, 1957). Legumes also increase soil acidification in arable cropping systems.

Acids may be produced in many of the nutrient cycles, however, acid production in the carbon and nitrogen cycles are considered the most important in agricultural and pasture ecosystems (Helyar and Porter, 1989).

Helyar (1976) emphasized, that nitrogen cycling in a closed ecosystem is neutral, because both processes of nitrogen oxidation (acid) and nitrogen reduction (alkaline) occurs within the plant, microorganism, or soil. One of the main processes in the nitrogen cycle which results in soil acidification of agricultural and pasture ecosystems is nitrate leaching (Haynes, 1983;

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Helyar, 1976; Helyar and Porter, 1989). Net efflux of anions or cations into the rhizosphere to maintain electroneutrality at soil root interface is another process related to the nitrogen cycle which may affect rhizosphere pH. When plants absorb nitrogen predominantly as NH_4^+ or biologically fix N an excess uptake of anions over cations will occur, resulting in a net efflux of H (Riley and Barber, 1971). Helyar (1976) emphasizes that if all the plant residues were returned in situ to the soil and no losses of N occurred then in the long term no net soil acidification would occur.

In carbon cycles acids are produced in association with plant and animal product removal (Helyar and Porter, 1989; Ridley et al., 1990). The removal of alkaline products seems to be more important in pasture ecosystems than in crop systems (Coventry and Slattery, 1991).

The objective of this study was to evaluate the effect of cropping systems on soil chemical characteristics, with emphasis on soil acidification.

Materials and methods

The experiment from which soil samples were obtained was carried over 10 years on a Dark Red Podzolic soil in the Brazilian taxonomy (Departamento Nacional da Produção Mineral, 1986). It is Paleudult in the US taxonomy (USDA Soil Conservation Service, 1975) and an Acrisol in FAO legend (FAO, 1974).

The experimental design was a Split-plot, with three replications. The plots (5×16 m) consisted of the ten cropping systems (Table 1), and the subplots (5×4 m) consisted of no N and N fertilization on maize. Nitrogen fertilizer (urea) was applied annually at 0 and 120 kg ha^{-1} to the maize crop.

At the beginning of the experiment in 1983, the soil was degraded eroded and compacted due to intensive cultivation and erosion. So in the beginning of the experiment (in 1983) the whole experimental area was deep plowed to reduce compaction. Except for *Spergula*+clover/maize, fallow/maize, and bare soil cropping systems, which had soil plowed from 1983 to 1987, in the other treatments the soil was not plowed (no-till system) in this period.

At the beginning of the experiment the soil (0 - 10 cm) had the following chemical characteristics: 19 mg kg^{-1} P (Mehlich); 130 mg kg^{-1} exchangeable K; 2.3% of organic matter; pH-H_2O 5.8 (Medeiros, 1985). In October of 1983, 52 kg ha^{-1} of P and 50 kg ha^{-1} of K were applied on the whole experimental area. Maize crop also received 31 kg ha^{-1} of P and 42 kg ha^{-1} of K annually. One-third of N fertilizer was applied at seeding and 2/3 N at 30 to 40 days after maize emergence. In 1993 Pioneer 3230 hybrid maize (*Zea mays* L.) was planted and the final population was approximately 35000 plants ha^{-1}. More details about the first eight years of the experiment are found in Medeiros et al. (1987), Testa et al. (1992) and Teixeira et al. (1994).

The total amount of C and N added or recycled by the different systems in 10 years was estimated just in the subplots which no N was applied. For the first 8 years it was used the data of Pavinato (1993), who measured the biomass (aboveground dry matter), C and N tissue content in winter and in summer species. For the last two years (from 1992 to 1994) it was measured aboveground dry matter, C and N contents in tissue of *Cajanus*, *Dolichos*, *Vigna*, *Macroptilium*, *Digitaria* and maize. For *Cajanus* and *Dolichos* it was sampled an area of 1m^2 and for *Vigna*, *Macroptilium* and *Digitaria* it was sampled an area of 0.5 m^2. Aboveground dry matter of maize was evaluated sampling 5 plants per subplot, correcting to the final population of 35,000 plants ha^{-1}. Samples of the crops were dried in oven on 60 °C until constant weight. C and N contents in plant tissue were determined according to methods of Walkley and Black and micro-Kjeldahl, respectively, as described by Tedesco et al. (1985).

Soil was collected only from the subplots without N fertilization, as the main objective of the study was to evaluate the effect of cropping systems on soil chemical characteristics. Maize grain yields were also measured in the N fertilized subplot using a 9 m^2 harvest area. Soil was sampled in September 1993 in the 0 - 2.5, 2.5 - 7.5 and 7.5 -17.5 cm depths. At the first two depths, a 10×50 cm soil strip was collected. The 7.5- 17.5 cm layer was sampled inside this strip, with an auger (8 subsamples). Soil samples were air dried and ground.

Except for pH-$CaCl_2$ and titratable acidity which were determined according to EMBRAPA (1979) methodology, the other chemical analyses followed those of Tedesco et al. (1985). Calcium, Mg, and Al were extracted with unbuffered 1 M KCl in a 1:10 soil:solution ratio. Calcium and Mg were measured by an atomic absorption spectrophotometer. Aluminum was measured by titrating the extract with 0.014 N NaOH. Potassium was measured by a flame photometer, with a double acid extract (0.05 N HCl + 0.025 N H_2SO_4. Effective cation exchange capacity (ECEC) was estimated through the sum of Ca, Mg, K, and

Table 1. Cropping systems studied

Systems	Winter	Summer
1[e]	Subterraneum clover+*Spergula*[b]	Maize
2	Oat	Maize
3	Oat+*Vicia*	Maize+Vigna
4[e]	Fallow	Maize+Dolichos
5	Oat+subterraneum clover	Maize
6	*Macroptilium* during 8 years[c]	Maize (1988 and 1993)
7	*Cajanus*	Maize+*Cajanus*
8	Fallow	Maize
9	*Digitaria* during 8 years[c]	Maize (1988 and 1993)
10[e]	Fallow (bare soil)[d]	Maize (1988 and 1993)

[a] *Spergula*:*Spergula arvensis*; subterraneum clover: *Trifolium subterraneum*; maize: *Zea mays*; oat: *Avena strigosa*; *Vicia*: *Vicia sativa*; *Vigna: Vigna unguiculata* subsp. *unguiculata*; *Dolichos*: *Lablab purpureus*; *Macroptilium*: *Macroptilium atropurpureum*; *Digitaria*: *Digitaria decumbes*
[b] Cultivated with wheat in the winter and with soybean in the summer up to 1986.
[c] During winter and summer.
[d] This treatment had some spontaneous grasses growing, controled with herbicides.
[e] Plots plowed 1983-1987; others no-till.

Table 2. Estimation of organic C and total N accumulated in the aboveground part of winter and summer crops in a period of 10 years

Cropping systems[a]	Carbon ($t\ ha^{-1}$)	Nitrogen ($kg\ ha^{-1}$)
1 Cl+Sp/M	41.6	1540
2 O/M	33.6	744
3 O+V/M+Vg	61.2	2310
4 F/M+Dl	47.2	2002
5 O+Cl/M	48.1	1310
6 Ma	43.7	1932
7 M+C	68.4	3124
8 F/M	13.6	344
9 Di	41.8	509
10 BS	5.1	115

[a] Cl–clover, Sp–*Spergula*, M–maize, O–oat, V–*Vicia*, Vg–*Vigna*, Dl–*Dolichos*, Ma–*Macroptilium*, C–*Cajanus*, F–fallow, Di–*Digitaria*, BS–bare soil.

Al. Organic C was determined by Walkley-Black procedure. The soil pH in water was measured in a 1:1 water:soil ratio.

Treatments means were compared with Tukey test at the 5% level. Soil characteristics were compared in each soil profile, in a monofactorial design (cropping systems). Maize yields were compared in a bifactorial design (cropping systems and N fertilization).

Results

N and C added by systems

The systems with cover crops (other than maize) added up to 5 times more C than the traditional system, fallow soil during the winter and maize during summer (Table 2). Estimation of N additions or recycling were up to 9 times higher in these systems than in fallow/maize.

Cropping systems presented a large variation in their C addition (between 5 and 68 t ha^{-1} in 10 years) and N addition or recycling (115 to 3124 kg ha^{-1} in 10 years). As C was incorporated into the system through photosynthesis, data of C in Table 2 represent addition to soil. In the case of N, there is, probably, differences between the crops in their potential for N recycling and for biological N fixation.

Cropping systems with grass covering the soil all over the year (oat/maize and *Digitaria*) recycled or fixed, in 10 years, larger amounts of N than fallow/maize and bare soil systems. At fallow/maize and bare soil systems there was probably higher losses of N, by nitrate leaching. Legume-based systems had estimations of total N accumulation in their biomass much higher than the non-legume systems, probably due to biological N fixation. Also it can not be rejected the possibility that some legumes had also recycled more N from the soil, reducing N losses through NO_3^- leaching.

Soil organic carbon

After ten years cropping systems affected soil organic C at all three depths (Table 3) with the greatest differences occurring in the surface layers, as organic materials were left on the surface (no-till system). Although not all systems differed significantly from the fallow/maize and bare soil, the more productive systems (in general the legume-based ones), which added higher amounts of C (Table 2), accumulated higher amounts of organic C in the soil (Table 3). For example the *Cajanus* + maize resulted in soil organic C contents 101, 66, and 31% higher than fallow/maize at 0 - 2.5, 2.5 - 7.5 and 7.5 -17.5 cm depths respectively. Soil organic C increased first in shallowest depths and later in the deeper depths respectively, in the 0 - 2.5, 2.5 - 7.5 and 7.5 -17.5 cm depths in the 3rd, 5th and 8th years (Pavinato, 1993; Testa et al., 1992).

Table 3. Organic C in the Dark Red Podzolic soil after 10 years of cropping systems

Cropping systems[a]	Depths (cm)			
	0 2.5	2.5 - 7.5	7.5 -17.5	0 - 17.5 cm
	(%)			
1 Cl+Sp/M	1.77 cde	1.38 abcd	1.10 ab	1.28 bcd
2 O/M	1.58 de	1.21 bcd	1.04 bcd	1.17 cde
3 O+V/M+Vg	2.15 bcd	1.53 ab	1.08 bc	1.37 bc
4 F/M+Dl	2.38 bc	1.40 abcd	1.04 bcd	1.33 bc
5 O+CI/M	1.91 cde	1.42 abcd	1.05 bcd	1.28 bc
6 Ma	2.78 ab	1.51 abc	1.03 bcd	1.42 b
7 M+C	3.10 a	1.81 a	1.24 a	1.67 a
8 F/M	1.54 de	1.09 cd	0.95 cd	1.08 de
9 Di	2.18 bcd	1.43 abcd	1.03 bcd	1.31 bc
10 BS	1.31 e	1.03 d	0.93 d	1.02 e
CV (%)	11	11	5	5

[a] Cl–clover, Sp–*Spergula*, M–maize, O–oat, V–*Vicia*, Vg–*Vigna*, Dl–*Dolichos*, Ma–*Macroptilium*, C–*Cajanus*, F–fallow, Di–*Digitaria*, BS–bare soil.
Means followed by the same letters in the column do no differ by Tukey test at p=0.05.

Table 4. Soil pH-H_2O after 10 years of cropping

Cropping systems[a]	pH in water (1:1)		
	Depths (cm)		
	0 - 2.5	2.5 - 7.5	7.5 - 17.5
1 Cl+Sp/M	5.28 bcd	4.83 c	4.75 d
2 O/M	5.40 abc	5.12 bc	5.00 bcd
3 O+V/M+Vg	5.28 bcd	4.98 bc	4.98 bcd
4 F/M+Dl	5.85 a	5.23 ab	5.04 bc
5 O+Cl/M	5.02 cd	4.85 c	4.87 cd
6 Ma	4.89 d	4.85 c	4.94 bcd
7 M+C	5.29 bcd	5.06 bc	5.01 bcd
8 F/M	5.48 abc	5.33 ab	5.06 bc
9 Di	5.43 abc	5.55 a	5.58 a
10 BS	5.59 ab	5.25 ab	5.19 b
CV (%)	3	2	2

[a] Cl–clover, Sp–*Spergula*, M–maize, O–oat, V–*Vicia*, Vg–*Vigna*, Dl–*Dolichos*, Ma–*Macroptilium*, C–*Cajanus*, F–fallow, Di–*Digitaria*, BS–bare soil.
Means followed by the same letters in the column do not differ by Tukey test at p=0.05.

Table 5. Exchangeable Al in the Dark Red Podzolic soil after 10 years of cropping systems

Cropping systems[a]	Depths (cm)		
	0 - 2.5	2.5 - 7.5	7.5 - 17.5
	(cmol kg^{-1})		
1 Cl+Sp/M	0.28 abc	0.71 ab	1.00 a
2 O/M	0.10 abc	0.29 abcd	0.44 ab
3 O+V/M+Vg	0.16 abc	0.54 abcd	0.56 ab
4 F/M+Dl	0.06 bc	0.22 cd	0.93 a
5 O+Cl/M	0.30 ab	0.72 a	0.86 ab
6 Ma	0.34 a	0.66 abc	0.98 a
7 M+C	0.13 abc	0.28 bcd	0.66 ab
8 F/M	0.08 bc	0.20 d	0.39 ab
9 Di	0.05 c	0.10 d	0.27 b
10 BS	0.09 bc	0.42 abcd	0.50 ab
CV (%)	53	36	32

[a] Cl–clover, Sp–*Spergula*, M–maize, O–oat, V–*Vicia*, Vg–*Vigna*, Dl–*Dolichos*, Ma–*Macroptilium*, C–*Cajanus*, F–fallow, Di–*Digitaria*, BS–bare soil.
Means followed by the same letters in the same column do not differ by Tukey at p=0.05.

Soil acidification

Cropping systems caused changes in soil pH (in water and in $CaCl_2$ solution) in each of the three depths (Table 4). At 0 - 2.5 cm depth, soil pH values were highest in maize+*Dolichos* and bare soil systems and were lowest in the oat+clover/maize and *Macroptilium* systems. At lower depths (2.5 - 7.5 and 7.5 -17.5 cm) clover and *Macroptilium* systems had the lowest and *Digitaria* the highest pH values. As expected the highest levels of soil exchangeable Al were found under clover and *Macroptilium* legumes and the lowest levels under *Digitaria* (Table 5).

By the 5th experimental year clover systems had the lowest pH values and highest Al levels (Testa, 1989). Soil pH changes of four cropping systems over the time using data collected initially (Medeiros, 1985), in the 5th (Testa, 1989), and in the 10th year are shown in Figure 1. Initial pH value in 1983 was from soil collected from 0 - 10 cm depth. Greatest soil pH decreases over time occurred at the 2.5 - 7.5 and 7.5 - 17.5 cm depths. Under clover and *Cajanus* soil pH in the 2.5 - 7.5 and 7.5 - 17.5 cm depths decreased more than under fallow/maize. Under *Digitaria* soil pH changed little over the time. Soil pH decrease at 2.5 - 7.5 cm depth was in the order of 0.1 unit $year^{-1}$ under the most acidifying system, clover+*Spergular*/maize, a higher rate than reported by Helyar (1976) and Haynes (1983).

Soil cation exchange capacity

Legume-based cropping systems with the highest soil organic matter content also had the highest soil ECEC

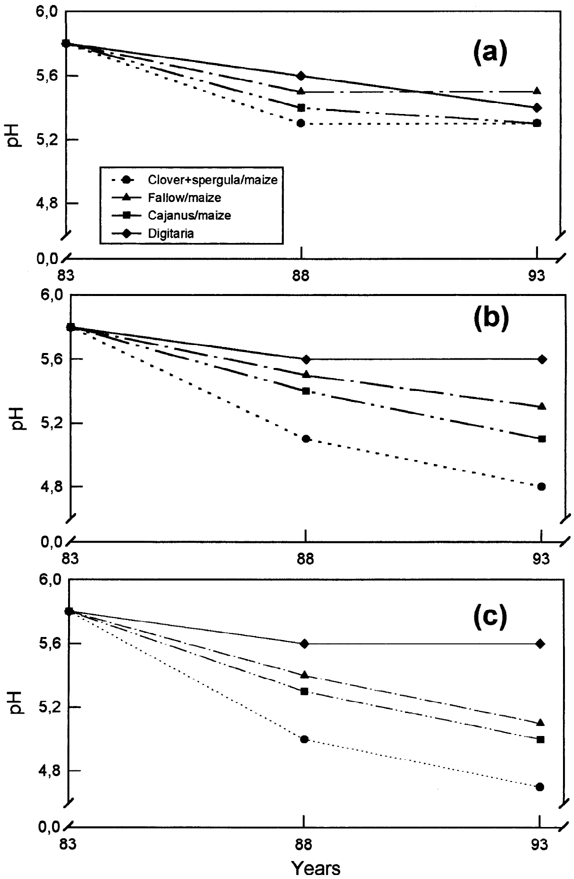

Figure 1. Soil pH changes along the 10 years period due to cropping systems: **a**: 0-2.5 cm; **b**: 2.5-7.5 cm; **c**: 7.5-17.5 cm soil layer.

(Table 6). *Cajanus* resulted in an ECEC that is 70% higher than fallow/maize in 0 - 2.5 cm layer. Cropping systems altered soil ECEC by the 5th year in the 0 - 2.5 and 2.5 - 7.5 cm depths (Testa et al., 1992) and by the 10th year at 7.5 -17.5 cm depth.

Regression analyses between ECEC and soil organic C showed that the relationship between ECEC and soil organic C was highly significant, and the regression equation is as follows:

$$ECEC = 1.68 + 1.78C(r^2 = 0.74**)$$

This relationship demonstrates that an increase of about 0.56 units of soil organic C results in an increase in ECEC of 1 cmol kg^{-1} of soil.

Multiple regression analysis between ECEC and soil organic C and soil pH was also significant and its correlation coefficient was larger than that of simple regression between effective ECEC and soil organic C, indicating that soil pH also affected ECEC. This regression equation is as follows:

$$ECEC = -2.95 + 1.69C + 0.92pH(r^2 = 0.80**)$$

Table 6. Effective cation exchange capacity of the Dark Red Podzolic soil after 10 years of cropping systems

Cropping systems[a]	ECEC		
	Depths (cm)		
	0 - 2.5	2.5 - 7.5	7.5 - 17.5
	(cmol kg^{-1})		
1 Cl+Sp/M	4, 1 b	3, 5 e	3, 1 c
2 O/M	4, 2 b	3, 6 de	3, 5 bc
3 O+V/M+Vg	5, 0 b	3, 8 cde	3, 5 bc
4 F/M+Dl	7, 7 a	4, 8 ab	4, 2 a
5 O+Cl/M	4, 3 b	3, 7 cde	3, 6 b
6 Ma	6, 9 a	4, 3 bc	3, 9 ab
7 M+C	7, 5 a	5, 0 a	4, 2 a
8 F/M	4, 4 b	3, 7 cde	3, 7 b
9 Di	5, 0 b	4, 1 cd	4, 0 ab
10 BS	4, 2 b	3, 4 e	3, 6 b
CV (%)	8	5	5

[a] Cl–clover, Sp–*Spergula*, M–maize, O–oat, V–*Vicia*, Vg–*Vigna*, Dl–*Dolichos*, Ma–*Macroptilium*, Ca–*Cajanus*, F–fallow, Di–*Digitaria*; BS–bare soil.
Means followed by the same letter in the column do not differ by Tukey at p=0.05.

Exchangeable cations

Cropping systems affected exchangeable K at 0 - 2.5 and 2.5 - 7.5 cm soil layers (Table 7). Highest K levels were found in *Cajanus*, *Dolichos* and *Macroptilium* systems, while clover + *Spergula*/maize system had the lowest K level. *Macroptilium*, *Digitaria* and bare soil had maize growing on in 1988/89, and had K fertilization in this year, while the other systems received K every year.

Soil exchangeable Ca and Mg differed according to cropping systems in the three soil layers (Table 7). The 0 - 2.5 cm layer showed the highest levels of Ca and Mg in the *Dolichos*, *Cajanus* and *Macroptilium* systems. The highest Ca and Mg levels in the 2..5 - 7.5 cm layer were found in the *Cajanus*, *Dolichos* and *Digitaria* systems. In the 7.5 - 17.5 cm layer the highest level of Ca occurred in *Digitaria* and *Cajanus* systems and the highest levels of Mg occurred in *Digitaria* system. At 2.5 - 7.5 and 7.5 - 17.5 cm depths lowest levels of Ca and Mg occurred in the clover systems.

Table 7. Exchangeable calcium, magnesium and potassium in a Dark Red Podzolic soil due to 10 year of different cropping systems

Cropping systems[a]	Calcium			Magnesium			Potassium		
	Depth (cm)			Depth (cm)			Depth (cm)		
	0-2.5	2.5-7.5	7.5-17.5	0-2.5	2.5-7.5	7.5-17.5	0-2.5	2.5-7.5	7.5-17.5
					(cmol kg^{-1})				
1 Cl+Sp/M	2.4 c	1.8 c	1.4 c	1.0 c	0.7 c	0.5 c	0.34 d	0.24 c	0.17 a
2 O/M	2.6 c	2.2 bc	2.0 ab	1.0 c	0.8 bc	0.8 bc	0.48 cd	0.41 abc	0.30 a
3 O+V/M+Vg	3.1 bc	2.1 bc	2.0 ab	1.3 c	0.9 abc	0.8 bc	0.40 cd	0.29 bc	0.17 a
4 P/M+Dl	4.7 a	2.9 a	2.0 ab	2.0 ab	1.2 a	1.0 ab	0.90 a	0.42 abc	0.25a
5 O+Cl/M	2.7 c	2.0 bc	1.9 abc	1.0 c	0.7 c	0.7 bc	0.34 cd	0.28 bc	0.18 a
6 Ma	3.9 ab	2.0 bc	1.5 bc	2.0 a	1.2 ab	1.0 ab	0.72 ab	0.46 ab	0.31 a
7 M+C	4.6 a	3.0 a	2.2 a	2.0 ab	1.2 a	1.1 ab	0.81 a	0.49 a	0.26 a
8 F/M	2.5 c	2.1 bc	2.0 ab	1.3 c	1.0 abc	0.9 ab	0.54 bc	0.40 abc	0.29 a
9 Di	3.1 bc	2.4 ab	2.3 a	1.4 c	1.2 a	1.2 a	0.46 cd	0.31 abc	0.22 a
10 BS	2.2 c	1.7 c	1.9 abc	1.5 bc	1.0 abc	1.0 ab	0.39 cd	0.28 bc	0.17a
CV (%)	11	10	10	12	14	15	13	19	31

[a] Cl–clover, Sp–*Spergula*, M–maize, O–oat, V–*Vicia*, Vg–*Vigna*, Dl–*Dolichos*, Ma–*Macroptilium*, C–*Cajanus*, F–fallow, Di–*Digitaria*, BS–bare soil.
Means followed by the same letter in the same column do not differ by Tukey test at p=0.05.

Table 8. Effect of cropping systems on maize yield in two levels of N fertilization

Cropping systems[a]	Grain yields	
	0 kg ha^{-1} N	120 kg ha^{-1} N
	(t ha^{-1})	
1 Cl+Sp/M	6.08 a A	6.55 A
2 O/M	2.00 b B	7.12 A
3 O+V/M+Vg	6.59 a A	7.56 A
4 F/M+Dl	5.98 a A	6.15 A
5 O+Cl/M	5.42 a A	7.01 A
6 Ma	5.74 a B	8.32 A
7 M+C	5.38 a A	7.23 A
8 F/M	1.10 b B	6.49 A
9 Di	1.28 b B	6.76 A
10 BS	2.02 b B	6.74 A
CV (%)	18	11

[a] Cl–clover, Sp–*Spergula*, M–maize, O–oat, V–*Vicia*, Vg–*Vigna*, Dl–*Dolichos*, Ma–*Macroptilium*, C–*Cajanus*, F–fallow, Di–*Digitaria*, BS–bare soil.
Means followed by the same or no small letter in the column and the same capital letter in the line do not differ by Tukey test at p=0.05.

Maize yields

Maize yields in 1993 without N fertilization were highest in legume-based systems and there were no significant difference among them (Table 8). In legume-based systems maize produced at least 3 t ha^{-1} more grain than the traditional fallow/maize system, and reached 6.6 t ha^{-1} grain yield even without N fertilization. Maize yields did not differ among cropping systems when 120 kg N ha^{-1} was applied (Table 7). Teixeira et al. (1994) and Pavinato (1993) also found a significant effect of cropping system on maize yield when no N fertilizer was applied. In this experiment the main determinant of grain yield is N supply to maize.

In the nonlegume systems (oat/maize, fallow/maize, *Digitaria* and bare soil) and in *Macroptilium* system N fertilization increased grain yield significantly (Table 8). Except for *Macroptilium* system, in the other legume-based systems there was no significant effect of N fertilization on maize yields probably due to an adequate supply of N from legumes. Although there was greater soil acidification under clover systems, maize yields in these systems did not differ from other legume systems.

Discussion

Legume-based systems with crops that grow throughout the year added and or recycled larger amounts of C and N and therefore resulted in the highest soil organic matter, ECEC and exchangeable cation levels.

There was more soil acidification in the clover cropping systems compared to the fallow/maize and bare soil treatments. *Dolichos* and *Cajanus* legumes had little effect on soil acidification, while Digitaria did not affect soil acidity. The rate of soil pH decrease (0.1 unit year^{-1}) under the more acidifying system (clover+*Spergula*/maize) was higher to rates reported by Helyar (1976) and Haynes (1983).

As described in the introduction, many studies report the increase of soil acidification in legume-based systems, and the main processes involved are the intense nitrification followed by NO_3^- leaching, the H_3O^+ excretion by legume roots and the export of animal and plant products. In the following paragraphs it is discussed how these processes affected soil acidification in this experiment.

The removal of cations in grain accounted little on soil acidification of the various cropping systems. Systems cropped with legume and maize every year had the highest yields (Pavinato, 1993; Teixeira et al., 1994). Oat/maize and fallow/maize had intermediate grain export. *Macroptilium*, *Digitaria* and bare soil had the smallest grain export, as they were cropped to maize only in 1988/1989. Coventry and Slattery (1991) also found little effect of grain removal on soil acidification of cropping systems.

The net efflux of anions or cations into the rhizosphere to maintain electroneutrality at the root soil interface is another process which can affect soil rhizosphere pH. Haynes (1983) emphasizes that acid soil tolerant tropical legumes, which have the lowest excess excretion of H_3O^+, also results in less soil acidity. *Cajanus*, *Dolichos* and *Macroptilium* are tropical legumes in contrast to clover which is a temperate legume (Allen and Allen, 1981). On the other hand non-legume systems may result in OH or HCO_3^- excretion and increased rhizosphere pH.

As a consequence of H_3O^+ root excretion, the plant material of legumes is of an “alkaline” nature (Ritchie and Dolling, 1985). Thus if plant residue is returned to the same place where root excretion occurred no net soil acidification would occur (Helyar, 1976). Nevertheless legume residues were surface placed (no-till system), while probably there was root activity in deeper soil layers.

Except for *Macroptilium*, legume-based systems did not increase soil acidification in the shallowest layer (0 - 2.5 cm), where the greatest soil organic matter accumulation occurred. These observations suggest that organic matter accumulation from legumes other than *Macroptilium* have reduced soil acidification (Miyazawa et al., 1993; Ritchie and Dolling, 1985).

In legume-based cropping systems nitrification followed by leaching is one of the main processes responsible for soil acidification (Helyar, 1976; Helyar and Porter, 1989). The present experiment confirmed that legume-based systems contained larger amounts of N in their aboveground (Table 2) and larger amounts of soil organic N than non-legume systems (Teixeira et al., 1994) resulting in greater N mineralization and nitrification. Differences in soil acidification among legume-based systems also may have resulted from differences in nitrate leaching. Greater root development of *Dolichos* and *Cajanus* compared to clover result in more nitrate recycling. The plant C/N ratio of clover may be narrower than the other legumes so that N mineralization occurs faster and N leaching is greater in the systems with this legume. Cropping systems resulting in the greatest differences in soil acidification (*Digitaria* and clover + *Spergula*/maize) also had the greatest differences in exchangeable Ca and Mg levels in the 7.5 -17.5 cm layer. It is possible that clover+Spergula/maize systems had increased NO_3^- leaching which must be accompanied by increased leaching of exchangeable Ca and Mg (Haynes, 1983). These observations support the hypothesis that nitrate leaching is an important process involved on soil acidification in this experiment.

The greatest soil acidification under clover systems did not result in a decrease of maize yield over the course of this experiment. It probably has not reached a critical level; also addition of mulch helps to buffer acidity induced problems.

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