Sulfur mineralization rates and potentials of soils

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Summary. Field-moist soil and glass beads mixtures were packed in glass tubes and leached with 100 ml of 5 mM $CaCl_2$ and incubated at 20 or 30 °C. The leaching procedure was repeated every 2 weeks for 14 weeks. The leachates were analysed for SO_4^{2-} and NO_3^-. The S uptake by three successive croppings of corn (*Zea mays* L.) or soybean [*Glycine max* (L.) Merr.] at 40- or 60-day intervals, respectively, or three cuttings of ryegrass (*Lolium multiflorum* L.) at 30-day intervals were studied under greenhouse conditions. Results showed that significantly greater amounts of S were mineralized at 30 °C than at 20 °C in each of 13 Iowa and 7 Chilean surface soils. Expressed as percentages of organic S in soils, the amounts of S mineralized in the Iowa surface soils in 14 weeks at 20 and 30 °C ranged from 1.2% to 9.8% and from 2.4% to 17.5%, respectively. The corresponding values for the Chilean soils ranged from 0.9% to 7.2% and from 1.4% to 12.1%. The Q_{10} values of S mineralization ranged from 1.7 to 4.4 (average 2.5) for the Iowa soils and from 1.7 to 3.1 (average 2.1) for the Chilean soils. The cumulative S mineralized at 20 °C in 14 weeks was significantly correlated with the cumulative N mineralized (linear model, $r = 0.72$**; quadratic model, $r = 0.84$***). Similarly, the cumulative S mineralized at 30 °C was significantly correlated with the cumulative N mineralized at this temperature (linear model, $r = 0.81$***; quadratic model, $r = 0.82$***). The potentially mineralizable S pool (S_0), calculated by using an exponential equation for the S mineralized at 20 °C, ranged from 5 to 44 mg kg^{-1} for the Iowa soils and from 10 to 25 mg kg^{-1} for the Chilean soils. The corresponding values obtained by using a reciprocal-plot technique ranged from 6 to 48 mg kg^{-1} and from 12 to 26 mg kg^{-1}, respectively. The S_0 values calculated for S mineralized at 30 °C, in general, were higher than those obtained at 20 °C. The S mineralization rate constant (k) and the time required to mineralize 50% of S_0 (K_t), calculated by using the cumulative SO_4^{2-} released during 14 weeks of incubation, varied considerably among the soils. Uptake of S by corn and soybean (tops + roots) were, in general, lower than the total SO_4^{2-} mineralized in 14 weeks at 20 °C.

Key words: Organic S − S uptake − Plants − Greenhouse experiments − Leaching tubes − Rate constants − Sulfur mineralization

It is generally accepted that plants assimilate S almost entirely in the SO_4^{2-} form; however, more than 95% of the total S in soils of the humid, semihumid and temperate regions is organic in nature. Therefore, S mineralization rates and potentials (S_0) are essential parameters in predicting plant nutritional needs and the amount of S fertilizer needed for optimum crop yields. Knowledge of the S mineralization rates and potentials of soils is also important for modeling the cycling of this element in the environment.

Mineralization of S in soils is mainly biological, and the amount of S mineralized in a given time depends on soil chemical and physical properties. Laboratory studies have shown that, in addition to temperature, moisture, pH and nutrient supply, S mineralization in soils is affected by organic-matter additions and plant growth (Tabatabai 1982). As pointed out by Maynard et al. (1985), however, any interpretation of S mineralization under laboratory conditions must be made with caution because the type of incubation method used affects the amount of inorganic S released. Differences in net S mineralization rates have been observed between open and closed soil-in-

cubation systems (Maynard et al. 1983). The open system gives significantly higher results and may simulate the removal of N and S by plants or loss of these elements through leaching processes (Tabatabai and Al-Khafaji 1980).

Most of the information available on S mineralization has been obtained from short-term incubations designed primarily for rapid methods that predict the S available to plants. Information on the effect of long-term incubation is needed because, if properly conducted, such an incubation and leaching procedure should simulate S mineralization occurring under field conditions. Studies by Tabatabai and Al-Khafaji (1980) showed that when surface-soil samples and glass beads mixtures were incubated in leaching tubes for 26 weeks at 20 or 35 °C, with intermittent leaching with 10 mM $CaCl_2$ to remove the SO_4^{2-} produced, a linear relationship was obtained between the cumulative amounts of S mineralized and time of incubation. However, little information is available about the relationship between the amount of organic S taken up by plants and that mineralized under laboratory conditions. In the present work, we studied long-term S mineralization in diverse soils from Iowa and Chile and compared the S mineralization rates and potentials of these soils with the amounts of organic S taken up by corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.] and ryegrass (*Lolium multiflorum* L.) under greenhouse conditions.

Materials and methods

Soils. Surface soils (0–15 cm) were selected to represent soils of Iowa and Chile and to give a wide range in chemical and physical properties (Table 1). Samples of field-moist soils were brought to the laboratory, passed through a 2-mm screen, and divided into two portions. One portion was placed in a polyethylene bag and stored in a refrigerator at 5 °C, and a subsample of this portion was used in studies of S mineralization and greenhouse experiments. The second portion was air-dried at room temperature (approximately 23 °C) for 48 h and stored in a tightly sealed bottle. A subsample of the air-dried portion was ground to pass a 100-mesh sieve.

In the analyses reported in Table 1, organic and inorganic S were determined as described by Tabatabai (1982), and the other analyses were performed as described by Dick and Tabatabai (1987). Organic C, total P, inorganic P and total S were determined in the <100-mesh soil samples. Inorganic C and particle-size distribution were determined in the <2-mm soil samples.

Leaching tubes. Twenty grams of yield-moist soil (on an oven-dry basis) and an equal weight of glass beads (350–370 μm in diameter) were mixed thoroughly and transferred into a leaching tube

Table 1. Properties of soils used

Soil		pH[a]		C		S		CEC[d] cmol (NH_4^+) kg^{-1} soil	Clay	Sand
Series	Subgroup	H_2O	$CaCl_2$	Org.	Inorg.[b]	Org.	SO_4^{2-}[c]		— g kg^{-1} —	
				— g kg^{-1} —		— mg kg^{-1} —				
Iowa soils										
Ida	Typic Udorthent	7.4	6.7	6	87	138	2	15.6	160	70
Hayden	Typic Hapludalf	5.8	5.1	8	0	126	2	10.5	140	530
Downs	Mollic Hapludalf	6.4	6.4	10	0	188	8	17.8	240	40
Luther	Aeric Ochraqualf	6.4	5.6	13	0	122	3	14.0	170	330
Fayette	Typic Hapludalf	7.4	6.9	15	29	221	5	17.8	180	40
Tama	Typic Argiudoll	5.4	5.1	22	0	232	8	18.6	230	50
Lester	Mollic Hapludalf	6.6	6.1	34	0	397	4	19.5	160	330
Clarion	Typic Hapludoll	6.2	5.4	34	0	316	3	25.9	230	310
Muscatine	Aquic Hapludoll	7.6	6.9	36	12	344	3	35.0	280	40
Nicollet	Aquic Hapludoll	6.4	5.9	37	0	387	3	25.8	210	400
Harps	Typic Calciaquoll	7.9	7.2	40	47	466	4	34.8	290	270
Okoboji	Cumulic Haplaquoll	7.0	6.7	43	0	432	5	36.1	260	300
Canisteo	Typic Haplaquoll	7.8	7.2	44	35	473	5	40.0	320	210
Chilean soils										
Alhue	Xeric Durandept	8.0	7.4	14	42	351	7	15.1	180	400
Constitucion	Ultic Paleustalf	5.6	5.1	16	0	154	5	9.3	140	640
Maipo	Typic Xerofluvent	7.8	7.1	20	35	1622	70	18.4	280	230
Aqua del Gato	Typic Pelloxerert	7.8	7.5	28	35	485	141	40.4	400	160
Collipulli	Typic Palehumult	5.7	5.1	34	0	363	3	28.2	420	220
Santa Barbara	Entic Dystrandept	6.0	5.4	84	0	636	12	39.6	170	200
Osorno	Typic Dystrandept	5.3	4.9	84	0	887	7	52.4	310	170

[a] Soil: water or soil: 0.01 M $CaCl_2$ ratio, 1:2.5
[b] $CaCO_3$ equivalent
[c] SO_4^{2-} extracted with 500 mg P l^{-1} as $Ca(H_2PO_4)_2$
[d] Cation exchange capacity

(Tabatabai and Al-Khafaji 1980). The soil and glass beads mixtures were leached with 100 ml of 5 mM $CaCl_2$ to remove the initial SO_4^{2-} and NO_3^-, and incubated at 20 or 30 °C after removal of the excess water under suction (6 kPa, 60 cm Hg). The soil and glass beads mixtures were leached every 2 weeks for 14 weeks, and the amounts of SO_4^{2-}-S and NO_3^--N produced were determined by ion chromatography as described by Dick and Tabatabai (1979). However, because no greenhouse experiments were conducted in this work to study N uptake by plants, only the results obtained for S mineralization are reported here. When needed, we calculated the total cumulative N mineralized in 14 weeks at each incubation temperature.

Greenhouse experiments. Plastic pots (Sweetheart Plastic, Inc., Wilmington, Massachusetts) of 473 ml capacity (10.5 cm upper diameter, 8 cm lower diameter and 7.5 cm in depth) were used for the greenhouse experiments. Each pot contained 500 g soil (on an oven-dry basis). Before potting, the soil was treated with macro- and micronutrients, except S, in amounts equivalent to those used by Cantarella and Tabatabai (1983), which were based on recommendations given by Allen et al. (1976). All nutrients (reagent-grade chemicals) were applied on an individual-pot basis.

In November 1984, three greenhouse experiments were carried out. The experiments involved uptake of S by corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], and ryegrass (*Lolium multiflorum* L.). The experiments were laid out as a complete randomized-block design with 20 treatments (20 soils) and 3 replicates.

In the experiments with corn (var. L.B73 × Missouri 17) and soybean (var. Weber), six seeds were germinated in each pot and thinned to five and four seedlings per pot, respectively. In the experiment with ryegrass, 1 g of ryegrass seeds was planted in each pot.

The pots were watered daily with a volume of deionized water equal to that lost during the previous 24-h period, as determined by weighing randomly chosen pots from each block. Sufficient deionized water was added daily to keep the soil moisture at 2/3 of field capacity (0.03 MPa). The temperature in the greenhouse fluctuated between 14 and 25 °C during the entire growing period, and lights were turned on for 14 h a day.

In the experiments with corn and soybean, the plants were cut at the soil surface after 40 and 60 days, respectively. After each cropping, the soil was removed from the pots, and the roots were carefully removed by hand from the moist soil and washed with deionized water. The moist soil was treated with 33 mg N pot^{-1} (as NH_4NO_3) and 33 mg K pot^{-1} (as KNO_3) in 15 ml solution and repotted. This was repeated for three successive croppings.

In the experiment with ryegrass, the plants were cut at about 2.5 cm from the soil surface every 30 days for a total of four cuttings. After each cutting, an additional nutrient solution (15 ml) containing 33 mg N pot^{-1} and 33 mg K pot^{-1} was added as described previously.

The dry-matter yield of corn, soybean and ryegrass tops and of corn and soybean roots was determined by weighing after drying at 65 °C for 48 h. The plant materials were ground to pass a 20-mesh sieve for total S determination, and then dried at 65 °C for at least 24 h before total S determination. The total S in the plant material was determined by the method of Tabatabai and Chae (1982), and the S yield was calculated from the dry-matter yield and the percentage of S in the plant material. The uptake of organic S was calculated by subtracting the total S in shoots and roots of 10-day-old seedlings produced in S-free fine glass beads and the initial SO_4^{2-} in soil from the S yield of crops grown under greenhouse conditions.

Equations used to calculated S_0. For estimating S_0, two equations were used, an exponential equation and a reciprocal-pot technique. The first equation is:

$$S_m = S_0[1 - \exp(-kt)]$$

where S_m = amount of S mineralization at a specific time (t) and k is the first-order rate constant.
The second equation is:

$$1/S_c = 1/S_0 + K_t/S_0 \cdot 1/t$$

where S_c = cumulative S mineralized at time (t) and K_t is a constant (K_t = the time required to mineralize 50% of S_0). When the results are plotted as $1/S_c$ vs $1/t$, the intercept on the y axis gives $1/S_0$, and the slope is equal to K_t/S_0.

Results and discussion

The types of relationship between cumulative S mineralized in soils incubated in leaching tubes at 20 or 30 °C and time of incubation are shown in Figs. 1 and 2. This relationship was linear for some soils (Fig. 1) and slightly curvilinear for others (Fig. 2). Signifi-
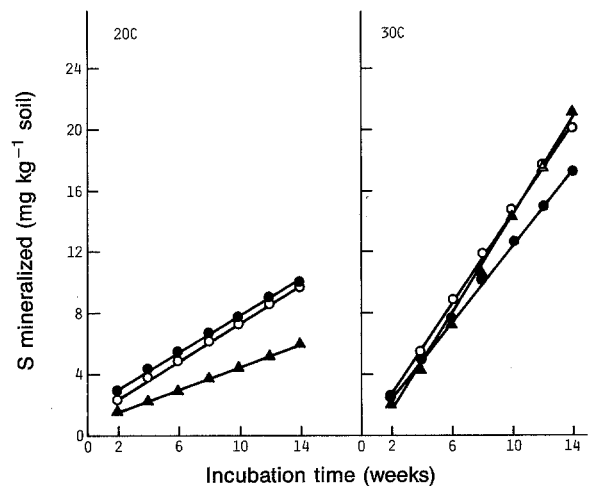
Fig. 1. Relationship between cumulative S mineralized in three Iowa field-moist soils, incubated in leaching tubes at 20 or 30 °C, and time of incubation. ●, Okoboji soil; ○, Muscatine soil; ▲, Clarion soil
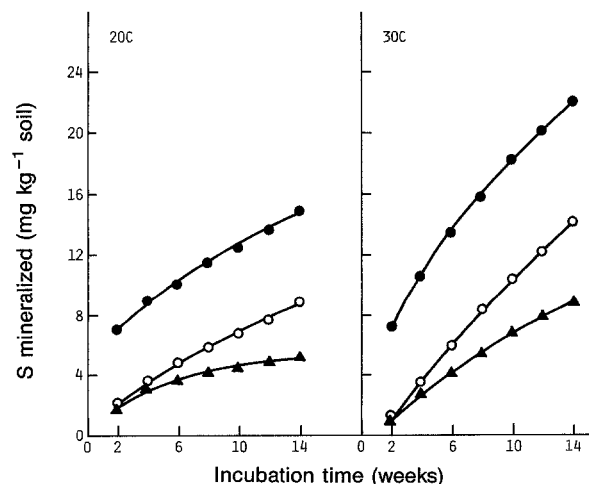
Fig. 2. Relationship between S mineralized in two Iowa and one Chilean field-moist soils, incubated in leaching tubes at 20 or 30 °C, and time of incubation, ●, Maipo soil; ○ Luther soil; ▲, Ida soil

cantly greater amounts of S were mineralized at 30 °C than at 20 °C in each of the soils studied. The parameters and r-values of the linear relationships between cumulative S mineralized in soils at 20 or 30 °C and incubation time are shown in Table 2. The slope values showed that the rates of S mineralization in Iowa soils at 20 and 30 °C ranged from 0.25 to 1.27 mg kg^{-1} week^{-1} and from 0.74 to 2.89 mg kg^{-1} week^{-1}, respectively, and fell within the ranges reported by Tabatabai and Al-Khafaji (1980) for 12 other Iowa soil samples. The rates of S mineralization in the Chilean soils ranged from 0.48 to 1.00 mg kg^{-1} week^{-1} and from 0.82 to 2.09 mg kg^{-1} week^{-1} at 20 and 30 °C, respectively, and were within the ranges obtained for the Iowa soils.

The amounts of S mineralized, Q_{10}, and percentages of organic S mineralized at 20 or 30 °C for 14 weeks are reported in Table 3. The amount of S mineralized in the Iowa surface soils at 20 and 30 °C ranged from 5.3 to 22.6 mg kg^{-1} soil (average 9.7 mg kg^{-1} soil) and from 10.1 to 40.2 mg kg^{-1} soil (average 18.5 mg kg^{-1} soil), respectively. The corresponding values for the Chilean soils ranged from 7.8 to 26.8 mg kg^{-1} soil (average 13.2 mg kg^{-1} soil) and from 13.0 to 47.1 mg kg^{-1} soil (average 22.9 mg kg^{-1} soil). Ex-

pressed as percentages of organic S in soils, the amounts of S mineralized in the Iowa soils in 14 weeks at 20 and 30 °C ranged from 1.2% to 9.8% (average 4.1%) and from 2.4% to 17.5% (average 7.5%), respectively. The corresponding values for the Chilean soils ranged from 0.9% to 7.2% (average 3.1%) and from 1.4% to 12.1% (average 5.5%). The results for the Iowa soils were within the ranges reported previously for 12 other Iowa surface soils (Tabatabai and Al-Khafaji 1980).

To determine the effect of temperature on S mineralization, we calculated ratios of the percentage of organic S mineralized at 30 °C to that mineralized at 20 °C. Table 3 shows that these ratios ranged from 1.3 to 5.2 for the Iowa soils and from 1.5 to 2.6 for the Chilean soils. The Q_{10} values calculated from the ratio of the slope of the linear-regression equation of S mineralization vs time at 30 °C to that of the linear relationship at 20 °C ranged from 1.7 to 4.4 (average 2.5) for the Iowa surface soils and from 1.7 to 3.1 (average 2.1) for the Chilean surface soils. In general, the Q_{10} values were higher than the ratio values obtained for the percentage of organic S mineralized in 14 weeks at 30 °C to that mineralized at 20 °C. These differences are mainly due to the errors associated with the

Table 2. Parameters and correlation coefficients (r) of linear relationships between cumulative S mineralized in soils (mg kg^{-1} soil), Y, at 20 or 30 °C and incubation time (weeks), X

| Soil	Parameters and correlation coefficient of linear relationship at temperature indicated					
	20 °C			30 °C		
	Intercept	Slope	r	Intercept	Slope	r
Iowa soils						
Ida	1.97	0.26	0.970[a]	0.14	0.74	0.993[a]
Hayden	1.86	0.53	0.991[a]	0.13	0.92	0.986[a]
Downs	3.74	0.62	0.995[a]	5.21	1.33	0.984[a]
Luther	1.33	0.55	0.985[a]	−0.69	1.08	0.987[a]
Fayette	0.87	0.47	0.986[a]	1.24	1.06	0.993[a]
Tama	5.81	1.27	0.963[a]	0.97	2.89	0.997[a]
Lester	1.21	0.56	0.994[a]	−1.56	1.52	0.989[a]
Clarion	0.79	0.37	0.993[a]	−2.13	1.64	0.993[a]
Muscatine	1.89	0.59	0.997[a]	0.05	1.24	0.998[a]
Nicollet	0.87	0.75	0.980[a]	−1.06	1.87	0.998[a]
Harps	2.12	0.25	0.981[a]	0.76	0.77	0.992[a]
Okoboji	1.22	0.62	0.999[a]	−0.20	1.46	0.987[a]
Canisteo	1.81	0.45	0.993[a]	−0.41	0.82	1.000[a]
Chilean soils						
Alhue	2.12	0.48	0.983[a]	1.69	0.82	0.994[a]
Constitucion	3.82	0.54	0.985[a]	6.87	0.91	0.955[a]
Maipo	6.13	0.64	0.995[a]	5.59	1.23	0.994[a]
Agua del Gato	13.50	1.00	0.844[a]	20.63	2.09	0.952[a]
Collipulli	1.19	0.56	0.994[a]	−1.85	1.76	0.999[a]
Santa Barbara	2.74	0.83	0.997[a]	−2.09	1.63	0.995[a]
Osorno	0.66	0.50	0.987[a]	−0.84	1.11	0.999[a]

[a] Significant at $P < 0.001$

Table 3. Amounts and percentages of organic S mineralized in soils incubated at 20 or 30 °C for 14 weeks

Soil	Amount of S mineralized at		Percentage of organic S mineralized at		Ratio[a]	Q_{10}[b]
	20 °C	30 °C	20 °C	30 °C		
	mg S kg^{-1} soil		%	%		
Iowa soils						
Ida	5.3	10.1	3.8	7.3	1.9	2.8
Hayden	9.1	12.2	7.2	9.7	1.3	1.7
Downs	12.4	23.0	6.6	12.2	1.8	2.1
Luther	9.0	14.2	7.4	11.6	1.6	2.0
Fayette	7.4	15.8	3.3	7.1	2.2	2.3
Tama	22.6	40.2	9.8	17.5	1.8	2.3
Lester	9.2	19.5	2.3	4.9	2.1	2.7
Clarion	6.1	21.3	1.9	6.7	3.5	4.4
Muscatine	10.0	17.2	2.9	5.0	5.2	2.1
Nicollet	11.9	25.0	3.1	6.4	2.1	2.5
Harps	5.6	11.3	1.2	2.4	2.0	3.1
Okoboji	9.9	19.9	2.3	4.6	2.0	2.4
Canisteo	7.9	11.2	1.7	2.4	1.4	1.8
Average	9.7	18.5	4.1	7.5	2.2	2.5
Chilean soils						
Alhue	8.7	13.0	2.5	3.7	1.5	1.7
Constitucion	11.1	18.6	7.2	12.1	1.7	1.7
Maipo	15.1	22.2	0.9	1.4	1.6	1.9
Agua del Gato	26.8	47.1	5.5	9.7	1.8	2.1
Collipulli	9.0	23.1	2.5	6.4	2.6	3.1
Santa Barbara	14.1	21.5	2.2	3.3	1.5	2.0
Osorno	7.8	14.8	0.9	1.7	1.9	2.2
Average	13.2	22.9	3.1	5.5	1.8	2.1

[a] Ratio of percentage of organic S mineralized at 30 °C to that mineralized at 20 °C

[b] Calculated from the ratio of the slope of linear-regression equation obtained for the results of S mineralized at 30 °C to that of S mineralized at 20 °C
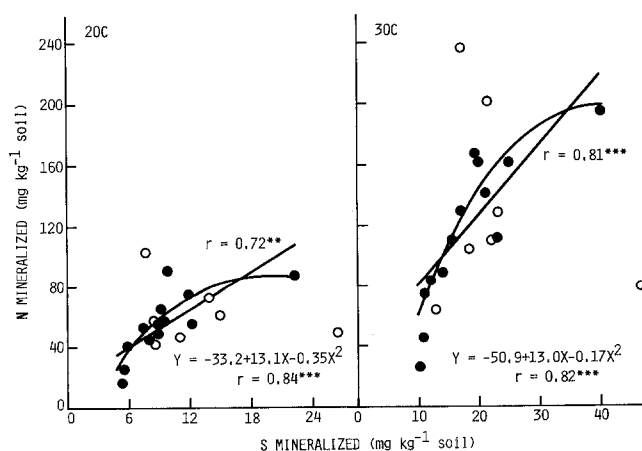
Fig. 3. Relationship between cumulative N and S mineralized in Iowa soils incubated in leaching tubes at 20 or 30 °C for 14 weeks. The results of the Chilean soils were not included in the regression analysis. ●, Iowa soils; ○, Chilean soils

methods used to calculate the Q_{10} values. Previous work with 12 Iowa surface soils showed that the Q_{10} values of S mineralization in 26 weeks ranged from 1.7 to 2.5 (average 1.9) (Tabatabai and Al-Khafaji 1980).

Statistical analysis showed that the cumulative S mineralized in 14 weeks at 20 and 30 °C was not significantly correlated with organic C, pH, organic S or cumulative N mineralized. However, when only the Iowa soils were considered, cumulative S mineralized at 30 °C was significantly, but negatively, correlated ($r = -0.67$*) with soil pH. Cumulative S mineralized at 20 °C in 14 weeks (Fig. 3) was significantly correlated with cumulative N mineralized (linear model, $r = 0.72$**; quadratic model, $r = 0.84$***). Similarly, cumulative S mineralized at 30 °C was significantly correlated with cumulative N mineralized at this temperature (linear model, $r = 0.81$***; quadratic model, $r = 0.82$***). These results support the previous finding that S mineralization in Iowa soils is significantly correlated with N mineralization when the two processes are studied in open-soil incubation systems (soil incubated under aerobic conditions in leaching tube).

The potentially mineralizable S values (S_0) and the rate constants (k and K_t) of S mineralization in soils at 20 or 30 °C are shown in Table 4. The S_0 values calculated by using the exponential equation for the S mineralized at 20 °C ranged from 5 to 44 mg kg^{-1} for the Iowa soils and from 10 to 25 mg kg^{-1} for the Chilean soils. The corresponding values obtained by using the reciprocal-plot technique ranged from 6 to 48 mg kg^{-1} and from 12 to 26 mg kg^{-1}, respectively. The S_0 values calculated from S mineralized at 30 °C, in general, were higher than those obtained at 20 °C. Some of the results obtained from the leaching tubes incubated at 30 °C did not obey the exponential equation (convergence of the non-linear model did not occur by using 50 iterations) or the reciprocal equation employed. Therefore, S_0 could not be calculated (Table 4). The first-order rate constants for S mineralization varied considerably among the soils and were affected by incubation temperature. It is difficult to account for the observed effect of temperature on the S_0 values because temperature is not a parameter in the equations used to calculate the mineralizable S pools.

The times required to mineralize 50% of S_0 (K_t) at 20 °C, calculated by using the reciprocal-plot technique, were markedly different among soils; they ranged from 4 to 36 weeks for the Iowa soils and from 2 to 14 weeks for the Chilean soils (Table 4). Only seven K_t values for S mineralization at 30 °C could be calculated, and four of these values were in the same other of magnitude as those obtained for the same soils when incubated at 20 °C. The K_t values obtained

Table 4. Potentially mineralizable S values (S_0) and rate constants (k and K_t) of S mineralization in soils incubated at 20 or 30° with successive leaching for 14 weeks

Soil	Incubation temperature[a]				K_t at temperature specified[b]	
	20°C		30°C		20°C	30°C
	S_0	k	S_0	k		
Iowa soils						
Ida	7 (7)	0.2089	37 (−)	0.0232	5	−
Hayden	12 (13)	0.1021	39 (−)	0.0279	8	−
Downs	13 (15)	0.1616	28 (31)	0.1151	5	7
Luther	13 (16)	0.0746	− (−)	−	14	−
Fayette	14 (11)	0.0595	36 (43)	0.0405	11	27
Tama	25 (48)	0.1468	160 (−)	0.0209	14	−
Lester	17 (13)	0.0547	− (−)	−	9	−
Clarion	12 (8)	0.0505	− (−)	−	8	−
Muscatine	13 (14)	0.0935	152 (−)	0.0086	9	−
Nicollet	44 (19)	0.0216	− (−)	−	14	−
Harps	5 (6)	0.2231	32 (25)	0.0303	4	20
Okoboji	19 (15)	0.0530	− (−)	−	10	−
Canisteo	9 (33)	0.1362	− (−)	−	36	−
Chilean soils						
Alhue	10 (12)	0.1273	21 (27)	0.0666	7	17
Constitucion	11 (14)	0.1903	19 (25)	0.2076	5	5
Maipo	14 (16)	0.2381	26 (29)	0.1295	3	6
Aqua del Gato	25 (26)	0.3180	47 (59)	0.2523	2	4
Collipulli	15 (12)	0.0596	− (−)	−	9	−
Santa Barbara	19 (20)	0.0963	− (−)	−	8	−
Osorno	21 (13)	0.0329	− (−)	−	14	−

[a] S_0, mineralizable S pool (mg kg^{-1} soil) calculated from cumulative S mineralized in soils incubated in leaching tubes at 20 or 30°C by using the exponential equation (figures in parentheses obtained by using reciprocal-plot technique); k, first-order rate constant (week^{-1}); − indicates that convergence of the linear model did not occur after 50 iterations
[b] Time (weeks) required to mineralize 50% of S_0 in soils, calculated by reciprocal-plot technique

Table 5. Uptake of organic S by corn, soybean and ryegrass

Soil	S yield of crop specified		
	Corn mg kg^{-1}	Soybean mg kg^{-1}	Ryegrass mg kg^{-1}
Iowa soils			
Ida	3.3	5.1	−0.1
Hayden	1.3	1.5	−1.3
Downs	1.1	10.3	0.3
Luther	1.5	1.8	−1.5
Fayette	4.6	5.6	−1.8
Tama	5.5	11.2	4.4
Lester	3.9	3.6	−1.2
Clarion	4.3	4.7	−1.0
Muscatine	5.0	6.2	−0.4
Nicollet	3.8	3.8	−0.7
Harps	3.6	2.2	−2.9
Okoboji	3.7	6.7	−3.2
Canisteo	1.1	0.7	−3.1
Chilean soils			
Alhue	8.4	12.7	0
Constitucion	4.3	2.5	−0.3
Maipo	−29.7	−24.3	−44.8
Aqua del Gato	−41.7	−92.8	−113.3
Collipulli	4.2	3.9	1.4
Santa Barbara	3.5	8.3	−2.8
Osorno	9.6	12.1	1.9

for the order three soils were markedly higher than those obtained at 20°C.

Net organic S uptakes by corn, soybean and ryegrass are shown in Table 5. The uptake of organic S by corn and soybean (tops+ roots) were, in general, less than the total amount of SO_4^{2-} mineralized in 14 weeks at 20°C. With two Chilean soils, which contained relatively high concentrations of SO_4^{2-}, the total uptakes of organic S by these crops were negative, suggesting that considerable amounts of SO_4^{2-} were being retained by these two soils. With the exception of the values obtained from five soils, the cumulative organic-S uptakes by ryegrass tops were negative, suggesting that the unrecovered roots contained a significant portion of the total plant S.

Statistical analysis showed that the dry-matter yield and S uptake by corn and soybean (tops + roots) and ryegrass (tops) were not significantly correlated with S_0 values or with the amount of N mineralized during 14 weeks at 20°C or 30°C.

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