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The capacity of soils to preserve organic C and N by their association with clay and silt particles

Jan Hassink
DLO Research Institute for Agrobiology and Soil Fertility (AB-DLO), P.O. Box 129, 9750 AC Haren, The Netherlands∗

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Abstract

Although it has been recognized that the adsorption of organics to clay and silt particles is an important determinant of the stability of organic matter in soils, no attempts have been made to quantify the amounts of C and N that can be preserved in this way in different soils. Our hypothesis is that the amounts of C and N that can be associated with clay and silt particles is limited. This study quantifies the relationships between soil texture and the maximum amounts of C and N that can be preserved in the soil by their association with clay and silt particles. To estimate the maximum amounts of C and N that can be associated with clay and silt particles we compared the amounts of clay- and silt-associated C and N in Dutch grassland soils with corresponding Dutch arable soils. Secondly, we compared the amounts of clay- and silt-associated C and N in the Dutch soils with clay and silt-associated C and N in uncultivated soils of temperate and tropical regions.

We observed that although the Dutch arable soils contained less C and N than the corresponding grassland soils, the amounts of C and N associated with clay and silt particles was the same indicating that the amounts of C and N that can become associated with this fraction had reached a maximum. We also observed close positive relationships between the proportion of primary particles < 20 μm in a soil and the amounts of C and N that were associated with this fraction in the top 10 cm of soils from both temperate and tropical regions. The observed relationships were assumed to estimate the capacity of a soil to preserve C and N by their association with clay and silt particles. The observed relationships did not seem to be affected by the dominant type of clay mineral. The only exception were Australian soils, which had on average more than two times lower amounts of C and N associated with clay and silt particles than other soils. This was probably due to the combination of low precipitation and high temperature leading to low inputs of organic C and N.

The amount of C and N in the fraction > 20 μm was not correlated with soil texture. Cultivation decreased the amount of C and N in the fraction > 20 μm to a greater extent than in the fraction < 20 μm, indicating that C and N associated with the fraction < 20 μm is better protected against decomposition.

The finding of a given soil having a maximum capacity to preserve organic C and N will improve our estimations of the amounts of C and N that can become stabilized in soils. It has important consequences for the contribution of different soils to serve as a sink or source for C and N in the long term.

Introduction

Fine-textured soils have higher organic C and N contents than coarse-textured soils when supplied with similar input of organic material (Amato and Ladd, 1992; Hassink, 1994; Hassink et al., 1997; Jenkinson, 1988) The difference is assumed to result from the greater physical protection of soil organic matter in fine-textured soils (Jenkinson, 1988; Van Veen and Kuikman, 1990). Considerable published evidence indicates that one of the principal factors responsible for physical protection of organic matter in soils is its ability to associate with clay and silt particles (Theng,

∗ FAX No: + 31505337291. E-mail: J. Hassink@ab.dlo.nl

1979). Several studies showed that the amount of C and N associated with clay and silt particles is mainly affected by soil texture and not by the input of organics to the soil, while organic matter in larger size fractions is mainly affected by the input organics and not by soil texture (Christensen, 1992; Garwood et al., 1972; Hassink, 1995; Quiroga et al., 1996). Although it has been recognized that physical protection mechanisms are important determinants of the stability of organic matter in soil (Van Veen and Kuikman, 1990) it has not been determined whether the capacity of soils to physically protect organic matter is limited and whether the capacity of soils to preserve organic matter can be quantified. Not only soil texture but also clay type may affect the capacity of soils to physically protect organic C and N. Specific surface areas of clays vary from 6–39 m^2 g^{-1} for kaolinite (Dixon, 1977) to 800 m^2 g^{-1} for smedite and vermiculite (Robert and Chenu, 1992). Soils dominated by clays with a high specific surface area are expected to adsorb more humic substances than soils dominated by clays with a low specific surface area (Tate and Theng, 1980). As the amounts of soil organic C and N are higher in old grassland and uncultivated arable soils (Bonde et al., 1992; Feller et al., 1991; Jenkinson, 1988; Lugo and Brown, 1993; Stevenson, 1982; Zhang et al., 1988), we assume that the relationship between soil texture and clay- and silt-associated C and N in old grassland and uncultivated soils represents the opacity of soils to preserve organic C and N. The first objective of this paper is to test whether there is really a maximum in the amount of C and N that can become associated with clay and silt particles. Therefore we compared the amounts of clay and silt associated C and N and C and N in coarser size fractions in two grassland with two corresponding arable soils. The second objective of this paper is to test whether for soils from both temperate and tropical regions a general relationship between soil texture, the dominant type of clay mineral and the capacity to preserve organic C and N can be found. To test this we compared clay and silt associated C and N in Dutch grassland soils with published results of corresponding measurements in uncultivated soils from different continents.

Materials and methods

We sampled the top 10 cm of grassland soils which had been under grass for at least 30 years. The grasslands were grazed by dairy cattle and received 400–500 kg fertilizer N per ha per year. To reach the first objective we sampled adjacent arable fields at two locations. In Tynaarlo the arable field had been under a 4 year rotation of winter wheat, sugarbeet, barley and ware potatoes for at least 25 years. In Cranendonck we compared the distribution of C and N in a 30 years old grassland field with a field that had been under maize for at least 25 years. We also compared the distribution of C and N in the top 10 cm with deeper soil layers (30–40 cm and 60–80 cm). Some characteristics of the grassland and arable soils are given in Table 1. Information about the dominant clay minerals in the different soils was taken from the literature (Breeuwsma, 1990; Favejee, 1949; Marel, 1949). The average precipitation in the Netherlands is 700–800 mm and the average temperature 8 °C.

Three mixed samples, each consisting of 20 bulked cores, were taken from every location. The samples were sieved through a 0.008 m mesh screen; roots and stubble were removed and the samples were analyzed separately. Dry soil (50 g) was suspended in 250 mL water for 24 hours. The samples were treated ultrasonically for 15 minutes with a probe-type ultrasound generating unit (Soniprep 150). Probe output was calibrated by measuring the temperature produced upon ultrasonifying a known mass of water for a specified time (North, 1976). Output power a was 30 W. Heat buildup in the soil suspension was controlled by a water cooling jacket. The dispersed soil suspension was transferred to a 1 L glass cylinder. The cylinder was shaken end over end until the soil was suspended. A table showing the settling-times for 20 μm particles at temperatures between 15 and 25 °C was constructed by applying Stokes' law and a particle density of 2.675 g cm^{-3}. After the correct settling time, particles < 20 μm were isolated by siphoning the suspension at the appropriate depth. The fractions were dried for 24 hours at 105 °C. They were ground and analyzed for total C and N using a Carlo Erba NA 1500 analyzer. Particle size distribution was determined after oxidation of organic matter with H_2O_2 and removal of $CaCO_3$ with HCl. The amounts of C and N associated with the particle size fraction < 20 μm were calculated by using the percentage of particles < 20 μm obtained after removal of organic matter and $CaCO_3$ and the C and N contents of the fraction < 20 μm obtained after sonification.

Total C in soil was defined as dichromate-oxidizable C according to Kurmies (Mebius, 1960). Total N was determined according to Deys (1961) by digestion with sulfuric acid and salycylic acid. To com-

Table 1. Some characteristics of the top 10 cm of the Dutch soils that were sampled

Location	C (%)	Cn	pH (KCl)	Granular composition % particles <			C associated with particles < 20 μm (g kg^{-1})	Dominant types of clay minerals[a]
				2 μm	20 μm	50 μm		
Grasslands								
Jubbenga	2.87	21.6	4.6	1.0	1.9	3.7	4.1	Q, K[b]
Cranendonck	1.50	19.5	5.4	1.0	3.5	8.5	3.6	Q, K
Heino 1	1.98	18.0	5.0	1.9	2.8	8.7	0.9	Q, K
Holten	2.27	17.5	5.1	2.5	3.6	12.0	1.0	Q, K
Tynaarlo	4.38	17.8	4.4	2.4	4.4	23.5	7.5	Q, K
Achterberg	3.09	17.5	4.9	3.0	5.8	9.0	10.2	Q, K
Markelo	3.91	17.2	5.2	3.4	5.4	12.4	3.0	Q, K
Heino 2	4.68	15.6	5.2	5.6	8.9	29.7	3.6	Q, K
Finsterwolde	5.37	10.9	5.0	8.4	13.3	23.2	11.1	I, S[c]
Lelystad	3.07	11.1	7.1	21.6	35.6	56.4	18.6	I, S
Burum	5.37	9.8	4.8	24.1	36.5	71.7	27.5	I, S
Aduard	3.55	10.1	5.6	29.8	45.5	69.4	13.5	I, S
Zaltbommel 1	3.99	9.7	5.8	25.8	42.6	67.2	19.9	I, S
Zaltbommel 2	6.07	9.2	5.4	51.1	76.0	86.4	31.0	I, S
Arable land								
Cranendonck	0.93	19.4	5.4	1.1	3.5	8.6	3.6	O, K
Tynaarlo	2.38	17.5	4.6	3.9	6.2	27.8	7.4	Q, K

[a]Favejee (1949), Marel (1949), Breeuwsma (1990).
[b]Q – quartz, K – kaolinite.
[c]I – illte, S – smectite.

pare these C and N analysis methods with the Carlo Erba analyzer (used to determine C and N in the < 20 μm fraction), we also determined total C and N in the grassland and arable soils from Tynaarlo and Cranendonck using the Carlo Erba NA 1500 analyzer. We found that differences in total C and N between the methods were less than 10%.

The amounts of C and N not associated with clay and silt particles was defined as total soil C and N minus C and N in the fraction < 20 μm. For the grassland and arable soils from Tynaarlo and Cranendonck we also determined the amounts of C and N in the fraction > 20 μm, by washing the sonicated suspension on a 20 μm sieve; the material accumulating on this sieve was considered to be the fraction > 20 μm. C and N in this fraction was determined using a Carlo Erba NA 1500 analyzer. For the Tynaarlo and Cranendonck soils, the difference between the amounts of C and N in the > 20 μm fraction determined by the Carlo Erba analyzer and the amounts of C and N in this fraction defined as the difference between total soil C and N and C and N in the < 20 μm fraction was less than 20% (Table 3).

To reach the second objective we compared total soil C and N and the distribution of C and N over the fractions < 20 μm and > 20 μm of the grassland soils and arable soils with published results of corresponding measurements in uncultivated soils and in corresponding soils after different periods of conversion to cultivated arable land. We chose 20 μm as the upper size limit for the clay and silt fraction (instead of the previously used 50 μm; Hassink, 1994), because in most studies 20 μm was taken as the upper size limit. We found data of the top layer (approximately 10 cm) of the following uncultivated soils and cultivated grasslands: a grassland soil in Germany (Leinweber and Reuter, 1992), prairie soils in Canada (Elustondo et al., 1990) and North America (Tiessen and Stewart, 1983; Balesdent et al., 1988; Zhang et al., 1988); savanna and forest soils in Africa (Nigeria, Senegal, Togo and Ivory Coast; Bates, 1960; Feller et al., 1991), forest soils in Middle and South America (Guadeloupe and Brazil; Feller et al., 1991; Bonde et al., 1992) and virgin soils in Australia (Turchenek and Oades, 1979; Dalal and Mayer, 1986, 1987). In most of these studies,

Table 2. Percentage of soil particles < 20 μm, actual, calculated maximum (max.) amount of C associated with the particles < 20 μm (C in fraction < 20 μm = 4.09 + 0.37 × % particles < 20 μm; Figure 3) and their difference (maximum – actual amount), the dominant types of clay minerals in the uncultivated soils of temperate and tropical regions referred to in this study, and the mean annual precipitation and temperature of the locations

Particles < 20 μm (%)	Amount of C associated with particles < 20 μm (g kg^{-1}) Actual	Max	Difference	Dominant types of clay minerals[a]	Mean annual precip. (mm)	Mean annual temp. (°C)
Australia: Dalal and Mayer (1986 a, b)						
86.8	13.4	36.2	–22.8	S, K	670	18.5
66.2	15.4	28.6	–13.2	Q, R	630	19.5
55.8	12.6	24.7	–12.1	R, I	670	18.5
52.1	11.1	23.4	–12.3	Q, R	610	19.9
82.3	6.0	34.5	–28.5	K, I	480	20.5
27.4	9.5	14.2	–4.7	K, Q	580	20.3
Australia: Turchenek and Oades (1979)						
50.7	19.7	22.8	–3.1	K, I	530[b]	11.7[b]
Senegal: Feller et al. (1991 a, b)						
18	6.0	10.8	–4.8	K, Q	800	29
Togo: Feller et al. (1991 a, b)						
18	5.5	10.8	–5.3	NA[c]	1040	27
Ivory Coast: Feller et al. (1991 a, b)						
35	12.7	7.0	–4.3	K, Q	1360	28
Nigeria: Bates, 1960						
13.4	7.0	9.0	–2.0	K	1230	27
Guadeloupe: Feller et al. (1991 a, b)						
70	30.0	3.0	0.0	K, H	3000	25
Brazil: Feller et al. (1991 a, b)						
70	26.1	30.0	–3.9	K, Go	1200	21
Brazil: Bonde et al. (1992)						
62.2	31.8	27.1	+4.7	K	1000–2000[b]	16–20[b]
Missouri, US: Balesdent et al. (1988)						
78[d]	30.5	33.0	–2.5	M	800–1400[b]	NA
Iowa, US: Zhang et al. (1988)						
55	28.8	24.4	+4.4	S	833	8
58	31.5	25.6	+6.0	S	833	8
Saskatchewan, Canada: Tiessen and Stewart (1983)						
41[d]	26.3	19.3	+7.0	S[d]	420[f]	1[f]
29[d]	16.7	14.8	+1.9	S	420	1
74[d]	23.4	31.5	–8.1	S	420	1
Quebec, Canada: Elustondo et al. (1990)						
61.2	23.6	26.7	–3.1	1 + Cl, Q[g]	800–1000[b]	4[h]
43.7	20.9	20.3	+0.6	1 + Cl, Q	800–1000	4
15.4	15.3	9.8	+5.5	Mi[e]	800–1000	4

Table 2. Continued

65.8	37.2	28.4	+8.7	Mi	800–1000	4
63.5	24.2	27.6	+3.4	I + Cl, Q	800–1000	4
16.7	15.7	10.3	+5.4	Mi	800–1000	4
34.8	18.6	17.0	+1.6	Mi	800–1000	4
Germany: Leinweber and Reuter (1992)						
37.6	17.9	18.0	–0.1	C, I	500–600[b]	8[b]

[a]S – smectite, K – kaolinite, Q – quartz, R – randomly interstratified, I –illite, H – hematite, Go – goethite, M –montmorillonite, Mi – mica, CI – chlorite, C – calcite.
[b]Estimated from The World Atlas of Agriculture. 1970. Committee for the World Atlas of Agricuiture, Instituto Geografico de Agostini, Novara, Italy.
[c]Not available.
[d]Interpolated from the data.
[e]Kodama (1979).
[f]Campbell et al. (1993).
[g]De Kimpe et al. (1979).
[h]De Kimpe et al. (1974).

Table 3. Amounts of C and N in the size fractions < 20 μm and > 20 μm and total soil C and N in the top cm of the grassland and arable soil in Tynaarlo and the top 10 cm and the soil layers at 30–40 and 60–80 cm depth in the grassland and maize field in Cranendonck analyzed by a Carlo Erba analyzer (g kg^{-1})

Location Treatment	C in fraction		Total C	N in fraction		Total N
	< 20 μm	> 20μm		< 20 μm	> 20 μm	
Tynaarlo						
Grassland	7.5	34.2	43.8	0.74	1.64	2.46
Arable	7.4	14.4	23.8	0.72	0.56	1.36
Cranendonck						
0–10 cm grass	3.6	12.2	15.0	0.32	0.49	0.77
30–40 cm grass	3.4	7.5	12.1	0.31	0.31	0.62
60–80 cm grass	3.4	6.4	9.7	0.31	0.26	0.55
0–10 cm maize	3.6	5.9	9.3	0.33	0.17	0.48
30–40 cm maize	3.5	3.3	7.1	0.31	0.09	0.36
60–80 cm maize	3.1	2.6	7.2	0.29	0.07	0.37

total soil C and N and the amounts associated with the particle size fraction < 20 μm were determined both in grasslands and uncultivated soils and in adjacent soils with similar characteristics that had been cultivated and used as arable land for different periods of time (5–120 years). In the soils from Central and South America, only C was determined. The dominant clay type and the climatic conditions were given in most studies. When these data were not presented in the paper, they were derived from other sources (Table 2).

Statistical analysis

The relationships between the percentage of soil particles < 20 μm and total soil C and N and C and N associated with the particle size fractions < 20 μm and > 20 μm were analyzed with correlation and regression techniques (Genstat, 1987).

Results

C end N in size fractions in soils with similar textures but differing in organic matter input (objective 1)

The first objective was to test whether the amounts of C and N that can become associated with clay and silt particles are limited. Despite the fact that the arable field from Tynaarlo, the maize field from Cranendonck and the deeper layers of the grassland arid maize field from Cranendonck had much lower total amounts of soil C and N than the corresponding top layers of the grassland fields, the amounts of C and N associated with the clay and silt fraction were not less (Table 3). The amounts of C and N in the fraction > 20 μm were less in the arable field from Tynaarlo arid the maize field from Cranendonck than in the corresponding grassland sites, and decreased with increasing depth at Cranendonck (Table 3).

Relationship between soil texture and total amounts of soil C and N in uncultivated and grassland soils from different continents

For uncultivated and grassland soils the total amounts of C and N in the top 10 cm, ranged from 8 to 60 and 0.5 to 6.5 gram kg^{-1} soil, respectively. There was no clear relationship between the C and N content of a soil and its clay and silt content (Figures 1 and 2). C and N contents varied considerably between soils with similar clay and silt content and were generally higher in the Dutch grassland soils than in the uncultivated soils of North, Middle and South America and Africa. Australian soils generally had the lowest C and N contents (Figures 1 and 2).

Relationship between soil texture and the amounts of soil C and N associated with clay and silt particles in uncultivated and grassland soils from different continents (objective 2)

In contrast to total C and N, there were highly significant positive correlations between the clay and silt content of a soil and the amounts of C and N associated with this fraction (Figures 3 and 4; C (g kg^{-1}) = 4.09 + 0.37 $\times$ % particles < 20 μm; N (g kg^{-1}) = 0.40 + 0.037 $\times$ % particles 20 μm; excluding the soils from Australia). The relationship between the clay and silt content of a native soil and the amount of C and N associated with this fraction held for soils from the Netherlands, North, Middle and South America and Africa. The amount of C associated with the clay and soil fraction was less than 10 g kg^{-1} soil in coarse-textured soils and up to 37 g kg^{-1} soil in fine-textured soils. For N, the corresponding amounts were 10 times lower. The dominant type of clay mineral present in the soil did not affect the relationship between the clay and silt content of the soils and the amounts of C and N associated with this fraction (Table 1, Figures 3, 4). The Australian soils showed different results; lower amounts of C and N were associated with the clay and silt fraction than in other uncultivated soils and no correlation between their clay and silt content and the associated amounts of C and N was found (Figures 3 and 4). The Australian soils were not different from the other soils with respect to dominant clay type. Compared to other locations, the Australian sites had a low precipitation in combination with a high temperature (Table 2).

Relationship between soil texture and the amounts of soil C and N in the fraction > 20 μm in uncultivated and grassland soils from different continents

The amounts of C and N in the fraction > 20 μm did not correlate with the clay and sift fraction and varied considerably between soils with similar clay and silt content (Figures 5 and 6). The amounts of C and N in the fraction > μm were generally higher in the grassland soils of the Netherlands (20–45 and 1–3.7 g kg^{-1} soil for C and N, respectively) than in the other soils (3–20 and 0.2–2.0 g kg^{-1} soil for C and N, respectively) and lowest in the soils from Australia (Figures 5 and 6).

Effect of converting uncultivated and grassland soils to cultivated arable land on the amounts of C and N in the fractions < 20 μm and > 20 μm in soils from different continents

The amounts of soil organic C and N were compared in pairs of soils with similar texture that had uncultivated or under grassland, or converted to cultivated arable land for different periods of time (5–120 years) in different experiments. Conversion to arable land generally led to a decrease in the amounts of soil C and N and the relative decreases in soil C and N were comparable.

In more than 90% of the soils, the relative decrease in the amount of C or N associated with the fraction < 20μm was smaller than the relative decrease in the amount of C or N in the fraction > 20 μm (Figure 7).

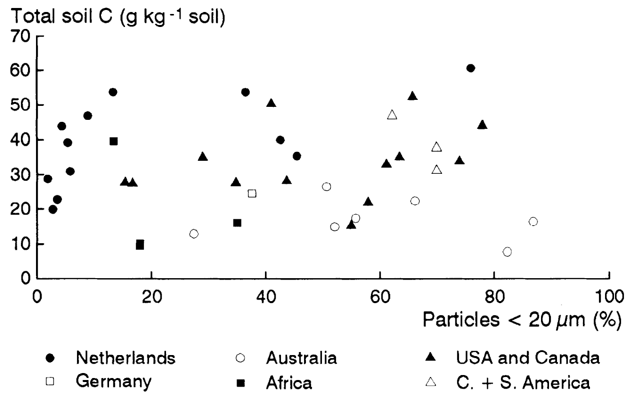

Figure 1. Relationship between total soil C (g kg^{-1} soil) and the percentage of soil particles < 20 μm in uncultivated and grassland soils of temperate and tropical regions.

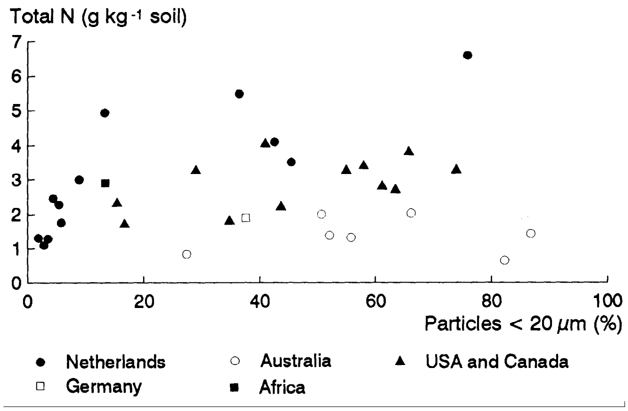

Figure 2. Relationship between total soil N (g kg^{-1} soil) and the percentage of soil particles < 20 μm in uncultivated and grassland soils of temperate and tropical regions.

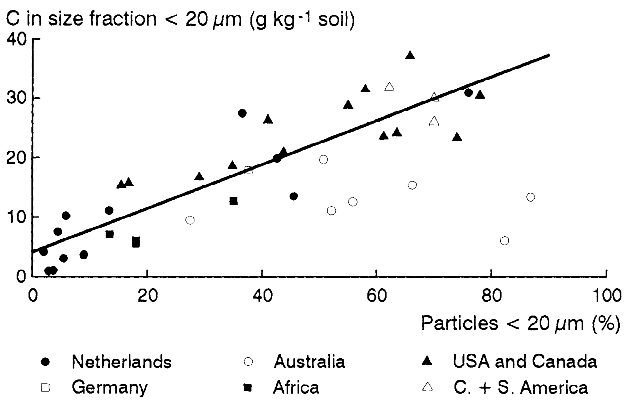

Figure 3. Relationship between C in the particle size fraction < 20 μm (clay and silt in g kg^{-1} soil) and the percentage of soil particles < 20 μm in uncultivated and grassland soils of temperate and tropical regions. C in fraction < 20 μm (g kg^{-1} soil, excluding Australian soils) = 4.09 (1,59) + 0.37 (0.04) $\times$ % particles < 20 μm. (r = 0.89; 0 = SE).

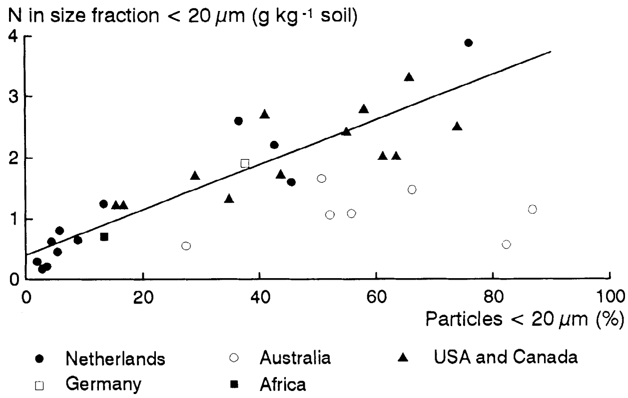

Figure 4. Relationship between N in the particle size fraction < 20 μm (clay and silt in g kg^{-1} soil) and the percentage of soil particles < 20 |mum in uncultivated and grassland soils of temperate and tropical regions. N in fraction < 20 μm (g kg^{-1} soil, excluding Australian soils) = 0.40 (0.15) + 0.037 (0.004) $\times$ % particles < 20 μm. (r = 0.90; 0 = SE).

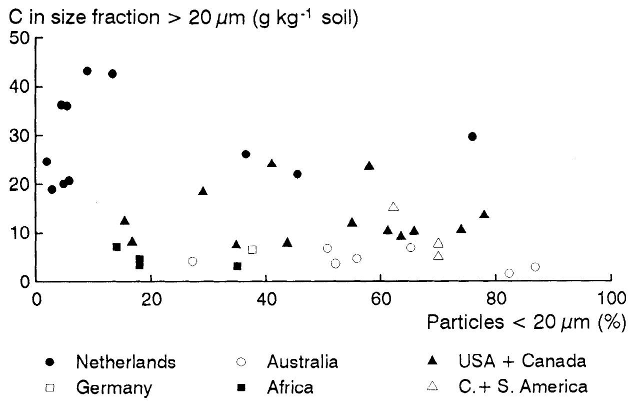

Figure 5. Relationship between C in the particle size fraction > 20 μm (g kg^{-1} soil) and the percentage of particles < 20 μm in uncultivated and grassland soils of temperate and tropical regions.

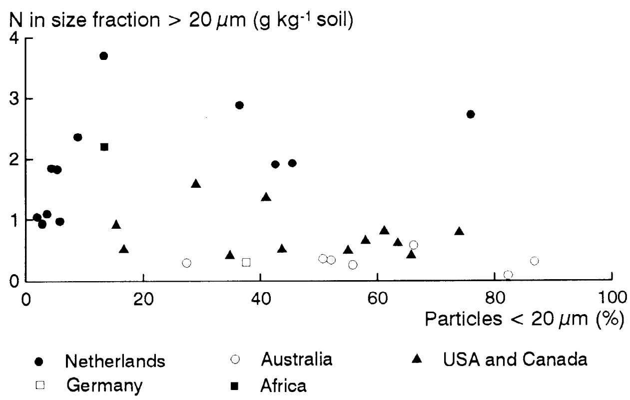

Figure 6. Relationship between N in the particle size fraction > 20 μm (g kg^{-1} soil) and the percentage of soil particles < 20 μm in uncultivated and grassland soils of temperate and tropical regions.

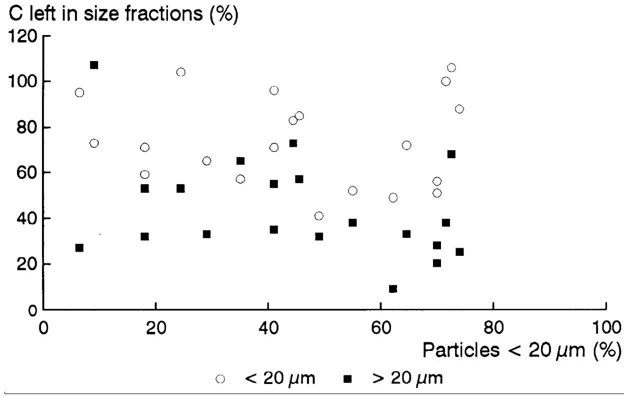

Figure 7. Relationship between the percentage of soil particles < 20 μm and the percentage of soil C or N in the particle size fractions < 20 μm and > 20μm after conversion of grasslands or uncultivated soils to cultivated arable land.

Cultivated arable soils generally contained less than 50% of the amount of C or N in the fraction > 20 μm of uncultivated and grassland soils; for the fraction < 20 μm the proportion of C or N left after conversion to arable land was generally more than 60%.

Discussion

The first objective was to test whether the amount of C that can become associated with clay and sift particles is limited. We found that although the top layers of the sandy grassland soils in Tynaarlo and Cranendonck contained more C than the corresponding arable sites and the deeper soil layers, the amounts of C associated with the clay and silt fraction were not different. The increases in soil C were only observed in the larger size fractions. This suggests that the amount of C that can become associated with the clay and silt fraction had reached a maximum in these sandy soils.

The second objective was to quantify a general relationship for soils from different continents between soil texture and the capacity of a soil for C and N to be associated with clay and silt particles. Therefore, we determined clay- and silt-associated C and N in old grassland soils and compared that with clay- and sift-associated C and N in uncultivated soils. Grasslands and uncultivated soils generally have higher C and N contents than cultivated arable soils, due to the higher incorporation of organic C, the absence of soil tillage and reduced exposure to erosion (Christensen, 1992; Elliott et al., 1993; Jenkinson, 1988; Lugo and Brown, 1993). We assumed that in all old grassland and uncultivated soils the amounts of C and N were at equilibrium and had reached a maximum under the given conditions.

We found close correlations between the amounts of C and N associated with the clay and silt fraction and the percentage of soil particles in this size fraction. Although Dutch grassland soils contained relatively high amounts of total soil C and N and C and N in the faction > 20 μm, C and N associated with the fraction < 20 μm was similar as for the uncultivated soils. This also suggests that the amounts of C and N that can become associated with the clay and silt fraction reached a maximum in all soils. The observation that the C content of clay particles was similar for grassland and arable soils, in spite of their differences in total C content (Hassink et al., 1997) is also in line with this assumption. Apparently the input of organic C into the soil was high enough to saturate the clay particles under arable farming. The extra input of C under grassland management could not be bound to clay particles and accumulated in fractions with a greater particle size.

The observations are in agreement with the results of laboratory studies with pure clays, where it has also been found that the amount of organics that can be bound to clay particles is limited (Harter and Stotzky, 1971; Marshman and Marshall, 1981; Pinck et al., 1954). In those studies, the amount of organics that could be bound per amount of dispersed, pure clay was generally higher than the amount of organics bound per amount of clay and silt in our study. This is logical, as the clustering of clay packets into stable microaggregates in the soil leads to a reduction in the specific surface area of the clays (Stotzky, 1986).

It may be expected that the amount of C and N that can be adsorbed by clay minerals is also affected by clay type. Specific surface areas vary from 2–4 m^2 g^{-1} for quartz (Wilding et al., 1977), 10–70 m^2 g^{-1} for kaolinite, chlorite and mica (Huang, 1990), 50–100 m^2 g^{-1} for illite to 800 m^2 g^{-1} for smectite and vermiculite (Robert and Chenu, 1992) and differences in specific surface could affect the capacity of clays to adsorb humic substances (Tate and Theng, 1980). Most clays with a low specific surface area, however, have a relatively high ratio of external to internal surface a whereas for clays with a high specific surface area the opposite is true (Robert and Chenu, 1992). Many humic compounds do not penetrate the interlayer space and adsorb only on the external surfaces (Robert and Chenu, 1992; Tate and Theng, 1980). In a recent study it was shown that the amount of fulvic adds that adsorbed to clay minerals was not related to the surface area of the clays (Varadachari et al., 1994). Also in the present study we observed no relation between the dominant clay type in the soil and the amount of organic C and N that was associated with the clay and silt fraction. This suggests that the surface area of clays determined in the laboratory is not a good indicator of the capacity of clays to adsorb organic C and N.

The amounts of C and N that can be associated by clay and sift particles also was not different for soils from temperate and tropical regions. In uncultivated systems in the tropics, the rate of input can be so high that the equilibrium level of organic matter is high in spite of the fact that the decomposition rate is also high (Greenland et al., 1992). The amounts of total soil C and N and C and N bound to clay and silt particles were lower for most Australian soils than for other soils. The combination of a very low annual precipitation and high temperatures (Table 2) lead to unfavourable conditions for plant growth and a limited input of plant residues into the soil. The input of organic C and N was obviously too low to reach an equilibrium and saturation level of the clay and silt particles similar to those in other uncultivated soils.

In agreement with the hypothesis, there was no correlation between the amounts of C and N in the fraction > 20 μm and soil texture. The amounts of C and N in coarser size fractions are related to the amount of residue that is incorporated into the soil and not to soil characteristics (Bonde et al., 1992; Hassink, 1995; Hassink et al., 1997). Due to the wide variation in the amounts of C and N in the fraction > 20 μm, correlations between total soil C and N and the percentage of particles < 20 μm were not clear.

The observation that the decrease in clay- and silt-associated C and N upon cultivation of soils was generally less than the decrease in C and N in the particle size fraction > 20 μm confirms that clay and sift particles protect C against microbial degradation. It is also in line with the general observation that in arable soils most of the soil organic matter is found in the clay and silt size fraction, whereas in forest and grassland soils the contribution of sand size organic matter to total soil organic matter is greater (Adams, 1980; Christensen, 1992).

The assumption that the protective capacity of a soil is limited is expected to have important consequences for the long term dynamics of soil organic matter and the role of different soil types as a source and sink term in the global C and N cycle on the long term.

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