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Original article

Effects of aggregation processes on distribution of aggregate size fractions and organic C content of a long-term fertilized soil

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ABSTRACT

Mineral and organic fertilizers are the important factors for maintenance and improvement of soil fertility and aggregation. Despite aggregation and aggregate stability are proxy of soil fertility, the connection between fertilization and aggregation is not direct, as short and long-term processes may affect the aggregate formation in different directions. In this study, the long-term effects of a 20-year application of mineral and organic fertilizers were studied in an intensive horticultural crop rotation with the following treatments: i) without fertilization (control soil), ii) nitrogen applied by mineral fertilizer, and iii) farmyard manure application with low (30 t ha^{-1} y^{-1}) or iv) high (60 t ha^{-1} y^{-1}) rates. In case of short-term aggregation process, K-polyacrylate was added to the soil to change aggregate composition and then the aggregated soils were incubated for 2 weeks. Long-term fertilization increased the soil organic C (SOC) content by 42–73% and the portion of small macroaggregates (1–0.25 mm) compared to control soil. In contrast, soil aggregation induced by K-polyacrylate showed an increase of the large macroaggregate (2–1 mm) portion independent of fertilization. Polyacrylate had no effect on soil microbial biomass C. According to the increased SOC content, the fertilization increased CO_2 efflux from soil (4.2–5.2% of SOC after 80 days of incubation). Short-term aggregation by K-polyacrylate decreased the SOC mineralization rate mainly of the labile C-pools. In conclusion the data of this study suggest that long-term fertilization mainly contributes to the formation of small macroaggregates. In contrast, the formation of large macroaggregates is mediated mainly by short-term processes and contributes to the decrease of SOC mineralization.

1. Introduction

Aggregation has major effect on C cycling in soil, contributes to fertility and reduces erosion. Aggregates are composed of primary mineral particles and organic binding agents [15,40]. The initial unit of aggregation is called microaggregate. According to Tisdall and Oades [40], the microaggregates (<0.25 mm) are bound together by organic compounds of different origin to form macroaggregates (>0.25 mm). The macroaggregates affect soil C storage by occluding organic residues, making them less accessible to degrading organisms and their enzymes. On the other hand, disruption of soil aggregates exposes physically protected organic material [28], increases aeration, activates microbial biomass, and enhances organic matter decomposition as well as CO_2 fluxes to the atmosphere [29]. The disruption or formation of stable macroaggregates by various management, e.g. tillage practice or organic inputs, affects C storage and the decomposition rates of soil organic carbon (SOC). Therefore, studies on formation and disruption of aggregates are highly significant to clarify the fertilization effects on C stock, SOC decomposition, CO_2 fluxes and microbial biomass.

This study was based on the long-term field experiment with various fertilization treatments common in horticultural practice. Horticulture is one of the most intensive forms of agriculture because i) high amounts of mineral and organic fertilizers are usually applied, ii) irrigation is frequently used to increase the yield, and iii) as a result, a high level of net primary production is common. So, transformation of the crop residues and organic fertilizers to SOC is an important factor affecting aggregate composition and structure [15,40].

Apart from the influence of organic matter, aggregation is also promoted by fungal hyphae [5,30]. Roots of vegetables (e.g. cucumber, celery, leek) can be readily colonized by mycorrhizal fungi [2,35]. Arbuscular mycorrhizal fungi produce copious amounts of an insoluble glycoprotein, glomalin [45] and polysaccharides, which contribute to aggregate stability [46]. Aggregation of soil particles can slow the turnover of the C [31]. Keeping in mind the positive

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effect of glycoproteins and polysaccharides on aggregation, the present experiment was designed to change aggregate composition in short term by adding K-polyacrylate, which is commonly used in agricultural practice and effectively stabilizes soil aggregates [24] especially in sandy soils [9]. K-polyacrylate does not influence microbial turnover directly as it quickly becomes unreactive [37].

The specific objectives were (i) to estimate the long-term effect of fertilization and short-term effect of K-polyacrylate on distribution of aggregate size fractions in a sandy soil, (ii) to evaluate the C stock and microbial biomass in the aggregate size fractions, and (iii) to clarify the effects of aggregation on decomposition rates of SOC.

2. Material and methods

2.1. Soil and long-term field experiment

Soil samples were taken in January 2008 from the 0–10 cm layer of a sandy Cambisol at the experimental plots of the long-term field trial "Trasse 2" of the Institute of Vegetable and Ornamental Crops (IGZ), Grossbeeren, Germany (52°20'56.70" N, 13°19'07.90" E). The climate conditions (1973–2002) at the site are characterized by a mean annual temperature of 8.8 °C and an average rainfall of 520 mm y^{-1} plus 150 mm y^{-1} irrigation water. The soil pH was 6.6, and the sand and clay content of the soil are 81 and 5%, respectively. The soil has a bulk density of 1.59 g cm^{-3}.

Soil samples were chosen from four treatments having a different fertilization history during 20 years (Table 1): 1) control soil (without mineral and manure fertilization), 2) with mineral N application 270 kg N ha^{-1} y^{-1} (N), 3) farmyard manure (FYM) application 30 t ha^{-1} y^{-1} (M), and 4) FYM application 60 t ha^{-1} y^{-1} (2M). Before plowing, the respective amount (30 and 60 t ha^{-1}) of well-decomposed FYM was applied to the plots (size: 4.5 m × 5.0 m). During the experimental period, the mean dry matter concentration of fresh FYM was 0.22 g g^{-1} and the mean C content was 0.31 g g^{-1} (oven-dry basis). Mineral N was applied as calcium ammonium nitrate at a high N level corresponding to 270 kg N ha^{-1} y^{-1}. The crop rotation was: white cabbage (*Brassica oleracea* L. var. capitata f. alba), carrot (*Daucus carota* L.), cucumber (*Cucumis sativus* L.), leek (*Allium porrum* L.), and celery (*Apium graveolens* L. var. rapaceum Mill.). At the time of harvesting, all the above-ground plant material (yield plus crop residues) were removed. After sampling, the soil was air-dried (20–30 °C), thoroughly mixed and sieved (2 mm). Thereafter all visible roots were carefully removed both with the electrostatic method [22] and manually by tweezers.

2.2. Treatments and incubation

Forty grams of soils were weighted into 250 ml closed glass vessels (Schott Duran, Mainz, Germany) and incubated at 20 °C. The experiment was set up with eight treatments in triplicates including two factors. The first factor was the long-term fertilization: control, N, M and 2M (as described above). The second factor was K-polyacrylate addition. No polyacrylate (−polyacrylate) or 400 mg polyacrylate (+polyacrylate) corresponding to 1% of soil dry weight was added to and thoroughly mixed. K-polyacrylate is a superabsorbent of water and a non-reactive, water-insoluble, stable polymer of acrylate salt of K. Mixed with sandy soils, it quickly absorbs water to form gel, which in turn increases the water-holding capacity [9]. The soil was moistened to 70% of water-holding capacity (WHC) with deionized water. Small vials with 3 ml of 1.0 M NaOH were placed in the vessels to trap CO_2. The traps were changed daily during the first 4 days, every 2–3 days over the next 10 days, and weekly during the remainder period. Additional triplicate blank vessels containing only the vials with NaOH served as controls to account for the CO_2 trapped from the air inside the vessels.

Table 1
Crop rotation in Grossbeeren Static Long-term Field Experiment.

Location	Grossbeeren, Germany (Arenic Luvisol)
Crop rotation since 1988	White cabbage (*Brassica oleracea* L. var. capitata f. alba), carrot (*Daucus carota* L.), cucumber (*Cucumis sativus* L.), leek (*Allium porrum* L.), and celery (*Apium graveolens* L. var. rapaceum Mill.).
Fertilizers	Mineral N fertilizer was applied as calcium ammonium nitrate. N level corresponding to a mean annual N input of 270 kg N ha^{-1} y^{-1}
Manure (FYM)	Mean annual inputs: 30 (60[a]) t ha^{-1} y^{-1} FYM Added dry matter – 6.5 (13[a]) t ha^{-1} y^{-1} C input through FYM – 2.05 (4.1[a]) t C ha^{-1} y^{-1} N input through FYM – 150 (300[a]) kg N ha^{-1}

[a] Double FYM dose.

2.3. Aggregate size fractionation at optimal soil moisture

Soil samples taken before incubation and sixteen days after the start of incubation were prepared for aggregate fractionation. Aggregates were isolated according to Kristiansen et al. [21]: 40 g were transferred to a nest of sieves (1 and 0.25 mm) and shaken for 90 s, and the 2–1 mm aggregates (large macroaggregates) were collected. The same procedure was done for the material retained on the 0.25 mm sieve, isolating the 1–0.25 mm aggregate size class (small macroaggregates). The remaining material passing through the 0.25 mm sieve was identified as aggregate class <0.25 mm (microaggregates). The recovery after sieving was more than 90% of soil weight. Small losses (<10%) were connected with the adhesion of soil particles on the sieves and were not removed by washing or any other strong disturbing methods, as they disrupt the aggregates and so affect the natural aggregate composition. The preliminary tests showed that the sieving duration was sufficient to quantitatively separate the various aggregate size classes while minimizing aggregate abrasion during sieving.

This aggregate size fractionation procedure was chosen because it is gentler than conventional wet and dry sieving techniques [8]. Wet-sieving releases water-soluble organic matter and dispersible colloids, altering the aggregate composition [44]. In turn, prolonged sieving of air-dry soil tends to increase aggregate abrasion rather than fragmentation due to the great tensile strength of dry aggregates (e.g. Munkholm and Kay, [26]). Following the same procedure as Kristiansen et al. [21] and Dorodnikov et al. [8], soil was fragmented for constituent aggregates when the water content of individual clods and peds was near the lower plastic limit, corresponding to the optimum water content at which soil friability is maximal [7].

2.4. Analyses of SOC, microbial biomass C and CO_2 efflux

The total C content was determined in ball-milled soil (bulk and aggregates) by dry combustion with a LECO CN2000 analyzer. As the soils were free of carbonates; total C was equivalent to soil organic C.

Microbial biomass (MB) C in soil (bulk and aggregates) samples before incubation was measured by the fumigation–extraction method [42]. Each replicate was divided into two equivalent portions; one was fumigated for 24 h with ethanol-free chloroform and the other was the unfumigated control. Both fumigated and unfumigated soils were shaken for 30 min with 0.05 M K_2SO_4 (1:4 soil: extraction ratio) [23], centrifuged and filtered. Extracts were analyzed for total C and N on a 'multi N/C 2100' (Analytik Jena, Germany). A K_C value of 0.45 [18,47] was used to calculate the C content of microbial biomass.

The CO_2 trapped in 1.0 M NaOH solution was precipitated with 0.5 M barium chloride ($BaCl_2$) and then the NaOH was titrated with 0.1 M HCl against phenolphthalein [48].

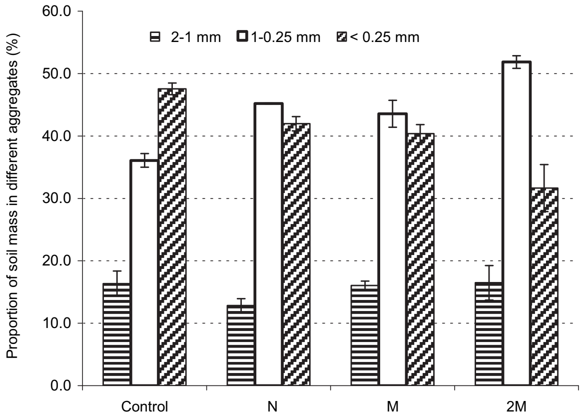

Fig. 1. Aggregate size distribution across different long-term management practices: (N: mineral (N) fertilized soil; M: manure-amended soil; 2M: manure amended in double manure dozing.) (*Error bars* represent the standard error of mean).

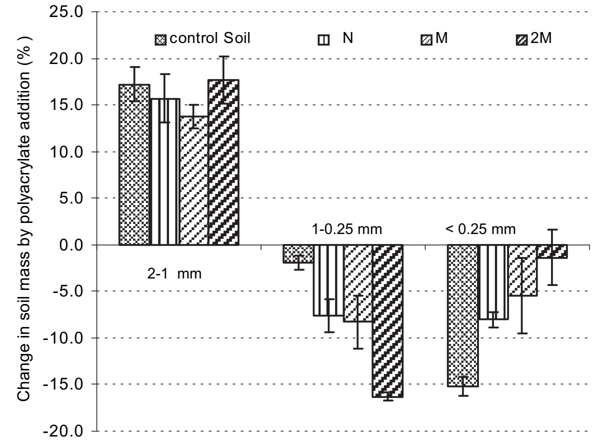

Fig. 2. Effect of K-polyacrylate (K-polyacrylate − control) on aggregate size fractions. (N: mineral (N) fertilized soil, M: manure-amended soil, 2M: manure amended in double manure dozing) (*error bars* represent the standard error of mean).

2.5. Estimation of labile and non-labile pools of soil organic C

The decomposition of the soil organic C was evaluated by a first-order two-component model [6].

$$C_{cum} = C_{lab}\left(1 - e^{(-k1 \cdot T)}\right) + C_{re}\left(1 - e^{(-k2 \cdot T)}\right) \quad (1)$$

where C_{cum} is the cumulative CO_2 evolution (g C kg^{-1} of soil) by time T; C_{lab} and C_{re} are the initial amounts of C in the labile and non-labile pools, respectively (g C kg^{-1} soil), k1 and k2 are the corresponding mineralization rate constants for each C-pools, and T is the time (days). Putting the C_{cum} and T values in the Eq. (1), C_{lab} and C_{re}, k1 and k2 values can be calculated.

2.6. Statistical analysis

The significance of the effects of fertilization on SOC content and aggregation was evaluated by ANOVA. Differences were considered as significant at the 0.05 error probability level. The results are presented as arithmetic means and standard errors (SE) of three replicates. A non-linear least-squares regression analysis for Eq. (1) was used to calculate parameters from cumulative C mineralization (Software STATISTICA 7.0).

3. Results

3.1. Long-term effects of fertilization and short-term K-polyacrylate effects on aggregate size fractions

The distribution of soil aggregates among the three size fractions differed widely (Fig. 1). In the control soil the large macroaggregates (2–1 mm) comprised the lowest portion (16%), followed by small macroaggregates (1–0.25 mm) and microaggregates (<0.25 mm). The proportion of small macroaggregates showed an increasing tendency (Control < M ≤ N < 2M) and the proportion of micro-aggregates was reverse (Control > N ≥ M > 2M). Although the effect of fertilizers was less pronounced for large macroaggregates, they ranged from 12.8 to 16.5% of total soil. Moreover, different rates of manure addition (M and 2M) only slightly affected the large macroaggregate portion, whereas the small macroaggregate portion increased with the amount of manure applied.

K-polyacrylate significantly increased soil aggregation ($p < 0.05$). There were significant three-way interactions of polyacrylate effect, aggregate size fractions and fertilization on distribution in aggregate size classes (Table 2). After sixteen days of incubation with polyacrylate, the proportion of large macroaggregates increased more in the control and 2M than in N and M soils. The large macroaggregate fraction increased from 13.7 to 17.7% of soil mass compared to the soil without polyacrylate by decreasing the small macroaggregates and microaggregates (Fig. 2).

3.2. Effects of long-term fertilization on soil organic C stock and microbial biomass

Twenty years of fertilization led to significant differences in the SOC and increased in the following order: Control < N < M < 2M. The effect of fertilization was also distinct for the SOC in different aggregate fractions (Fig. 3). Irrespective of fertilization, micro-aggregates had a greater C content. The SOC content of large macroaggregates increased significantly ($p < 0.05$) with mineral and manure fertilization, peaking with 2M. The SOC content of micro-aggregates followed almost the same trend (Control < M < N < 2M).

Microbial biomass was strongly correlated with the organic input into the soil ($r^2 = 0.97$, $P < 0.05$). Mineral and manure fertilization increased microbial biomass C (MBC) from 0.4 to 0.6%

Table 2
ANOVA results of the effects of aggregate size, long-term fertilization and K-polyacrylate on distribution of aggregates size classes and SOC content in aggregates.

Effect	Distribution of aggregates size classes			SOC content in aggregates		
	df	*F*	*p* level	df	*F*	*p* level
1. Polyacrylate effect	1	0.05	0.828	1	559.403	**0.000**
2. Fertilization	3	0.06	0.980	3	63.601	**0.000**
3. Aggregate size	2	700.16	**0.000**	3	150.893	**0.000**
1 × 2: Polyacrylate effect × Fertilization	3	0.10	0.957	3	11.724	**0.000**
1 × 3: Polyacrylate effect × Aggregate size	2	439.57	**0.000**	3	65.433	**0.000**
2 × 3: Fertilization × Aggregate size	6	37.88	**0.000**	9	1.806	0.106
1 × 2 × 3: Polyacralate effect × Fertilization × Aggregate size	6	20.28	**0.000**	9	1.042	0.430

Significant effects are marked in bold.

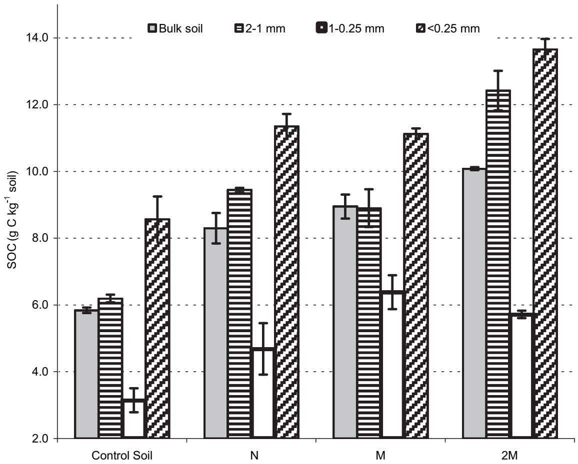

Fig. 3. Effect of long-term fertilization practice on SOC stock of different soil aggregate fractions. (N: mineral (N) fertilized soil, M: manure-amended soil, 2M: manure amended in double manure dozing) (*error bars* represent the standard error of mean).

of the SOC content. The lowest value was observed in the control (22 mg C kg^{-1} soil) and increased in N (36 mg C kg^{-1}), manure M (49 mg C kg^{-1}) and 2M (59 mg C kg^{-1}) soils (Fig. 4).

Without manure application, MBC was high in microaggregate fractions in control and N soils. Increasing rates of manure addition only slightly affected MBC in the microaggregates, while increased MBC in small and large macroaggregates. This result showed that manure application enhanced microbial biomass in all aggregates. However, this manure-induced increase was stronger in macro- versus to microaggregates.

3.3. *Effect of long-term fertilization on SOC mineralization*

At the first day of incubation (directly after wetting the soil to 70% WHC), the CO_2 evolution rate was high and ranged from 19 to 38 μg C $g\,g^{-1}$ soil d^{-1} for all soils. The emission rate decreased sharply over the next 2–4 days. The CO_2 emission intensity became almost constant for all soils and ranged from 3.5 to 5.4 μg C g^{-1} soil d^{-1} after 21 days of incubation.

The cumulative CO_2–C release (C_{cum}) after 80 days of incubation ranged from 3.2 to 4.5% of native SOC (Fig. 5). The estimated C_{lab}

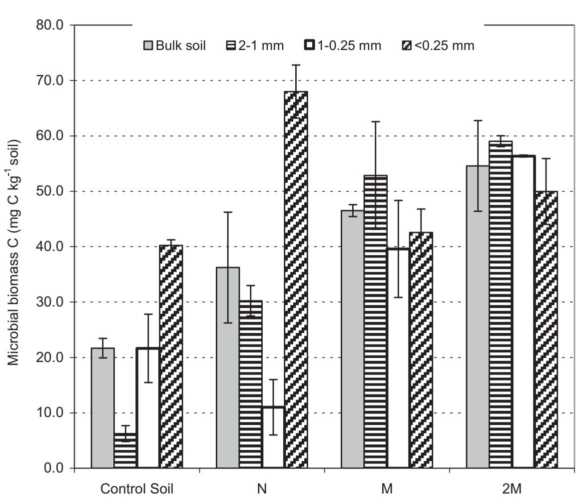

Fig. 4. Effect of long-term fertilization on soil microbial biomass C content of different aggregate size fractions (N: mineral (N) fertilized soil, M: manure-amended soil, 2M: manure amended in double manure dozing) (*error bars* represent the standard error of mean).

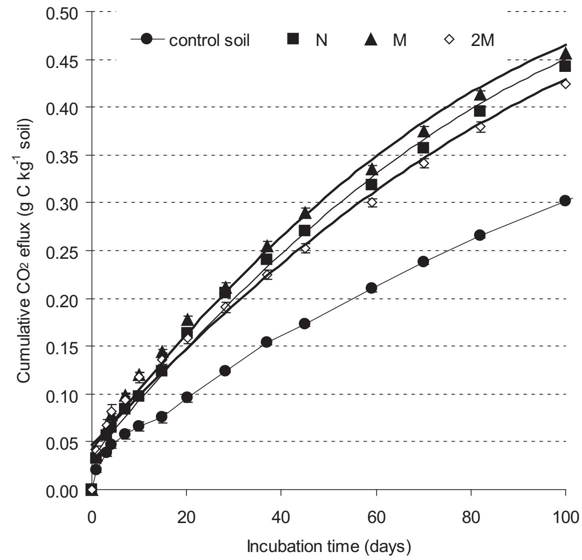

Fig. 5. Cumulative CO_2 mineralization during incubation: in absolute values. (N: mineral (N) fertilized soil, M: manure-amended soil, 2M: manure amended in double manure dozing) (Standard errors are less than symbol size ($n = 4$)).

(from Eq. (1)) was higher in manure-amended soils (M and 2M) compared to the control and mineral N fertilized soils. Manure amendment decreased the decomposition rate of C_{lab} compared to control and mineral N fertilized soils. However, the fertilization effect was not significant on C_{re} and on corresponding decomposition rate (Table 3).

Aggregation by polyacrylate significantly ($p < 0.05$) decreased the decomposition rate (k1) of the C_{lab} pool over the control without polyacrylate. Thus, the corresponding half-life was increased.

4. Discussion

4.1. *Effects of fertilization and K-polyacrylate on aggregate size fractions*

The used sieving procedure showed that long-term fertilization altered the distribution of aggregate size fractions. Cultivation without fertilization or manuring over the last 20 years (control soil) showed abundant microaggregates (47% of total soil mass). Microaggregates are consolidated into macroaggregates [34] through the higher derived SOC in soils [13,33]. As a result of long-term fertilization the microaggregate portion decreased by 6–16% of soil mass and increased the small macroaggregates by 9–16% in N, M, and 2M compared to the unfertilized soil. This fertilizer effect, however, only slightly (12–16% of soil mass) affected the large macroaggregates. The large macroaggregates are less stable because of the high sand content in the soil and therefore, they remained unchanged even by 2M fertilization.

Previous studies [9,41] indicated that polyacrylate mixed with sandy soils, quickly uptake water and form gels resulting in an increase of the water-holding capacity. Due to the bonding effect of polyacrylate with soil particles and its swellability, an improved and stable structure of the soil is obtained. In the present study, irrespective of soil fertilization, K-polyacrylate decreased both small macro- and microaggregate portions by increasing large macroaggregates (13.7–17.7%). The effect was more pronounced in the unfertilized soil (Fig. 1). The negative effect of polyacrylate on microaggregates was linearly correlated ($r^2 = 0.91$, $p < 0.05$) with the same on small macroaggregates (Fig. 2).

Table 3
Content of labile (C_{lab}) and recalcitrant (C_{re}) carbon pools in long-term fertilized and control soils.

Soils	SOC content (mg C g^{-1}soil)		Decomposition rate ($days^{-1}$)			
	Before polyacrylate addition		Before polyacrylate addition		After polyacrylate addition	
	C_{lab}[a]	Cre[a]	k1[a]	k2[a]	k1[a]	k2[a]
Control soil	0.035 ± 0.003	0.898 ± 0.095	0.631 ± 0.202	0.004 ± 0.001	0.128 ± 0.026	0.005 ± 0.001
N	0.053 ± 0.007	0.810 ± 0.052	0.474 ± 0.176	0.007 ± 0.001	0.329 ± 0.048	0.006 ± 0.000
M	0.070 ± 0.005	0.751 ± 0.031	0.398 ± 0.078	0.007 ± 0.001	0.247 ± 0.031	0.005 ± 0.001
2M	0.070 ± 0.003	0.924 ± 0.050	0.551 ± 0.079	0.005 ± 0.000	0.308 ± 0.043	0.004 ± 0.001

N: mineral (N) fertilized soil, M: manure-amended soil, 2M: manure amended in double manure dozing; C_{lab} and k1 = amount and decay rate of labile SOC pool; C_{re} and k2 = amount and decay rate of recalcitrant SOC pool.
[a] mean ± standard error.

4.2. Effect of fertilization on SOC content across soil aggregate fractions

The unfertilized soil had a low SOC content (5.84 g C kg^{-1} soil). Von Lützow et al. [25] reported that the high stabilization of SOC partly reflects high clay content. As the experimental soil contained only 5% clay, high C accumulation is hardly possible. The long-term fertilization increased the SOC content directly and indirectly – by increasing both the crop yield and the crop residues (stubble, root biomass, rhizodeposition). In this horticultural crop rotation, the 'above-ground biomass', and sometimes the whole vegetative part (e.g. carrot, leek), were completely removed from the field. It can therefore be assumed that mainly rhizodeposition contributed to SOC formation in the treatment with mineral N fertilization. Rühlmann and Ruppel [32] calculated that manure addition had almost no effect on mean annual total rhizodeposition in the same soil. This explains small increase (only 0.65 g C kg^{-1}) of the SOC in manured soil over the mineral N fertilized soil (2.05 Mg C ha^{-1} y^{-1}) (Table 1). However, similar to the findings of Gerzabek et al. [11], manure C input of 2.05 and 4.09 Mg C ha^{-1} y^{-1} in the M and 2M treatments increased SOC stock linearly over the control.

After aggregate fractionation on day 16, the SOC was highest in microaggregates, followed by large and small macroaggregates. This reflects the long-term C input by manure and by crop residues, which preferentially sequestered in microaggregates [20] because of higher biophysical and chemical protection compared to that in macroaggregates [17]. This also explains the low SOC content in small macroaggregates. A relatively high SOC content in large macroaggregates is connected with better occlusion of plant debris compared to small macroaggregates.

4.3. Effect of fertilization on microbial biomass C in soil aggregate fractions

Soil microorganisms play an important role in the formation and stabilization of aggregates [39] contributing to SOC accumulation. In turn, available SOC enhances microbial biomass [34]. Organic fertilization may increase the microbial availability of plant substances, e.g. sugars, proteins and cellulose [1] and increased MBC content by 70–150% of control soil (Fig. 4). Manure contains various forms of labile C (e.g. polysaccharides, amino acids, peptides) that can stimulate further growth of microbial biomass [27,35]. Moreover, the cumulative effect of long-term manure use can persist for several years after cessation [12] and had pronounced effect on microbial biomass [38]. This implies more (0.52 and 0.54% of SOC) MBC in manure-amended (M and 2M) versus mineral-fertilized (N) (0.44% of SOC) soil.

Adding K-polyacrylate had no influence on microbial biomass within 16 days. Soil microorganisms are unable to decompose polyacrylate polymers because of its low solubility [4] and the stability of the C–C backbone of polyacrylate polymers (approximately 10% $year^{-1}$) [36].

Similar to other studies [4,8], higher microbial biomass in micro- versus macroaggregates in control and mineral N fertilized soils was documented in the present study. However, contrasting results were also reported [14] and could reflect the differences in aggregate separation by wet and dry sieving. During fractionation some microorganisms may be transferred from the surfaces of larger to smaller aggregates (dry sieving) or adhere to aggregates during slaking in water (wet sieving) [3]. In contrast, the sieving at the moisture close to the lower plastic limit is less destructive [21] and yields a high recovery of microbial biomass [8]. In both manure-amended soils MBC was higher in large macroaggregates than in small macroaggregates and microaggregates (unlike control and N soils) (Fig. 4), reflecting the significant impacts of occluded organic C.

4.4. Long-term fertilization and aggregation effect on SOC decomposability

The soil incubation revealed a significant effect of fertilization on SOC mineralization. The CO_2 efflux rate was high for all fertilized and control soils just after rewetting [44]. In the first day of incubation, the CO_2 efflux was high (30–38 μg C g^{-1} d^{-1}) in fertilized soil and lower (19 μg C g^{-1} d^{-1}) in the control with the lowest SOC. The rapid CO_2 emission during the first 7–10 days originated mainly from the easily decomposable pools. The CO_2 evolution rate leveled off in all soils after 21 days of incubation. This is because the most labile pools were exhausted and the stable SOM pools were mineralized [10,43]. After 80 days the cumulative CO_2 emission corresponded to 3.2–4.7% of the SOC. This high decomposability of SOC was due to the low (5%) clay content in the soil. Clay-rich soils show usually lower CO_2 losses per unit of SOC [19].

The double exponential model (Eq. (1)) describes the decomposition rates of the labile (C_{lab}) and recalcitrant pools (C_{re}) of SOC. The similar models were widely applied to predict C mineralization of soil organic matter or plant materials [8,43]. The C_{lab} can reasonably be used as a sensitive indicator of soil respiration as affected by long-term managements. Microorganisms derive most of their energy from readily available SOC [34]. Therefore, C_{lab} was linearly correlated ($R^2 = 0.92$) with MBC. However, C_{lab} and the corresponding decomposition rate, k1 were high in the control soil. Fertilization (N, M and 2M) increased C_{lab} and decreased its decomposition significantly ($C > 2M > N > M$) (Table 3). The sizes of C_{re} as estimated by the double exponential model varied slightly amongst the four different soil types (Table 3). The average half-lives of C_{re} ranged from 93 to 190 days for these fertilized and control soils.

Adding K-polyacrylate to soil decreased k1 by 31–80% over the control without polyacrylate, even though polyacrylate had no direct effect on microbial activity or SOC decomposition. This decrease of k1 was due to a strong positive effect of polyacrylate on the formation of large macroaggregates. Macroaggregates reduced decomposability of SOC because occluded organics is protected against microbial attacks [16]. Manuring increased the small macroaggregate portion. As a result, k1 was deceased compared to N and control soil.

However, the high sand content failed to provide stability for large macroaggregates with N fertilization and manuring. In contrast, polyacrylate facilitated the formation of the large macroaggregates and significantly reduced the decomposition rate of the labile and non-labile pools of SOC. In conclusion this study revealed that short-term aggregation reduces SOC decomposition and thus facilitates C-retention in the experimental sandy soil. Moreover, as the other soil types may have different responses for short-term and long-term aggregation, it could be an interesting issue for future study.

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