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Manure Fertilization for Soil Organic Matter Maintenance and its Effects Upon Crops and the Environment, Evaluated in a Long-term Trial

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Introduction

Soil organic matter (SOM) content and turnover are regarded as important indicators of soil fertility. For crop production, it is of prime interest to know which immediately beneficial effects these indicators have on land use criteria such as crop yield, yield stability and environmental impact. The significance of well-developed soil biological characteristics for successful crop growth and yield is not quite clear, despite numerous studies on this issue. With manure fertilization, increased SOM contents have been observed in several field trials in central and Northern Europe, mostly carried out under site conditions very similar to ours (Asmus *et al.*, 1987; Asmus, 1992; Garz and Stumpe, 1992; Neméth and Tóth, 1992; Kätterer and Andrén, 1999). In some of these trials, crop yield and a variety of soil characteristics have been evaluated. Higher SOM contents have been found to have positive effects on yield and yield components of cereals (Görlitz and Asmus, 1984; Schnieder, 1984; Görlitz, 1986) as well as on soil density, pore volume and maximum water capacity (Asmus *et al.*, 1987). However, in a trial with generally high SOM contents (the lowest was 1.72% C), different humus contents had no significant effects on yield when optimum mineral fertilization was applied (Stumpe *et al.*, 1983).

The aim of the fertilization trial started at our institute in 1980 is to study the long-term effects of manure and mineral fertilization. In particular, the interplay of fertilization, soil fertility and crop yield is being investigated. The results of two crop rotation periods, i.e. the last 8 years,

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are reported here. Attention focuses on the question of whether there are fundamental differences between farmyard manure and mineral fertilization as regards soil fertility indicators, crop yield and the soil's function as a carbon sink or source.

Materials and Methods

A long-term field trial on a sandy orthic Luvisol with 590 mm precipitation per year and 9.5°C annual mean temperature is being carried out to compare three types of fertilizer: (i) composted farmyard manure (CFM); (ii) composted farmyard manure with application of all biodynamic preparations (CFMBD); and (iii) mineral fertilization (MIN, i.e. calcium ammonium nitrate, super phosphate and potassium magnesia). Production and use of the preparations were described by Steiner (1924) for the first time. Further details are given by, for instance, Koepf (1981). Each type of fertilizer is applied at three different levels, corresponding to a total nitrogen content of 60, 100 and 140 kg ha^{-1} N to wheat and rye and 50, 100 and 150 kg ha^{-1} N to potatoes. The nine treatments are implemented identically in four replicates on four fields with four different crops. This gives 36 plots in each of the four fields. Manure is applied before sowing or planting, mineral fertilizer is applied to spring wheat and potatoes before sowing and planting, and to winter rye in spring. To cereals, a part of the nitrogen amount in the medium and high fertilization treatments (20 and 40 kg ha^{-1} N) is applied during tillering as liquid manure in CFM and CFMBD or as calcium ammonium nitrate in MIN. The legume crop remains unfertilized in all treatments. The nutrient amounts applied yearly with the mineral and manure treatments are listed in Table 4.10.1.

Straw of the MIN plots remains on the field, but is removed from the CFM and CFMBD plots. Crop rotation is red clover (*Trifolium pratense* L.), alternatively Persian clover (*Trifolium resupinatum* L.), spring wheat (*Triticum aestivum* L.), potatoes (*Solanum tuberosum* L.) and winter rye (*Secale cereale* L.). The trial has been under way with this design since 1985/86. It started in 1980 with the aim of investigating the effects of fertilization on food quality (Abele, 1987). Therefore, from 1980 to 1984, the trial had the same treatments at a higher level of manure fertilization and a different crop rotation. Except for fertilization, all other elements of cultivation are the same in all treatments and follow normal organic farming practices. More details of the trial have been published earlier by Bachinger (1996) and by Raupp (1996).

Where statistical requirements were fulfilled, analyses of variance were calculated, taking type and level of fertilizer as fixed effects and replicates and years as random. In the tables, mean values of the main effects with different letters are significantly different ($P < 0.05$). The least significant difference (LSD) stated in Table 4.10.2 refers to the interaction between fertilization type and level ($P < 0.05$). With the yield results of different treatments, a bivariate correlation was calculated according to the method described by Sokal and Rohlf (1995).

Results and Discussion

SOM content in topsoil was found to be higher with manure than with mineral fertilization. Table 4.10.2 shows the latest available results of 1998, after 18 years of differentiated fertilization. The highest content was observed in the treatment with biodynamic preparations. This level is equivalent to the 1.05% C_{org} analysed by Abele (1987) with a mixed sample of each field at the beginning of the trial in 1980. Thus, only the organic fertilizer with biodynamic preparations was able to maintain SOM content until the present day; applying the same quantities of organic matter but

Table 4.10.1. Nutrient amounts (kg ha^{-1}) applied yearly with solid and liquid manure or mineral fertilizer (phosphorus, potassium and sulphur amounts in CFM and CFMBD are averages of 5 years; the other values are constant every year).

	Low				Medium				High			
Fertilization	N	P	K	S	N	P	K	S	N	P	K	S
CFM												
Solid	60	16	76	9	80	21	101	12	100	26	126	15
Liquid	0	0	0		20	1	33		40	2	66	
CFMBD												
Solid	60	17	81	9	80	23	108	11	100	29	135	14
Liquid	0	0	0		20	1	32		40	2	65	
MIN	60	50	75	73	100	75	100	102	140	100	125	132

Table 4.10.2. Organic carbon content (% dry matter) in topsoil after 18 years of manure or mineral fertilization (mean values of four fields in 1998).

Fertilization	CFM	CFMBD	MIN	Average
Low	0.83	0.95	0.79	0.86[a]
Medium	0.93	0.99	0.79	0.90[b]
High	0.98	1.07	0.80	0.95[c]
Average	0.91[b]	1.00[c]	0.79[a]	LSD_{05} = 0.05

[a,b,c]Mean value of either type or level of fertilization with different superscript letters are significantly different ($P < 0.05$).

omitting the preparations gave lower C_{org} values. The effect of fertilization levels depends significantly upon their type. Whereas increasing amounts of mineral fertilizer had no effect upon SOM content, higher levels of manure fertilization preserved higher organic carbon contents. C_{org} differentiation set in during the first years of the trial between 1980 and 1983/84 (values presented by Bachinger, 1996). In all treatments, C_{org} levels have now been fairly constant for > 10 years.

Bachinger (1996) investigated soil microbial parameters in 1988–1991. As an example, the results of 1989 are shown in Table 4.10.3. The treatments with high and constant humus values also had the higher biological activity. Protease and dehydrogenase activity as well as microbial biomass (chloroform fumigation extraction) were more pronounced in the manure than in the mineral treatments. A further study found higher amino acid contents in the manure compared with the mineral treatments (Scheller *et al.*, 1997). This is an indication of the important role of farmyard manure and amino acids for humus synthesis.

Crop yield (Table 4.10.4) did not show the same pattern as soil parameters. Whereas spring wheat gave the same yield with all types of fertilizer, winter rye had 33% and potatoes 10% higher yields with mineral than with

Table 4.10.3. Averages of soil microbiological parameters in topsoil by type and level of fertilization; results of 1989 (Bachinger, 1996).

Fertilization	CFM	CFMBD	MIN	Low	Medium	High
PA[1]	0.27^b	0.26^b	0.20^a	0.25^a	0.25^a	0.23^a
C_{mic}[2]	34.9^b	37.8^b	26.1^a	30.6^a	34.1^a	34.2^a
DHA[3]	109.1^b	121.9^c	75.9^a	94.5^a	103.8^a	108.6^a

[a,b,c]Mean values within a half-row with superscript different letters are significantly different ($P < 0.05$).
[1]Protease activity (mg g^{-1} Tyr); method of Ladd and Butler (1972).
[2]Microbial biomass (SIR; mg 100 g^{-1} C); method of Anderson and Domsch (1978).
[3]Dehydrogenase activity (µg 10 g^{-1} TPF); method of Thalmann (1967).

Table 4.10.4. Crop yield (dt ha^{-1}) by type and level of fertilization, averages of the 1992–1995 and 1996–1999 crop rotation periods.

Fertilization	CFM	CFMBD	MIN	Low	Medium	High
Winter rye	28.3^a	29.8^a	37.7^b	28.1^a	31.7^b	36.1^c
Spring wheat	38.9	39.3	41.0	36.8^a	40.2^b	42.2^c
Potatoes	247^a	262^b	271^b	230^a	262^b	288^c

[a,b,c]Mean values within a half-row with different superscript letters are significantly different ($P < 0.05$).

manure fertilization, compared with CFM. The biodynamic preparations increased potato yields by 15 dt ha^{-1} (6%) on average over all years. Higher levels of fertilization influenced yields positively with all crops. Basically, the yields reflect the specific nitrogen demand of each crop at various growth stages in combination with the different nutrient availability of organic or mineral fertilizer in those stages. Spring wheat, cultivated in the year after the legume crop, generally may have the benefit of a favourable position in the crop rotation. This may explain why there was no yield difference between manure and mineral fertilization.

The yields of all crops are not very high and varied considerably from year to year, most likely because of the extreme site conditions: a sandy soil and dry-warm climate with drought from May to July in most years. Irrigation is possible, but only at low levels of 20–60 mm $year^{-1}$ because of the limited capacity of our equipment. In cereals, the occurrence of weeds depended on fertilization, but did not explain the yield differences between treatments (Raupp *et al.*, 1998). Severe pest or disease problems only arise with potato late blight in some years, causing more severe infestation in mineral treatments, and by colorado beetle. In spring wheat, yield stability, i.e. fluctuation over the years, differed between organic and mineral fertilization. Figure 4.10.1 shows the correlation between the yields of the mineral and manure treatments (in both cases at a high fertilization level) over the last 14 years. If the yield difference is the same over the entire yield range, the slope of the major axis of the ellipse should be at 45°, i.e. not significantly different from 1. However, the slope is < 1 for the medium and high fertilization level ($P < 0.05$; Table 4.10.5). Thus, under good growth conditions, minerally fertilized wheat yielded more than manure fertilized wheat. However, yield declined much more in years of poor conditions. In these years, the plant–soil system with manure fertilization seems to be able

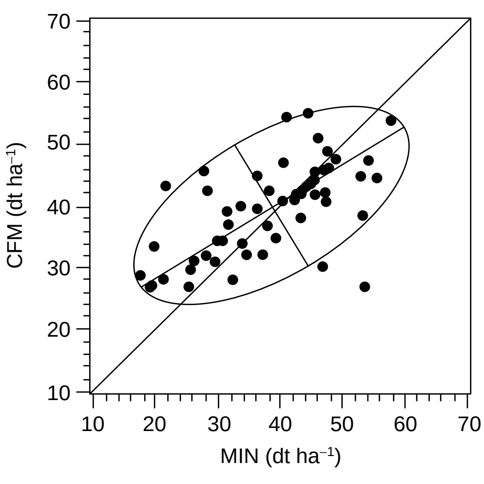

Fig. 4.10.1. Bivariate correlation between spring wheat yields with the high level of mineral fertilization and of composted farmyard manure (results of four replicates and 14 years, $n = 55$; confidence ellipse for $P < 0.05$).

Table 4.10.5. Bivariate correlation between spring wheat yields with composted farmyard manure (Y1) and mineral fertilization (Y2) at three fertilization levels; results of four replicates and 14 years, $n = 55$ ($P < 0.05$).

Fertilization	Major axis regression	Confidence limits for the slope b
Low	Y1 = 5.786 + 0.815 Y2	0.596 < b < 1.092
Medium	Y1 = 16.925 + 0.550 Y2	0.333 < b < 0.816
High	Y1 = 15.956 + 0.620 Y2	0.416 < b < 0.868

to compensate for poor environmental conditions and yielded up to 10 dt ha^{-1} more than the mineral treatments. Possible compensation mechanisms may include increased root growth with manure fertilization (reported by Bachinger, 1996 for CFMBD) or modified morphological characteristics and yield components (studied by Boemer-Schulte, 1992 in this trial).

With respect to global climate change, currently there is a debate on whether soils can be either a source or a sink of atmospheric carbon dioxide (IPCC, 1996; GACGC, 1998). The issue of which conditions can switch a source to a sink and vice versa is of special interest. A recent study in the USA reported that SOM is increased by organic farming methods (Drinkwater *et al.*, 1998). The authors describe organically managed soils as a substantial carbon sink for carbon dioxide from the atmosphere. The manure treatments in our trial contain 3.6–8.4 t ha^{-1} more carbon in the topsoil than the corresponding minerally fertilized plots. These differences are several times higher than those reported in the USA study. However, in contrast to the American experiment, the C_{org} differences in our trial are the outcome of varying degrees of reduction, not of humus accumulation. Even the soil fertilized with farmyard manure was a carbon source, though to a much lesser extent than the minerally fertilized soil. Carbon losses could only be avoided when farmyard manure application was combined with the biodynamic preparations. Probably the effect of a treatment depends upon the pre-history of the soil. We intend to investigate this matter in more detail, although its relevance to the atmospheric carbon dioxide budget is limited.

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