Effects of increasing fertilization in organic farming fodder cultivation and market crop systems

Results from long-term field trials on different soil and climatic conditions in eastern Germany

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Abstract

In 1992 on experimental stations of the Saxony State Institute of Agriculture two organic field trials were set up on loamy sand and a loess loam in western Saxony, eastern Germany. In these long-term field trials questions of fodder cultivation and market crop systems, crop rotations with legume-grass, wheat and maize, different organic fertilizer regimes and nutrient cycling were analyzed regarding their effects on soil fertility, yield and quality of the plant products. The main results and conclusions of the first nine years of these organic field trials are introduced and summarized here.

Keywords: organic farming, fodder cultivation system, market crop system, legume-grass, wheat, maize, organic manure, soil fertility, nutrient dynamics, yield, plant product quality, environmental effects

Introduction

In the early 1990s, an increasing proportion of organic farms (Anon., 1991) with few or no livestock were established in eastern Germany. The lack of experience in this field resulted in management problems concerning these cultivation systems (Stolze, 1997; Rahmann *et al.*, 2004). It was therefore decided to start complex long-term field trials, in which fodder cultivation and market crop systems including different organic fertilizer intensities as used in organic practice were analyzed regarding their short- and long-term effects on soil fertility, yield and quality of the harvested products and the environment. Later on, questions of crop rotation and nutrient cycling as well as trace gas dynamics became important given the upcoming changing climatic conditions. The aim of these trials is to establish and demonstrate optimum, environmentally sustainable methods of organic crop production for direct practical use.

Site conditions and experimental design

The trials were set up on experimental field stations of the Saxony State Institute of Agriculture (Sächsische Landesanstalt für Landwirtschaft) in 1992. The Spröda site (about 51°35’N, 12°25’E) is in the north of the city of Leipzig, 120m above sea level. It consists of a flat area on an Albic Luvisol of loamy sand (Sl) with 6% clay. The climatic situation is dry and warm with precipitation of 547 mm a^{-1} and a mean temperature of 8.8°C (in 1994–99: just 368mm and 9.9°C, resp.). The Methau site (about 51°05’N, 12°50’E) is in the south-east of Leipzig. It is 265m above sea level and is a flat-hilly area with a Gleyic Luvisol soil of loam (L) containing 15% clay. The weather conditions are moderately dry and moderately warm with 693mm precipitation (1994–99: 662mm) and a temperature of 8.4°C (8.8°C).

The trials were set up on formerly conventionally cultivated arable land in a four-factorial split-plot design with 4 replications. The large plots represent the fodder cultivation system (legume-grasses and crop residues including straw were harvested) and the market crop system (legume-grasses were used for mulching or green manuring; crop residues remained on the field). The medium-sized plots contain the fertilizer types (cattle stable manure + liquid manure, cattle slurry, legume-grass mulch application, mineral N fertilization) and the fertilizer amounts (0–2 manure-units, MU, 1 MU = 80 kg N_t ha^{-1} a^{-1}, 1 manure unit is defined as the number of livestock needed to produce enough manure to meet the nitrogen requirements of 1 ha of crop land) and the small plots represent additional cultivation methods (different row spacing, and with and without liquid manure incorporation).

In the fodder cultivation system, the fertilizer regimes with four treatment levels of stable manure and of slurry (0, 0.5, 1 and 2 MU ha^{-1} a^{-1}) and 1 treatment with optimum mineral N fertilization were realized on both locations. In the market crop system of the Spröda site, four treatment levels were established with mulch and slurry, four levels were established with stable manure and mulch at the Methau site, and 1 treatment with optimum conventional N fertilization was established at each location and cultivation system. Because of common use in organic practice in the market crop systems also stable manure and slurry regimes were established.

The overview of factorial and treatment design is as follows:

- A – cultivation system
  - 1 – fodder cultivation system
  - 2 – market crop system
- B – fertilizer type
  - 0 – without
  - 1 – cattle stable manure + liquid manure
  - 2 – cattle slurry
  - 3 – legume-grass mulch
  - 4 – mineral N
- C – fertilizer level
  - 0 – optimal mineral N fertilization
  - 1 – 0.0 DU ha^{-1} a^{-1}
  - 2 – 0.5 DU ha^{-1} a^{-1}
  - 3 – 1.0 DU ha^{-1} a^{-1}
  - 4 – 2.0 DU ha^{-1} a^{-1}
- D – additional cultivation method
  - 1 – small row spacing, without liquid manure incorporation
  - 2 – large row spacing, without liquid manure incorporation
  - 3 – large row spacing, with liquid manure incorporation.

The crop rotation with main and catch crops has changed with time. The basic rotation course is two years of legume-grass (*Trifolium pratense, Medicago sativa, Festuca pratensis, Phleum pratense, Lolium perenne*), one year of spring wheat (*Triticum aestivum*) and one year of silage and grain maize (*Zea mays*). Fertilizer application is based on the N_t content of the manure, and the amounts actually applied are somewhat different from those intended (see Beckmann *et al*., 2001). The mineral N fertilization of the conventional treatment is performed with calcium ammonium nitrate using model-calculated amounts as used in conventional practice (after Förster *et al*., 1997).

Because of the complex character of the trial objectives discriminant analyses were chosen for statistical analysis (Table 1). Detailed information about the site conditions, the experimental design, the crop rotation, the applied fertilizer amounts of the crop species, the analytical methods and the statistical analyses are reported by Beckmann *et al*. (2001). The methods used for trace gas measurements are given by Model (2004).

Table 1: Results of the stepwise discriminant analysis of the trials

Variables	Standardized discriminant function coefficients (%)			
	Location	Cultivation system	Fertilizer type	Fertilizer level
N_{min} (spring)	7.7	1.8	-	4.6
N_{min} (autumn)	1.9	-	10.7	5.6
Net mineralization (autumn – spring)	2.3	24.6	10.1	12.8
Net mineralization (spring – autumn)	-	1.6	8.0	8.6
N_{min} (positive sum)	3.7	4.7	10.3	8.8
N_{min} (negative sum)	4.0	-	15.8	3.3
N fixation	1.4	10.0	-	-
N input (total)	2.6	-	-	-
N removal	19.9	4.8	-	13.8
N surplus	-	22.3	-	2.7
N crop yield	21.5	4.0	-	8.7
DM growth (per 100 kg N uptake)	8.2	5.3	8.3	-
DM legume-grass	4.6	0.8	6.8	-
DM spring wheat	3.2	1.3	3.9	4.3
DM maize	2.5	2.6	2.8	4.3
N content (legume grass)	2.9	0.5	4.9	3.7
N content (spring wheat)	5.8	7.9	10.4	8.0
N content (maize)	4.5	3.9	6.7	4.4
Falling number (wheat)	0.4	0.9	5.3	3.4
Net energy lactation (maize)	1.0	1.2	-	-
C_{org} (soil)	1.1	1.7	1.9	3.1
N_t (soil)	0.6	0.3	4.1	-

F value matrix of groups	Location	System	Type	Level
	Methau Spröda 1084***	1 2 217***	1/3 2 2 17.2** 4 22.2*** 24.6***	1 2 3 2 215** 3 852*** 328** 4 3003*** 2464*** 1012***

- = variables excluded; * = p 0.05, ** = p 0.01, *** = p 0.001

Key results and discussion

Soils and environment

The spring (March) and autumn (September – October) N_{min} levels (soluble NO_3-N + NH_4-N, 0–90 cm soil depth) during crop cultivation are shown in Figures 1 and 2 (statistical analysis, see Table 1). The highest N_{min} values were found for the cropping position after ploughing in the legume-grass. Similar results were also given by Hess (1989) and Schmidt (1997). The following rotational sequences were characterized by gradually lower N_{min} levels followed by the lowest N_{min} values of the soils with the repeated cultivation of a two-year legume-grass. A characteristic course of the N_{min} levels, which can be regarded as a typical sign of potential crop productivity, was established from these results, helping to design a colour scheme for use in organic farming practical crop rotation arrangements (Kolbe, 1998, 2006a).

The quantities of N losses through soil removal and leaching processes were substantially higher in the mineral N plots than in all other organic fertilizer regimes, as can be derived from Figure 3. In addition, even the elevated N input values of high fertilizer amounts and the high input and low N removal values of the market crop system only led to slight differences in the N removal and leaching potential of the soils (Figure 3, Table 2). The simultaneous application of N and organic matter through manuring seems to be important for interpreting these results (Kolbe, 2004). These favourable environmental aspects especially valid for the dry climatic conditions in eastern Germany can be regarded as another basic result for effects of increasing fertilizer inputs within the allowable range of organic agriculture. These results were supported on organic farms, where relatively low N_{min} contents after harvest, and low leaching and surplus amounts from N budget calculations were reported (Kolbe *et al.*, 1999a; Kolbe, 2000; Hege *et al.*, 2003; Menge, 2005).

It should be mentioned that the very high N surplus amounts of the market crop regimes of the trials were caused by difficulties in calculating the correct N amounts, because the reduced N fixation potential of the legumes and the N losses through ammonium volatilization were not exactly known (Beckmann *et al*., 2002). No significant different N budgets were calculated between the fertilizer types (see Table 1). Influences on yields as well as on N budgets and efficiency rates are reported in more detail in Kolbe *et al.* (1999a) and Beckmann *et al*. (2001).

Although additional mineral P, K, Mg and Ca treatments were not carried out during the whole trial period, the development of these elements is of special importance (Figure 4). The pH values did not changed much since the start of the trial. However, especially in the market crop systems, the DL-soluble K and the $CaCl_2$-soluble Mg values decreased in lower rates, and in Spröda the DL-soluble P values already increased. The main factor of these differences was the less pronounced element removal values through legume-grass mulching instead of material cut and take off in the fodder cultivation system. In addition, the increasing manure input also led to levelled soluble elements in the ranges of up to 3 mg P or K and 2 mg Mg 100^{-1} g^{-1} of the soil.

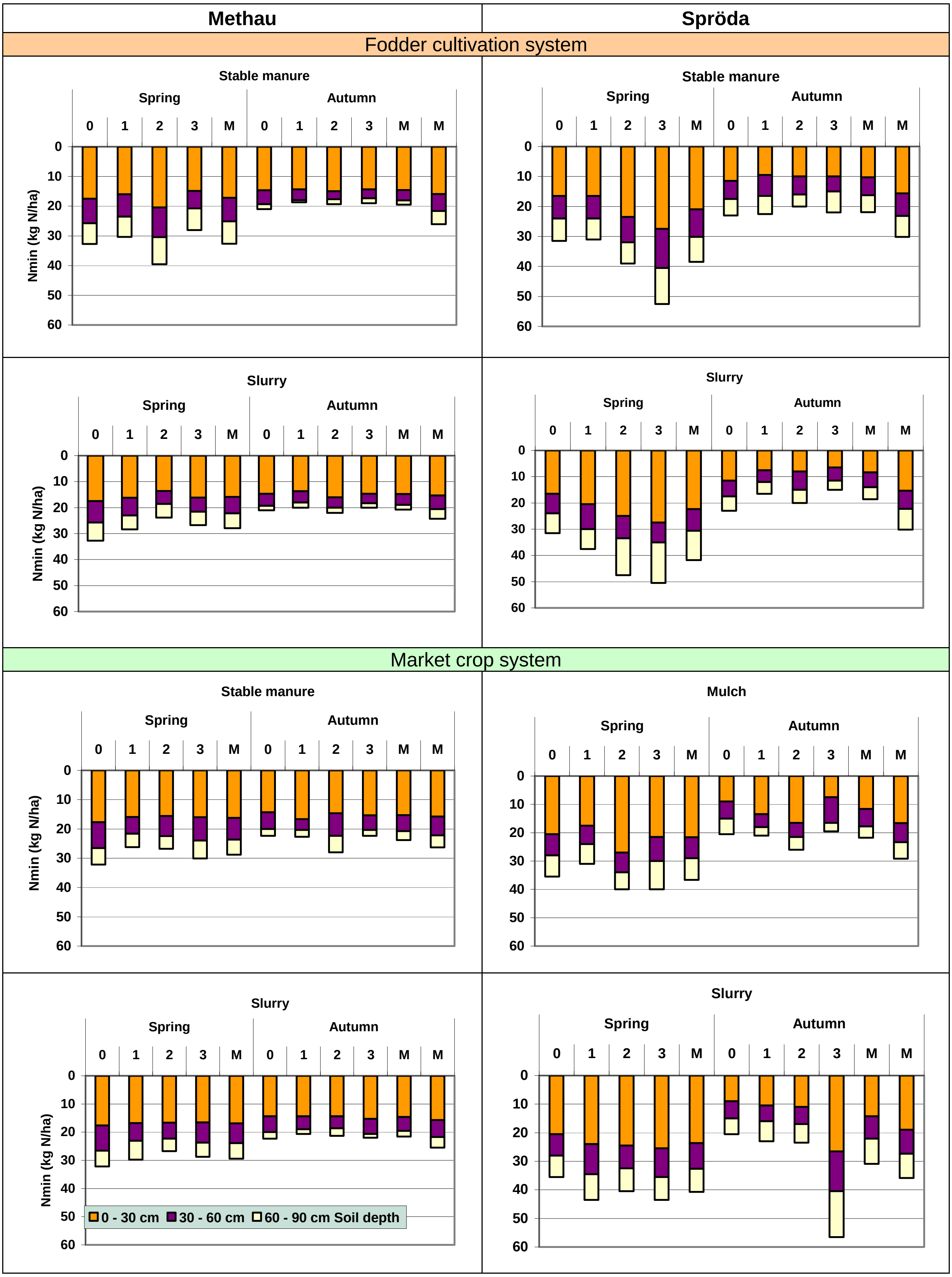

Figure 1: Effects of location, cropping system and organic fertilizer application on the N_{min} content (0–90 cm soil depth) in spring and autumn under legume-grass cultivation (0 = 0.0, 1 = 0.5, 2 = 1.0, 3 = 2.0 MU $ha^{-1}a^{-1}$; M = mean value)

Figure 2: Effects of location, cropping system and increasing organic fertilizer treatment on the N_{min} content in spring and autumn under two years of spring wheat and maize cultivation (0 = 0.0, 1 = 0.5, 2 = 1.0, 3 = 2.0 MU $ha^{-1}a^{-1}$; M = mean value)

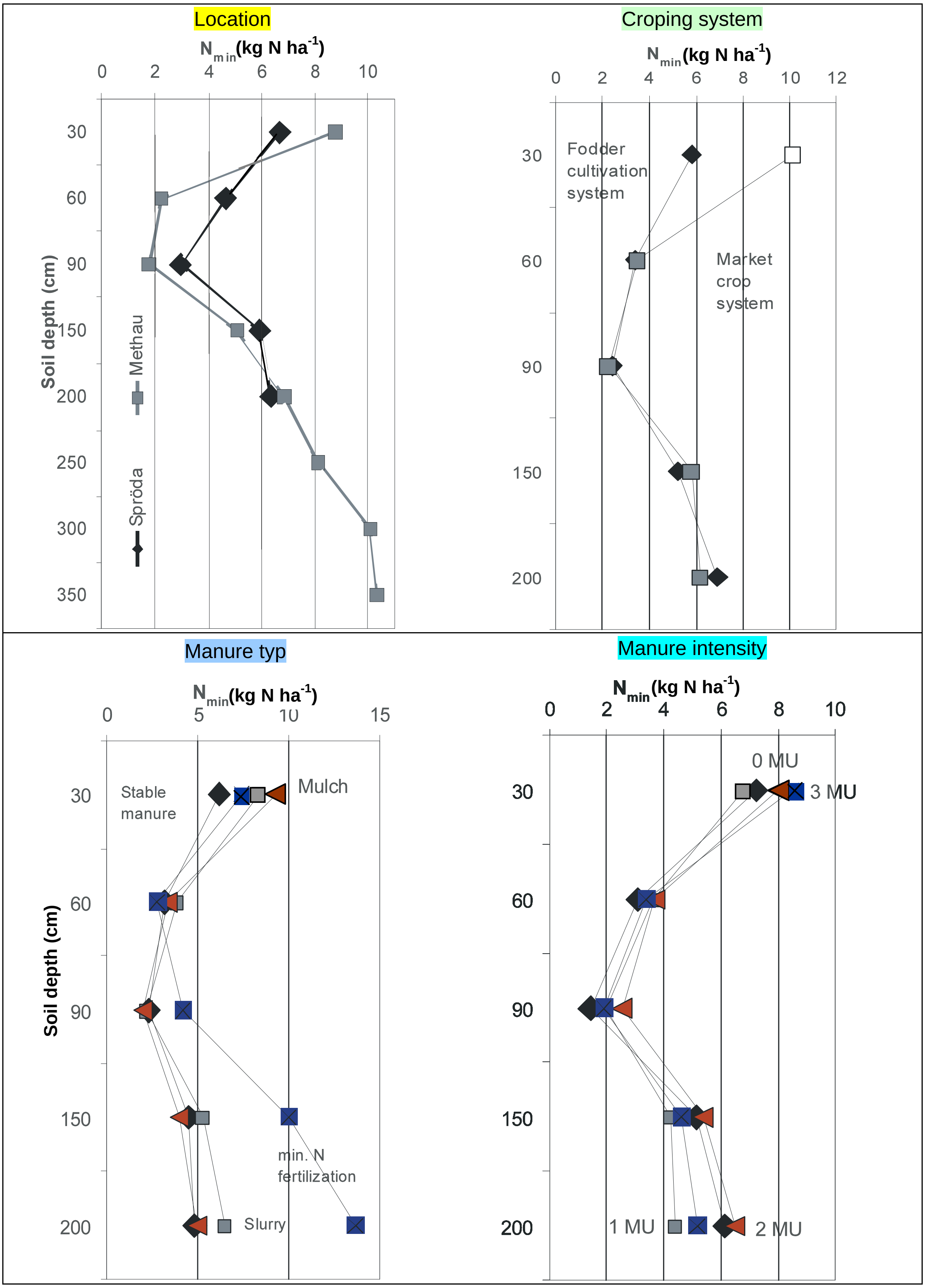

Figure 3: Effects of location, cropping system, fertilizer type and fertilizer treatment level on the N_{min} contents in the soil depth profile in autumn/winter 2000/2001 (0 = 0.0, 1 = 0.5, 2 = 1.0, 3 = 2.0 MU $ha^{-1}a^{-1}$; M = mean value)

Table 2: Measured N budgets for the effects of cultivation system and organic fertilizer treatment levels (mean location values)

Cropping system Manure treatment (1993 - 1999)	Legume N fixation[1]	Input[2]	Removal	Surplus	N efficiency
	(kg N ha^{-1})				(Input = 100 %)
Fodder cultivation system	53.7	151.2	162.4	-11.2	107.4
Market crop system	43.3	221.5	120.7	100.8	54.5
0.0 MU	48.7	100.4	121.6	-21.2	121.1
0.5 MU	48.5	138.1	124.3	13.9	90.0
1.0 MU	48.5	171.3	126.7	44.6	74.0
2.0 MU	49.0	221.1	131.9	89.2	59.7

[1] = model calculated (Förster et al., 1997)
[2] = inclusive measured N deposition (Spröda = 30 kg, Methau = 45 kg N ha^{-1} a^{-1})

Also Oehl *et al.* (2002) and others reported, that the P contents of the soil will change according to the input of organic manures in an organic long-term trial in the Switzerland. The organic P content of the soil was increased and the P dynamic was changed in the long run. The organic P fraction of the soils is not contained and recorded by the usual soil analysis for plant available nutrients. From P budget calculations could be derived the result, that the soluble P concentrations of the soils will be leveled down, when the P budgets change to negative values (see Schulte, 1996; Quirin, 2004). Finally, from concluding remarks of these observations and special evaluations of long-term trials a base fertilizing method was built up for use in organic agricultural practice (Kolbe *et al.*, 1999b).

The change in organic matter is known to be relatively slow, with high dispersion from year to year. Therefore, these trial data are given as mean values between the two locations (Figure 5). After nine years of fertilizer application, a significant increase in the C_{org} levels and the C/N ratios of the soil were to be observed in high organic matter input treatments. Increasing organic matter contents and, over this, elevated microbial biomass amounts could be measured in other organic long-term trials as a result of the steadily organic matter input (Anon., 1995; Raupp, 2001; Mäder *et al.*, 2002; Köpke *et al.*, 2006). Higher organic matter concentrations were also analyzed from organic compared to conventional cultivated farm land (Capriel, 2006).

Although the DM input in the market system of the trials was higher, because of the high organic matter application in these plots through the mulch materials, the pure market system treatments without any additional fertilizer application lead to a decreased C_{org} content, especially in the Spröda trials on sandy soils (Beckmann *et al.*, 2002; see also Figure 5). These results were interpreted in connection with specific effects of high amounts of easily soluble organic matter incorporation, which may have initiated a large so-called priming effect. These results seem to be of high importance for maintaining the soil fertility of stockless farming and also for (conventional) mulching systems with large dissemination. Because such observations under field conditions are very rare in the literature, these results will have to be proven through further observations.

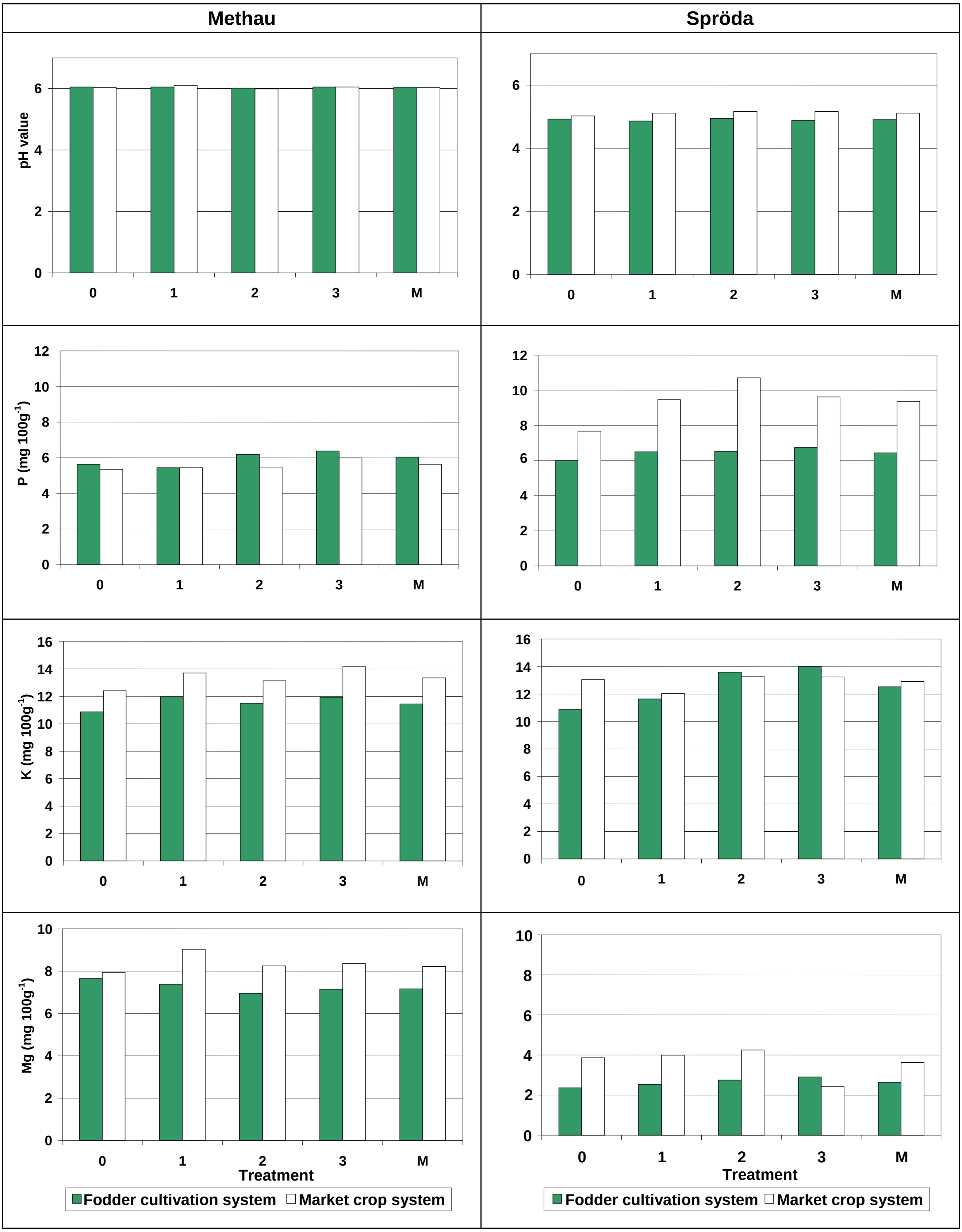

Figure 4: Effects of location, cropping system and the fertilizer treatment levels on pH values, and the soluble P, K and Mg levels of the soil (0 – 20 cm) after 9 trial years (0 = 0.0, 1 = 0.5, 2 = 1.0, 3 = 2.0 MU ha^{-1}a^{-1}; M = mean value, 1992 Methau: 6.2 pH, 6.6 mg 100g^{-1} P, 15.5 mg 100g^{-1} K, 9.6 mg 100g^{-1} Mg; 1992 Spröda: 5.1 pH, 7.4 mg 100g^{-1} P, 16.2 mg 100g^{-1} K, 4.7 mg 100g^{-1} Mg)

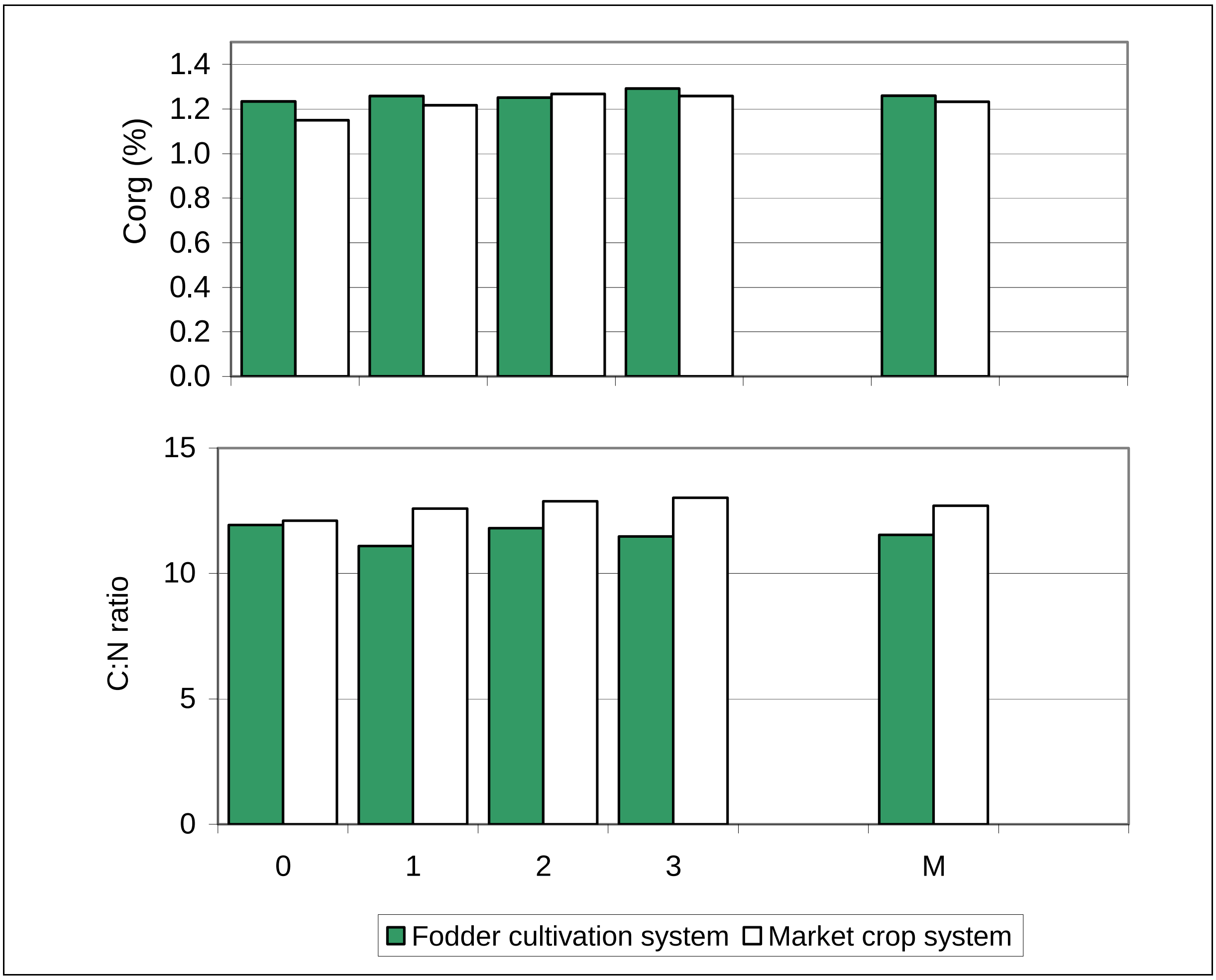

Figure 5: Effects of cropping systems and increasing organic fertilizer treatment on the mean location C_{org} levels and the C/N ratios of the soil (0 – 20 cm) after 9 trial years (0 = 0.0, 1 = 0.5, 2 = 1.0, 3 = 2.0 MU $ha^{-1}a^{-1}$; M = mean value; 1992: 1.3 % C_{org}, 11.8 C:N ratio)

At the Spröda site, tests were carried out from 1997 until 1999 to measure N_2O, CO_2, CH_4 and NH_4 trace gas fluxes and to test liquid fertilizer application methods. Detailed results are presented by Beckmann *et al*. (2002), Model *et al*. (1999, 2003, 2004) and Model (2004). Highly fluctuating rates of N_2O and CO_2 emissions were measured throughout the crop rotation (results not shown). Short periods of high emissions appeared depending on the actual weather conditions after fertilizer application and after the ploughing-in of legume-grasses. At mean seasonal values, the market crop systems showed somewhat higher emissions than the fodder cultivation system (Table 3). Between 1 kg and 2 kg N_2O-N emissions was related to 100 kg ha^{-1} N_t input. Altogether, the CO_2 uptake through plant and soil organic matter incorporation was much higher than the emissions (Model, 2004). CH_4 emissions were only measured in very short periods after liquid manure application (from manure storage). Altogether, the cultivation systems showed relatively high CH_4 uptake rates throughout the crop rotation, especially the fodder crop system. Compared with conventional farming conditions, the N_2O and CO_2 emissions were relatively low and the CH_4 uptake appeared relatively high (Model, 2004; Jungkunst *et al.*, 2006). Up to now, measurements of trace gas emissions from organic field plots are very rare.

Table 3: Trace gas fluxes throughout the years 1997 – 99 in the fodder cultivation and market crop system of the Spröda site (Model, 2004)

		Summer half-year 1997	Winter half-year 1997/98	Summer half-year 1998	Winter half-year 1998/99	Summer half-year 1999	Mean values year^{-1}
CO_2-C (kg ha^{-1} a^{-1})	Fodder cultivation system	17500	5400	12900	5300	10300	9907
	Market crop system	18500	6200	15100	4000	10000	10505
N_2O-N (kg ha^{-1} a^{-1})	Fodder cultivation system	0.9	2.1	2.7	0.4	4.2	2.2
	Market crop system	1.4	1.7	2.7	0.4	6.2	2.5
CH_4-C (kg ha^{-1} a^{-1})	Fodder cultivation system	1.2	1.5	1.1	0.2	0.5	1.0
	Market crop system	1.0	0.9	1.1	0.3	0.7	0.9

Crops

For better comparison in the following figures, the crop yields are shown in grain equivalents (GE of DM) as mean values of the crop rotations for the first nine trial years. While the organic fertilizer treatment levels were extremely different, no significant differences are to be observed between the yields of the not directly fertilized legume-grass (Figure 6, Table 1). Increasing fertilization systems only led to slight decreases in the mean GE yields (mean value between 470–510 dt FM, 80–100 dt DM). This trend was paralleled by a decrease in the N content of the legume-grass crop from 2.91% without organic fertilization and 2.80% with 2 MU ha^{-1} of fertilization, possibly due to a decrease in the legume content of the standing crop (Beckmann *et al.*, 2002), while in addition only slight differences in the N_{min} level of the soils in spring and autumn were measured (see Figure 1).

For the wheat and maize crops following the legumes, the mean yields between the two locations were different. Because of the very low precipitation, the mean grain yield of wheat was 17.1 dt ha^{-1} while that of maize was 69 dt DM ha^{-1} at Spröda, the figures for Methau being 45.1 dt wheat grain and 186 dt DM maize yield. These observations were similar to crop yields on other organic long-term field trials on a sandy soil and on a loam (chernozem) under comparable dry conditions (Zimmer & Dittmann, 2004; Koch, 2006).

Therefore, these results of the first rotations of the trials were intended to optimize strategies for crop rotations geared to the changing climatic conditions of eastern Germany (Beckmann *et al.*, 2002). Mainly due to the distinctly dry conditions of the spring and early summer, the crop rotation periods originally planned for the trials were changed by the cultivation of winter cereals (wheat, triticale) instead of spring wheat.

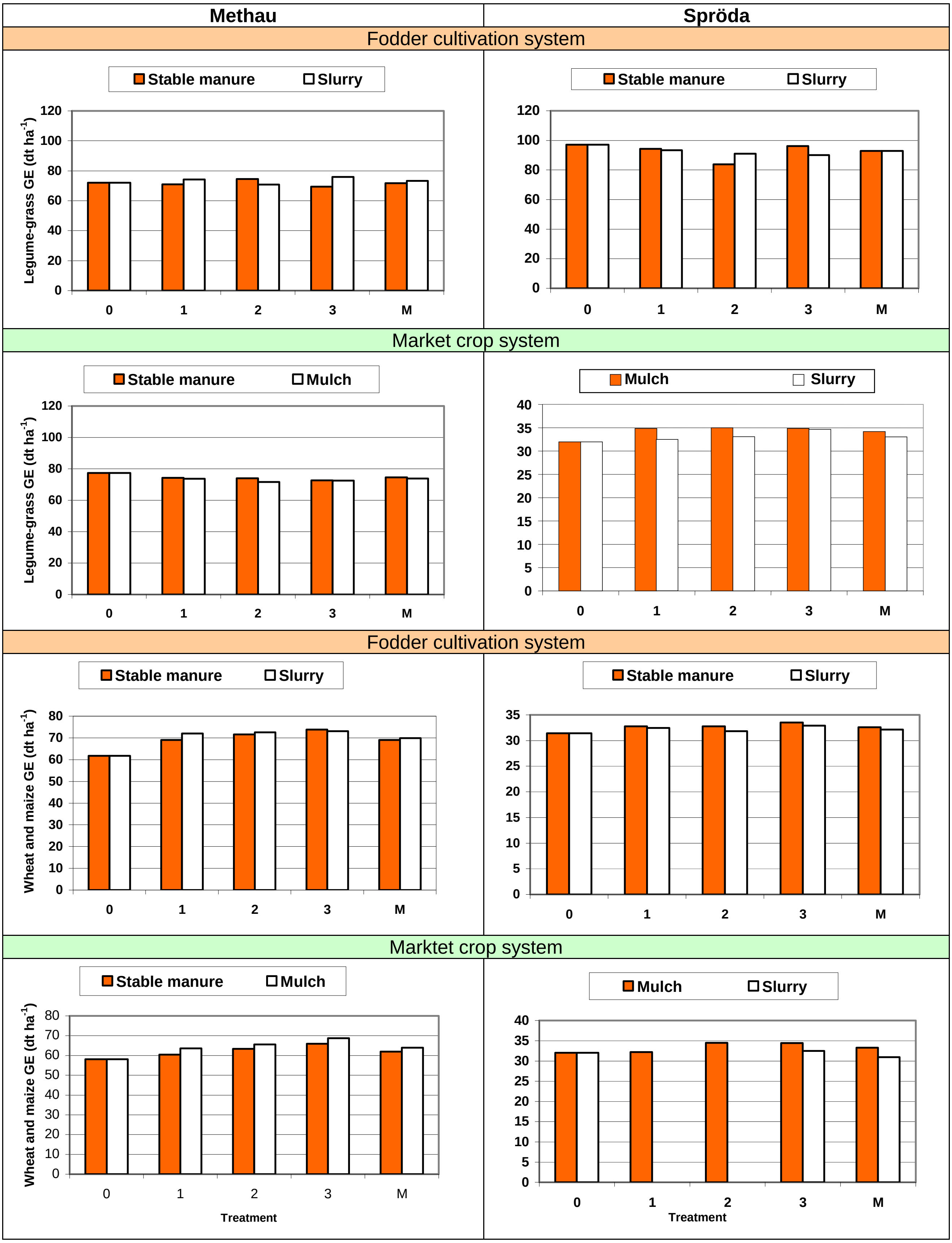

Figure 6: Effects of location, cropping system and organic fertilizer treatment (0 = 0.0, 1 = 0.5, 2 = 1.0, 3 = 2.0 MU $ha^{-1}a^{-1}$; M = mean value) on grain equivalent (GE) yields of three years of legume-grass and mean values for two years of wheat grain and two years of maize production

At Spröda, the different manure treatments were followed by a significant but slight yield increase of 0–5 dt GE ha^{-1} (Figure 6, Table 1). The mineralization of the organic manures may have been low in spring and no differences were noticed between the fertilizer types. As a result of the dry seasons, reduced plant growth and hence relatively high N_{min} levels were measured after harvest (see Figure 2), the increase in the soil organic matter content being higher in Spröda than Methau (Beckmann *et al*., 2001). For to improve nutrient efficiency these results also had implications for future dry season management strategies for organic agricultural systems with different organic fertilization regimes and in relation to favourable methods of irrigation.

Compared without manure treatment at Methau, the yield increase was about 10 dt GE ha^{-1} with 2 MU ha^{-1} a^{-1} (Figure 6, Table 1). In these first trial periods, no clear differences in the yield effects emerged between the fertilizer types. Related to the differing developments in the soil organic matter levels, the yield effects between stable manure and slurry application systems proved to be of higher significance in the later periods of the trials. Slurry gave a more direct yield increase while the stable manure led via increased organic matter levels in the soil to a higher crop yield (Beckmann *et al*., 2002; Kolbe, 2007). Which of these strategies is more sustainable in the long run will be of future interest.

The main conclusion to be drawn from these trials and from the literature was that legume-grasses show a high degree of adaptation to changing conditions, which had consequences for the efficiency of the whole system, including the resulting environmental effects. Accordingly, on systems with low manure additions and relatively low available nitrogen (N_{min}) in the soils, a higher production potential could be concluded for legumes, including nitrogen fixation, the release of nitrogen and the yields of the following crops. On highly fertilized systems, decreased legume production potential was noted with possibly lower rates of nitrogen fixation (see Schmidtke & Rauber, 2000; Beckmann *et al*., 2002; Kolbe, 2004; Rasmussen *et al*., 2006).

Extremely important results were also provided by the calculated mean yield values between fodder cultivation and the market crop system of the trials. A significant decrease in grain yield of about 5 dt ha^{-1} and in maize of about 9 dt DM ha^{-1} compared to the fodder cultivation system appeared very surprising because of the substantially higher N inputs of the mulched legume-grass in the market crop system (see Table 2). Further evaluations indicated a number of causes (Beckmann *et al*., 2002; Kolbe *et al*., 2003; Heuwinkel c*it. in* Schmidt, 2003): mulching led to lower legume proportions and lower nitrogen fixation rates and, hence, also to N losses through ammonium volatilization in the mulched materials. Altogether, these effects led to higher potential N losses through the market crop system, indicated by the higher N surplus in Table 2. In addition, the application of the straw from wheat and grain maize with their high C/N ratios resulted in higher soil N fixation, an increase in the soil C/N ratio and unfavourable N_{min} levels in these stockless systems (Figures 2 and 5).

These basic results were a great help for working out and understanding some main problems of stockless farming, including their economic consequences, enabling specific tasks for future research to be identified. The trials were set up with the aim of strengthening market crop systems by mulching the legume-grasses. These hypotheses had to be refuted, and the specific intentions for managing stockless arable systems were changing in a steady process of feedback between this advancing knowledge and agricultural practice (Schmidt, 2003).

Increased usage of fertilizer also led to higher N contents of wheat grain and maize, especially with slurry and mulch fertilization. However, the mean increase was only 0.2% N through the organic fertilizer regimes (results not shown). Therefore, the possibilities of increasing the N contents of the plant products (e.g. to improve baking quality) by using these basic fertilization strategies were relatively low (see also Anon., 1995; Raupp, 1998). Using mulch or slurry application strategies as top dressings including injection methods seems to be more successful (Beckmann *et al*., 2002). An increase in the N content and, at the other end of the scale, a significant low DM growth per unit of N uptake was realized with mineral N fertilization (Figure 7, Table 1). The DM growth of the crops and also the specific nitrogen recovery rate were therefore higher through organic fertilizer regimes.

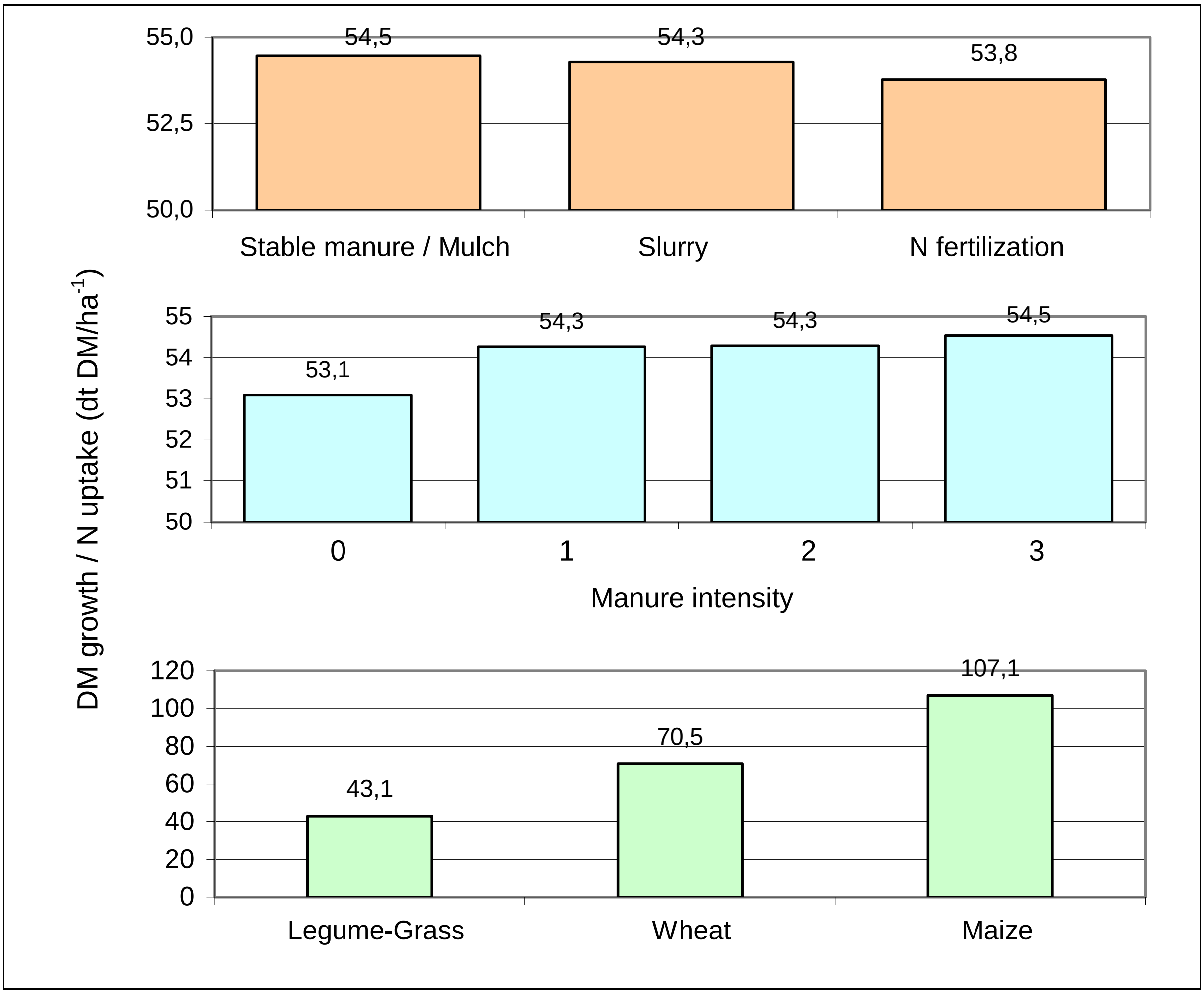

Figure 7: Effects of fertilizer type and fertilizer application rates on the ratios between mean N uptake and DM growth of the crops (mean location values; 0 = 0.0, 1 = 0.5, 2 = 1.0, 3 = 2.0 MU $ha^{-1}a^{-1}$)

Conclusion

The two long-term trials were set up to test main hypotheses for important forms of organic farming under the specific soil and climatic conditions in eastern Germany. After carefully testing the hypotheses and ascertaining the main facts, these trials will be not continued 'forever' because such multi-factorial long-term trials require large amounts of time and resources.

As described above in detail and reviewed by the literature, many interesting and fundamental results have been obtained through these trials:

- The problems of market crop systems, especially in the field of N management, have been clearly worked out;
- The interaction between organic fertilization or fertilizer type in connection with legume-grass adaptation on crop yields and system efficiency;
- The distinct effects of changing climatic conditions on fertilizer and crop rotation strategies.

On the other hand, some important effects described have not yet been clarified, and so these trials will have to be continued until the following questions can be answered:

- Are the negative effects of legume-grass mulching on organic matter levels of the soil of substantial significance?
- What differences appear in the long-term use of the tested fertilizer types on crop yields, quality, nutrient efficiency and environmental effects?
- Are the adapted crop rotation strategies more successful against the specific climatic conditions of dry seasons?

Given increasing institutional uncertainty, these days the decision-making structure often favours short-term options, chiefly because of the lack of an overview of technical expertise and the economic consequences, even in farming. This situation known from other long-term trials has sadly also affected the trials described here. Therefore, great commitment (including of a private nature) and even civil courage will be needed if these trials are to be successfully concluded.

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