CALCULATION OF OPTIMAL CARBON CONTENT IN ARABLE SOILS DEPENDING ON SITE CONDITIONS AND MANAGEMENT SYSTEMS.

M. Körschens[A], and E. Schulz[B]
[A] Institute for Soil Science and Plant Nutrition, Martin-Luther-University Halle -Wittenberg, Lauchagrund 1, 06246 Bad Lauchstädt, Germany, e-mail: m.koerschens@worldonline.de
[B] Centre for Environmental Research Leipzig-Halle Ltd., Department of Soil Science, Theodor-Lieser Str. 4, D-06120 Halle/Saale, Germany, e-mail: elke.schulz@ufz.de

Abstract
Carbon plays a significant role for soil conservation and environment. The knowledge of optimal carbon content is a precondition to maintain soil fertility and yield formation as well as for estimating the possibility for carbon sequestration. To solve this problem long-term experiments are necessary. Basing on the results of 12 long-term experiments at 9 different locations the optimal carbon content is derived from the view of the yield formation and environmental protection. A minimum content of decomposable soil organic matter (SOM) is necessary for yield formation. Upper limits result from environmental aspects and should not exceed considerably the level necessary for yield formation.

Additional Keywords: soil organic matter, fertilization, FYM, environmental protection

Introduction
Carbon plays a significant role for soil conservation and environment. The knowledge of optimal carbon content is a precondition to maintain soil fertility and yield formation as well as for estimating the possibility for carbon sequestration. The knowledge in this field is still very insufficiently and controversial opinions are discussed. First solutions for Central European site conditions are published by Körschens et al. (1998) basing on results from long-term field experiments and extensive soil analyses. A fundamental change in agriculture can be observed during the last decades. With increasing application of mineral fertilizers, plant protection agents and mechanization yields drastically increased and concomitantly the harvesting and root residues remaining on the field represent an important source for SOM. For example in the last 50 years, yields of winter wheat increased by 4 to 5 t/ha and harvesting and root residues by 1 t/ha as well. Today nutrient supply for the crops is covered better, cheaper and more effective avoiding pollution of adjacent compartments applying mineral fertilizers.

Therefore, SOM today plays only a secondary role for yield formation. Problems of environmental protection connected with global carbon and nitrogen cycling are of increasing focus. Consequently high yields are prerequisite for a sustainable and non-polluting plant production. Recommendations such as set aside as well as renouncement of mineral fertilizers and chemical plant protection, promoted by the European Union, only help to decrease of the food overproduction, however, not in favour of environmental protection.
All further views is to be proceeded from the following premises:
1. At least two SOM fractions should be considered: one being relatively inert (hardly involved in mineralization processes), the other being decomposable and thus dependent on soil and crop management
2. The production of plant biomass is the only practicable possibility of binding CO_2 from the atmosphere.
3. The favorable effect of SOM contributes to crop yield increase up to 10 % on sandy soils and up to 5 % on loamy soils. This means that the yield potential can be exploited up to 90 % using exclusively mineral fertilization.
4. The ranges for the optimal quantities of C and N in soil are narrow. Under the conditions of the Central Europe (mean annual temperature between 6° C and 10 ° C and mean annual precipitation 450 to 800 mm) the optimal content of mineralizable carbon ranges between 0.2 and 0.6 % and that of nitrogen 0.02 and 0.06 %.

Materials and Methods
Changes in C_{org} in soil occur almost exclusively in the decomposable part and proceed relative slowly. Therefore investigations for evaluating optimal contents of SOM require long-term field experiments with a duration of several decades. As a precondition
- treatments contain all important combinations of organic and mineral fertilization,
- treatments of the experiment are unchanged since the beginning,
- intensive soil investigations were accomplished,
- all results are completely documented.

For the following evaluation the results of such experiments were used.

Results and Discussion

All procedures of the evaluation of the influence of SOM on the environment require the knowledge of optimal SOM content. For this reason fertilization variants from long-term field experiments were selected in which the combination of organic and mineral fertilization was close to optimum. This means that further fertilization did not increase the yields, and simultaneously, the highest effectiveness of the N-fertilization has been achieved (most favourable N-balance). Fertilization system at these variants provided high and stable yields, nutrient efficiency was high and therefore, the environmental impact is low. At the site Bad Lauchstädt three different long-term field experiments were used. Besides of the yields and N-balances carbon and energy balances were evaluated as well (Rathke et al., 2002). As a result of the evaluation of yields, nitrogen efficiency, carbon gain and energy balances the fertilization of 10 t/ha FYM + NPK was the most favourable (table 1 and figure 1).

Table 1. Selected long-term fertilization experiments and the optimal amount of FYM

Nr.	site	Initial year	clay content %	average temp. °C	precipitation mm	optimal FYM t/ha.a	author
1	Bad Lauchstädt	1902	21	8,7	484	10	Körschens et al., 1994 Rathke et al., 2002
2	Braunschweig	1952	6	8,8	618	10	Rogasik et al., 2003
3	Methau	1966	16	8,0	600	10	Albert, 1999
4	Seehausen	1967	8	9,0	556	12	Leithold et al., 1997
5	Spröda	1966	6	8,3	540	10	Albert, 1999
6	Speyer	1958	9	9,8	583	15	Bischoff a. Emmerling, 2003
7	Müncheberg	1962	5	8,2	521	8	Rogasik et al., 2003
8	Groß Kreutz	1967	2	8,9	537	10-15	Asmus, 1995, Zimmer a. Roschke, 2001
9	Thyrow	1937	3	8,6	520	10	Lettau a. Ellmer,1997
	average					10,8	

Several authors estimated the necessary amount of primary organic matter (POM) for maintaining the optimal SOM content basing on the results of 12 long-term field experiments at 9 different locations.
An average demand for FYM was determined to be 10.8 $t.ha^{-1}.a^{-1}$. The differences in the organic carbon content between unfertilized variants and the optimum fertilized variants ranged between 0.11 % C_{org} on a sandy soil and 0.51 % C_{org} on loess black soil. (Figure 1)

Yield

The results of the long-term experiments show that for an ecologically and economically justifiable high yield a minimum content of SOM is necessary. Higher contents do not bring any advantages.

Nitrogen

Nitrogen plays a very important role in the environment. The evaluation of the influence of different soil management systems on the environment requires the comparison of the efficiency of mineral nitrogen with the efficiency of FYM nitrogen. The results of many long-term experiments under different local conditions show that compared to mineral N the utilization of FYM nitrogen is about 30 % lower. The upper limit of the SOM content results from the N - quantity which can be mineralized annually and which can be taken up by the cultivated crops. A soil well supplied with SOM mineralizes annually 50 to 100 kg $N.ha^{-1}$. Additionally, the atmospheric deposition amounts about 50 kg $N.ha^{-1}$. Higher amounts of N-mineralization from increased contents of decomposable SOM may cause N-losses affecting adjacent compartments (atmosphere, hydrosphere).

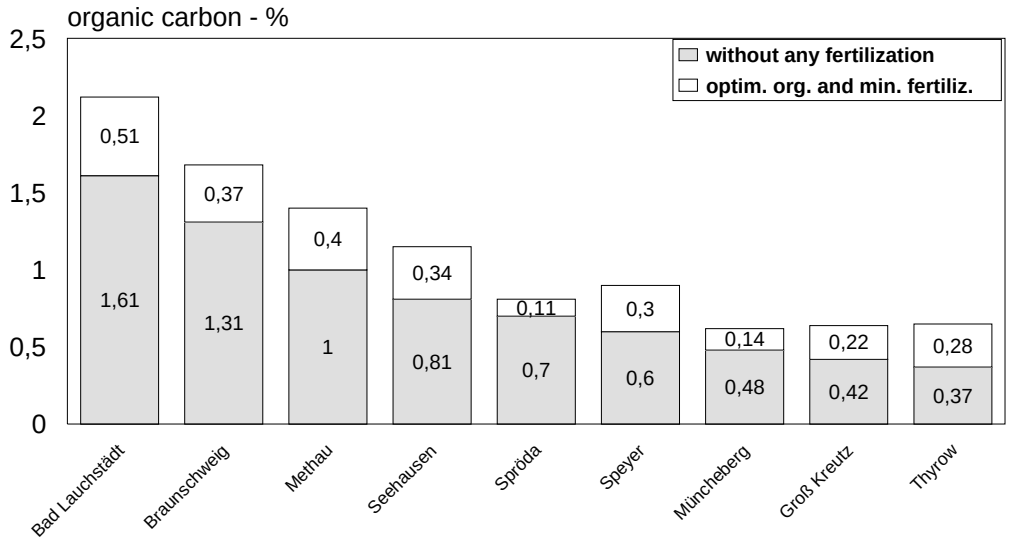

Figure 1. Content of organic carbon (0-30 cm) depending on fertilization in 12 long-term Experiments at 9 different locations in Germany

It should be taken in account that SOM mineralization proceeds even in time periods in which there are no crops for taking up nitrogen. In the succession cereals - sugar beets, for example this period may extend six to eight months, including the winter months. As the microbial activities proceed even at temperatures close to zero there is a considerable nitrogen loss. That means, with view on environmental protection a small content of SOM is favourable.

Carbon
Beside nitrogen also carbon plays an important role for environmental protection what remains frequently unconsidered. In connection with that the question of the carbon sequestration has to be discussed. It is not meaningful to enrich the soil with C if this is inevitably connected with high losses. In this case organic substance can better be used directly for power production. An increase of the C content in the soil requires a very high expenditure as a function of the local conditions (mineralizing intensity) and the kind of the primary organic matter (humification coefficient). Thus e.g. on black earth (21 % clay) in Bad Lauchstädt 13 % of C supplied with the FYM accumulated after a time period of 100 years. In contrast, in a loamy soil in Halle/S. (12 % clay) only 6 % of with regular straw fertilization supplied C remained after 48 years (Schmidt and Merbach, 2004). After reaching the flow equilibrium practically no further C will be accumulated. That means, compared to a supply of organic matter necessary for the yield formation an additional supply is not meaningful. Carbon can be used with substantially higher effectiveness for the substitution of fossil sources of energy.

Summary and Conclusions
High yields contribute to environmental protection. The renouncement of crop yields is also a renouncement of the CO_2 binding potential at the same time. With the use of mineral fertilizers, up to 10 times higher quantity of energy can be gained. The predominant part of the POM is used for the production of food and feeds, as raw material and/or as source of energy. The latter is at present only very limited considered. A part of the grown biomass such like roots and harvest residues as well as FYM or slurry acts as an input into the soil for the reproduction of the SOM. For the roots and harvest residues this is mandatory. About 60 % of the demand of POM are covered by the post harvest and root residues. The amount of the post harvest residues increased in the last two decades with increasing yields substantially. From the environmental protection point of view both high production of plant biomass and simultaneously the most meaningful use of the assimilated carbon should be taken into consideration. That means, all POM which is not necessary for the reproduction of SOM to maintain the optimal level, should be used as a direct source of energy.

The present results, especially the evaluation of many long-term experiments, allow the following conclusions:

1. The importance of soil organic matter (SOM) for nutrient supply for the plants strongly decreased in the last decades, on the other hand it plays an increasingly role for environmental protection.
2. As a condition for ecological and economically justifiable high yields a minimum content of decomposable SOM is necessary. Upper limits result from the view of environmental protection and should not lie considerably above the level necessary for the yield formation.
3. It is practically impossible to reduce CO_2 concentration in atmosphere by means of carbon sequestration to mineral soils. The necessary input of primary organic matter largely exceeds the quantity which can be accumulated.

References

Albert E. (1999) Wirkung einer langjährig differenzierten mineralisch-organischen Düngung auf Ertragsleistung, Humusgehalte und N-Bilanz, UFZ-Bericht Nr. 24/1999 Internationales Symposium „Dauerdüngungsversuche als Grundlage für nachhaltige Landnutzung und Quantifizierung von Stoffkreisläufen“ vom 03.06. – 05.06.99 in Halle, 59-62.

Asmus F. (1995) Ergebnisse aus einem langjährigen Dauerversuch zur organisch-mineralischen Düngung auf Tieflehm-Fahlerde. Arch. Acker- Pfl. Boden., Berlin, 39, 359-367**.**

Bischoff, R. and Emmerling, R. (2003) Auswirkungen differenzierter organischer und mineralischer Düngung auf die Nährstoffsalden und Bodengehalte – Ergebnisse langjähriger Dauerversuche. In press.

Körschens M., Stegemann K., Pfefferkorn A., Weise V., Müller A. (1994) Der Statische Düngungsversuch Bad Lauchstädt nach 90 Jahren. B. G. Teubner Verlagsgesellschaft Stuttgart-Leipzig.

Korschens, M., Weigel, A., Schulz, E. (1998) Turnover of Soil Organic Matter (SOM) and Long-Term Balances - Tools for Evaluating Sustainable Productivity of Soils. Z. Pflanzenernähr. Bodenk., 161, 409-424

Leithold G., Hülsbergen K.-J., Michel D., Schönmeier H. (1997) Humusbilanz – Methoden und Anwendung als Agrar-Umwelt-Indikator. In: Initiativen zum Umweltschutz, Bd. 5, 43-54, Deutsche Bundesstiftung Umwelt, Osnabrück, Zeller-Verlag

Lettau T. and Ellmer F. (1997) Kohlenstoffgehalte und -bilanzen nach langjährig differenzierter Düngung eines Sandbodens - Ergebnisse aus einem Dauerfeldversuch. 109. VDLUFA-Kongress 15. Bis 19. September 1997 in Leipzig, VDLUFA-Verlag Darmstadt, S. 99.

Rathke,G.-W., Korschens, M., Diepenbrock, W. (2002) Substance and Energy Balances in the „Static Fertilization Experiment Bad Lauchstädt“ Arch. Acker- Pfl.. Boden, Vol. 48, pp 423-433

Rogasik J., Schroetter S., Funder U., Schnug E., Kurtinecz P. (2004) Long-term fertilizer experiments as a data base for calculating the carbon sink potential of arable soils. Archives of Agronomy and Soil Science, Vol. 50, pp 11 – 19

Schmidt, L. and Merbach, W. (2004) Reaktion des Boden -C und N –Gehaltes auf Düngung – Ergebnisse von Dauerversuchen in Halle/S., Deutschland. Archives of Agronomy and Soil Science, Vol. 50, pp 49-57

Zimmer, J. and Roschke, M. (2001) Einfache Reproduktion der organischen Bodensubstanz auf Sandstandorten – Erfahrungen aus Dauerversuchen im Land Brandenburg. „Landwirtschaft in mittel- und osteuropäischen Ländern – Potenziale und deren Nutzung“, VDLUFA – Schriftenreihe 57/2001, Kongressband 2001, Teil II, CD – ROM, Berlin 2001, S. 481 - 489