Long-term soil carbon changes in different agricultural management systems under past and future climate

Master's Thesis

Faculty of Science

University of Bern

presented by

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2010

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Abstract Carbon stored in soils represents the largest terrestrial carbon pool. It contains about twice as much carbon as that found in the atmosphere and about three times as much as that in vegetation. As a result, small changes in the soil organic carbon (SOC) pool could have dramatic impacts on the concentration of CO_2 in the atmosphere. Therefore, the response of SOC to global warming is critically important. Furthermore, in the 1995 Intergovernmental Panel on Climate Change (IPCC) Assessment, agriculture was estimated to be responsible for 20% of the annual increase in anthropogenic greenhouse gas emissions (Paustian et al. (1997); Cole et al. (1997)). Therefore, sustainable and efficient crop yield agricultural systems have been sought, and a fertile soil has been one of the key factors of this kind of agricultural system. Sustainable management of agricultural land aims at maintaining and enhancing food production, reducing the level of production risk, protecting the potential of natural resources, and preventing degradation of soils and water quality. Agronomists have also recognized the benefits of maintaining and increasing Soil Organic Matter (SOM), which adds to soil fertility, water retention, and long-term sustainable crop productivity. In this study, I simulate the long-term SOC content changes over time in different management systems, i.e. organic farming system versus conventional farming system (intensive farming system with mineral fertilizers). There are four simulations in this study. In simulation 1, I discuss the importance of initial SOC content for SOC change over time, and which soil management system has more capability to recover from depleted SOC condition. In simulation 2, I discuss SOC change with measured climate data from 1977 to 2004, for each soil management system. I also compare the result in this study with the result in Leifeld et al. (2009). In simulation 3, I discuss SOC change under expected future climate change from 2005 to 2050 for each soil management system. In simulation 4, I compare SOC change under current and expected climate change conditions and without considering climate change. Then, I discussed which agricultural soil management system is more effective under current climate change. The results show that there is no significant difference with respect to SOC change over time between organic farming systems on the one hand, and a soil management system which combines a conventional farming system (applying mineral fertilizers) and an organic farming system on the other. Both an organic farming system and a soil management system which combines a conventional farming system and an organic farming system are more stable than a conventional farming system, with regard to SOC content over time. However, under current/future climate change scenarios, a conventional farming system loses less SOC than organic farming systems. From these results, I consider that the change of microbial processes under future climate change will have a larger effect on organic farming systems than conventional farming systems. The conventional farming system will not be affected dramatically because mineral fertilizers are already mineralized chemically. However, organic farming systems which apply plant residues and manure/slurry will be affected more than conventional farming systems by climate change. In contrast, a conventional farming system shows a faster rate of SOC change than the organic farming systems in this study. Moreover, concerning the differences between the results in this study and in Leifeld et al. (2009), I consider that the timing of carbon input (such as manure and plant residue) and type of manure have a large effect on SOC change over time than the weather condition. As the conclusion, a soil management system which

combines an organic farming system with mineral fertilizers as a supplement is the most effective soil management system with regard to the SOC content under climate change. For retaining SOC and mitigating greenhouse gases in agricultural management systems, plant protection management systems and the timing of carbon input application are also important.

Acknowledgments I thank to Prof. Dr. Jurg Fuhrer, Dr. Jens Leifeld, Prof. Dr. Martin Grosjean for helpful comments and support. I also thank Stipendium der Schweizerischen Eidgenossenschaft (ESKAS) for financing my study in Switzerland. I am grateful to Dr. Alex Coad for checking my English and his support during my Master studies in Europe. I also thank the following people (in alphabetical order): Mayumi Kung, Erich Lang, Miriam Lang, Tsuneo Nemoto, Fabian Mauchle, Richard Wartenburge as well as my friends in the Graduate School of Climate Science at the University of Bern.

Contents

1 Introduction

Since the industrial revolution, human activity has increased the concentration of various greenhouse gases, leading to increased radiative forcing from carbon dioxide, methane, tropospheric ozone, nitrous oxide and other greenhouse gases.

Soils contain about twice the amount organic carbon in the atmosphere (See Figure 1 and also Watson et al. (2000)). As a result, small changes in the soil organic content (SOC) pool could have dramatic impacts on the concentration of CO_2 in the atmosphere. Therefore, the response of SOC to global warming is important.

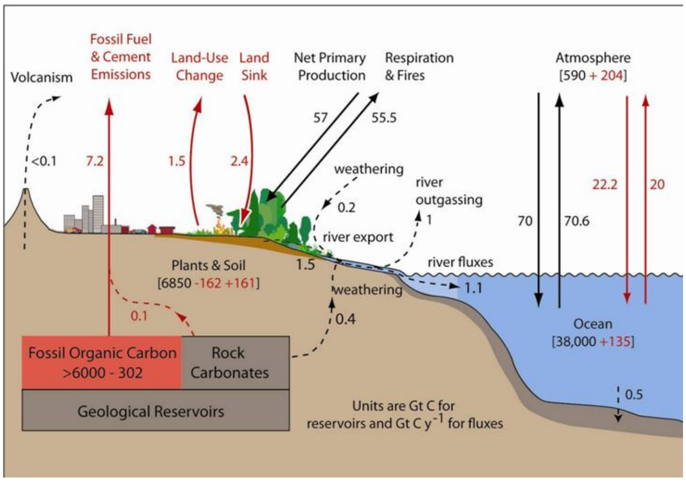


Figure 1: Global Carbon Budget 2000-2005, GlobalCarbonProject (2006))

In the 1995 Intergovernmental Panel on Climate Change (IPCC) Assessment, agriculture was estimated to be responsible for 20% of the annual increase in anthropogenic greenhouse gas emissions (Paustian et al. (1997); Cole et al. (1997)). Therefore, sustainable and good crop yield agricultural systems have been sought, and a fertile soil has been one of the key factors of this kind of agricultural system. A fertile soil provides essential nutrients for crop plant growth, enhances biological diversity and activities, builds a soil structure and amplifies decomposition. Agricultural activities also affect the emission of greenhouse gases from the soil. Figure 2 shows the agricultural activities and emissions of greenhouse gases from soil to the atmosphere.

This explains that conversion from natural to agricultural systems, agricultural activities and livestock farming enhance soil degradation, decrease soil organic carbon content, and reduce biomass production and biomass return to the soil. These effects become a cause of greenhouse gas emission from the soil. Figure 3 shows the relationship between soil degradation and emission of greenhouse gases.

This explains that mismanagement of the soil leads to soil degradation and leads to more greenhouse gas emission from the soil. As Figure 2 and Figure 3 are showing, soil management in agriculture plays an important role in the mitigation of greenhouses gases. Furthermore, agronomists have recognized the benefits of maintaining and increasing soil organic matter (SOM), which adds to soil fertility, water retention, and long-term sustained crop productivity (Schlesinger (2000); Parshotam

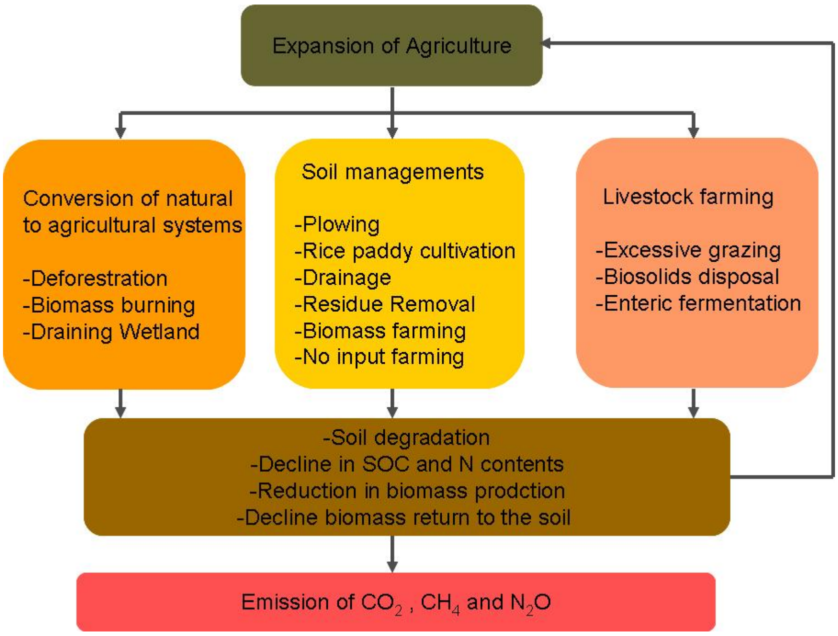


Figure 2: Agricultural activities and emission of greenhouse gases from soil and terrestrial/aquatic ecosystems to the atmosphere (Based on Lal (2002))

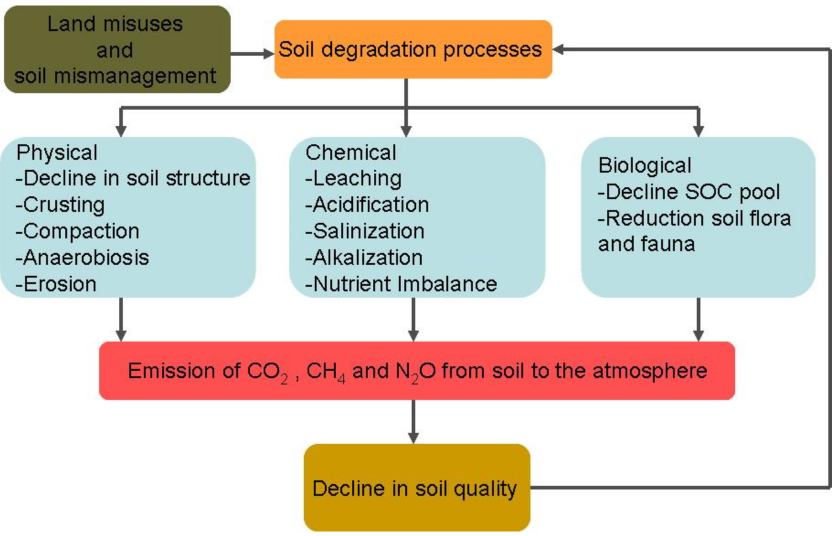


Figure 3: Soil degradation and emission of greenhouse gases to the atmosphere (Based on Lal (2002))

et al. (2001)). For these reasons the preservation of carbon stocks is in the interest of farmers and the community. Several studies have investigated the effect of organic farming systems on soil carbon stock as a promising agricultural system.

Drinkwater et al. (1998) report that an organic farming system has positive effects on soil carbon because their organic farming system showed a significant increase in SOC even though every plot received equal amounts of carbon input. Furthermore, organic farming enhances microbial biomass and activities and this enhancement plays an important role in sustaining an abundant and active soil biological community (Gunapala and Scow (1998); Mäder et al. (2002); Fließbach et al. (2007)). Wells et al. (2000) report that, in comparison to conventional systems, organic farming systems have higher soil organic carbon, microbial biomass, total nitrogen, total phosphorus, exchangeable nutrient cations, water-holding capacity and aggregate stability. Mäder et al. (2002) indicate that an organic farming system promotes root colonization and soil aggregation by mycorrhizae. In organic farming systems, more soil microbial biomass could be expected than for the conventional system, since the soil aggregate stability is correlated with microbial biomass and earthworm biomass (Mäder et al. (2002); Fließbach et al. (2007)).

On the other hand, Leifeld et al. (2009) indicated that some of the positive results on the carbon stock in the soil might reflect the fundamental differences between management and experimental sites. Wells et al. (2000) also concede that conventional farming systems have smaller fertilizer inputs and their phosphorus absorption capacity is not different from organic farming systems. Fließbach et al. (2007) report that the organic farming system has enhanced the biological parameters of soil quality compared to conventional farming systems. Furthermore, they indicate that the effects of the bio-organic system on the soil quality were less pronounced in the Swiss organic farming systems. Leifeld et al. (2009) report that the organic farming system does not positively affect the soil organic matter quality and quantity but that organic fertilizers do positively affect the soil organic matter quality and quantity.

In the DOK (D: bio-Dynamic, O: bio-Organic, K: german "Konventionell" integrated) field experiment, crop rotation, tillage and residue management are the same for each soil management system. Therefore, results obtained from the DOK experiment are reliable, and I use the DOK experiment in this study.

1.1 Contents and aim of this study

This study is roughly divided into four different simulations (See Table 1 for an overview).

First, in simulation 1-1, the RothC model and DOK field experiment data sets were used. The difference of SOC change of two simulation management systems were compared. The first simulation took simulated SOM pools content in November 2004 as an initial SOC content (management "simulated SOM pools content"), while the second simulation took measured SOM pools content in November 2004 as an initial SOC content (management "measured SOM pools content"). These simulations were undertaken for different soil management systems to investigate the importance of initial SOC content on subsequent SOC change. I did this simulation for 100 years, applying

Table 1: The overview of this study

Simulation Nr.	Material	Method	Aim
Simulation 1-1	-RothC model -DOK field experiment data -Averaged weather data (77-04) -Averaged plant residue and manure input (until 1977)	Comparing the difference of SOC change between two different simulation managements: -The simulation: Simulated SOM pools content in Nov 2004 as initial SOC content ("simulated SOM pools content") -The simulation: Measured SOM pools content in Nov 2004 as initial SOC content ("measured SOM pools content")	To study the Importance of the initial SOC content on the SOC change
Simulation 1-2	-RothC model -DOK field experiment data -Averaged weather data (77-04) -Averaged plant residue and manure input (until 1977)	How many years it takes to reach the equilibrium point of SOC -With averaged carbon input until 1977 (high amount input) -With averaged weather data (77-04) -For two different simulation managements: "measured SOM pools content" and "simulated SOM pools content"	-The effect of each soil management system on SOC change over time -Which soil management system has more capability to recover from the depleted SOC condition.
Simulation 2	-RothC model -DOK field experiment data -Weather data measured at a MeteoSwiss station near the DOK site (Temperature and Precipitation) -Calculated Evapotranspiration by regression -Averaged plant residue and manure input (77-04)	SOC change under actual weather data from 1977 to 2004 -With measured initial SOC in 1977 -With averaged plant residue and manure input (77-04)	To Know -The importance of climate change effect and soil management effect on SOC change over time. To compare -SOC change in this simulation with that in Leifeld et al. (2009) - SOC change without climate change (77-04) in simulation 4
Simulation 3	-RothC model -DOK field experiment data -Future climate data by OcCC (2007) climate scenario -Averaged plant residue and manure input (77-04)	SOC change under expected future climate change from 2005 to 2050 -With simulated initial SOC content 2005 -With averaged plant residue and manure input (77-04)	To know - The importance of future climate change effects on SOC change by comparing the SOC change without future climate change scenario in simulation 4 - The important of soil management effect on SOC change under future climate change.
Simulation 4	-RothC model -DOK field experiment data -Averaged weather data (77-04) -Measured weather data by MeteoSwiss station near from DOK site (Temperature and Precipitation) -Future climate data by OcCC (2007) climate scenario -Averaged plant residue and manure input (77-04)	Comparing SOC change under climate change and without climate change (1977-2050) -With measured initial SOC in 1977 -Averaged plant residue and manure input (77-04)	To compare - SOC change under climate change and without climate change To discuss - The ideal soil management under climate change To know - The important of soil management effect on SOC change under climate change.

averaged plant residue and manure input according to the amounts applied until 1977 (high carbon input management). Regarding weather data, I used averaged weather data from 1977 to 2004 which was measured at the MeteoSwiss station in Basel-Benningen which is 7km away from the DOK experiment site. Table 2 contains the averaged climate data for the period 1977-2004.

Table 2: Averaged climate data for 28 years (1977-2004)

	Temperature (°C)	Precipitation (mm)	Evapotranspiration (mm)
Jan	1.4	52.9	4.8
Feb	2.7	49.3	7.2
Mar	6.7	52.4	15.5
Apr	9.4	63.7	22.9
May	13.7	90	40.3
Jun	17	85.7	57.4
Jul	19.2	92.2	70.7
Aug	18.9	76.1	69.3
Sep	15	71.5	46.3
Oct	10.7	74.4	27.7
Nov	5.2	60.4	11.6
Dec	2.8	61.8	6.7

I also simulated how many years it will take to reach the SOC equilibrium point (starting point: SOC content in November 2004) with a high amount of carbon input (which has been applied until 1977) but without any climate change effect (Simulation 1-2). This simulation was undertaken in order to know two points: the effect of each soil management system on SOC change over time, and how the SOC change differs over time with regard to the initial SOC content. I did this simulation for 100 years using averaged weather data from 1977 to 2004 which was measured at the MeteoSwiss station in Basel-Benningen.

Second, I simulated the change of SOC content with measured weather data from Basel-Binningen from 1977 to 2004, for each of the different soil management systems (Simulation 2). In this simulation, I calculated the average plant residue and manure input amount for each month from 1977 to 2004 for each plot and added this monthly average plant and manure input amount for each month (See Table 3 and Table tab:averageaddmanure).

This simulation was done to know the effect of climate on SOC change over time and to compare the importance on the SOC change between climate change effects and the effects of soil management system in the past. The result of simulation 2 was compared with the result of Leifeld et al. (2009) in order to investigate the accuracy of the result of this study, before then moving on to an investigation of SOC change under the future climate change.

Third, I simulated the change of SOC content with expected future climate change from 2005 to 2050, with regards to each organic and conventional soil management system (Simulation 3). In this simulation, I used the future climate scenario from OcCC (2007) for estimating the future climate and I used the average plant residue and manure input amount for each month from 1977 to 2004 for each plot and added this monthly average plant and manure input amount for each month. This simulation was undertaken in order to estimate the climate change effect on SOC over time, and

Table 3: Averaged plant residue input content (t C ha^{-1}) Jan 1977-Dec 2004 for each month

	NOFERT				CONMIN				BIODYN				BIOORG				CONFYM			
Plot Nr.	5	39	55	95	6	40	56	96	12	46	50	90	18	28	68	84	24	34	62	78
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	0.03	0.02	0.03	0.03	0.04	0.04	0.03	0.04	0.04	0.04	0.05	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05
Apr	0.17	0.15	0.16	0.18	0.05	0.27	0.25	0.26	0.26	0.25	0.31	0.24	0.25	0.24	0.24	0.26	0.30	0.30	0.31	0.32
May	0.10	0.09	0.09	0.09	0.14	0.14	0.13	0.13	0.14	0.14	0.16	0.13	0.13	0.13	0.13	0.14	0.15	0.15	0.15	0.16
Jun	0.12	0.11	0.11	0.11	0.15	0.14	0.13	0.14	0.16	0.15	0.18	0.14	0.15	0.13	0.14	0.15	0.17	0.17	0.17	0.17
Jul	0.20	0.18	0.19	0.19	0.28	0.28	0.26	0.26	0.28	0.27	0.32	0.26	0.27	0.26	0.26	0.27	0.30	0.30	0.30	0.31
Aug	0.12	0.11	0.11	0.13	0.19	0.19	0.17	0.18	0.18	0.17	0.17	0.16	0.17	0.16	0.16	0.17	0.21	0.21	0.21	0.22
Sep	0.17	0.15	0.16	0.16	0.24	0.23	0.21	0.21	0.24	0.23	0.28	0.21	0.22	0.22	0.21	0.23	0.26	0.27	0.27	0.28
Oct	0.08	0.08	0.08	0.08	0.12	0.12	0.11	0.11	0.12	0.11	0.13	0.11	0.11	0.11	0.11	0.12	0.13	0.13	0.13	0.13
Nov	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.99	1.22	1.41	1.35	1.57	1.30	1.61	0.89	1.42	1.37	1.61	0.93	1.30	1.59	1.28	1.65	1.37	1.28	0.96	1.33

Table 4: Averaged manure input content (t C ha^{-1}) Jan 1977-Dec 2004 for each month

	NOFERT				CONMIN				BIODYN				BIOORG				CONFYM			
Plot Nr.	5	39	55	95	6	40	56	96	12	46	50	90	18	28	68	84	24	34	62	78
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.10	0.10	0.10	0.10
Mar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.10	0.18	0.18	0.18	0.18	0.52	0.52	0.52	0.52
Apr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.34	0.34	0.34	0.40	0.40	0.40	0.40	0.14	0.14	0.14	0.14
May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.16	0.16	0.16	0.16
Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.03	0.03	0.03	0.03	0.08	0.08	0.08	0.08
Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.13	0.13	0.13	0.13	0.05	0.05	0.05	0.05
Aug	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.07	0.07	0.07	0.07
Sep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oct	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.11	0.11	0.11	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.04	0.04	0.07	0.07	0.07	0.07	0.00	0.00	0.00	0.00
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.85	0.85	0.85	0.85	0.99	0.09	0.99	0.99	1.16	1.16	1.16	1.16

to compare the importance on the SOC change between estimating climate change effects and the effects of soil management systems in the future.

Finally, I simulated the SOC content change under averaged weather data from 1977 to 2004 which was measured at the MeteoSwiss station in Basel-Benningen (Table 2) with initial SOC content in 1977. I did this simulation from 1977 to 2050. Then, in simulation 4, I compared the result of SOC change under averaged weather data from 1977 to 2004 (with no climate change) and the result of SOC change in simulation 2 and 3. This fourth simulation was undertaken in order to estimate the climate change effect on SOC content change for each soil management systems, and to identify an appropriate soil management system under future climate change condition.

The aim of this study is to simulate and discuss the long-term changes in soil carbon content in different management systems (i.e. the organic farming system versus the conventional farming system) under current and future climatic conditions over time. Another important objective in this study is to find an appropriate soil management system which emit less greenhouse gases from agricultural field. The characteristics in this study (that is, the differences between this study and Leifeld et al. (2009)) are as follows:

1. Using averaged content of plant residue and manure input for current and future climate change (Simulation 2 and 3)[1]
2. Using the regression equation between temperature and evapotraspiration for estimating evapotranspiration[2]
3. This study did not distinguish the difference between manure types in organic farming systems[3]

2 Material and methods

2.1 Data source and site characteristics

2.1.1 Long-term field experiment: DOK experiment in Switzerland

Several long-term field data sets which compare organic farming systems and conventional farming systems have been collected, and one of the best documented is the DOK experiment in Switzerland (Mäder et al. (2002)).

In 1978, the DOK field experiment was set up at Therwil (7°33'E, 47°30'N) in the vicinity of Basel, Switzerland (See Figure 4), by the Agroscope Reckenholz Tänikon research Station (ART Zürich Reckenholz) and the Research Institute of Organic Agriculture (FiBL, Frick) (Fließbach et al. (2007)). It includes 96 experimental plots: 8 treatments × 4 replications × 3 crops planted simultaneously in each system every year, $100m^2$ each(Leifeld et al. (2009)).

[1]This is for removing the effect of changes in the amount of fertilizers on soil organic carbon (SOC) content change. This study tried to concentrate only on the climate change effect on SOC content change.

[2]Leifeld et al. (2009) used the evapotranspiration data which was calculated by the MeteoSwiss.

[3]Leifeld et al. (2009) distinguish between manure types.

In this study, five treatments out of the eight treatments in the DOK field experiment were used as the data sets. Figure 5 shows that each treatment was replicated four times in the field and cultivated with the same crop at the same time (for more details, see FiBL. et al. (2000); Fließbach et al. (2007); Leifeld et al. (2009)). The five farming systems[4] are different in fertilization management and plant protection strategies (This is explained more in Section 2.1.1 "several soil management systems").

The soil of the site is a haplic luvisol (sL)(typic Hapludalf (Fließbach et al. (2007)) or Argalf (Leifeld et al. (2009)) on alluvial loess (Fließbach et al. (2007); Leifeld et al. (2009)).

The climate data of the site is reported in Section 2.1.2.

Several soil management systems In this study, I did not consider the different types of manure for each farming systems as the windows version RothC model can not distinguish composted manure, rotted manure and stacked manure. However, the different types of manure might also be important for SOC change (Freibauer et al. (2004)). This is because composting manure enhances its stability (Fließbach et al. (2007)).

In the DOK experiment, as organic farming systems, there are livestock-based systems: a bio-organic management system (BIOORG), a bio-dynamic management system (BIODYN) and a conventional farming system with manure management (CONFYM). CONFYM includes mineral fertilizers and organic fertilizers. We also considered two additional conventional (non-organic) farming systems, which were fertilized exclusively with mineral fertilizers (CONMIN) or unfertilized (NOFERT). NOFERT is a control management system. Regarding each soil management system, crop rotation (1 cycle of crop rotation = 7 years), tillage (moldboard plowing 18-20 cm deep and harrowing), applied manure rate levels and residue management are the same (Leifeld et al. (2009)).

However, the type of fertilizers and methods of plant protection are different. Manure and slurry were applied as organic fertilizers to BIODYN, BIOORG and CONFYM. The applied manure and slurry content from 1978 to 2004 are shown in Table 5. In Table 5, the applied manure and slurry content are the same for BIODYN, BIOORG and CONFYM, but the types of applied manures are different: composted manure, rotted manure and stacked manure for BIODYN, BIOORG and CONFYM respectively (Fließbach et al. (2007); Leifeld et al. (2009)). Composted manure, rotted manure and stacked manure mean aerobically composted, slightly aerobically rotted and anaerobically stacked respectively (Siegrist et al. (1998); Fließbach et al. (2007); Leifeld et al. (2009)). These differences are not considered in this study.

For BIODYN and BIOORG, plant protection management systems are the same: Mechanical weed control, indirect disease control methods and bio-control for the insect control. CONFYM and CONMIN took the same plant protection methods: Mechanical and herbicides weed control, chemical disease and insect control (Fließbach et al. (2007); Leifeld et al. (2009)). CONMIN does not include the application of any organic fertilizers but exclusively mineral fertilizers. Plant protection strategies are the same as for CONFYM. NOFERT management does not receive any fertilizers but the plant protection strategies are the same as for BIODYN and BIOORG. It also includes

[4]NOFERT, CONMIN, BIODYN, BIOORG and CONFYM.

biodynamic preparations (Table 5)(Fließbach et al. (2007)).

The rate of plant residue input and clay content are varied in every soil management system (Table 6). In simulation 1-1 and 1-2, I used averaged plant residue and manure input before 1977. This amount of input is much higher than the amount of input used nowadays.

The BIODYN management system includes biodynamic preparations, composted aerobically with some herbal additives, manure and slurry, but it was managed without mineral fertilizers and pesticides. BIOORG is the organic farming management system with slightly rotted manure and slurry but without mineral fertilizers, pesticides and composted manures. In this management system, $CuSO_4$ was applied to the cultivation of potatoes until 1991. CONFYM is a conventional farming system but it is amended with stacked manure, slurry, supplemental mineral fertilizers, as well as chemical pesticides. This management system uses plant growth regulators (following Fließbach et al. (2007) and Leifeld et al. (2009), see Table 5).

In simulation 1-1 and 1-2, I applied two different initial SOM contents: measured SOM content in November 2004 and simulated SOM content in November 2004. Regarding measurement of SOM content, Leifeld et al. (2009) used the method of Zimmermann et al. (2007). This is explained more in Section 2.2.1. In simulation 2, I applied the measured SOM content in 1977 in Leifeld et al. (2009) as initial SOM contents. In simulation 3, I applied the simulated SOM content in November 2004 as the initial SOM content. In simulation 4, I applied the measured SOM content in 1977 in Leifeld et al. (2009) as the initial SOM content for the simulation under no climate change condition. Regarding the simulation under climate change condition, the initial SOC contents are the same in simulation 2 and 3.

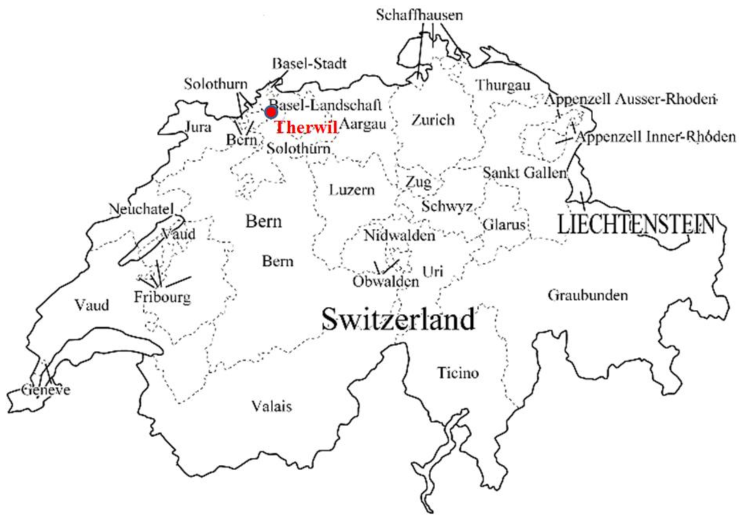


Figure 4: DOK experiment site in Switzerland

Crop rotations According to Fließbach et al. (2007) and Leifeld et al. (2009), crop rotations are the same for the all of the plots in the DOK field experiment. The first crop rotation (1978-1984) was Potato (*Solanum tuberosum, L.*) and green manure for the first year, Winter wheat 1 (*Triticum*

Table 5: Details of the farming systems of the DOK field experiment (based on Leifeld et al. (2009); Fließbach et al. (2007)).

	Soil management system							
	BIODYN		BIOORG		CONFYM		CONMIN	NOFERT
Manure type	Composted FYM[a]	Slurry	Rotted FYM	Slurry	Stacked FYM	Slurry	-	-
Fertilization								
$CR^b 1 (LU^c ha^{-1})$	0.6	1.2	0.6	1.2	0.6	1.2	Unfertilized	-
CR 2	0.6	1.2	0.6	1.2	0.6	1.2	-	-
CR 3	0.7	1.4	0.7	1.4	0.7	1.4	-	-
CR 4	0.7	1.4	0.7	1.4	0.7	1.4	-	-
Mineral Fertilizer	-		Rockdust, K Magnesia		Mineral fertilizer as supplement		Only Mineral Fertilizer	-
Plant protection								
Weed control	Mechanical				Mechanical and herbicides			Mechanical
Disease control	Indirect methods				Chemical (thresholds)			Indirect methods
Insect control	Plant extracts, bio-control				Chemical (thresholds)			Plant extracts, bio-control
Special treatments	Bio-dynamic preparation		$CuSO_4$ in potatoes until 1991		Plant growth regulators			Bio-dynamic preparation

a: FYM = farmyard, b: CR = crop rotation, c: Livestock unit

Table 6: Plant residue input content, clay content and C-stock (Based on Leifeld et al. (2009)).

	NOFERT				CONMIN				BIDYN				BIOORG				CONFYM			
Plot number	5	39	55	95	6	40	56	96	12	46	50	90	18	28	68	84	24	34	62	78
Annual plant input[a] pre-1977	2.87	2.31	2.70	2.20	2.94	2.29	2.65	2.17	2.97	2.11	2.73	2.89	2.12	3.22	2.13	2.29	1.99	2.90	1.88	2.41
Mean plant residue input pre-1977	2.52				2.51				2.68				2.44				2.29			
Annual plant input[a] 1977-2004	0.99	0.89	0.93	1.33	1.22	1.42	1.30	0.96	1.41	1.37	1.61	1.28	1.35	1.30	1.28	1.38	1.57	1.61	1.59	1.65
Clay contents (1977)[b]	18.6	13.6	14.4	24.1	16.8	14.1	15.4	25.7	15.2	16.2	16.5	23.2	13.7	16.3	14.7	14.8	15.8	14.5	14.3	13.4
C-stock 1977 [a]	48.6	39.2	44.3	46.7	48.6	39.2	44.3	46.7	47.9	38.3	45.8	51.1	37.1	52.1	37.7	40	36.6	46.6	34.6	40.2
C-stock 2004 [a]	33.6	29.8	32.7	38.6	40.1	33.4	33.1	47.4	44.7	39.4	44	53.5	37.3	43.1	35.1	37.3	35.4	38.1	34.9	39.2

[a]: t C ha^{-1}, [b]: in the % unit

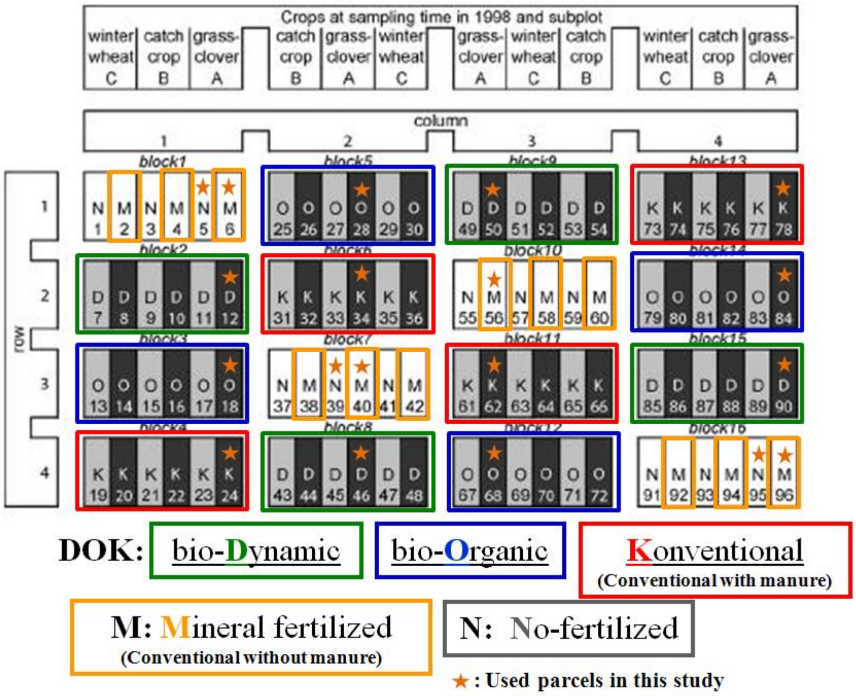


Figure 5: The site of DOK field experiment (Based on FiBL. et al. (2000); Fließbach et al. (2007))

aestivum, L.) and fodder intercrop for the second year, White cabbage (*Brassica oleracea, L.*) for the third year, Winter wheat 2 for the fourth year, Winter barley (*Hordeum vulgare, L.*) for the fifth year, Grass-clover 1 (STM330 °)for the sixth year and Grass-clover 2 for the seventh year. The second crop rotation (1985-1991) was replaced of White cabbage in the first one by Beetroots (*Beta vulgaris, L.*). The third crop rotation (1992-1998) was the same as the second one. The fourth crop rotation (1998-2004) involved replacing Grass-clover 1 (STM430 °) in the second and third crop rotation by Soybean (*Glycine max(L.) Merr.*); and Grass-clover 2 in the second and third crop rotation was replaced by Silage maize (*Zea mays, L.*) as shown in Table 7).

2.1.2 Applied climate data sets

From 1977 to 2004 Since 1977, the monthly climate data concerning daily temperature (°C) and precipitation (mm) was measured in the Basel-Binningen MeteoSwiss station. MeteoSwiss calculated the daily evapotranspiration (ET) by the Equation 1, Equation 2, Equation 3 and Equation 4 which were reported in Mdaghri-Alaoui and Eugster (2001).

$$A = -0.12 + 0.00306h - 2.83 * 10^{-6} * h^2 + 9.45 * 10^{-10} * h^3 \tag{1}$$

where h represents the elevation of the site.

$$B = 0.5387 - 0.0003263h - 6.525 * 10^{-7} * h^2 \tag{2}$$

Table 7: Crop rotation details for four cycles (based on Fließbach et al. (2007); Leifeld et al. (2009)

Years of the crop rotation	CR 1 1978-1984	CR 2 1985-1991	CR 3 1992-1998	CR 4 1999-2005
1	Potatoes (*Solanum tuberosum, L.*) Green manure	Potatoes Green manure	Potatoes	Potatoes
2	Winter wheat 1 (*Triticum aestivum, L.*) Fodder intercrop	Winter wheat 1 Fodder intercrop	Winter wheat 1 *Sunflower/vetch catchcrop*	Winter wheat 1 *Sunflower/vetch catchcrop*
3	White cabbage (*Brassica oleracea, L.*)	Beetroots (*Beta vulgaris, L.*)	Beetroots	Beetroots
4	Winter wheat 2	Winter wheat 2	Winter wheat 2	Winter wheat 2
5	Winter barley (*Hordeum vulgare, L.*)	Winter barley	Grass-clover 1 (STM430 °[a])	Soybean (*Glycine max(L.)Merr.*)
6	Grass-clover 1 (STM330 °[b])	Grass-clover 1 (STM330 °)	Grass-clover 2	Silage maize (*Zea mays, L.*)
7	Grass-clover 2	Grass-clover 2	Grass-clover 3	Grass-clover 1 (STM430 °)

[a]STM430 °: *Trifolium pratense* L. 3%;*Trifolium repens* L. 11%; *Dactylis glomerata* L. 14%; *Festuca rubra* L. 8%; *Phleum pratense* L. 8%; *Lolium.perennne* L. 28%; *Poa pratensis* L. 28%

[b]STM330 °: *T. pratense* L. 9%; *T. repens* L. 12%; *D. glomerata* L. 15%; *Festuca pratensis* HUDS. 36%; *P.pratense* L. 8%; *L.perennne* L. 18%

$$C = -0.5068 * sin(\frac{2\pi}{365}DOY + 0.5593) - 0.0711 * sin(\frac{4\pi}{365}DOY + 0.6112) + 0.6271 \quad (3)$$

where DOY represents the day of the year.

$$ET = C\left[A\frac{103 - RH}{100}(t_s + 2t_p) + B\right] \quad (4)$$

where ET (mm) was measured during the period of t_p days. RH represents the relative humidity (%) and t_s represents the total duration of hours of sunshine duration.

Campbell and Norman (1998) calculated ET with daily measured global radiation (GR) and T.

In this calculation, as I missed GR data from 1977 to 1980, I calculated daily and monthly GR from 1977 to 1980 from the relationship between measured GR and sunshine duration (SD) from 1981 to 2009.

However, I do not have any future climate scenario for GR and SD. Therefore, I did not use this equation for calculation of ET in this study.

Instead, I took the daily and monthly ET 1977-2004 from the relationship between measured temperature (T) and ET data which is calculated by MeteoSwiss from January 1980 to December 2009 (Equation 5)[5].

$$ET = 0.0019^{*}T^3 + 0.085^{*}T^2 + 1.2T + 2.4 \quad (5)$$

I performed some regressions of monthly data of ET and T, and ET and GR, and it appears that the relationship between ET and T is sufficiently to be used meaningfully in this study (Figure 6). As I lack GR data from 1977 to 1980 and for the future GR scenario, the regression relationship between ET and T for calculating ET was taken (Equation 5), while the relationship between ET and GR was not investigated further.

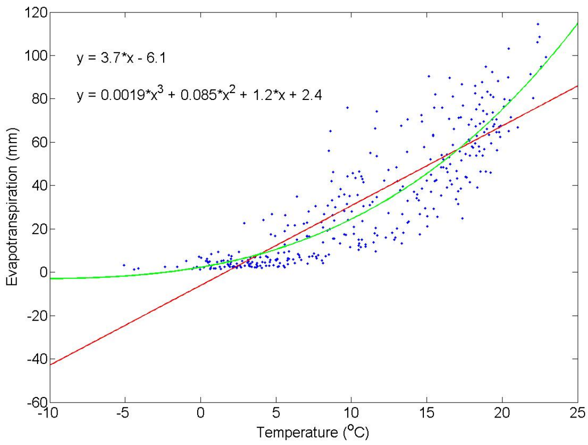


Figure 6: Regression of monthly temperature and monthly evapotranspiration

I compare the regression relationship between monthly ET data in this study and monthly ET data

[5] T is temperature.

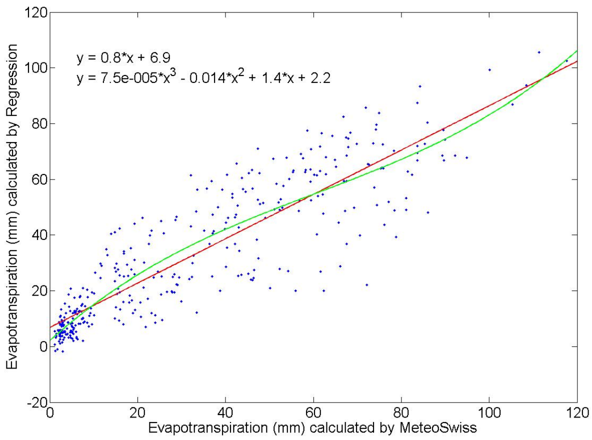


Figure 7: Regression of monthly evapotranspiration between MeteoSwiss and this study

from MeteoSwiss. In the regression based on monthly ET data sets, I find a much better correlation between them (Figure 7). I also took the multiple linear regression: T and P for calculating ET.[6] This is because calculating ET by applying a regression between T and ET often underestimates monthly ET. However, monthly ET often become negative by this multiple linear regression (even if it does not become negative with the regression relationship between ET and T). Therefore, I used the regression relationship between ET and T for calculating the ET in this study (Equation 5).

The climate of the site is relatively dry and the mean precipitation is 791mm per year and mean annual T for the period 1864-2007 is 9.7 °C (Leifeld et al. (2009)). From 1977 to 2004, the gradient of best fit line for temperature, precipitation and evapotranspiration are 0.07 (^{o}C year^{-1}), 0.24 (mm year^{-1}) and 0.39 (mm year^{-1}) respectively. These gradients show that the climate change tendency from 1977 to 2004 is increasing temperature, precipitation and evapotranspiration. For simulation 1, I used the monthly averaged weather data for every plot and ever year: monthly mean temperature (°C), monthly mean precipitation (mm) and the monthly ET (Table 2) which were measured at the MeteoSwiss station in Basel-Benningen. Therefore, no climate change impact is considered in this simulation.

In simulation 2, I used the actual past monthly weather data for temperature and precipitation which was collected at the nearby weather station of the MeteoSwiss in Basel-Binningen (Figure 8 and Figure 9). Regarding the ET data, I used Equation 5 with the measured temperature data in Basel-Binningen (Figure 10).

From 2005 to 2050 For estimating future weather, I used the future climate scenario in OcCC (2007). OcCC (2007) reports the predicted temperature and precipitation changes in North and South Switzerland in 2030, 2050 and 2070, and compares these figures with averaged temperature and precipitation from 1961 to 1990. In this study, the future climate scenario for the North Switzerland is applied. Regarding the temperature, it represents the expected rise in temperature in 2050 relative to

[6]The equation of multiple linear regression of monthly T and monthly P for monthly ET is ET = 0.1299 + 3.7151*T - 0.1340*P + 0.0035*T*P

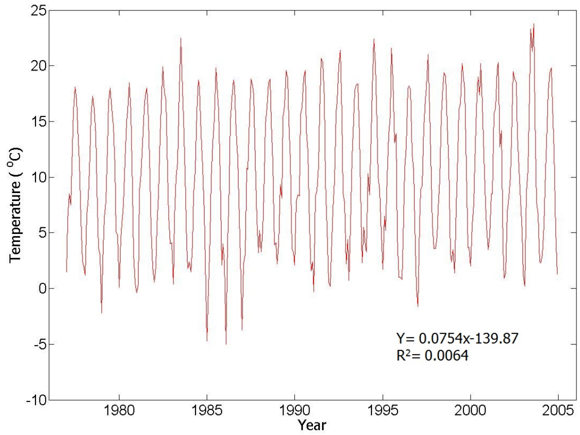


Figure 8: Monthly Temperature 1977-2004

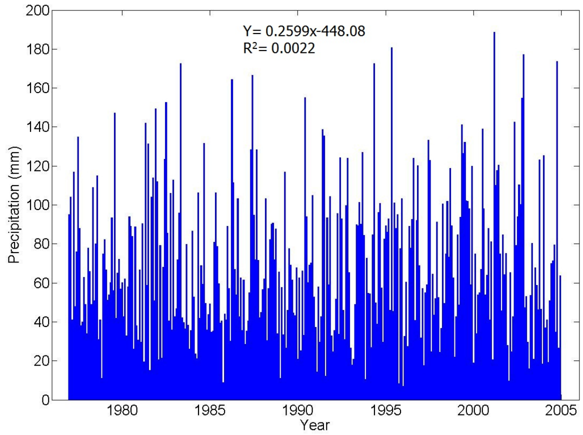


Figure 9: Monthly Precipitation 1977-2004

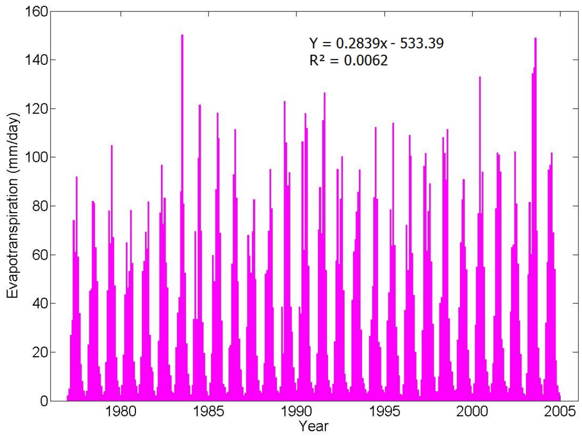


Figure 10: Monthly Evapotranspiration 1977-2004

averaged temperature from 1961 to 1990. Regarding the precipitation, it represents the percentage of precipitation expected in 2050 relative to averaged precipitation from 1961 to 1990 (Table 8). In this study, as I miss weather data from 1961 to 1976, I used the average weather data at the MeteoSwiss station in Basel-Binningen from 1977 to 2004 (Table 2) as the relative weather data for simulating the future weather data with the future climate scenario in OcCC (2007).

Table 8: OcCC (2007) future climate scenario

		D,J,F	M,A,M	J,J,A	S,O,N
Temperature (^{o}C)	2050	1.8	1.8	2.7	2.1
Precipitation (%)	2050	1.08	0.99	0.83	0.94

Months are represented by letters. e.g. D = December

In this study, the future climate scenario for 2050 was applied for 2005-2050. I lack weather data in Basel-Binningen from 1961 to 1976 as the relative weather data for this future climate scenario, and so I used averaged climate data from 1977 to 2004 in Basel-Binningen (which is used for simulation 1 in this study) as the average temperature and precipitation values (Table 2). Regarding temperature, I divided expected temperature rise (^{o}C)(future climate scenario 2050) by 45 years for the future climate scenario for 2050. Then, I added an expected increment for each month and each year for 2005-2050. In this way, I make a linear interpolation between 2005 and 2050 with the highest temperatures corresponding to 2050.

For example, scenario 2050 in OcCC (2007) indicates the temperature in December will rise 1.8 (^{o}C) relative to averaged temperature from 1961 to 1990 (Table 8). In this study, I used averaged weather data from 1977 to 2004 as the relative weather data for simulating future climate data. Then, I divided 1.8 (^{o}C) per 45 years and added it to the averaged temperature data in December for 45 years (2005-2050). Therefore, the expected temperature in December 2005 in this study is 2.84 (^{o}C) (See Equation 6).

$$\frac{1.8(^oC)}{45(year)} + 2.8(^oC) = 2.84(^oC) \tag{6}$$

Regarding precipitation, at first, I calculated expected precipitation in 2050 by using the future climate scenario relative to averaged precipitation from 1977 to 2004. I divided the difference of precipitation between in 2050 and relative precipitation by 45 years. Then, I added this divided difference in each month for each year, to implement a linear interpolation between 2005 and 2050.

For example, scenario 2050 indicates that the precipitation in December will increase 1.08 percent relative to averaged precipitation from 1961 to 1990 (Table 8). Therefore, expected precipitation in December in 2050 in this study is 66.74 mm (See Equation 7).

$$61.8(mm) * 1.08 = 66.7(mm) \tag{7}$$

Then, I divided the difference between expecting precipitation in 2050 and relative precipitation by 45 years (See Equation 8).

$$\frac{66.7(mm) - 61.8(mm)}{45(year)} = 0.11(mm) \tag{8}$$

The result of Equation 8 is added to each year for 45 years. Therefore, the expected precipitation in December 2005 in this study is 61.91 mm (See Equation 9).

$$61.8(mm) + 0.11(mm) = 61.91(mm) \tag{9}$$

ET was calculated by Equation 5 using the expected temperature which was calculated with future climate scenario. The expected climate data from 2005 to 2050 in this study are shown in Figure 11, Figure 12 and Figure 13.

2.2 Model

2.2.1 RothC model

For simulating SOC, I used the Rothamsted Carbon Model (RothC model: Coleman and Jenkinson (1996)). The RothC model is one of the leading SOM turnover models and is widely used worldwide

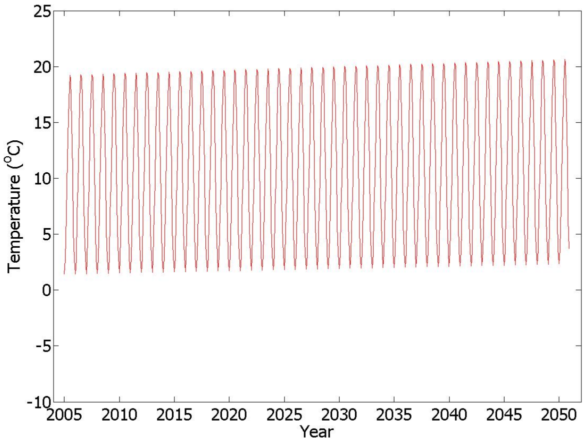


Figure 11: Monthly simulated temperature 2005-2050

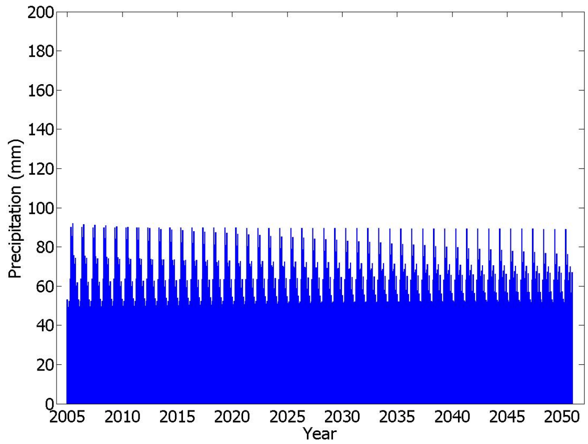


Figure 12: Monthly simulated precipitation 2005-2050

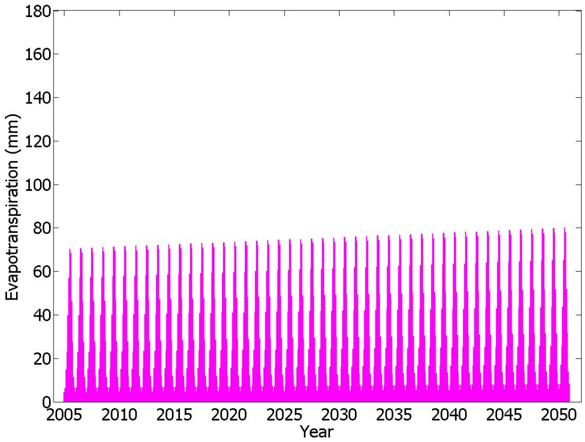


Figure 13: Monthly simulated evapotranspiration 2005-2050

(for some applications, see Smith et al. (1997); Parshotam et al. (2001); Ludwig et al. (2005); Shirato et al. (2005); Shirato and Yokozawa (2006); Lugato et al. (2007); Zimmermann et al. (2007)). This model has been applied to sites with diverse agricultural management systems. An advantage of the RothC model is the small number of parameters needed to initialize the model (Zimmermann et al. (2007)). Furthermore, the RothC model has a simpler structure than other models, and the few input parameters in the RothC model are easily obtainable. It has the advantage of being testable with existing datasets and applicable over a wide area (Shirato et al. (2005)).

The RothC model contains five components of soil organic matter (SOM), including two plant litter components (Decomposable Plant Material (DPM) and Resistant Plant Material (RPM)) and three other soil organic carbon pools (Microbial Biomass (BIO), Humified Organic Matter (HUM), Inert Organic Matter (IOM), See Figure 14. IOM is defined as inert organic matter with a radiocarbon age of 50,000 years. The plant material (DPM and RPM) is decomposed to CO_2 (lost from the system), microbial biomass (BIO) and humified organic matter (HUM) depending on the clay content (Jenkinson (1990); Zimmermann et al. (2007)). BIO and HUM are decomposed again to CO_2, BIO and HUM. The decomposition rate changes, depending on temperature, moisture and degree of soil cover. In the RothC model, the carbon is lost as CO_2, and the Inert Organic Matter (IOM) pool is resistant. SOC in agricultural soil management systems is influenced by organic matter additions, fertilization, irrigation and crop rotation (Stewart et al. (2007)).

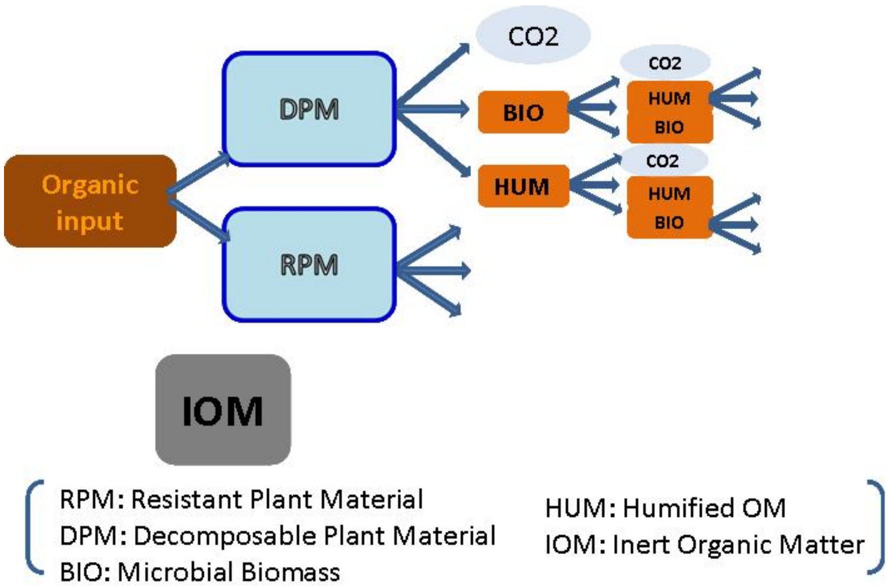


Figure 14: RothC model (Based on Coleman and Jenkinson (1996))

Soil pools For simulating the RothC model, I need each soil pool's quantity (DPM, RPM, BIO, HUM and IOM) at the starting point. In simulations 1-1 and 1-2, I used measured and simulated values for the SOM pool's content (in t C ha^{-1} units) in November 2004 as the initial SOM pools content.

I got the "simulated SOM pools content" values from simulation results for 1977 to 2004, following Leifeld et al. (2009).

The "measured SOM pools content" values were taken from Leifeld et al. (2009). They measured SOM pools content by the method of Zimmermann et al. (2007). More details can be found in the illustration in Figure 15 and Figure 16.

In this method, 30 grams of the soil (sieved less than 2 mm) were added into 150 ml water and scattered using a calibrated ultrasonic probe-type instrument with output-energy of 22 J/ml. This suspension was sieved over a 63 μm hole sieve until the water became clear. After drying at 40 °C and weighing, the fraction left in the sieve (> 63 μm) contains sand and stable aggregates (S+A) and particulate organic matter (POM). POM was separated by stirring sieve contents (more than 63 μm) with sodium polytungstate at a density of 1.8 g/cm. The fraction which is less than 63 μm was strained through the 0.45 μm hole nylon mesh and the fraction which is less than 0.45 μm was dried at 40 °C and weighed. This fraction is called dissolved organic carbon (DOC). The fraction between 0.45 μm and 63 μm are silt and clay (s+c). s+c was oxidized by NaOCl (6 %, 60 g/l) to extract resistant soil organic carbon (rSOC). 1 g of s+c was oxidized for 18 hours at 25 °C with 50 ml of 6 %

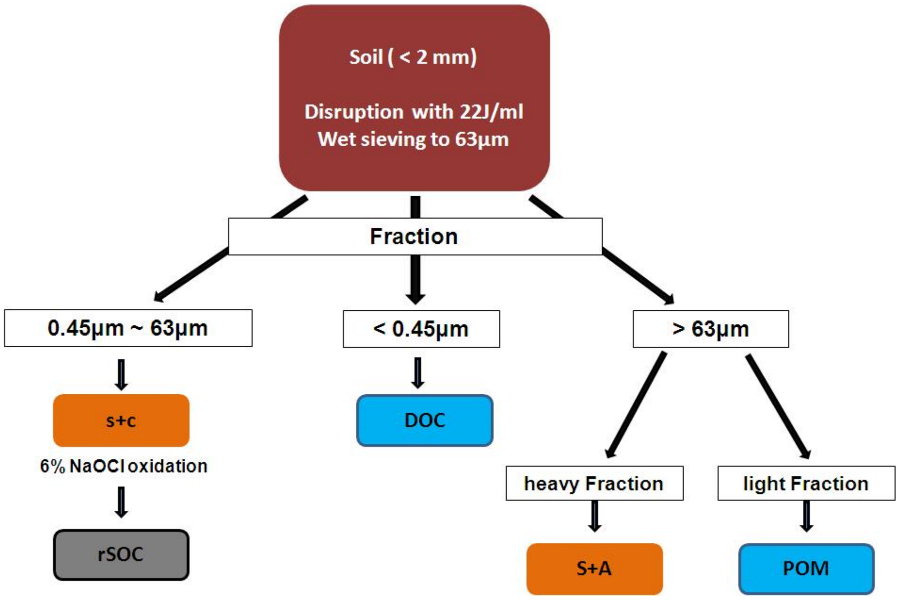


Figure 15: SOM fractionation process (Based on Zimmermann et al. (2007))

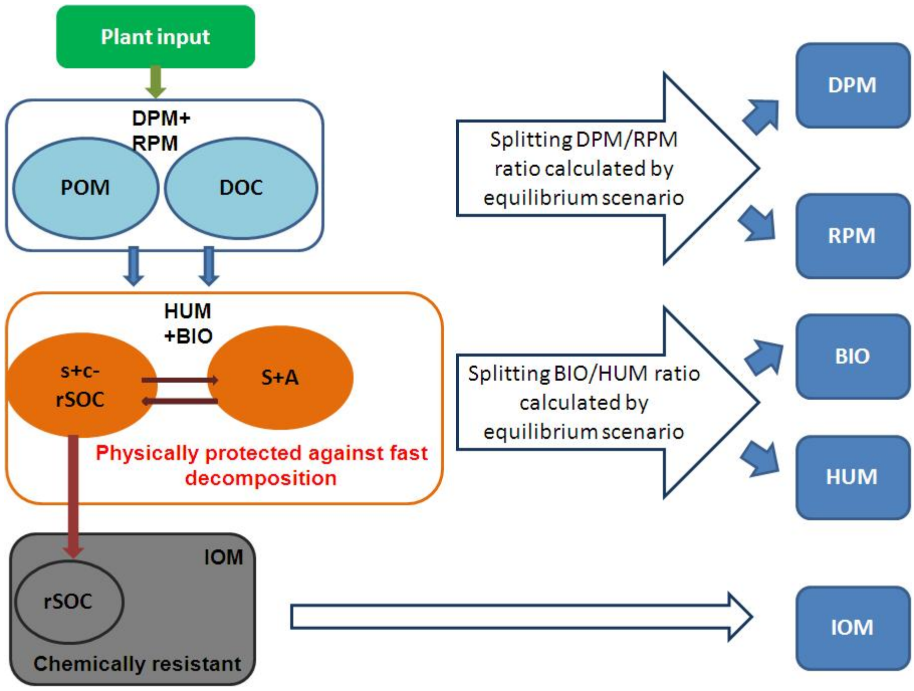


Figure 16: Summarizing and splitting SOM pools from SOM fractions (Based on Zimmermann et al. (2007))

NaOCl adjusted to pH 8 with concentrated HCL. This oxidation process was repeated twice (Figure 15, Zimmermann et al. (2007)).

In the RothC model, SOM is separated into five pools (See Figure 14). At first, most of the plant materials were subdivided into DPM and RPM. At the same time, plant debris in soil can be found in the POM fraction, and most of the POM and DOC can be decomposed to CO_2. So, Zimmermann et al. (2007) compared the SOC values in POM and DOC with SOC values of DPM and RPM pools. In the RothC model, stabilized SOM is HUM and this is decomposed by the microbial biomass. In the measurement process, the s+c and the S+A fractions are physically protected against fast decomposition. This being so, Zimmermann et al. (2007) compared the SOC values in s+c and S+A fractions (but without the rSOC fraction) with those of HUM and BIO pools. BIO is in the fraction less than 63 μm. The rSOC fraction which derives from the s+c fraction is not decomposed by microbes and this is compared with the IOM pool. In this method, the sum of SOC in POM and DOC fractions should be divided according to the ratio between DPM and RPM pools, which can be obtained by the RothC model for equilibrium conditions. The same method was used for dividing s+c and S+A fractions into BIO and HUM pools (Figure 16).

2.3 Statistical software

I used Matlab®R2009a for statistical analysis.

2.4 Simulation

The RothC model was used to simulate soil carbon content change over time for the different soil management systems in this study (See also Table 1).

In simulation 1-1, I simulated SOC change for different initial SOM pools contents. This was done by basing the simulation on both measured and simulated values for the SOM fractions content (in t C ha^{-1} units) in November 2004 (explained more in Section 2.2.1). In this simulation, the baseline climate condition was the average climate condition for the period 1977-2004. I applied averaged plant residue and manure input amount from 1977 to 2004 for each month in this simulation.

In simulation 1-2, I simulated how many years it takes to reach the equilibrium point of SOC (the point of "input organic carbon content = output organic carbon content") with the amount of plant residue and manure inputs which were applied until 1977. This was also done by basing the simulation on both measured and simulated values for the SOM fractions content (in t C ha^{-1} units) in November 2004, using the average climate condition for the period 1977-2004 as the baseline climate data. I applied averaged plant residue and manure input amount from 1977 to 2004 for each month in this simulation.

In simulation 2, I simulated SOC change with actual past weather data at the MeteoSwiss station in Basel-Benningen from 1977 to 2004. Regarding the plant residue and manure input, I calculated the average of measured plant residue and manure input content about each month for 27 years (1977-2004) for each plot and added this average plant residue and manure input content in each month (See Table 3 and Table 4). The different type of manures were not considered in this simulation.

In simulation 3, I simulated the SOC change after introducing future climate change and varying the distribution of the SOM fraction from 2005 to 2050. For estimating the future climate data, I used the future climate scenario of OcCC (2007). In this simulation, I applied the same amount of plant residues and manure input which were applied in simulation 2.

In simulation 4, I simulated the SOC content change under averaged weather data from 1977 to 2004 which was measured at the MeteoSwiss station in Basel-Benningen (Table 2) with initial SOC content in 1977. I did this simulation from 1977 to 2050. Then, I compared the result of SOC change under averaged weather data from 1977 to 2004 (under no climate change) and the result of SOC change in simulations 2 and 3. This simulation was undertaken in order to estimate the climate change effect on SOC content change for each soil management system, and to find an appropriate soil management system under future climate change conditions.

2.4.1 SOC change with a high amount of plant residue input which has been applied until 1977 (Simulation 1)

The difference of SOC change between the "simulated SOM pools content" simulation and "measured SOM pools content" simulation (Simulation 1-1) With the RothC model and DOK field experiment data sets, I compared the SOC change between two simulation management systems: the simulation with simulated SOM pools content in November 2004 (management "simulated SOM pools content") and the simulation with measured SOM pools content in November 2004 (management "measured SOM pools content"). In this simulation, I applied the amount of plant residue and manure input which were applied until 1977. The aim of this simulation is to study the importance of the initial SOC content on the SOC change about each different soil management systems. For removing climate effects on SOC change, I used average climate data from 1977 to 2004 as the baseline climate condition in the model which includes no climate change impact.

The equilibrium point of SOC content based on measured and simulated distributed organic fraction content (Simulation 1-2) This simulation was done to determine how many years it takes to reach the equilibrium point of SOC (the point where input organic carbon content = output organic carbon content) with a high amount of carbon input which has been applied until 1977 (see Table 6). The management system which arrives at the equilibrium point of SOC faster is the management system which is easier to recover from the depleted carbon condition (i.e. where input organic carbon content < output organic carbon content). Regarding the initial content of SOM fractions, I used the measured and simulated values (in t C ha^{-1} units) in November 2004. For the "measured SOM pools content", I used the content of SOM pools measured as given in Leifeld et al. (2009)(Figure 15 and Figure 16). The "simulated SOM pools content" comes from the simulation of the RothC model from January 1977 to December 2004 which is also given in Leifeld et al. (2009). In this simulation, I also used average climate data from 1977 to 2004 as the baseline climate condition in the model which includes no climate change impact.

The aim of this simulation (simulation 1-1 and 1-2) is to investigate two points:

1. The effect of each soil management system on SOC change over time.

2. Which soil management system has more capability to recover from the depleted SOC condition.

2.4.2 SOC change with actual weather data from 1977 to 2004 (Simulation 2)

In this simulation, I used the RothC model for simulating the SOC content change over time. As input data, I used the actual weather data from 1977 to 2004 at the MeteoSwiss station in Basel-Binningen. Regarding the applied plant residue and manure input content, I applied the average of measured content of each month for 27 years (1977-2004). The average plant residue and manure input content was calculated for each plot (Table 3 and Table 4).

The initial SOM fraction content was the measured SOC fraction content in 1977. I did not consider the differentiation of manure types in this study.

For simulating the future SOC change under conditions of climate change, I have to apply the averaged plant residue and manure input content, because I do not know the real plant residue and manure input content in the future. Therefore, I do the 1977-2004 SOC change simulation with the averaged plant residue and manure input content, even if Leifeld et al. (2009) already reported a similar simulation: 1977-2004 SOC change at the Therwil site with real plant residue and manure input content. Details on the differences between this study and Leifeld et al. (2009) can be found in the Introduction.

The aim of this simulation is:

1. To know the importance of the climate change effect and the soil management effect on SOC change over time.

2. To evaluate the accuracy of the simplistic simulations undertaken in this study, by comparing the results with those in Leifeld et al. (2009).

3. Comparing the result of this simulation and the SOC change without climate change from 1977 to 2004 in simulation 4.

2.4.3 SOC change with expected future weather data from 2005 to 2050 (Simulation 3)

In this simulation, simulated SOC changes under the expected future climate data when the future climate scenario in OcCC (2007) is used. The details of concerning the creation of this future climate data are explained in Section 2.1.2. Plant residue and manure input content, in this simulation, are the averaged content from 1977 to 2004 as in the other simulations. The initial SOC content was the simulated SOC content in 2004 in simulation 2. This is because there will be no gap between the final SOC content in simulation 2 and the initial SOC content in simulation 3, then it is easier to compare a simulation result with and without climate change from 1977 to 2004.

The aims of this simulation are:

1. To know the importance of future climate change effects on SOC change by comparing the result of this simulation and the SOC change without any climate change scenario in the future.

2. To know the importance of the effect of soil management on SOC change under future climate change.

2.4.4 SOC change from 1977 to 2050 with and without climate change (Simulation 4)

In this simulation, I investigated SOC change for each soil management system in two different climate conditions: with climate change (real climate change from 1977 to 2004 and expected climate change from 2005 to 2050) and without climate change (under averaged weather data from 1977 to 2004).

The aims of this simulation are:

1. To know the importance of climate change effects on SOC change by comparing SOC change with climate data which include measured past weather data and expected future weather data and the SOC change without any climate change scenario.

2. To know the important of soil management effect on SOC change under future climate change conditions.

3. To discuss the ideal soil management system under climate change.

3 Result

3.1 Simulation 1

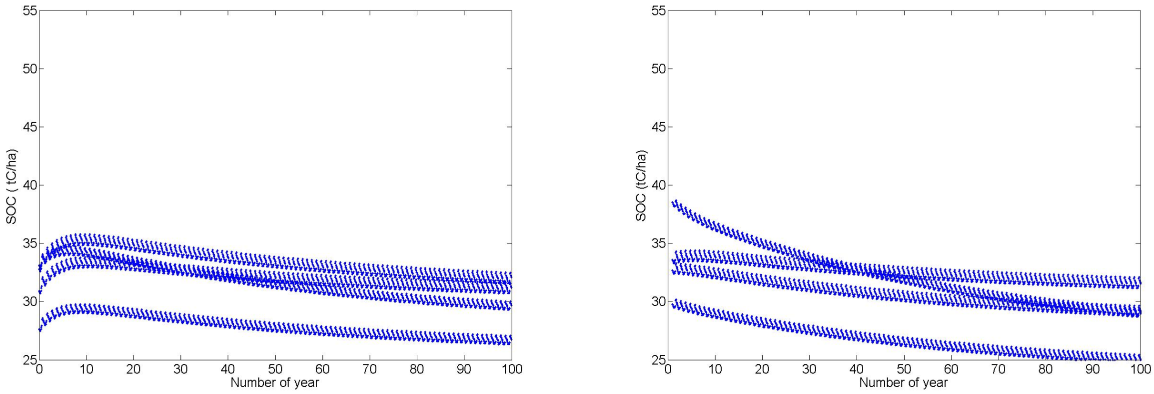
The initial SOM pool sizes are the simulated SOM pools content in November 2004 (denoted "simulated SOM pools content") and the measured SOM pools content in November 2004 (denoted "measured SOM pools content") for each plot. Plant residue input and manure input content are the high amounts which were applied until 1977.

3.1.1 Simulation 1-1

In Figure 17(a), which is the "simulated SOM pools content" simulation of the NOFERT management system, the SOC content increases at the beginning, then it decreases gradually afterwards. However, the NOFERT management system shows a similar tendency in SOC change in the "simulated SOM pools content" simulation and in the "measured SOM pools content" simulation (Figure 17(a) and Figure 17(b)). In this simulation, SOC content decreases only for the NOFERT management system. This is because the NOFERT management system is the control management system, and so I did not input any plant residue and manure input.

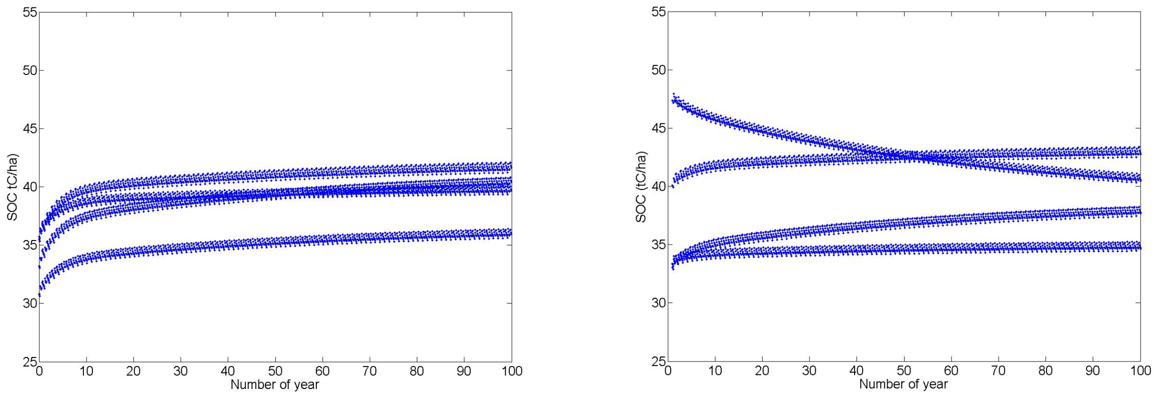
In the CONMIN management system, I do not find any big difference between "simulated SOM pools content" simulation and the "measured SOM pools content" simulation.

In the BIODYN management system, I can observe a large difference between the "simulated SOM pools content" simulation and the "measured SOM pools content" simulation. In the "measured



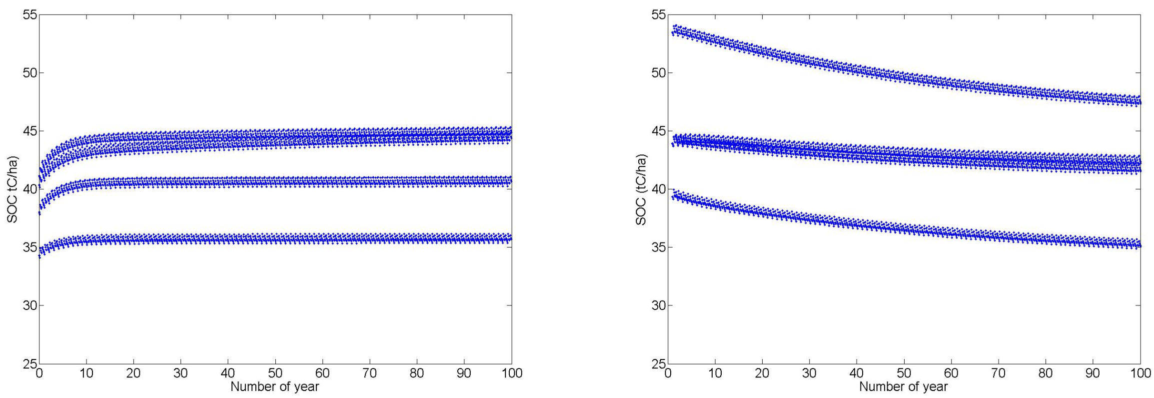
(a) With simulated initial SOM pools content (b) With measured initial SOM pools content

Figure 17: NOFERT management SOC change with simulated and measured initial SOM pools content under averaged climate data from 1977 to 2004



(a) With simulated initial SOM pools content (b) With measured initial SOM pools content

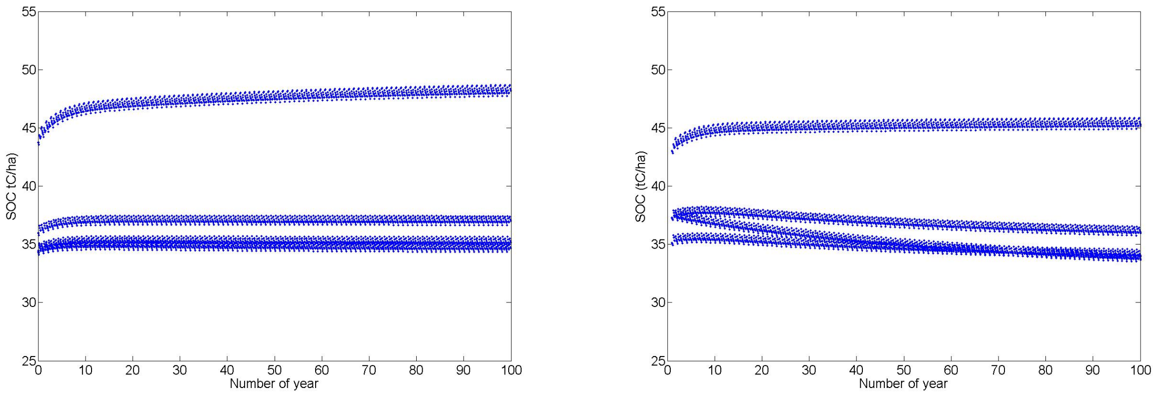
Figure 18: CONMIN management SOC change with simulated and measured initial SOM pools content under averaged climate data from 1977 to 2004



(a) With simulated initial SOM pools content (b) With measured initial SOM pools content

Figure 19: BIODYN management SOC change with simulated and measured initial SOM pools content under averaged climate data from 1977 to 2004

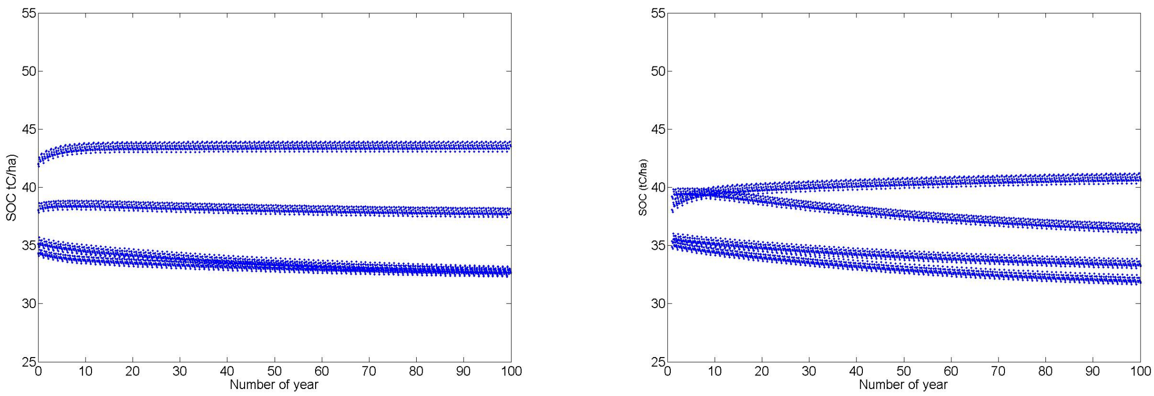
SOM pools content" simulation, every plot shows decreasing tendencies and the initial SOC was much higher than the simulated one (Figure 19(a) and Figure 19(b)).



(a) With simulated initial SOM pools content (b) With measured initial SOM pools content

Figure 20: BIOORG management SOC change with simulated and measured initial SOM pools content under averaged climate data from 1977 to 2004

In the BIOORG management system, I do not find any big difference between "simulated SOM pools content" simulation and the "measured SOM pools content" simulation.



(a) With simulated initial SOM pools content (b) With measured initial SOM pools content

Figure 21: CONFYM management SOC change with simulated and measured initial SOM pools content under averaged climate data from 1977 to 2004

In the CONFYM management system, I do not find big any difference between "simulated SOM pools content" simulation and the "measured SOM pools content" simulation.

In general, plots which contain a high initial SOC content, decrease their SOC content over time and reach a similar amount of SOC content as that observed for the other plots (Figure 18(b) and Figure 19(b)). Furthermore, at the end of the simulation (in 100 years), the SOC contents of the "simulated SOM pools content" simulation and the "measured SOM pools content" simulation are similar for each soil management system. In this simulation, if the initial SOC contents are similar, then the SOC change tendencies are also similar over time. As the plant residue and manure input amounts are high, SOC contents tend to increase (except NOFERT management system). The initial SOC contents are often underestimated by the RothC model. In particular, concerning some plots in the CONMIN and BIODYN management systems, the initial SOC content is considerably underestimated when compared with the measured SOC content (Figure 18(a) and Figure 19(a)).

From these simulation results, using different values for initial SOC content possibly leads to different SOC change over time in the RothC model, because the initial values are important for subsequent SOC change in the RothC model.

3.1.2 Simulation 1-2

In this simulation, I analyzed the equilibrium point for each soil management system. The equilibrium point of SOC change is the point where input organic carbon content equals output organic carbon content. Therefore, the soil management system which arrives earlier at this equilibrium point is the management system which recovers the soil carbon content faster.

Table 9 shows the SOC change over time with a high amount of plant residue and manure input in the "simulated initial SOM pools" simulation for each soil management system. In the NOFERT management system, three out of four plots arrive at the equilibrium point within around 90 years. One plot does not arrive at the equilibrium point even after 100 years. In the CONMIN management system, two plots arrive at the equilibrium point within around 30 years, but the other plots arrive at the equilibrium point after 70 years. On the other hands in the BIODYN, BIOORG and CONFYM management systems, almost all of the plots arrive at the equilibrium point after around 10 to 20 years.

Table 10 shows the SOC change over time with a high amount of plant residue and manure input in the "measured initial SOM pools" simulation for each soil management system. In the NOFERT management system, the results show are similar to those obtained from the "measured initial SOM pools" simulation. The equilibrium point is at around 90 years. In the CONMIN management system, one plot arrives at the equilibrium point after 60 years. Regarding the other plots, it is difficult to define the equilibrium point as SOC contents change continuously. In the BIODYN management system, almost all of the plots arrive at the equilibrium point after 90 years. In the CONFYM management system, the equilibrium point is around at around 70 years. In the BIOORG management system, the equilibrium point can be observed slightly earlier than results of the other organic farming management systems. The equilibrium point is at around 60 years.

These results shows that soil management systems, which include organic farming systems, have more capacity to recover the soil carbon content than soil management systems which do not include organic farming systems. The initial SOC content has a large effect on the SOC recovery capacity in organic farming systems.

3.2 Simulation 2

The simulation results for SOC change from 1977 to 2004 for each soil management system, with measured weather data in Basel-Binningen, are in Figure 22(a) - Figure 22(e).

The NOFERT and CONMIN management systems (Figure 22(a) and Figure 22(b)) show similar tendencies for change in SOC content over time. In these figures, SOC content is decreasing sharply

Table 9: SOC change over time with high amount of plant residue and manure input in the "simulated initial SOM pools" simulation

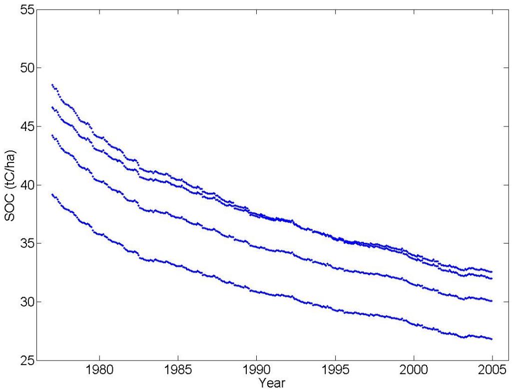
	NOFERT				CONMIN				BIODYN				BIOORG				CONFYM			
Plot Nr.	5	39	55	95	6	40	56	96	12	46	50	90	18	28	68	84	24	34	62	78
Initial	32.8	27.7	30.9	33.2	35.6	30.9	33.3	35.8	40.4	34.4	38.1	41.2	34.4	43.8	34.5	36.1	35.2	42.1	34.4	38.2
In 10 years	35.3	29.5	33.5	34.3	39.7	33.8	37.4	38.6	43.0	35.5	40.4	44.1	34.9	46.6	35.2	37.0	34.6	43.4	33.7	38.5
In 20 years	34.9	29.1	33.2	33.6	40.2	34.4	38.2	39.0	43.4	35.6	40.5	44.4	34.9	47.1	35.2	37.0	34.2	43.4	33.5	38.3
In 30 years	34.3	28.6	32.8	32.8	40.7	34.8	38.7	39.2	43.8	35.8	40.7	44.6	34.9	47.5	35.3	37.1	34.0	43.6	33.4	38.4
In 40 years	33.9	28.2	32.5	32.1	40.8	35.0	39.0	39.3	43.8	35.7	40.6	44.6	34.8	47.5	35.2	37.0	33.6	43.5	33.2	38.1
In 50 years	33.4	27.9	32.2	31.6	41.0	35.2	39.3	39.4	43.9	35.7	40.6	44.7	34.8	47.7	35.2	37.0	33.4	43.5	33.0	38.1
In 60 years	33.0	27.6	31.9	31.1	41.2	35.4	39.6	39.4	44.1	35.7	40.6	44.7	34.7	47.8	35.2	37.0	33.2	43.5	32.9	38.0
In 70 years	32.7	27.3	31.7	30.6	41.3	35.6	39.9	39.5	44.2	35.7	40.6	44.8	34.7	47.9	35.2	37.0	33.1	43.5	32.8	37.9
In 80 years	32.5	27.1	31.5	30.3	41.4	35.7	40.1	39.6	44.2	35.7	40.6	44.8	34.7	48.0	35.2	37.0	32.9	43.5	32.7	37.9
In 90 years	32.2	26.9	31.4	30.0	41.6	35.8	40.2	39.6	44.3	35.7	40.6	44.8	34.7	48.1	35.2	37.0	32.8	43.5	32.7	37.8
In 100 years	32.1	26.9	31.3	29.0	41.8	36.1	40.5	39.6	44.5	35.8	40.8	45.5	34.8	48.4	35.3	37.1	32.8	43.7	32.7	37.9

Blue: SOC change is 0.1 (t C ha^{-1}), Red: No SOC change

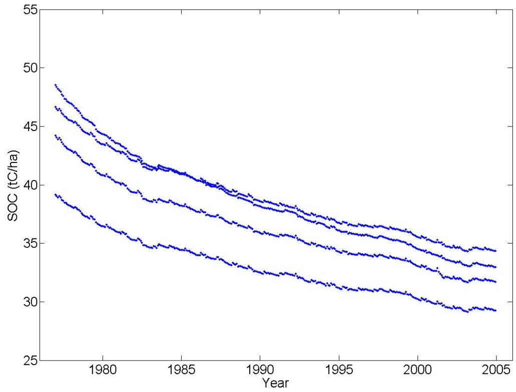
Table 10: SOC change over time with high amount of plant residue and manure input in the “measured initial SOM pools” simulation

	NOFERT				CONMIN				BIODYN				BIOORG				CONFYM			
Plot Nr.	5	39	55	95	6	40	56	96	12	46	50	90	18	28	68	84	24	34	62	78
Initial	33.6	29.8	32.7	38.5	40.1	33.4	33.1	47.4	43.9	39.4	43.9	53.5	37.3	43.0	35.1	37.2	35.4	38.1	34.9	39.2
In 10 years	33.8	28.9	32.4	36.3	41.7	34.1	35.0	45.6	44.0	38.5	43.6	52.6	36.7	44.7	35.4	37.7	35.1	39.6	34.3	39.2
In 20 years	33.4	28.1	31.8	34.9	42.0	34.2	35.6	44.6	43.7	37.8	43.3	51.6	36.1	44.9	35.1	37.4	34.7	39.8	33.9	38.7
In 30 years	33.1	27.5	31.3	33.7	42.2	34.3	36.1	43.8	43.4	37.3	42.9	50.8	35.6	45.0	34.9	37.1	34.4	40.0	33.5	38.3
In 40 years	32.8	27.0	30.8	32.7	42.3	34.4	36.4	43.1	43.2	36.8	42.6	50.1	35.2	45.1	34.7	36.9	34.2	40.2	33.1	37.8
In 50 years	32.5	26.5	30.4	31.8	42.4	34.5	36.8	42.5	43.0	36.4	42.4	49.4	34.9	45.1	34.6	36.7	34.0	40.3	32.8	37.5
In 60 years	32.3	26.1	30.1	31.1	42.5	34.6	37.0	42.0	42.8	36.1	42.2	48.9	34.6	45.2	34.4	36.5	33.8	40.4	32.6	37.2
In 70 years	32.1	25.8	29.8	30.4	42.6	34.6	37.3	41.5	42.7	35.8	42.0	48.4	34.3	45.2	34.3	36.4	33.6	40.5	32.3	36.9
In 80 years	31.9	25.5	29.6	29.9	42.7	34.7	37.5	41.1	42.5	35.5	41.8	48.0	34.1	45.2	34.2	36.2	33.5	40.6	32.2	36.7
In 90 years	31.7	25.2	29.4	29.4	42.8	34.7	37.6	40.8	42.4	35.3	41.7	47.7	33.9	45.2	34.1	36.1	33.4	40.6	32.0	36.5
In 100 years	31.7	25.1	29.2	29.8	42.9	34.8	37.9	40.0	42.4	35.2	41.7	47.1	33.8	45.4	34.1	36.9	33.3	40.8	31.9	36.4

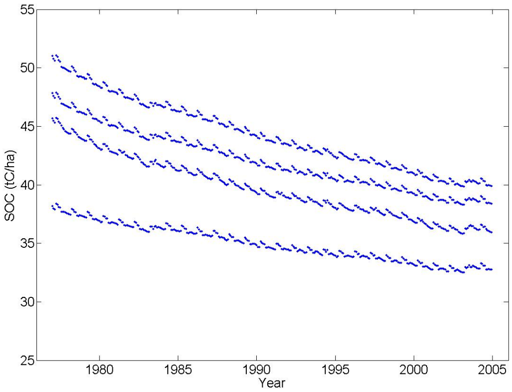
Blue: SOC change is 0.1 (t C ha^{-1}), Red: No SOC change



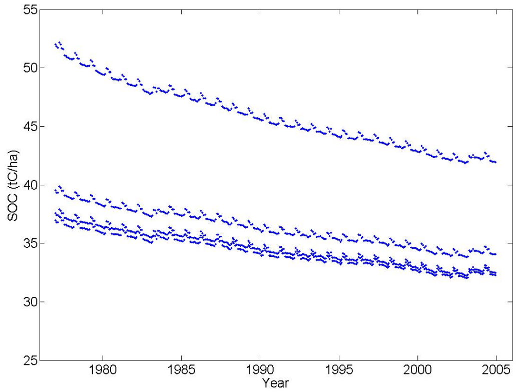
(a) NOFERT management



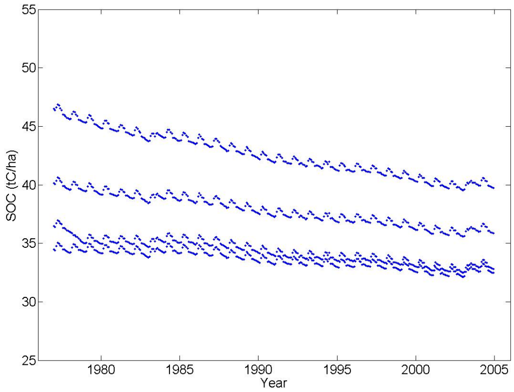
(b) CONMIN management



(c) BIODYN management



(d) BIOORG management



(e) CONFYM management

Figure 22: SOC change with measured weather data 1977-2004

and SOC content is not scattered over time. The initial SOC content is similar in the NOFERT and CONMIN management systems, but the final SOC content is lower in the NOFERT management system than in the CONMIN management system. In the BIODYN, BIOORG and CONFYM management systems (Figure 22(c), Figure 22(d) and Figure 22(e)), SOC contents are decreasing more gradually than in the NOFERT and CONMIN management systems. The initial SOC content is varied among the BIODYN, BIOORG and CONFYM management systems. However, the final SOC contents are similar in those three soil management systems. Among the BIODYN, BIOORG and CONFYM management systems, the differences in the soil management systems concern the amounts of plant residues applied in each month of the year. The same plant protection management programmes are applied to the BIODYN and BIOORG management systems. Slightly different plant protection managements programmes are applied to the CONFYM management system. However, there is no difference in the amount of plant residue applied from 1977 to 2004. The applied amount of manure is the same for the BIODYN, BIOORG and CONFYM management systems. Mineral fertilizers are applied also as a supplement to the CONFYM management system. Types of manure are not distinguished.

These results seem to show us that soil management systems with organic farming systems hold more stable SOC content in the soil and retain SOC in the soil better than no-organic farming soil management systems. However, the CONFYM management system shows the most moderate decreasing slope of SOC change over time. This does not mean that soil management systems with mineral fertilizers is ineffective at retaining SOC. Soil management systems with only mineral fertilizers are less effective in retaining SOC, but soil management systems combined with mineral fertilizers and organic farming systems seem to be the most effective soil management strategy with regard to the SOC content under recent climate change.

3.2.1 Reality of this simulation

I also examined the reality of simulation 2 by comparing it with the result of Leifeld et al. (2009) and measured SOC content in 2004 by the method of Zimmermann et al. (2007).

Table 11 shows the declining gradient of SOC change in each soil management system from 1977 to 2004 with climate change in this study and Leifeld et al. (2009).

Table 11: Comparison of the slope of SOC change (t C ha^{-1} $year^{-1}$) in this study (Nemoto) and Leifeld et al. (2009) 1977-2004

	NOFERT		CONMIN		BIODYN		BIOORG		CONFYM	
	Leifeld*	Nemoto	Leifeld	Nemoto	Leifeld	Nemoto	Leifeld	Nemoto	Leifeld	Nemoto
plot1	-0.50	-0.52	-0.39	-0.49	-0.22	-0.31	-0.10	-0.07	-0.04	-0.12
plot2	-0.37	-0.38	-0.25	-0.31	-0.11	-0.19	-0.26	-0.33	-0.13	-0.23
plot3	-0.42	-0.44	-0.33	-0.39	-0.22	-0.32	-0.11	-0.18	0.00	-0.08
plot4	-0.43	-0.45	-0.33	-0.40	-0.28	-0.37	-0.11	-0.19	-0.05	-0.15

* : Leifeld et al. (2009)

In this Table, the gradient of SOC change in this study is steeper than in the results of Leifeld et al. (2009). In the NOFERT management system, the gradients of this study and in Leifeld et al.

(2009) are similar. In the other management systems, there are differences between 0.06 and 0.1 (t C ha^{-1} $year^{-1}$).

Figure 23 shows the regression results concerning the declining slope of the SOC change for each soil management system from 1977 to 2004 in this study and in Leifeld et al. (2009).

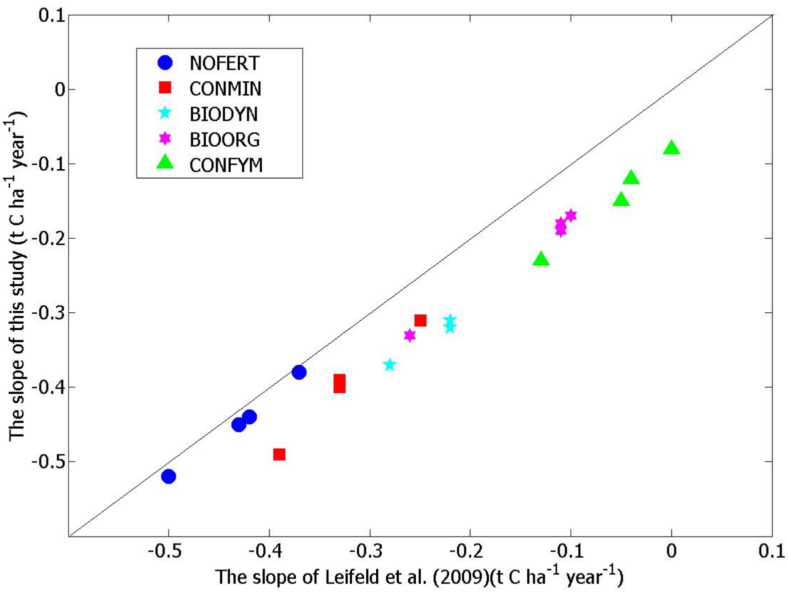


Figure 23: Comparison of the the slope for SOC change for each soil management systems in Leifeld et al. (2009) and in this study

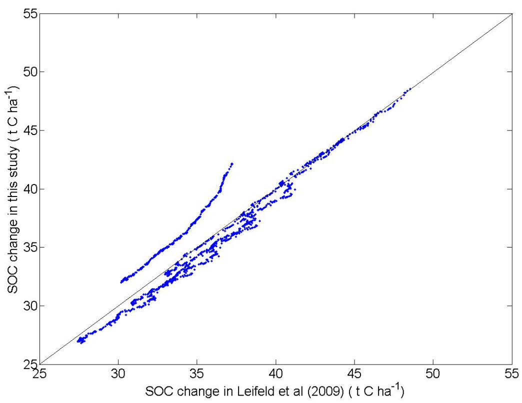
Figure 23 shows a correlation between Leifeld et al. (2009) and this study for gradients of SOC change over time in the NOFERT management system than in the other management systems.

Figure 24(a) - Figure 24(e) show the regression results of SOC content (t C ha^{-1}) change from 1977 to 2004 in Leifeld et al. (2009) and this study.

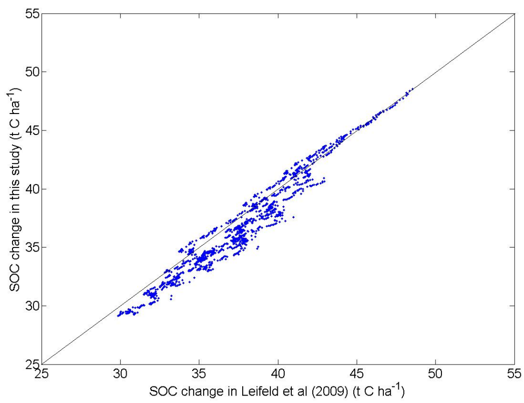
In the NOFERT and CONMIN management systems, the result of SOC change from 1977 to 2004 in Leifeld et al. (2009) and in this study are closely related (Figure 24(a) and Figure 24(b)). In the BIODYN and BIOORG management systems, I find an adequate correlation between Leifeld et al. (2009) and this study (Figure 24(c) and Figure 24(d)).

However, in the CONFYM management system, I find some correlation between Leifeld et al. (2009) and this study (Figure 24(e)), but it is weak.

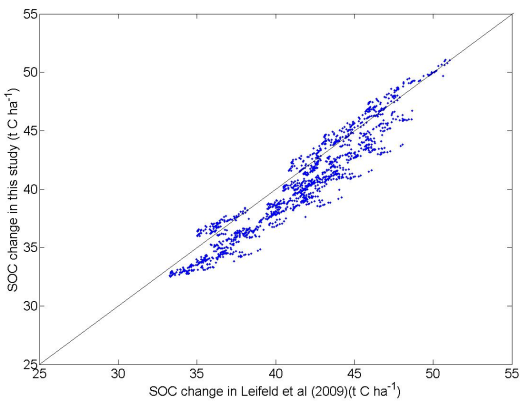
In the NOFERT and CONMIN management systems, the gradient of SOC change is similar in this study and in Leifeld et al. (2009). However, in the other organic farming management systems, there are some significant differences between the result of Leifeld et al. (2009) and this study. Furthermore, the SOC change gradient in this study is steeper than the SOC change gradient in Leifeld et al. (2009). This means that the amount of plant residue and manure input applied will affect SOC change, depending on when that carbon input is applied to the soil (Freibauer et al. (2004)). This is because Leifeld et al. (2009) applied real plant residue and manure input each year, but this study took the average plant residue and manure input for each month from 1977 to 2004.



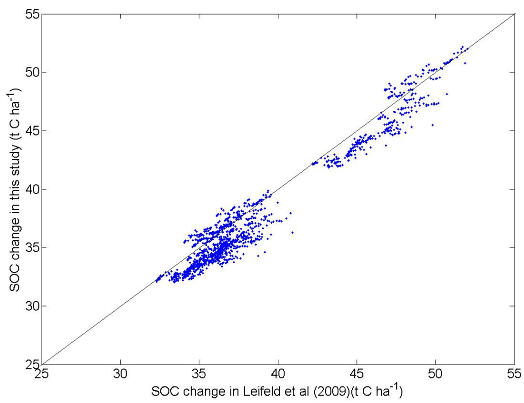
(a) NOFERT management



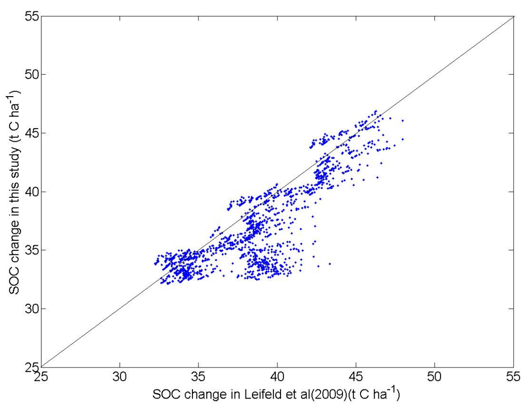
(b) CONMIN management



(c) BIODYN management



(d) BIOORG management



(e) CONFYM management

Figure 24: Regression between SOC content 1977-2004 in Leifeld et al. (2009) and in this study

This means that this study applied a small amount of plant residue and manure input to each plot in each month, but Leifeld et al. (2009) applied plant residue and manure input at intervals that may exceed one month. The different types of manure might be also important for SOC change (Freibauer et al. (2004)).

Table 12 compares values of SOC content (t C ha^{-1}) in 2004 obtained from the simulations, measured values of SOC content in Leifeld et al. (2009), and the simulated values of SOC content in this study.

Generally, in Table 12 the simulated SOC content in 2004 by Leifeld et al. (2009) is closer to the measured SOC content than the results of this study. On the other hand, the simulated SOC content in this study and the simulated SOC content in Leifeld et al. (2009) are similar. If there is a big deviation between simulated SOC content in Leifeld et al. (2009) and measured SOC content, there is also a big deviation between simulated SOC content in this study and measured SOC content. Therefore, it should be possible to confirm that the method of this study is accurate enough to do simulation 3.

3.3 Simulation 3

Simulation 3 shows the SOC content change under the future climate change from 2005 to 2050.

In the NOFERT and CONMIN management systems, the initial SOC content is lower than for the other management systems. Furthermore, the change in SOC content is steeper for the NOFERT and CONMIN than for the other management systems, and the final SOC content is around 10 (t C ha−1) less than for the other management systems (Figure 25(a) and Figure 25(b)).

The BIODYN and BIOORG management systems show similar patterns for SOC change. The initial SOC content is similar in the BIODYN, BIOORG and CONFYM management systems (Figure 25(c), Figure 25(d) and Figure 25(e)). However, the SOC change rate is more rapid in the BIODYN and BIOORG than in the CONFYM management system (Table 13).

In Table 13, the gradient of SOC change from 1977 to 2004 is steeper than the SOC change from 2005 to 2050.

Table 14 shows SOC content (t C ha^{-1}) in 1977, 2004 and 2050 in this study. In Table 14, the NOFERT and CONMIN management systems lose almost a half of the initial SOC content from 1977 until 2050. On the other hand, the BIODYN, BIOORG and CONFYM management systems lose between 20 to 35 % of the initial SOC content until 2050. Table 14 also shows that the standard deviation gets closer for each plots, in each soil management system.

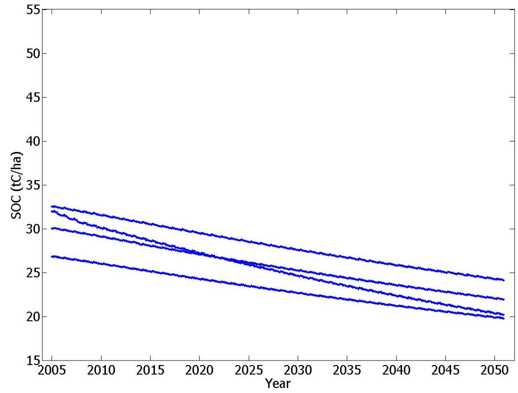
These results show that the BIODYN, BIOORG and CONFYM management systems emit less greenhouse gas from agricultural ground. Furthermore, these soil management systems which include organic fertilizers retain more SOC than conventional farming systems.

3.4 Simulation 4

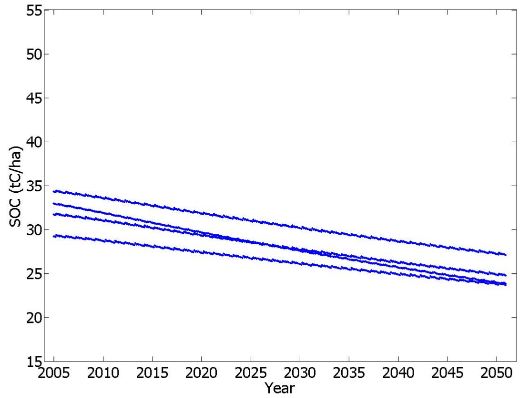
I also simulated SOC content change with averaged weather data from 1977 to 2004 (see Table 2) and the initial SOC content in 1977 for each soil management system. This is the simulation under no

Table 12: Simulated SOC content in 2004 in this study (Simulation 2) and measured/simulated SOC content in 2004 in Leifeld et al. (2009)(t C ha^{-1})

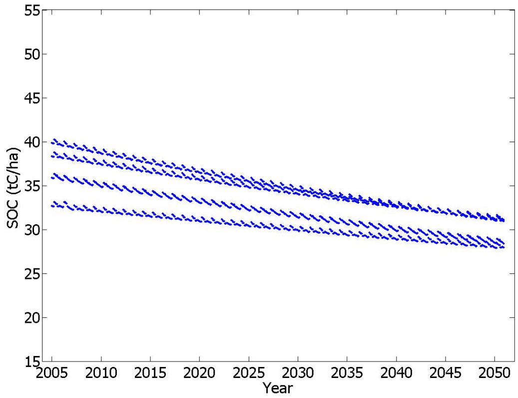
	NOFERT				CONMIN				BIODYN				BIOORG				CONFYM			
Plot Number	5	39	55	95	6	40	56	96	12	46	50	90	18	28	68	84	24	34	62	78
Measured (Leifeld et al. (2009))	33.6	29.8	32.7	38.6	40.1	33.4	33.1	47.4	44.7	39.4	44.0	53.5	37.3	43.1	35.1	37.3	35.4	38.1	34.9	39.2
Simulated (Leifeld et al. (2009))	32.8	27.7	30.9	33.1	35.5	30.8	33.2	35.8	40	34.4	38.1	41.2	34.4	43.8	34.5	36	40.6	42.1	34.4	38.1
Simulated (this study)	32.0	26.8	30.1	32.5	33.0	29.3	31.7	34.3	38.4	32.7	35.9	39.9	32.3	41.9	32.5	34.1	32.8	39.7	32.5	35.9



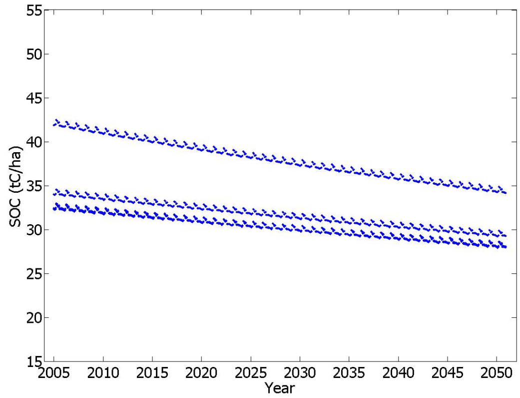
(a) NOFERT management



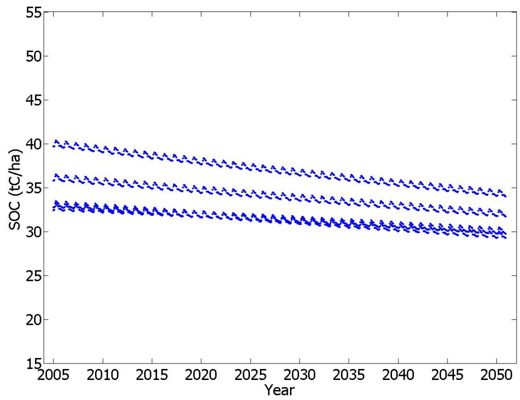
(b) CONMIN management



(c) BIODYN management



(d) BIOORG management



(e) CONFYM management

Figure 25: SOC change with estimated climate data 2005-2050

Table 13: Comparison of slope of simulation results (t C ha^{-1} $year^{-1}$) 2005-2050 and 1977-2004

	NOFERT		CONMIN		BIODYN		BIOORG		CONFYM	
	77-04	05-50	77-04	05-50	77-04	05-50	77-04	05-50	77-04	05-50
plot1	-0.52	-0.25	-0.49	-0.20	-0.31	-0.16	-0.07	-0.09	-0.12	-0.08
plot2	-0.38	-0.16	-0.31	-0.12	-0.19	-0.10	-0.33	-0.17	-0.23	-0.13
plot3	-0.44	-0.18	-0.39	-0.15	-0.32	-0.16	-0.18	-0.10	-0.08	-0.06
plot4	-0.45	-0.18	-0.40	-0.16	-0.37	-0.19	-0.19	-0.10	-0.15	-0.09

Table 14: Comparison of SOC content (t C ha^{-1}) and its rate of change 1977-2050

	NOFERT	CONMIN	BIODYN	BIOORG	CONFYM
SOC in 1977	44.6(±4.1)	44.6(±4.1)	45.7(±5.5)	41,6(±7.1)	39,4(±5.3)
SOC in 2004	30.7(±2.6)	32.1(±2.2)	36.7(±2.4)	35.2(±3.4)	35.2(±2.6)
SOC in 2050	21.5(±2.0)	24.8(±1.6)	29.6(±1.7)	29.9(±2.9)	31.2(±2.2)
Loss rate (1977-2004)	0.31	0.28	0.20	0.15	0.11
Loss rate (2005-2050)	0.30	0.23	0.19	0.15	0.11
Loss rate (1977-2050)	0.50	0.44	0.35	0.28	0.21

Numbers in brackets represent standard deviation

climate change. Then, I compared SOC content change under measured climate condition from 1977 to 2004, and estimated climate conditions from 2005 to 2050 (the simulation under climate change) and under averaged climate condition (simulation under no climate change). From 1977 to 2004, the gradients of best fit line for temperature, precipitation and evapotranspiration are 0.07 (^{o}C year^{-1}), 0.24 (mm year^{-1}) and 0.39 (mm year^{-1}) respectively (See Figure 8 - Figure 10). These gradients show that the climate change tendency from 1977 to 2004 is increasing temperature, precipitation and evapotranspiration.

Figures 26(a) - 26(e) show the simulation results for SOC change from 1977 to 2050 with and without climate change.

In Figure 26(a) and Figure 26(b), degradation of SOC content without climate change is steeper than SOC change with climate change. This tendency becomes clearer in simulation since 2005.

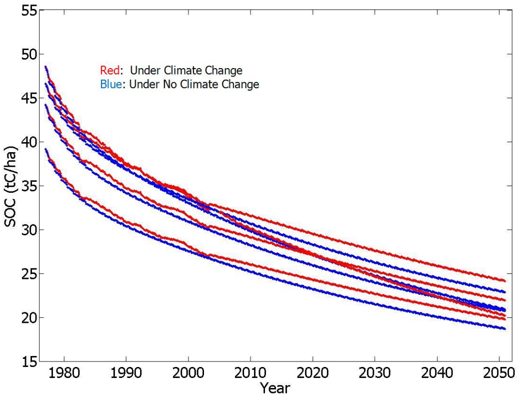
In Figure 26(c), Figure 26(d) and Figure 26(e), degradation of SOC content with climate change is more steep than without climate change. This tendency becomes more significant in the simulation from 2005. The degradation tendency in each soil management system can also be clearly observed in Table 15.

Table 15: Slope of SOC change for each soil management system for the simulation without climate change (the simulation with averaged weather data from 1977 to 2004 (1977-2050)) and the simulation with climate change (the simulation involving measured weather data (1977-2005) and expected future climate data (2005-2050))

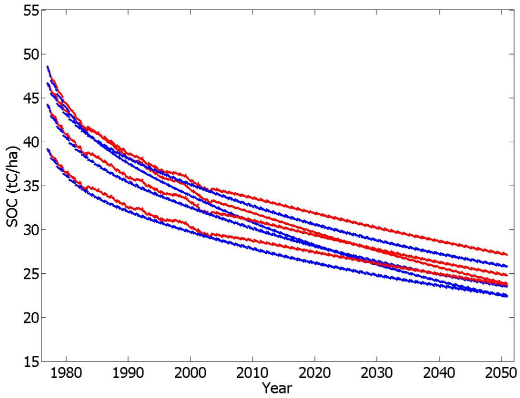
	Period	NOFERT	CONMIN	BIODYN	BIOORG	CONFYM
No Climate Change	1977-2004	-0.20(±0.03)	-0.25(±0.06)	-0.28(±0.08)	-0.20(±0.08)	-0.13(±0.06)
	2005-2050	-0.45(±0.05)	-0.40(±0.07)	-0.12(±0.04)	-0.09(±0.03)	-0.05(±0.03)
With Climate Change	1977-2004	-0.45(±0.05)	-0.42(±0.09)	-0.30(±0.08)	-0.21(±0.08)	-0.15(±0.06)
	2005-2050	-0.19(±0.04)	-0.18(±0.01)	-0.15(±0.04)	-0.11(±0.03)	-0.08(±0.03)

Numbers in brackets represent standard deviation

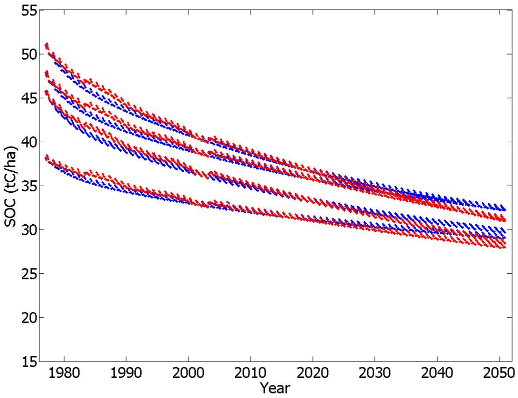
In Table 15, the NOFERT and CONMIN management system show a significant difference in SOC change gradient between the simulation with climate change and the simulation without climate change. On the other hand, the BIODYN, BIOORG and CONFYM management systems do not show a significant difference in the SOC change gradient between the simulation with climate change and the simulation without climate change. From 1977 to 2004, the gradients of best fit line for temperature, precipitation and evapotranspiration are 0.07 (^{o}C year^{-1}), 0.24 (mm year^{-1}) and 0.39 (mm year^{-1}) respectively. These gradient show that the climate change tendency from 1977 to 2004 is increasing temperature, precipitation and evapotranspiration.



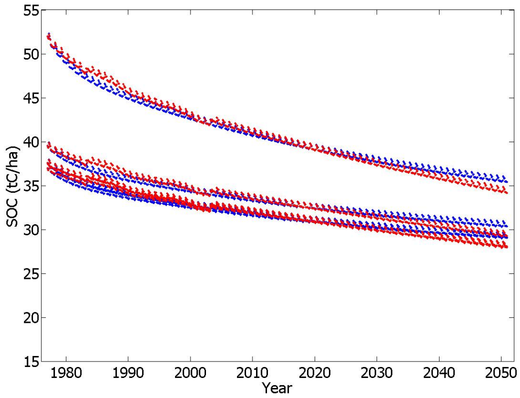
(a) NOFERT management



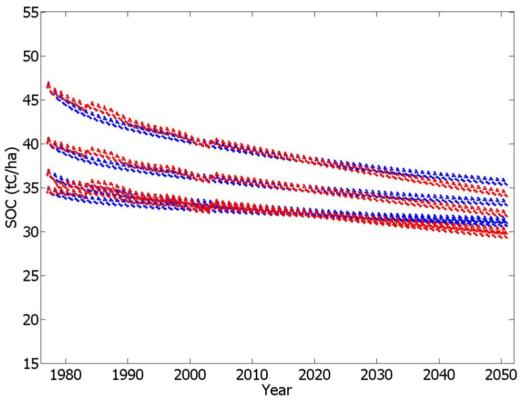
(b) CONMIN management



(c) BIODYN management



(d) BIOORG management



(e) CONFYM management

Figure 26: SOC change with climate data which includes climate change effect (measured weather data 1977-2004 and estimated future climate data) and with climate data which does not include climate change effect (averaged weather data 1977-2050 for each month)

These results show that the conventional farming system will not be affected dramatically because mineral fertilizers are already mineralized chemically. However, organic farming systems which apply plant residues and manure/slurry will be affected more than conventional farming systems by climate change. On the other hand, conventional farming systems show faster rates of SOC change rate than the organic farming systems in this study.

4 Discussion

As mentioned in the Introduction, in the DOK field experiment, crop rotation, tillage and residue management are the same, and the application rates of farmyard manure in the different soil management systems are at similar levels. I could not distinguish between different type of manure in this study. Therefore, I do not pay attention to differences in the results of the BIODYN and BIOORG management systems.

4.1 Simulation 1

The initial contents of SOM fractions are measured in 2004 for each plot using the same method as in Zimmermann et al. (2007). These initial contents of SOM fractions are varied in each plots. The possible cause for this variation in SOC content for each plot is the land-use condition between 1957 to 1973, though there is not enough documentation for the land-use history during this period. Fließbach et al. (2007) indicate that the year before the DOK experiment started, the area has been cropped with grass-clover. Furthermore, between 1973 and 1976, the field was cultivated for vegetables and grain crops by rotating based on integrated production without manure amendment (Fließbach et al. (2007)). Therefore, the area was cultivated homogeneously since 1973, but I do not know how the area was treated between 1957 to 1973. It might be possible the soil management during this period (1957-1973) contributed to variation in the SOC stock for each plot. This variation in SOC stock content for each plot might not have changed since 1977 because these plots were treated homogeneously after this date.

4.1.1 Simulation 1-1

Each management system includes different plots. Comparing the “simulated SOM pools content” simulation and the “measured SOM pools content” simulation, the initial contents of SOM fractions has a large effect on subsequent change in SOC over time. Even in the same soil management system, differences in the initial SOC content affect SOC change over time.

Clay content in each plot is related to land history and it affects SOC content over time (Leifeld et al. (2009)). In Table 6, clay content is varied in each plot. In general, if the clay content is high, then the carbon stock in the soil is also high in 1977. From these simulation results, using different values for initial SOC content possibly leads to different SOC change over time in the RothC model, because the initial values are important for subsequent SOC change in the RothC model.

4.1.2 Simulation 1-2

In the "simulated initial SOM pools" simulation, each soil management system arrived at the equilibrium point earlier than the "measured initial SOM pools" simulation. In particular, the BIODYN, BIOORG and CONFYM management systems show significantly different equilibrium points in the "simulated initial SOM pools" simulation and the "measured initial SOM pools" simulation. In both the "simulated initial SOM pools" simulation and the "measured initial SOM pools" simulation, the BIODYN, BIOORG and CONFYM management systems arrived at the equilibrium point much earlier than the NOFERT and CONMIN management systems. These results show that a soil management system which contains an organic farming system (even if it also applies mineral fertilizers as a supplement) is more stable with regard to the SOC content, and has more capacity to recover from depleted SOC content condition.

4.2 Simulation 2

In this simulation, the SOC content decreases over time. The relationship between carbon input and output affects SOC change. SOC storage might increase by increasing the amount of crop residue input, manure input and other organic amendments. Furthermore, it might also increase by fertilization or irrigation treatments which improve crop productivity, terrestrial biomass and root production (Stewart et al. (2007)). Therefore, with the high rate of carbon input which was applied until 1977, SOC content will increase because the amount of carbon input is higher than the amount of carbon output. However, high rates of manure application are not sustainable, because the terrestrial carbon reservoir capacity is limited, and excess manure leads to groundwater pollution by nitrate and fecal bacteria (Zhang et al. (1996); Krapac et al. (2002)). This could be harmful for human health and the environment. Moreover, high carbon input application leads to increased greenhouse gas emission, and this is not desirable. This explains current efforts to lower the rate of application of manure in agricultural soil management systems. Stewart et al. (2007) report that SOC levels could decrease via respiration, erosion and leaching.

In this simulation, the initial SOC content is the measured SOC content in 1977 in Leifeld et al. (2009). The variation of the initial SOC content for each plot should happen for the same reasons discussed in Section 4.1. The NOFERT and CONMIN management systems show similar changes in SOC; with SOC declining faster than in the other management systems. On the other hand, the BIODYN, BIOORG and CONFYM management systems show a similar trend: a scattered but gradually declining trend. Furthermore, the SOC content in 2004 for the NOFERT and CONMIN management systems is less than that of the BIODYN, BIOORG and CONFYM management systems (even if the initial SOC content in 1977 is not significantly different from the other soil management systems). These results seem to show us that soil management systems with organic farming systems hold more stable SOC content in the soil and retain SOC in the soil better than no-organic farming soil management systems. However, the CONFYM management system shows the most moderate decreasing slope of SOC change over time. This does not mean that soil management systems with mineral fertilizers is ineffective at retaining SOC. Soil management systems with only mineral fertilizers are less effective in retaining SOC, but soil management systems combined with mineral fertilizers and organic farming systems seem to be the most effective soil management strategy with regard to the SOC content under recent climate change. There is no significant relation between weather data and SOC change over time for each soil management systems.

Comparing Leifeld et al. (2009) and this study, we observe differences in the amount of applied plant residue and manure input, differences in the equation for simulating the evapotranspiration values and differences in how different types of manure are treated. The simulation in Leifeld et al. (2009) uses conditions which are closer to reality than for this study, but this study tried to focus on the climate change effect on SOC change over time.

In general, Leifeld et al. (2009) shows results which are closer to the measured SOC content in 2004. On the other hand, the simulated final SOC content (in 2004) in this study and the simulated final SOC content (in 2004) in Leifeld et al. (2009) are similar (Table 12). If there is a big deviation between simulated SOC content in Leifeld et al. (2009) and measured SOC content, there is also a big deviation between simulated SOC content in this study and measured SOC content. Therefore, it should confirm that the method of this study is accurate enough.

In the NOFERT and CONMIN management systems, the gradient of SOC change is similar in this study and in Leifeld et al. (2009). However, in the other organic farming management systems, there are some significant differences between the result of Leifeld et al. (2009) and this study. Furthermore, the SOC change gradient in this study is steeper than the SOC change gradient in Leifeld et al. (2009). This means that the amount of plant residue and manure input applied will affect SOC change, depending on when that carbon input is applied to the soil (Freibauer et al. (2004)). This is because Leifeld et al. (2009) applied real plant residue and manure input each year, but this study took the average plant residue and manure input for each month from 1977 to 2004. This means that this study applied a small amount of plant residue and manure input to each plot in each month, but Leifeld et al. (2009) applied plant residue and manure input at intervals that may exceed one month. The different types of manure might be also important for SOC change (Freibauer et al. (2004)). This is because composting manure enhances its stability (Fließbach et al. (2007)). Furthermore, Zaller and Köpke (2004) report that, for plots which were applied with composted farmyard, this latter was decomposed significantly faster and showed higher biomass and abundance of earthworms than other plots to which composted farmyard[7] was not applied. The equation for calculating the evapotranspiration is different in this study and in Leifeld et al. (2009). However, in the NOFERT and CONMIN management systems, the gradient of SOC change and regression results are similar in Leifeld et al. (2009) and this study. Therefore, the timing of carbon input (for example, manure and plant residue) and type of manure have a larger effect on SOC change over time than the weather condition.

[7]The experimental site of Zaller and Köpke (2004) is located on the Wiesengut certified organic research farm of the Institute of Organic Agriculture, University of Bonn (65 m a.s.l.; 7^{o}'17E, 50^{o}'48N)

4.3 Simulation 3

In simulation 3, SOC also decreases over time but it decreases more gradually than in simulation 2. The SOC content will never become zero, even if it continues to decrease over time with a small carbon input, but it will arrive at an equilibrium point (Schimel et al. (1997); Stewart et al. (2007); West and Six (2007)). Physical soil properties have also been linked to soil carbon saturation (Stewart et al. (2008)). The accelerated soil erosion by anthropogenic perturbations would be one of the big destructive processes for SOC storage (Lal (2003)).

In Table 13, the gradient of SOC change from 2005 to 2050 is gradual. The plot which contains a high initial SOC content shows steeper SOC change over time than the other plots which contain less initial SOC content. I consider that the SOC equilibrium amount is around 30 (t C ha^{-1}) and 25 (t C ha^{-1}) in organic farming systems and conventional farming systems respectively, according to results in simulation 3. Therefore, the plot which contains more SOC content than saturated SOC content decreases rapidly until it approaches the SOC equilibrium point, depending on weather conditions and soil management. In simulation 3, the initial SOC content is less than in simulation 2. Then, the gradient of SOC change from 2005 to 2050 is more gradual than SOC change from 1977 to 2004.

However, from 1977 to 2004, weather data contains unusual weather events. In the future climate scenario, temperature and evapotranspiration increase gradually and precipitation decreases gradually over time. This difference might also affect the gradual SOC change in simulation 3. The NOFERT and CONMIN management systems show steeper SOC change than the other soil management systems as in simulation 2. The CONFYM management system shows the most gradual SOC change in simulation 3 and this tendency is also observed in simulation 2.

Table 14 shows that the NOFERT and CONMIN management systems lost almost half of the initial SOC content from 1977 until 2005. On the other hand, between 20 and 30 % of initial SOC content was lost in the BIODYN, BIOORG and CONFYM management systems. This means that the BIODYN, BIOORG and CONFYM management systems emit less greenhouse gas from agricultural ground. Furthermore, these soil management systems which include organic fertilizers retain more SOC than conventional farming systems. In Table 14, the standard deviations for each plot in the same soil management systems become smaller in 2050, for each soil management system. This means that the SOC content of each plot in the same soil management system approaches the SOC equilibrium point. From the result of simulation 2 and 3, I consider that the soil management system with only mineral fertilizers is not effective in retaining the SOC content. Soil management systems with no carbon input lose much more SOC than the other soil management systems, even if the same plant protections, tillage managements, similar soil structure and crop rotation are applied. The SOC equilibrium point of this management system is lower than for the other management systems. However, there is no significant difference in SOC change over time between the soil management system which combines a mineral fertilizers farming system and an organic farming system (CONFYM), and absolute organic farming systems (BIODYN and BIOORG). I consider that the BIODYN, BIOORG and CONMIN management systems are effective soil management systems for retaining SOC in agricultural management systems.

4.4 Simulation 4

Lal (2004) indicates that estimated climate change may affect soil moisture and temperature regimes. Furthermore, changes in soil moisture and temperature regimes might affect species composition in the ecosystem. These changes affect the SOC pool and soil physical properties because of the biomass changes in the soil. In particular, soil temperature is important for microbial processes. Therefore, increasing soil temperature will promote the mineralization of plant residue and manure input and lead to a decrease in SOC content (Lal (2004)) under future climate change.

In this simulation, I obtained some interesting results. In the NOFERT and CONMIN management systems, the simulation without climate change leads to lower SOC than the simulation with climate change. On the other hand, in the BIODYN, BIOORG and CONFYM management systems, simulation without climate change loses less SOC than the simulation with climate change. However, the NOFERT and CONMIN management systems lost around 50 % of their SOC content from 1977 to 2050.

I consider that the change of microbial processes under future climate change will have a larger effect on organic farming systems than on conventional farming systems. This is because organic farming systems contain plant residue and manure inputs which need to be decomposed by microbial processes. As discussed above, the estimated climate change may affect soil moisture and temperature regimes. Then, changes in soil moisture and temperature regimes might affect species composition in the ecosystem. These changes affect the SOC pool and soil physical properties because of biomass changes in the soil. In particular, soil temperature is important for microbial processes. Therefore, increasing soil temperature will promote the mineralization of plant residue and manure input and lead to a decrease the SOC content (Lal (2004)) under future climate change.

The conventional farming system will not be affected dramatically because mineral fertilizers are already mineralized chemically. However, organic farming systems which apply plant residues and manure/slurry will be affected more than conventional farming systems by climate change. On the other hand, conventional farming systems show faster rates of SOC change rate than the organic farming systems in this study. Steeper SOC change indicates more CO_2 emission from the soil management system. Therefore, I consider that CONFYM management system which combines an organic farming system with supplementary mineral fertilizers is the most effective soil management system with regard to SOC content under current climate change.

For retaining SOC and mitigating greenhouse gases in agricultural managements, plant protection managements and the timing of carbon input application are also important.

5 Conclusion

The conclusions in this study are:

1. A conventional farming system without manure shows a faster rate of SOC loss than the organic farming systems in this study.

2. A soil management system which contains an organic farming system (even if it also applies mineral fertilizers as a supplement), is more stable with regard to the SOC content. These soil management systems also have a greater capacity to recover from depleted SOC conditions.

3. The timing of carbon input (such as manure and plant residue), and type of manure, have a larger effect on SOC change over time than weather conditions.

4. Organic farming systems which apply plant residues and manure/slurry will be affected more by climate change, than conventional farming systems which apply only mineral fertilizers. This is because estimated climate change may affect soil moisture and temperature regimes. Changes in soil moisture and temperature regimes might affect species composition in the ecosystem. These changes affect the SOC pool and soil physical properties because of the biomass changes in the soil.

5. The CONFYM management system which combines an organic farming system with supplementary mineral fertilizers is the most effective soil management system with regard to the SOC content under current and future climate change.

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