Dossier
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The DOK Trial

A 45-year comparative study of organic and conventional cropping systems

FiBL

The DOK trial has investigated the differences between organically and conventionally farmed arable crops since 1978. This report summarises the most important findings from more than 40 years of research for interested agriculture experts, consultants and researchers in a concise and comprehensive way.

The DOK trial compares biodynamic (BIODYN), bio-organic (BIOORG) and conventional (CONFYM) agricultural systems. The trial thus simulates farms that conduct arable and livestock farming. The exclusively mineral-fertilised, conventional CONMIN system represents a livestock-free cropping system. In each of the BIODYN, BIOORG and CONFYM systems, two fertiliser intensities are examined.

The results of the research relate to five crops in a seven-year crop sequence, which follow each other with a time lag in three subplots: winter wheat, potato, grass clover, soya and silage maize. This report presents results related to yield, soil quality, nutrient supply, biodiversity and climate.

Content

Reading aid

This complex topic cannot be presented without abbreviations and technical terms. Readers can find a list of abbreviations and a glossary on page 51.

Different lowercase letters are used in tables and charts to differentiate between statistical terms.

Foreword

Inspiring and reliable results in the service of sustainable food security

Rarely have scientific experiments been designed to last as long as the DOK trial. This continuity is particularly valuable for investigating many research questions, as the relevance of some results only becomes apparent after a long time period. This also applies, for example, to long-term observations of the effects of climate change. Short-term results are relevant, but they cannot capture the long-term effects of external influences that unfold over time. From the very first year of the DOK trial, various external influences presented themselves due to the methods chosen for conducting the experiment, and the questions that researchers proposed – depending on the objects of investigation and the social issues at the time – have evolved over the years and decades.

I have known about the DOK trial since its very beginning, now decades ago – and that it compares short- and long-term effects of different cropping systems in terms of yield and yield potential as well as their impact on the environment. The focus is primarily on soil fertility, climate, nutrient flows and biodiversity. The DOK trial is a prime example of successful collaboration between Swiss Federal Research Institutes (now Agroscope) and FiBL. As a researcher at ETH Zurich, later as the person responsible for policy development at the Federal Office for Agriculture, and today in the service of global food security and nutrition at the UN Committee for World Food Security, I have always known that the results of the DOK trial show where the differences between biodynamic, bio-organic and conventional cropping systems lie in relation to current research questions and how the systems are developing.

A closer look at the DOK trial also raises many questions about the research design itself and the development of the individual methods of cultivation. What kind of changes are occurring? For example, the original 'conventional' system has become 'integrated production'. Organic systems are also changing, for example with new varieties, crop rotations, machinery and biological pest control. Interesting questions arise, not only from the point of view of research but also from the perspective of sustainable food security and practice. The individual chapters of this publication provide answers to many of these questions and outline the development of the methodological approaches and the questions addressed by the research.

When considering global, sustainable food security, it must be asked to what extent organic cultivation methods can contribute to attaining it. Do we need more or less organic farming, or should the entire agricultural sector switch to organic? These are provocative questions to which there are no easy answers. What is certain is that the very high amounts of post-harvest food loss, food waste (especially in households), and animal fodder grown on arable land can be reduced, which contradicts the assertion that more land is needed as the population increases. In other words: scarcity is relative. Considerations of these questions are legitimate when one compares the environmental impact of the various cropping systems and the subsequent costs that society must bear.

A particular challenge for FiBL and Agroscope is the long-term financing of the DOK trial. It is very important to emphasise the two dynamics mentioned here: long-term effects and cropping systems. The successful acquisition of numerous third-party funds for the DOK trial from other federal offices, the Swiss National Science Foundation and the EU impressively demonstrates that this type of long-term research is relevant for both basic and applied research. The DOK trial has thus become an important national and international research platform.

I invite you to read this report. It is stimulating and impressive in its scientific rigour. That is why the DOK trial has also made it into the scientific 'Hall of Fame': the journal *Science*. May the DOK trial continue to provide impressively reliable results and valuable guidance for a long time to come.

B Lehmann

President of the FiBL Foundation Council
Prof Dr Bernard Lehmann

Cutting-edge research with practical relevance

The issue of environmentally sound and productive agriculture has been topical for decades. Many different cropping systems for the arable production of food and animal fodder are practised around the globe. Entire societies and generations are discussing the advantages and disadvantages of organic and conventional farming systems.

In Switzerland pioneers of organic farming practice, scientists and politicians already took up this discussion back in the early 1970s and established the DOK trial in Therwil, in the canton of Baselland in 1978. **DOK** stands for bio**D**ynamic, bio**O**rganic and conventional (**K***onventionell* in German). The trial investigates the three cropping systems with two fertiliser intensities defined by the livestock density.

Highly topical issues such as climate change and climate adaptation, the loss of biodiversity, the growth of the world's population and dependence on raw materials demand, now more than ever, scientific examination of the way we produce food and feed.

The DOK trial has been comparing agricultural production systems for more than 45 years and has thus created a scientific basis for the controversial debate on the prospects of organic farming.

A scientific basis for political questions

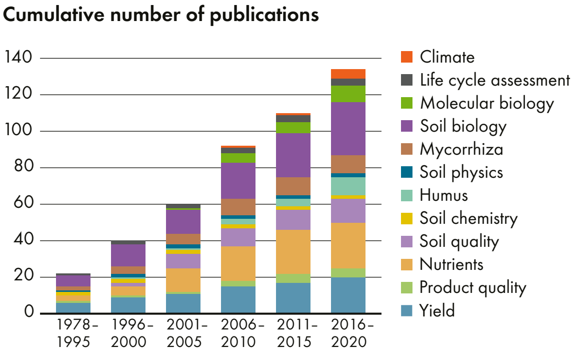
The highlight of the DOK trial to date was undoubtedly a scientific article on soil fertility and biodiversity in organic farming published in the journal *Science* in 2002. This made organic farming a respectable topic, as it was soon recognised to offer solutions to the major environmental problems of agricultural production.

Current research projects in the DOK trial consider the issues of soil quality, biodiversity and climate, all of which are highly relevant from a global societal perspective and are crucial for our future.

National and international significance

Over 40 years, more than 120 scientific publications, plus doctoral theses and a large number of student theses, have emerged from the DOK trial (Figure 1). Countless visitors from countries around the world, farmers, university students, pupils and also high-ranking scientists from the best universities have visited the experiment and conducted research projects related to it.

Figure 1: Number of publications in scientific journals



In 2015, the Swiss State Secretariat for Education, Research and Innovation included the DOK trial in the 'Swiss Roadmap for Research Infrastructures', which collects national studies of the greatest significance. The DOK trial thus entered the pantheon of Swiss science.

The trial is part of a circular research approach: open questions from agricultural practice are first investigated in the DOK fields using state-of-the-art methods, which are then followed by detailed greenhouse and practice-related studies. The new findings are in turn integrated into the current field research. As a result, the DOK trial often plays a prominent role in current issues in national and international agricultural and environmental research and field studies.

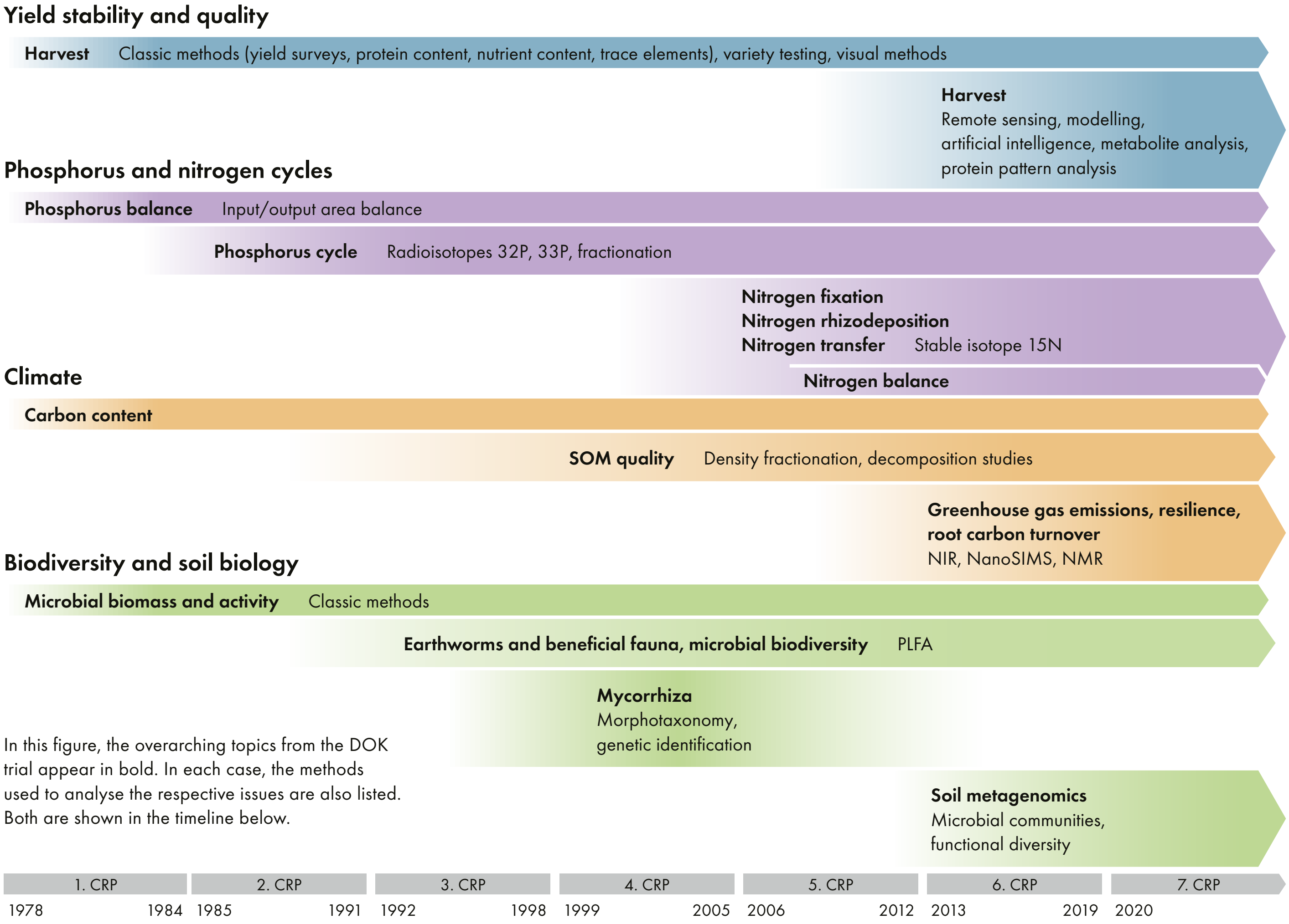
That the DOK trial has a permanent place in cutting-edge academic research, which is further demonstrated by the quality of the research and the continued relevance of the issues under investigation. Here are a few examples:

- A total of seven projects that were part of the Swiss National Research Programme ‘Soil as a Resource’ used the DOK trial as a testing ground. They investigated the connection between soil properties and functions and agricultural production.[1]
- In a highly regarded EU project on soil quality, an international research team investigated the influence of cultivation on soil ecosystem services. The DOK trial was an important pillar of the research plattforms.[2]
- For a Swiss National Science Foundation (SNSF) project, FiBL soil researchers are investigating how cropping systems in the DOK trial affect humus quality and humus turnover.[3]
- Since 2016, international research groups have been investigating the influence of cropping systems on the drought stress tolerance of crops and microbial communities.[4]
- An SNSF project on the relation between microbial biodiversity in soil and the nitrogen cycle is currently entering its final phase.
- A new EU breeding project is analysing the microbial communities on seeds from cultivated plants.[5] In a second project, a research team is developing a framework for monitoring soil fertility.[6]

Open questions have prompted researchers to design further long-term trials on specific topics. These include a field trial on the effects of reduced tillage, of fertilisation strategies and of biodynamic preparations. The trial plots were established in Frick in 2002. FiBL’s system comparisons in India, Kenya and Bolivia, which began in 2005, also have their origins in the success story that is the DOK trial.

[1]NRP 68, [2]iSQAPER, [3]DynaCarb, [4]BiodivERsA (SOIlClIM, Biofair and Microservices), [5]Liveseeding, [6]Benchmarks

Figure 2: Research topics and methods over time



In this figure, the overarching topics from the DOK trial appear in bold. In each case, the methods used to analyse the respective issues are also listed. Both are shown in the timeline below.

Different conditions at the outset

While the issues addressed by the DOK trial are now a matter of public debate, the conditions for the pioneers in the 1970s were completely different: against all odds, a small group of organic farmers and their supporters in Switzerland advocated for the scientific study of organic farming.

As a result of their successful advocacy, the Research Institute of Organic Agriculture (FiBL, founded in 1973), together with the then Eidgenössischen Forschungsanstalt für Agrikulturchemie und Umwelthygiene (Swiss federal research centre for agricultural chemistry and environmental hygiene), was commissioned to compare the three farming systems – biodynamic, bio-organic and conventional – in a long-term trial. FiBL is mainly responsible for the organic trial plots, while Agroscope, the Swiss centre of excellence for agricultural research, is responsible for the conventionally farmed trial plots.

Science paired with practice as a recipe for success

In order to guarantee the practical relevance of the study, organic farmers were involved already in the planning stages, and especially during the realisation of the experiment. Their commitment to the trial and their continued interest in the findings have urged the scientists to produce their best work. In addition to the scientific publications, an important goal was to make the findings accessible to farmers and other interested parties.

Thanks to the meticulous documentation of the cultivation measures and the many analyses, the DOK trial is now one of the best-documented agricultural areas in the world. The trial and the data collected become more valuable from year to year due to the long duration and the consistency of the recorded data.

Researchers and farmers meet at the annual DOK field excursions (above in 2012, below in 2023).

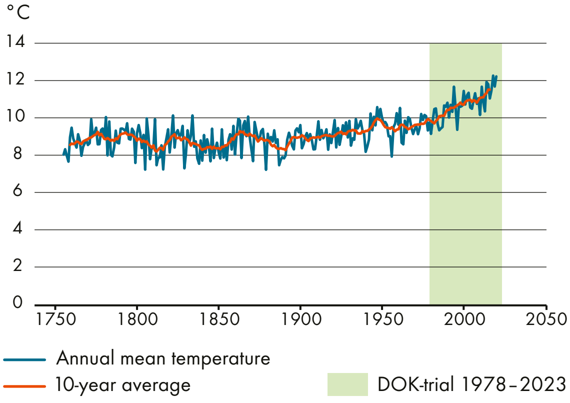
The site

The trial areas are located in the Leimental, south-west of Basel in the Upper Rhine Plain.

Climate

The Upper Rhine Plain has a favourable climate in terms of warmth and humidity. The average annual temperature was 9.7 °C until the end of the last century. The average for the years 2010–20 was 11.2 °C. Annual precipitation currently averages 872 mm.

Figure 3: Temperature change



Annual average and moving average of the air temperature in Baselland, measured at an altitude of 1 metre. Between 1978 and 2010, the temperature increased by 1.5 °C.

Soil and geology

The trial is located in the south-east corner of the Upper Rhine Plain and is surrounded by foothills of the Jura Mountains. The Rhine Valley floor is filled with thick layers of gravel, which were overlaid with fine material (loess) from the alluvial plains of the glacial forelands during the last glacial period. This created fertile loamy soil in the swales.

The loess in Leimental is deep. Moderately developed brown earth (“Parabraunerde”) soils have formed on it, which in some places tend towards pseudogley soils. The soils are decalcified but still contain individual rock fragments from the nearby Jura Mountains. The soils are between 1 and 1.3 m deep and are, therefore, deeply penetrated by roots.

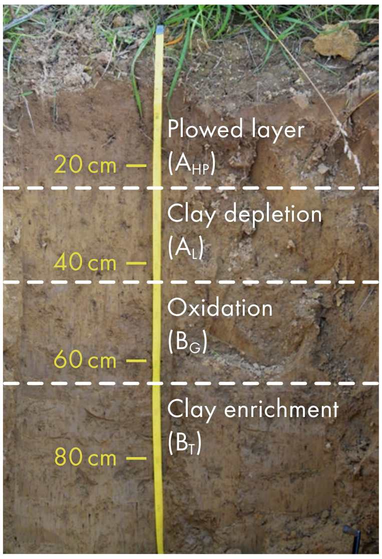
Due to the regular flooding of the nearby Birsig river, sediments of various grain sizes were deposited in the past. The soils on the DOK trial sites are composed of 70 % silt and contain only a small amount of sand. The clay sedimented in small pools of water, so it is somewhat irregularly distributed.

Table 1: Soil texture in the DOK cropping systems.
Mean values of the weight percentages and standard deviation (SD)

System	Clay (%)	SD	Silt (%)	SD	Sand (%)	SD
NOFERT	16.2	2.4	70.7	3.2	11.4	2.3
BIODYN 1	16.8	1.8	69.5	2.2	11.6	1.7
BIOORG 1	14.9	1.7	71.6	2.3	11.7	1.2
CONFYM 1	14.3	1.7	71.7	0.9	12.1	1.2
BIODYN 2	17.1	1.9	69.2	2.1	11.3	2.5
BIOORG 2	15.1	1.5	71.4	2.1	11.4	0.9
CONFYM 2	14.5	1.6	70.9	1.7	12.6	1.5
CONMIN	16.7	2.5	70.0	2.1	11.3	1.2

The average clay content in the DOK plots is 15.6 % (median 15.3 %), with the lowest values at 12.5 %. In eight plots in the north-west corner of the trial, however, the clay content reaches values of 20 to 25 %. This zone with high clay content is clearly demarcated from the neighbouring plots. The influence of the clay content is taken into account in statistical evaluations, especially when it comes to assessing the effects of the cropping system on the soil.

The soil has a small proportion of macropores, which is why it warms up slowly in spring. It also tends to become waterlogged, which is why dark patches can be seen – known as iron and manganese concretions (pseudogley). As a result, the soil can only be worked during short windows of time, and mechanical hoeing in spring and early summer is difficult. The soil allows water to rise from deeper soil layers through capillary transport, so dryness has not been a major problem in summer so far.



Soil profile from the DOK trial area.
Shown here are the horizons (soil layers) of the decalcified, deep brown earth.

The soils of the CONMIN (left) and BIODYN 2 (right) cropping sytems after a heavy rainfall in November 2002. The silting on the soil surface was much more pronounced in the CONMIN system.

The trial

The DOK trial compares biodynamic **(BIODYN)**, bioorganic **(BIOORG)** and conventional **(CONFYM)** agricultural systems that simulate farms with arable and livestock farming.

The two organic systems comply with the Bio Suisse and Demeter guidelines. In line with the Demeter guidelines, field and compost preparations are used in the BIODYN system and the celestial objects are taken into account. The conventional CONFYM system corresponds to today's integrated production, with an equalised nutrient balance and plant protection according to economic damage thresholds.

In addition to the cropping systems with simulated livestock farming, an exclusively mineral-fertilised conventional system that represents livestock-free agriculture **(CONMIN)** has been in place since the second crop rotation period (1985).

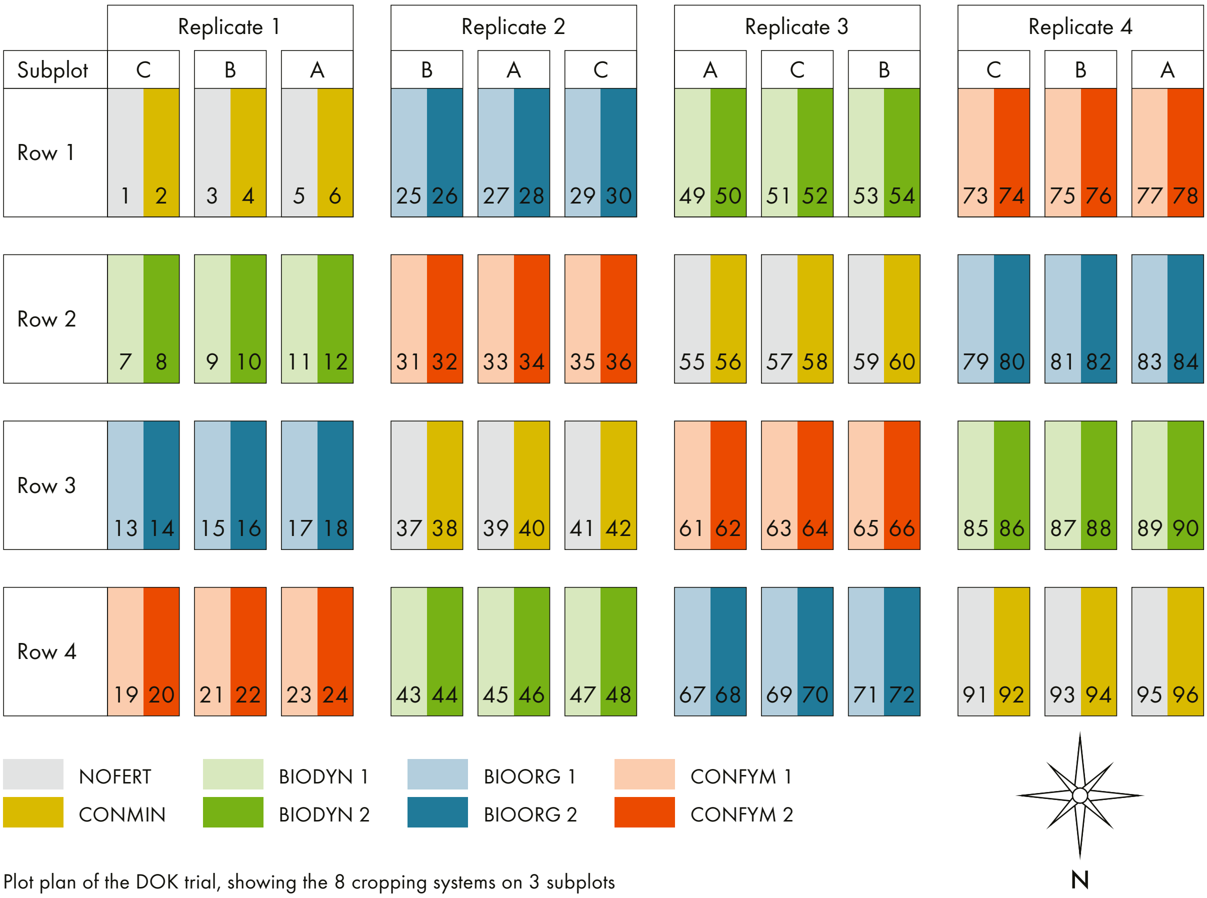
In each of the BIODYN, BIOORG and CONFYM systems, two different fertilisation intensities are being investigated for each cropping system. The fertiliser intensity is based on two livestock stocking densities: 1.4 fertiliser livestock units (LU) corresponds to the average livestock stocking density per hectare in Switzerland, while 0.7 corresponds to a lower stocking density. The farmyard manure is obtained from farms that operate according to the respective system. In the conventional systems, mineral fertilisers are applied in accordance with the Principles of Fertilisation of Agricultural Crops in Switzerland (GRUD).

In one control system **(NOFERT)**, no fertiliser has been used since the start of the trial. Biodynamic field preparations 500 and 501 have also been used here since the beginning of 1978; plant protection is in accordance with the BIODYN measures.

Aerial view of the four replicates of the DOK trial in 2017, each with three plots:
Subplot A winter wheat 2 with a section for a variety trial at the edge of the plot, subplot B soya, subplot C winter wheat 1.
In addition, rainout shelters of the SoilClim project can be seen in selected plots.

Experimental design

Figure 4: Plot map



Plot plan of the DOK trial, showing the 8 cropping systems on 3 subplots (A, B and C, each divided into 4 rows and 4 replicates).

The trial consists of 96 individual plots, each of which measures 5 × 20 metres. The eight systems are laid out in four replicates. Each system is represented in every row and every column in a randomised block design. In this way, the variability of the location can be balanced out and statistically accounted for.

In addition, three different crops from the seven-year crop rotations are grown side by side each year. Crops are rotated at staggered intervals across three parallel subplots (A, B and C) to balance out weather-related annual fluctuations in yield. Thus, in each crop rotation period, the plot yields of at least 12 years of cultivation (3 subplots × 4 replicates) can be analysed for each crop and each system. The statistical model for evaluating soil quality takes the subbplot into consideration and the clay content in each plot, which is an important factor in site variability.

Fertilisation

Livestock density on typical mixed Swiss farms is 1.4 LU per hectare which corresponds to the farmyard manure amount at fertiliser level 2. Half the farmyard manure volume from 0.7 LU (fertiliser level 1) was introduced as a control variant to simulate a farm with less livestock. Slurry is used to manage current agricultural production, and manure is used as a slow-release basic fertiliser.

While BIODYN receives only farmyard manure, the BIOORG plots are additionally supplied with small amounts of mineral potash (Patentkali or Kalimagnesia).

In the CONFYM 2 system, larger quantities of mineral fertiliser are applied until the standard fertilisation levels according to GRUD are achieved. In the CONFYM 1 system, both the quantity of farmyard manure and the quantity of mineral fertiliser are reduced by half.

Since the introduction of integrated production in 1992, the mineral nitrogen stocks in the soil have been accounted for in calculations of fertiliser amounts in conventional systems. The aim is to adjust fertilisation according to plant demand.

The full fertilisation levels of the various systems are not nutrient-equivalent. This means that the total fertiliser quantities and the nutrients contained in the fertiliser vary between the systems depending on typical farming practice. Fertilisation with farmyard manure under the experimental conditions is oriented towards so-called indicator elements, which are specified in a fertilisation plan for each crop rotation period. Phosphorus (P) plays a decisive role here. If a fertilisation plan cannot be strictly followed in a year, it can be corrected in the next year.

Changes during the experiment

In the first and second crop rotation period (CRP), the fertilisation rate was 0.6 LU for fertiliser level 1 and 1.2 LU for fertiliser level 2. At the beginning of the third CRP, the fertiliser rates were increased to the values mentioned above due to the increased proportion of forage crops in the crop rotation.

In the fourth CRP, the organic farm from where the farmyard fertilisers originate, switched and due to a different stabling system, the ratios for manure and slurry changed.

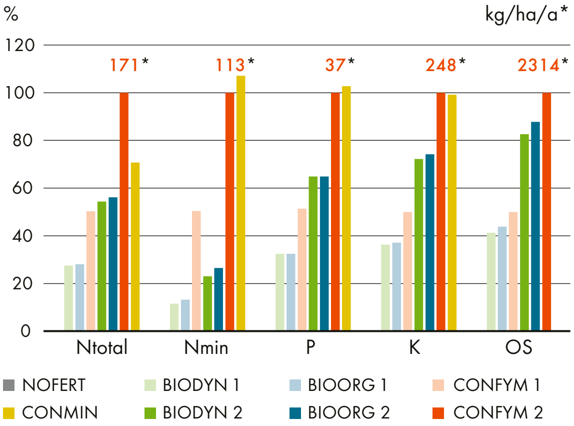
Different farmyard manure treatment

In the BIODYN, BIOORG and CONFYM systems, farmyard manure is stored and processed differently according to the practices of the respective system:

- as manure compost in BIODYN
- as rotted manure in BIOORG
- as stacked manure in CONFYM

The loss of organic matter during storage is lowest with stacked manure and increases from rotted manure to manure compost.

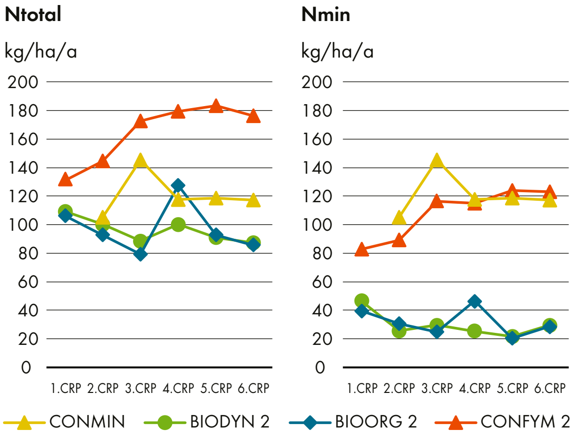
Figure 5: Amounts of applied nutrients



Applied amounts of total nitrogen (Ntotal), mineral nitrogen (Nmin as ammonium and nitrate in farmyard and mineral fertilisers), phosphorus and potassium from organic and mineral sources, as well as the amount of organic substance (OS) applied as manure and slurry. All figures are average values over the CRP 2–6 and relative to the CONFYM 2 system, the absolute quantities of which are shown in red.

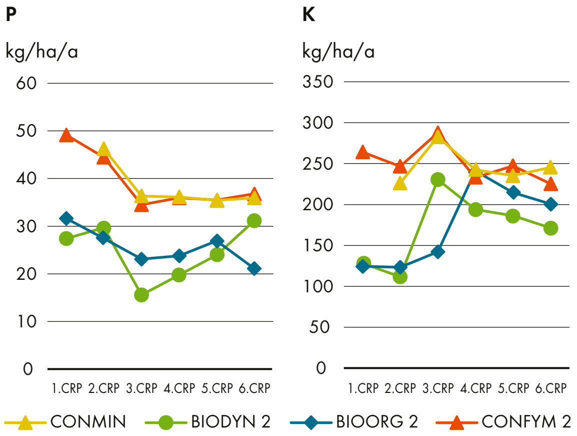
Figure 5 clearly shows that during the five crop rotation periods from 1985 onwards, 45 % less total nitrogen (N), 75 % less mineral nitrogen (Nmin), 35% less phosphorus (P) and 27 % less potassium (K) were used in the two organic systems than in CONFYM 2. The amount of organic substance added with the farmyard manure was 1 % lower in BIOORG and 17% lower in BIODYN than in CONFYM 2. The reason for the different values was the change in farmyard manure due to the different storage and processing methods.

Figure 6: Nitrogen fertilisation



Total nitrogen (Ntotal) and mineral nitrogen (Nmin as ammonium and nitrate). The organic systems receive N exclusively from manure and slurry – the conventional systems use mineral fertiliser to reach the standard fertilisation level.

Figure 7: Fertilisation with phosphorus and potash



In BIOORG, approved K fertilisers are also applied in small amounts in addition to farmyard manure.

The nitrogen supply in the CONFYM system has increased significantly (Figure 6). This is due to the fact that, after the third CRP, forage crops (grass clover, maize) with high N demand were grown in three years and the fertiliser recommendations increased due to higher anticipated yields. Because in CONFYM only 60 % of the nitrogen in the farmyard manure is taken into account according to GRUD, the total N fertilisation is significantly higher than in CONMIN at 171 kg/ha and year.

The mineral-fertilised CONMIN system uses an average of 50 kg less **nitrogen (N)** for fertiliser. This difference corresponds to the unaccounted amounts of N in the farmyard manure, which can also lead to environmental problems due to gaseous losses (ammonia and nitrous oxide) and leaching (nitrate).

In the organic systems, an average of 95 kg N per hectare is used in fertiliser, of which only 30 kg is mineral as ammonia and, therefore, directly effective. The organically bound part of the nitrogen from farmyard manure only becomes plant-available ammonium and nitrate through mineralisation in the soil. Overall, the N supply in the organic systems is rather stable.

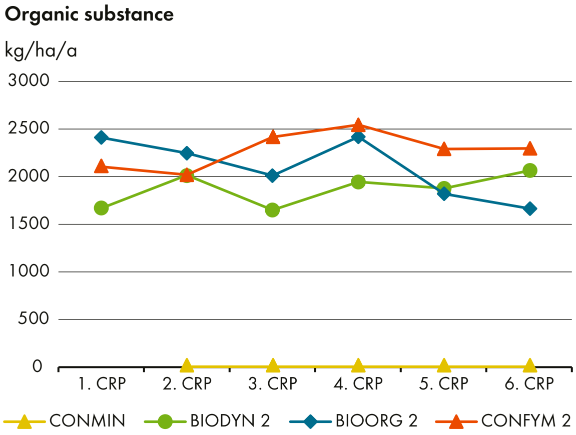
Phosphorus (P) is a plant nutrient whose global deposits are reaching their limits. P fertiliser, therefore, is expensive. In the DOK trial, P fertilisation in the conventional systems is carried out according to the standard, whereby the soluble nutrients in the soil are taken into account. The applied quantities were also adjusted to be in line with the GRUD revisions. The increase in BIODYN is presumably related to the increased P applications via farmyard manure since the third CRP.

Since the start of the DOK trial, **potassium (K)** has been used heavily in fertilisation in the conventional system because the soluble K content in the soil was low. In BIOORG, some potash magnesia is added, while in BIODYN no additional potash fertiliser is used. The increase in potassium in the third CRP in the organic systems can be only partially explained by the increase in farmyard manure quantities. In principle, slurry contains more potassium than manure.

Commercial fertilisers and plant protection products used for winter wheat in the conventional CONMIN system.

DOK trial plots with wheat and rainout shelters to investigate drought effects on soil biodiversity.

Figure 8: Addition of organic substance



The farmyard fertilisers used are manure and slurry. Apart from water, their main components are organic substances and minerals. The diagram shows how much organic substances from fertiliser from 1.4 livestock units per hectare per year ends up in the soil.

The loss of organic substance of the farmyard manure as a result of the different storage types in the three systems is also reflected in the quantities applied. Compared to CONFYM, 12 % less organic matter was applied in BIOORG and 17 % less in BIODYN. In BIODYN particularly, the composting of manure leads to a loss of organic matter.

The amount of liquid manure, on the other hand, hardly differed. The changed housing system in BIOORG led to more organic substances with the same nutrient quantities in the fourth CRP. In CONFYM, the quantities already began to increase in the third CRP.

Crop rotation

The seven-year crop rotation with two years of soil rest without ploughing under grass clover is typical for livestock farms in Switzerland. The annual crops are root and tuber crops (potatoes and beetroots), cereals (wheat, barley), maize, cabbage and soya. Catch crops are used either as green manure or as fodder (the biomass is harvested) (Table 2). The crop rotation is a compromise between the different cropping systems and was slightly adjusted after each CRP. Potatoes, winter wheat and grass clover were grown in each CRP. In the initial phase of the trial, barley and white cabbage were also part of the crop rotation. White cabbage was soon replaced by beetroot in the second CRP (1985) due to the high labour intensity required to grow it. At the beginning of the third CRP (1992), a third year of temporary ley (grass clover) was grown instead of barley, as the cereal-oriented crop rotation led to root rot diseases in all systems. Maize and soya have been grown since 1999, and the temporary ley was cultivated again for two years. The position of the crops was then slightly changed in each CRP until 2013. The reasons for the changes were the optimal utilisation of nitrogen in the crop rotation and the system-independent occurrence of pests, especially wireworms in potatoes when grown after the grass-clover ley.

Table 2: Development of the seven-crop rotation since the start of the trial

Year	1. CRP 1978–1984	2. CRP 1985–1991	3. CRP 1992–1998	4. CRP 1999–2005	5. CRP 2006–2012	6. CRP 2013–2019
1	Potato	Potato	Potato	Potato	Silage maize	Silage maize
	Green manure	Green manure	Green manure			Green manure
2	Winter wheat 1	Winter wheat 1	Winter wheat 1	Winter wheat 1	Winter wheat 2	Soya
	Winter forage	Winter forage	Winter forage	Green manure	Green manure	
3	White cabbage	Beetroot	Beetroot	Soya	Soya	Winter wheat 1
				Green manure	Green manure	Green manure
4	Winter wheat 2	Winter wheat 2	Winter wheat 2	Silage maize	Potato	Potato
5	Barley	Barley	Grass clover 1	Winter wheat 2	Winter wheat 2	Winter wheat 2
6	Grass clover 1	Grass clover 1	Grass clover 2	Grass clover 1	Grass clover 1	Grass clover 1
7	Grass clover 2	Grass clover 2	Grass clover 3	Grass clover 2	Grass clover 2	Grass clover 2

Winter forage is harvested, while green manure remains on the field and is worked in.

Plant protection

Until 1992, pesticides were generally applied according to a fixed spraying schedule in the conventional systems. With the third crop rotation, integrated production (IP) was introduced, in which pesticides are only used once the threshold for the economic limit of tolerance has been reached. The use of pesticides in the conventional systems was based on current legislation and application recommendations.

In the conventional systems, an average of 3 kg of active ingredients were applied per hectare of arable land per year (Figure 9). Fungicides and herbicides accounted for the majority of these applications. Insecticides were applied only rarely and in small quantities. Since the 1980s, the amount of active ingredients applied has decreased sharply, which can also be attributed to the use of highly effective plant protection products (PPP) that require low dosages per application. Within the same period, the number of applications of active ingredients has doubled (Figure 10).

The organic systems use the option of biological pest control and disease prevention measures. In the BIODYN system, only the biologically produced toxin of *Bacillus thuringiensis* (BT), a bacterium, is used as an insecticide against the Colorado beetle.

Potatoes

In potato cultivation, late blight *(Phytophtora infestans)* and the Colorado beetle *(Leptinotarsa decemlineata)* cause considerable damage. In the conventional systems, an average of 15 treatments of herbicides, insecticides and fungicides were necessary per year. In the BIOORG system, seven insecticide applications and copper as a fungicide were used. In the biodynamic system, four treatments with BT preparations were applied.

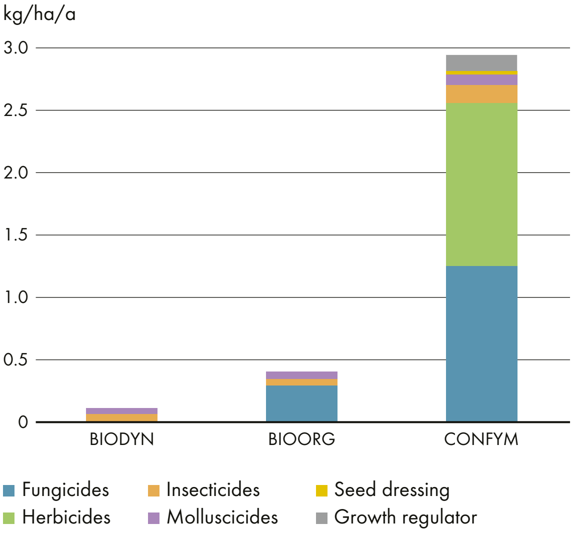
Cereals, maize and soya

Conventional cereals are treated three to four times with herbicide, fungicide and a growth regulator. Maize and soya generally only require one herbicide treatment and one treatment against slugs. The European corn borer is controlled with *Trichogramma* wasps.

Seeds

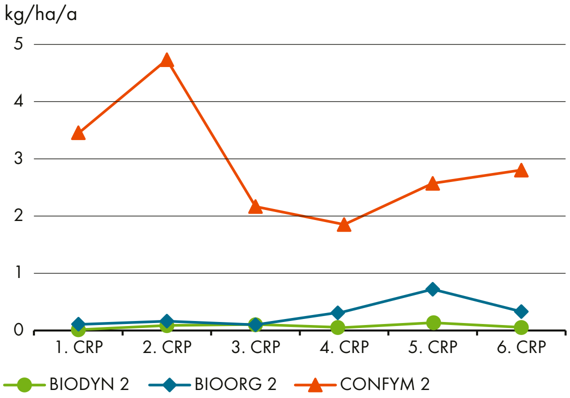
The seed and plant material were dressed in the conventional systems, but not in the organic systems. Since 1998, the seed for the organic systems has come from organic producers.

Figure 9: Quantities of active ingredients applied



Average quantities of active ingredients used over all trial years in kilograms per hectare and year. CONMIN received the same quantities as CONFYM. It should be noted that no PPPs were applied in years when grass clover was cultivated. However, the average values also include the grass clover years.

Figure 10: Development of applied pesticides over time



Average quantities of active ingredients in all plant protection products used in a crop rotation period in the three main systems of the DOK trial. Time course over six crop rotation periods. CONMIN received the same quantities as CONFYM. Figures in kilograms of active ingredients per hectare and year.

Soil cultivation

The plough is used for tillage before the root crops and cereals are planted. At the beginning of the trial, the ploughing depth in the organic systems was slightly shallower at 15–20 cm than in the conventional systems, which used a ploughing depth of 20–25 cm. Since the third crop rotation, all systems have been ploughed to a uniform depth of 20 cm. In the organic systems, mechanical weeding with hoes and harrows, which work the soil superficially, is used more frequently. Potatoes and maize are also hoed in the conventional system.

In all cropping systems the plots were ploughed before wheat and root crops were cultivated.

Table 3: Characteristics of the DOK cropping systems

Cropping system	NOFERT	BIODYN		BIOORG		CONFYM		CONMIN
Livestock units per hectare	–	0.7	1.4	0.7	1.4	0.7	1.4	–
Fertilisation								
Farmyard manure	–	Manure compost and slurry		Rotted manure and slurry		Stacked manure and slurry		–
Mineral fertiliser	–	Rock dust		Rock dust Potash magnesia		Urea, ammonium nitrate, calcium ammonium nitrate, triple superphosphate, potassium chloride		
Plant protection								
Weed control	Mechanical, by harrowing and hoeing					Mechanical and with herbicides		
Plant diseases	–	Indirect measures		Indirect measures, copper sulfate for potatoes		Fungicides		
Pests	Biological control (*Bacillus thuringiensis*), plant extracts, preventive measures					Insecticides, biological control, slug pellets and preventive measures		
Special features	Biodynamic preparations			–		Growth regulators		

Crop yield

The graphs and tables in the following chapter show the average yields of a crop rotation period with three harvests and four field replicates (n = 12).

It should be noted that the yields given are absolute dry matter (100 % DM). In agricultural practice, yields are often stated with a residual moisture content: e.g. wheat, 86 % DM and 14 % water; for soya, 89 % DM and 11 % water. This means that the wheat yields shown here must be multiplied by a factor of 1.16 in order to be comparable with the yield figures used in practice. For soya, the factor 1.12 applies. For grass clover, DM yields are also given in practice, as is usually the case for silage maize. For potatoes, fresh matter yields are used for marketing purposes.

Winter wheat

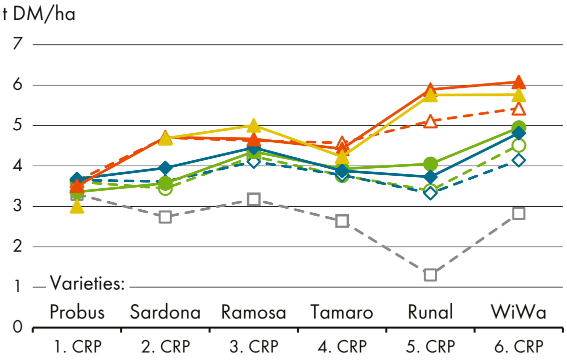
Grain yield

Common wheat varieties with very good baking quality have been cultivated throughout the trial. In the first CRP, all systems achieved similar yields and probably benefited from the previous management practices. In the conventional systems, lodging occurred, which is why the long-strawed Probus variety was unable to convert the applied nitrogen into high yields. Only in the first CRP the CONMIN plots remained unfertilised and, therefore, they showed unusually low yields. The average winter wheat yields from 1985 to 2019 in the organic systems have been 21 % lower than in CONFYM. In what follows, the yield differences only from the second crop rotation period onwards are discussed.

At best, conventional grain yields reached six metric tonnes of dry matter per hectare. This corresponds to the typical yield level in this region of Baselland.

Figure 11: Development of grain yield for winter wheat 1 and winter wheat 2

Winter wheat 1 yield



Winter wheat 2 yield

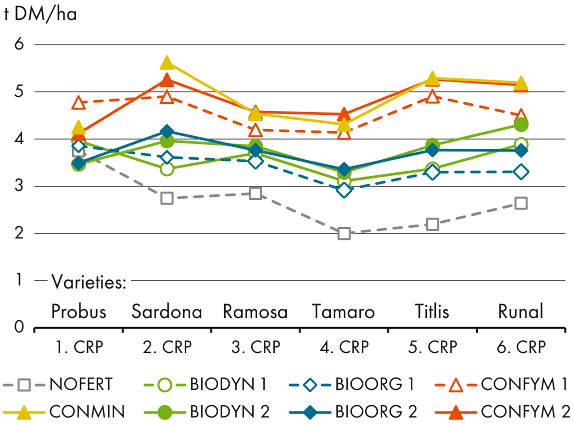


Table 4: Average yield of winter wheat 1 and 2 (1985–2019)

		0.7 LU			1.4 LU			
	NOFERT	BIODYN 1	BIOORG 1	CONFYM 1	BIODYN 2	BIOORG 2	CONFYM 2	CONMIN
t DM/ha	2.51	3.68	3.56	4.71	4.01	3.96	5.05	5.04
0.7/1.4		92 %	90 %	93 %	100 %	100 %	100 %	
BIO/CON		77 %		100 %	79 %		100 %	

Harvesting the edge of a winter wheat plot. Only the central area of the plot is used to determine the exact yield.

The two organic systems as well as the two conventional systems differ only slightly in their development of yields (Figure 11). The cultivation of modern varieties has increased the yields of all cropping systems. In the last two crop rotation periods, yields were higher in the biodynamic system than in the bio-organic system. This could be related to the cultivation of the Wiwa variety, which was bred biodynamically, as well as to the slightly better soil structure and higher biological activity in BIODYN compared to BIOORG. The Nmin content in BIODYN is also always slightly higher than in BIOORG in spring. It is also interesting to note that the unfertilised NOFERT system still produces around two metric tonnes of grain yield per hectare.

Winter wheat 1 has a more favourable position in the crop rotation than winter wheat 2. In the first four crop rotation periods, it benefited from the favourable preceding crop effect of potatoes with or without green manure. The proximity to grass clover likely also had a positive influence on the yield of wheat 1.

On average for the two organic systems, winter wheat 1 had 18 % less grain yield than the two conventional systems, and winter wheat 2 had 23 % less. This small difference may be related to their position in the crop rotation. Since the sixth CRP, the above-mentioned variety (Wiwa) has been used for winter wheat 1. The conventional Runal variety was used for winter wheat 2. Until 2015, the same wheat varieties were grown in both positions in the crop rotation.

In the reduced fertilisation levels, the yields are on average 8 % lower than when using typical fertilisation practices. In this context it is noteworthy that, despite the reduced fertiliser quantity, a higher yield is achieved in the conventional CONFYM 1 system than in the organic systems that use typical fertilisation practices. This result is probably also due to the more effective chemical plant protection and the directly plant-available N fertilisers in the conventional systems. With reduced fertilisation, however, the humus content and thus also the nitrogen reserves in the soil decrease (see chapter "Nutrient dynamics").

Straw yield

Straw yield is also important for animal husbandry, as straw is used for bedding and finds its way back to the field via manure. Although growth regulators (CCC or Moddus) are used in conventional systems, the straw yield in organic systems is 8 % to 10 % lower than in conventional systems. The yield reduction for straw is lower than for grain.

Table 5: Mean value of straw yields of winter wheat 1 and 2 (1985–2019)

		0.7 LU			1.4 LU			
	NOFERT	**BIODYN 1**	**BIOORG 1**	**CONFYM 1**	**BIODYN 2**	**BIOORG 2**	**CONFYM 2**	**CONMIN**
t DM/ha	4.14	6.17	5.82	6.69	7.20	6.86	8.02	7.55
0.7/1.4		86 %	85 %	83 %	100 %	100 %	100 %	
BIO/CON		92 %		100 %	90 %		100 %	

Yield determing factors

In winter wheat, yield determing factors performed significantly better in the conventional systems than in the organic systems: the number of ear-bearing stalks per m^2 was significantly higher in CONFYM 2, with 571 stalks, than in BIOORG 2, with 383 stalks. The thousand-grain weight was 42 g in CONMIN as compared to 39 g in BIOORG 2.

Product quality

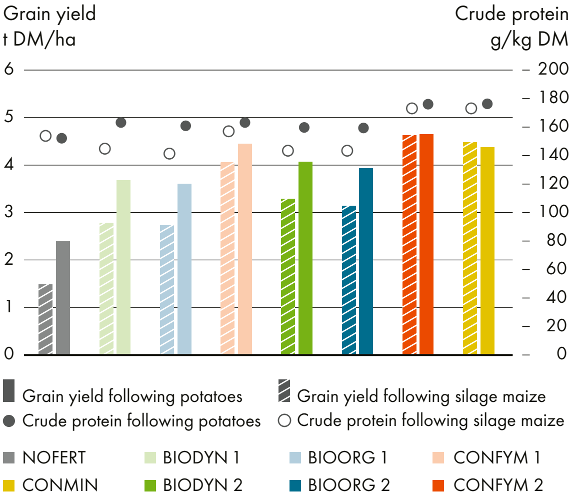
Parameters such as the content of minerals, carbohydrates, proteins and fatty acids are important attributes of the nutritional quality of wheat. In addition, quality characteristics, for example those that influence baking quality, take priority. The DOK trial investigated whether and how cropping systems influence quality criteria.

The crude protein content of the conventional wheat was significantly higher (Figure 12). Interestingly, the difference between fertiliser levels 1 and 2 in the organic system did not lead to any significant improvement in crude protein content.

In contrast, the effect of potatoes as the preceding crop (as compared to silage maize as the preceding crop) had a significantly greater effect on grain yield and crude protein content in the organic systems. In contrast, the influence of the preceding crop was not detectable in the conventional systems. The wheat was more evenly supplied with N during the entire development of the organic system when potato (rather than maize) was the preceding crop, which also affected the crude protein content. In the CONFYM 1 system with reduced fertilisation, significantly higher grain yields and crude protein contents were measured than in the organic systems that used typical fertilisation practices (BIOORG 2, BIODYN 2).

No significant system-related influences were found for micronutrients, amino acid content and baking quality properties. The same applies to metabolic parameters such as element and sugar concentrations. The antioxidant potential also did not differ between the systems.

Figure 12: Winter wheat yields and crude protein content



Winter wheat yields in the DOK cropping systems for subplots with either maize or potatoes as preceding crops. The data show mean values for the years 2003 and 2010.

The various cropping systems have no influence on many of the crop quality characteristics of wheat.

Mycotoxin

Mycotoxins play an important role in the product quality of wheat. These are trichothecenes, which are produced when the grain is infected with *Fusarium* fungi and can be harmful to human and animal health even in low concentrations. Of the mycotoxins that are analysed, only deoxynivalenol (DON) and nivalenol (NIV) were detected at low levels in all cropping systems. DON is most frequent and is about ten times less toxic than NIV.

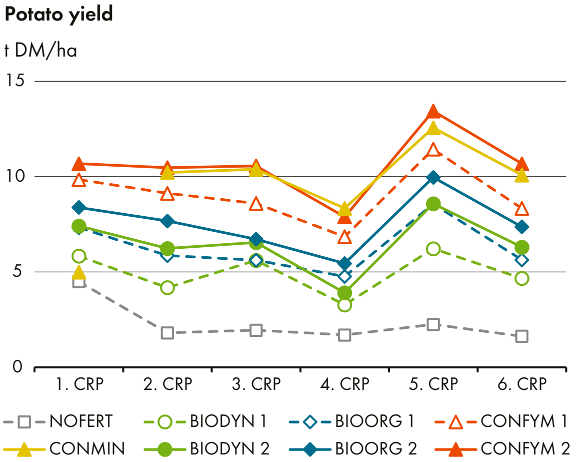
Potatoes

Pre-sprouted seed potatoes were planted, and in conventional systems they were usually treated against fungi. Since 2006, the potatoes have been grown after soya or winter wheat instead of after grass clover, and since then they have shown a positive yield trend in all systems.

The tuber yield of BIOORG 2 was on average 35 % lower than that of CONFYM 2. That of BIODYN 2 was even 42 % lower than that of CONFYM 2. The potatoes in the organic systems often show a lack of potassium and nitrogen. The vegetation period of the potatoes in BIODYN is also shortened, as no fungicides are authorised in this system, so the plants that are attacked by late blight *(Phytophtora infestans)* die off early. To protect the tubers, the haulm is usually cut off relatively early. The preventive treatments with copper-containing products (copper hydroxide, copper oxysulphate, copper sulphate) allow the plant a slightly longer vegetation phase in BIOORG than in BIODYN, where copper is not permitted. Today, the amount of copper permitted in potato cultivation in Switzerland is 4 kg per hectare, which is significantly lower than the previous rates. Copper in the soil represents a permanent potential burden for microorganisms and molluscs, which is why alternatives are being sought.

Ridged potato plants in the DOK trial.

Figure 13: Development of potato yields



In the CONFYM 2 system, 37 % of the manure quantity of the entire CRP is added to potatoes, while only 25 % is added in BIOORG 2. The plants nitrogen demand hardly coincides with the mineralised nitrogen from manure, resulting in shortages in growth phases with high demand. Thus the conventional systems with mineral fertiliser are better nourished.

In the case of potatoes, the particularly efficient CONFYM 1 system with reduced fertilisation and 15 pesticide sprays is worth highlighting, as the yields are also higher than in the organic systems, which used typical fertilisation practices.

In the third CRP, copper was not used in BIOORG, so the yields here are at the same level as in BIODYN. In the other CRPs, the yields in BIOORG are mostly higher than in BIODYN. This underscores the importance of plant protection in this very sensitive crop.

Table 6: Average value of potato tuber yields from 15 years of cultivation (1985–2019)

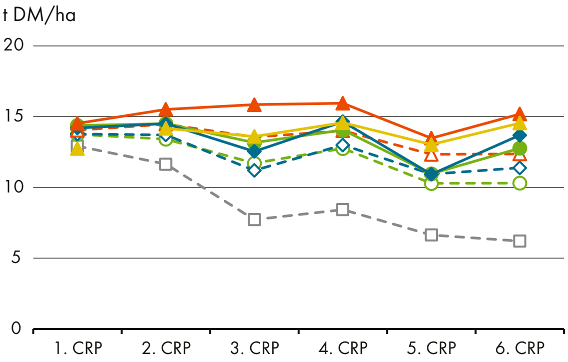
		0.7 LU			1.4 LU			
	NOFERT	BIODYN 1	BIOORG 1	CONFYM 1	BIODYN 2	BIOORG 2	CONFYM 2	CONMIN
t DM/ha	1.87	4.79	6.09	8.87	6.32	7.44	10.61	10.32
0.7/1.4		76 %	82 %	84 %	100 %	100 %	100 %	
BIO/CON		61 %		100 %	66 %		100 %	

Grass-clover ley

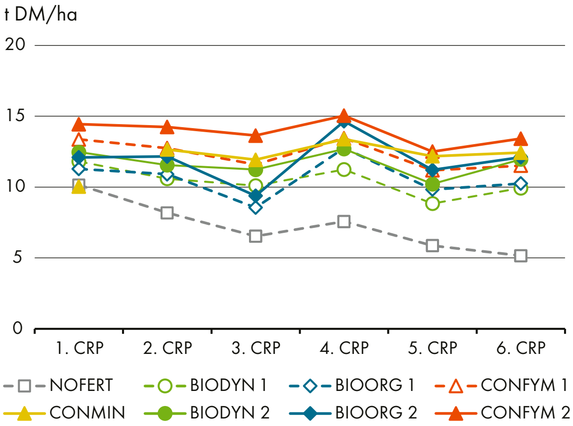
The dry matter yields of grass clover shown here are the result of the respective totals of up to five cuts per year for the two main harvest years (Figure 14). Early mowing in the sowing year or at the beginning of the year were not taken into account. Grass clover is sown in September and not ploughed again until the third spring afterwards, so that the soil is not ploughed for two and a half years.

Figure 14: Grass clover yield development

Grass clover yield (1st main harvest year)



Grass clover yield (2nd main harvest year)



Grass clover yield in the first and second main harvest year as the sum of four to five cuts per year.

Two-year-old clover-grass mixtures form the backbone of the seven-year crop rotation in the DOK trial. The grasses already dominate the conventional clover-grass stocks in the second year, while the clover usually remains present longer in the organic systems.

The difference in yield between the organic and conventional systems in the first harvest year at the same fertilisation level is relatively low at 10 to 11 %. CONFYM 2 had the highest average yield. The two organic systems with reduced fertilisation had 19 % less yield and the unfertilised system had 40 % less yield than CONFYM 2 (Table 7).

In the second harvest year, yields were on average 12 % lower than in the first year for all systems. The relatively small yield differences between organic and conventional cropping systems can be explained by the clover in the mixture, which fixes more nitrogen from the air via rhizobia bacteria in the organic systems. The long growth period of the grass clover and the intensive rooting of the soil by these mixtures also play a role. The fixation capacity of the clover in the mixture was 178 to 300 kg N per hectare and year. In addition, the roots of the grass clover were well colonised with mycorrhizal fungi, which help to absorb nutrients.

Table 7: Mean value of clover yields over 30 yield years, per system

		0.7 LU			1.4 LU			
	NOFERT	BIODYN 1	BIOORG 1	CONFYM 1	BIODYN 2	BIOORG 2	CONFYM 2	CONMIN
t DM/ha	7.40	10.92	11.25	12.72	12.31	12.58	14.48	13.25
0.7/1.4		89 %	89 %	88 %	100 %	100 %	100 %	
BIO/CON		87%		100 %	90%		100 %	

Silage maize

Maize was introduced into the fourth crop rotation period of the DOK trial because it was playing an increasingly important role in agricultural practice as a source of roughage for cattle.

With up to 20 metric tonnes of dry matter per hectare, the maize yield is clearly superior to that of the temporary ley (Figure 15), though maize is less versatile as a source of fodder.

When fertilised according to common practice, the maize yields of the organic systems were 11 and 15 % lower than in CONFYM 2. With reduced fertilisation, the yield was still 10 % lower than in CONFYM 1. Only half as much maize grew in the unfertilised plots in NOFERT. The low yield reduction of maize in the organic systems as compared to the conventional systems can be explained by the fact that maize has a long growth period and can absorb the mineralised nitrogen from the soil stocks and farmyard manure until autumn. So far, the incidence of diseases and pests in maize has also been low. In all systems, the European corn borer is controlled with *Trichogramma* wasps.

Figure 15: Silage maize yield development

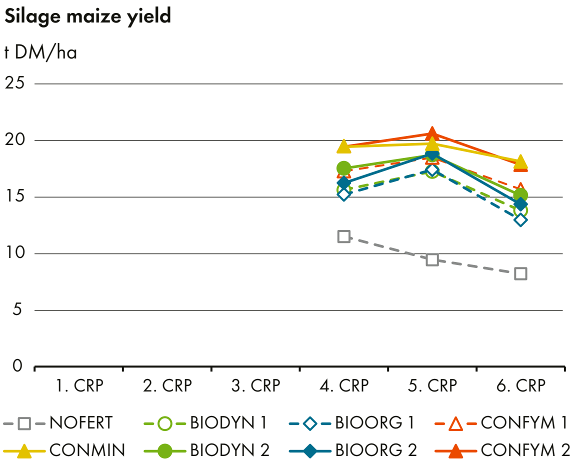


Table 8: Average silage maize yields over 9 yield years, per system

		0.7 LU			1.4 LU			
	NOFERT	BIODYN 1	BIOORG 1	CONFYM 1	BIODYN 2	BIOORG 2	CONFYM 2	CONMIN
t DM/ha	9.74	15.57	15.21	17.15	17.14	16.48	19.31	19.12
0.7/1.4		91 %	92 %	89 %	100 %	100 %	100 %	
BIO/CON		90 %		100 %	87 %		100 %	

The silage maize on the trial plots is harvested in late summer.

Soya

Like maize, soya was introduced in the fourth crop rotation period. Breeding progress allowed for the cultivation of cold-tolerant varieties in more northern climates. In addition, soya is in demand as a product for human consumption and for animal feed. Thanks to its symbiosis with *Bradyrhizobium japonicum*, soya is largely self-sufficient in terms of nitrogen, which makes it well-suited for organic crop rotations. The bacterium must be added at sowing, as it does not occur naturally in Swiss soils. The nitrogen supply is, therefore, not a limiting factor for soya as it is for the other crops in the rotation. In addition, the pressure on soya from pests and diseases is still low.

Favoured by these factors, soya achieves the same yields in both organic and conventional systems (Figure 16). Nitrogen fertilisation was not applied in any of the systems. All cropping systems that use typical fertilisation practices have comparable yields, while the CONFYM 1 system with reduced fertilisation achieves slightly better yields than the two organic systems at fertilisation level 1 (Table 9). This is an indication that phosphorus and potassium are growth-limiting elements with reduced fertilisation. A good P supply is essential for optimum biological N fixation.

Soya plant in bloom.

Figure 16: Development of grain yield for soya

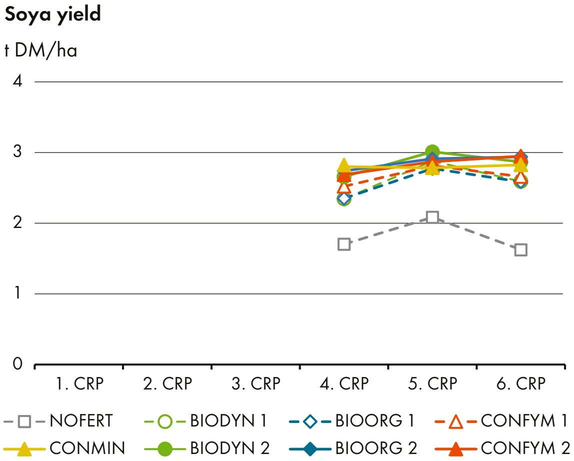


Table 9: Average value of soya yields over 9 yield years, per system

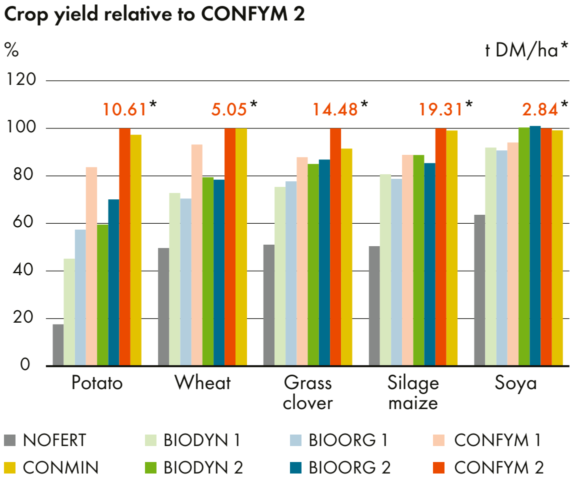
		0.7 LU			1.4 LU			
	NOFERT	BIODYN 1	BIOORG 1	CONFYM 1	BIODYN 2	BIOORG 2	CONFYM 2	CONMIN
t DM/ha	1.80	2.61	2.57	2.67	2.85	2.86	2.84	2.81
0.7/1.4		92 %	90 %	94 %	100 %	100 %	100 %	
BIO/CON		97 %		100 %	101 %		100 %	

Each year, three crops are grown in the DOK trial. In 2023, they were maize, potatoes and soya.

Crop comparison

The comparison of yields in Figure 17 clearly shows the different sensitivities of the crops to the cropping system. In contrast to potatoes, soya seems to be fairly unaffected by organic or non-organic systems. In addition to being limited by nitrogen and potassium, diseases and pests play a major role in the yield of potatoes, whereas soya, as a newly introduced crop in our climate, has hardly any problems with this. Even with legumes, the lower yields with the reduced fertilisation level show that with 0.7 LU/ha in organic systems, the P and K supply is scarce even in fertile soil, as few or no supplementary fertilisers are used. In the long term, organic systems must either remain dependent on permitted mineral or organic commercial fertilisers or use recycled fertilisers such as green compost or solid or liquid digestate.

Figure 17: Average yield of all main crops



Average yield compared to the CONFYM 2 system from the second to sixth CRP; maize and soya only from the fourth to sixth.

In short: crop yield

Compared to conventional systems, the organic systems achieved lower yields with fewer nutrients and pesticides used. Soya is an exception, as it does not rely on nitrogen delivery from the soil, so soya yields were equally high in both systems. Grass clover showed only a slight reduction in yield in the organic systems, while potatoes showed a significant reduction. It is interesting to note that at half the fertilisation intensity, yields were higher in the conventional CONFYM system than in the organic systems that use typical fertilisation practices. This is an indication of the influence of plant protection and easily soluble nutrients on yields, especially in the case of potatoes and wheat. Preceding crops, green manures and breeding objectives tailored to organic farming can further increase the yield potential for organic farming.

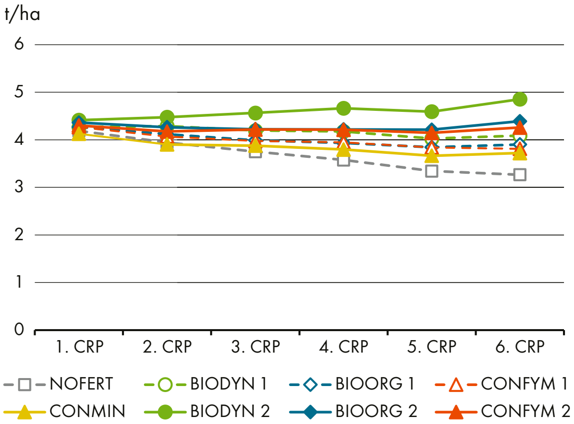
Nutrient dynamics

Nitrogen

Most of the nitrogen (N) in the soil is in organic form. Mineral nitrogen is directly available and thus very relevant for plant nutrition. On average across all systems, the total N content in the top 20 cm of the soil was 1.6 g per kg of soil. At a depth of 30 to 50 cm, the total content of N was only about half as high.

The C/N ratio of the soil organic matter hardly changed over the DOK trial period. The mean value was constant at 9 ± 0.11 and showed no effects related to the cropping system.

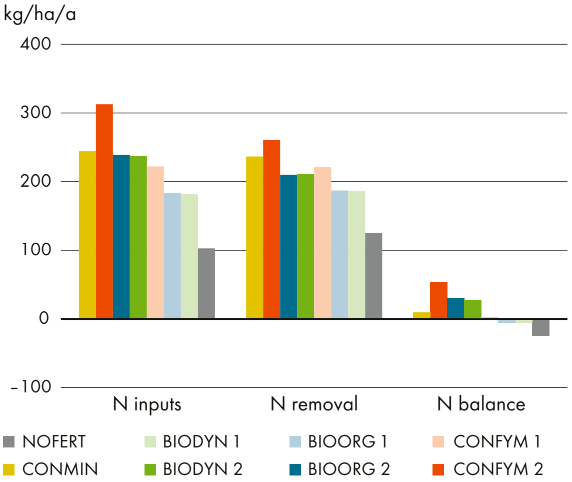
Figure 18: Total nitrogen stock in the soil



N supply in the top 20 cm of the soil. Mean value of the measurements during each crop rotation period. The data were calculated from the total N content, taking into account the bulk density of the soil, measured in the first CRP.

Between 3.2 and 4.9 metric tonnes of N stock were measured per hectare at a soil depth of 0 to 20 cm. In the BIODYN 2 system, the N stock increased by 9 kg per year (Figure 18). In the BIOORG 2 and CONFYM 2 systems, the N stocks in this soil layer were constant over time. In all other systems, the N stocks decreased by up to 20 kg per year in the unfertilised control. The results show that the N stocks in the soil could not be maintained in the systems with reduced fertilisation. This means that nitrogen utilisation in these systems is not sustainable.

Figure 19: Nitrogen balance



N balance with inputs from fertilisation, deposition, seed and N fixation from the atmosphere, as well as exports via crop removal. Average values from five crop rotation periods between 1985 and 2019.

Soil surface balances were calculated for the period from 1985 to 2019. These compare the N supply with the N removal by the crop. The nitrogen supply variables are:

- Fertilisation
- Symbiotic N_2 fixation
- N deposition
- N in the seed

In the systems with conventional fertilisation, the balance between supply and removal was positive and ranged from a surplus of 23 kg (BIODYN 2 and BIOORG 2) to 46 kg (CONFYM 2) of nitrogen per hectare per year (Figure 19). In the purely mineral-fertilised CONMIN system, the balance was even. The systems with reduced fertilisation showed annual deficits of between 5 and 10 kg of nitrogen per hectare. In the non-fertilised NOFERT system, the deficit was 31 kg per hectare per year (Table 10).

Nitrogen losses due to leaching

The negative N balances with reduced and no fertilisation show that more N is released from the soil organic matter than is reincorporated. With conventional fertilisation, however, the N stocks increased less than would have been expected based on the N balances. In CONFYM 1 and CONMIN, on the other hand, the N stocks decreased more than would have been expected based on the negative balances.

These deviations can be explained by the fact that ammonia emissions during fertiliser application, denitrification losses or nitrate leaching are not taken into account in the soil surface balance. The sum of these losses amounts to 12 to 47 kg per hectare per year with conventional fertilisation.

The changes in N stocks in the deeper soil layers were not investigated until later: soil samples were taken from a depth of 30 to 50 cm in 2019 and 2020. There were significantly smaller differences in N stocks between the systems at that depth than at a soil depth of 0 to 20 cm. The effect of the lack of fertilisation was only evident in NOFERT at a depth of 30 to 50 cm.

Efficient nitrogen utilisation

The nitrogen utilisation efficiency (NUE) can also be derived from the soil surface balance: this gives an indication of how much of the supplied N is taken up by the plants. A NUE above 100 % means that more N is removed than is supplied and, therefore, suggests that N is released from the soil organic matter (humus). For the systems with conventional fertilisation and CONMIN, the NUE was between 85 and 100 % (Table 10). The NUE here refers to the total N supply and shows that both farmyard manure and mineral fertilisers as well as the biologically fixed nitrogen were used efficiently in the DOK trial.

Binding of atmospheric nitrogen

Legumes form a symbiotic relationship with rhizobia: In visible nodules on the root, the bacteria convert molecular atmospheric nitrogen (N_2) into ammonium, which the plant can utilise to form proteins. The symbiotic N_2 fixation was the largest source of N in all systems, except in the mineral fertilised CONFYM 2 and CONMIN systems. The systems using reduced fertilisation showed similar fixation performance to those using conventional fertilisation. In CONMIN, however, the fixation performance was significantly lower. The most N was fixed by the clover in the temporary leys, followed by soya beans and the catch crops.

N fixation by rhizobia requires a good supply of phosphorus, potassium and trace elements in the soil. In the unfertilised system, N_2 fixation has decreased over time, which is most likely due to the decreasing levels of plant-available phosphorus and potassium in these soils.

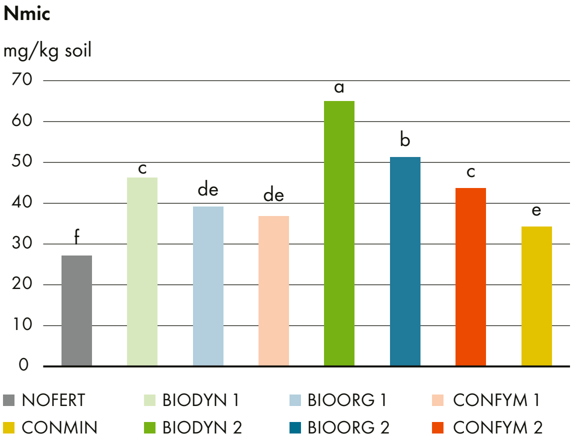
Table 10: Nitrogen inputs and losses in the DOK systems
Mean value from the five crop rotation periods between 1985 and 2019

Details in kg/ha/a	Fertiliser	Symbiotic fixation	Deposition and seed	Harvest	Balance	Change in soil stock	Utilisation efficiency
NOFERT	0	75	21	128	-31.1	-26.2	133 %
BIODYN 1	47	112	21	189	-8.7	-9.1	105 %
BIOORG 1	48	111	21	190	-9.6	-10.0	106 %
CONFYM 1	85	112	21	223	-4.5	-11.2	102 %
BIODYN 2	93	122	21	214	22.9	9.3	91 %
BIOORG 2	96	119	21	213	23.7	1.2	90 %
CONFYM 2	171	117	21	264	45.9	-0.7	85 %
CONMIN	121	99	21	240	2.1	-10.0	99 %

Nitrogen in microbial biomass

Soil microorganisms can store large amounts of nitrogen in their biomass (Nmic). Figure 20 shows Nmic contents in the soil. Taking into account the soil volume and the storage density of the soil, the BIODYN 2 system harbours up to 150 kg Nmic per hectare. The nitrogen in microorganisms serves as a temporary store for N in the soil, which is released again after the death of microorganisms (due to frost or dehydration, for example) when there is sufficient soil moisture and becomes available to the plants.

Figure 20: Microbial biomass



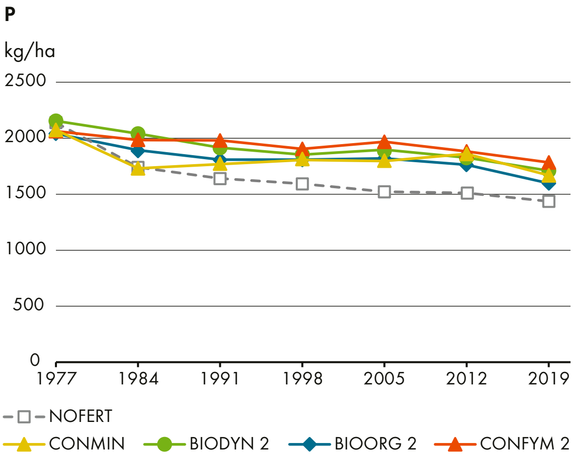
Microbially bound nitrogen in the eight systems of the DOK trial. Mean value from analyses of all plots in spring in 1998, 2006, 2012 and 2019.

Repeated measurements of the microbial biomass at the end of the last four crop rotation periods revealed significantly more microbially bound nitrogen in the BIODYN 2 system as compared to BIOORG 2, and even more so to CONFYM 2. The CONMIN system showed similar values to the systems with reduced fertilisation. The NOFERT system exhibited the lowest levels of Nmic.

Phosphorus

Before the DOK trial was established in 1977, the phosphorus stocks of each plot in subplot C were measured: At the time, the P stock in the top 20 cm of the soil was around 2100 kg/ha (Figure 21). The soil was, therefore, well supplied with P.

Figure 21: Total phosphorus stock in the topsoil



Phosphorus (P) stock in the soil layer at a depth of 0 to 20 cm over the course of six crop rotation periods with differentiated management in subplot C (n = 4).

The farmyard manure is spread by hand on the DOK plots.

Since then, a decrease has been observed in all cropping systems, though the stock in CONMIN (after its establishment in 1984; previously NOFERT) has remained relatively constant. The decrease in P stocks in NOFERT was almost 20 %, while the organic systems had, on average, 5 % lower P stocks than CONFYM 2.

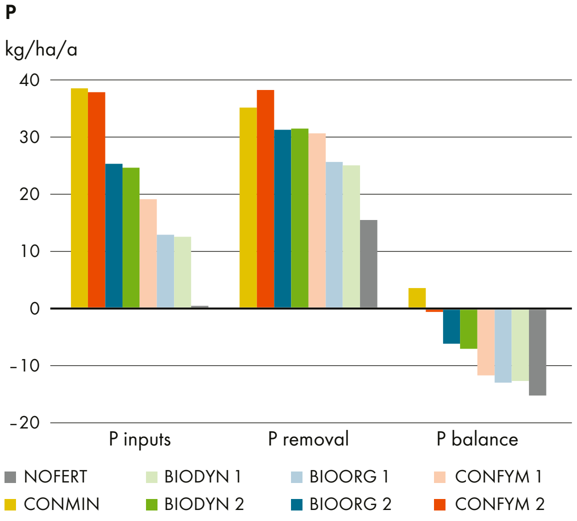
Phosphorus balance

The phosphorus balance is the difference between the phosphorus supplied through fertiliser and seed and the phosphorus removed when harvesting the crop (Figure 22). In the CONFYM 2 system, the average supply was 40 kg P per hectare per year. In the BIODYN 2 and BIOORG 2 systems, it was around 38 % lower at 25 to 26 kg P per hectare per year. The ratios between the systems with reduced fertilisation are similar, but at a lower level.

At 32 kg, the P removed when harvesting the crop was only 16 % lower in the organic systems with conventional fertilisation than in CONFYM 2, where it was 38 kg per hectare per year. This indicates that P from fertilisation is used more efficiently in the organic systems. At the same time, however, there is a continuous depletion of P stocks in the soil in all systems except CONMIN.

Due to the low solubility of phosphorus, the crops in the first CRP in particular benefited from the initially high P supply. At the same time, system-specific differences in P availability could already be identified at the beginning of the DOK trial (Figure 23).

Figure 22: Phosphorus balance

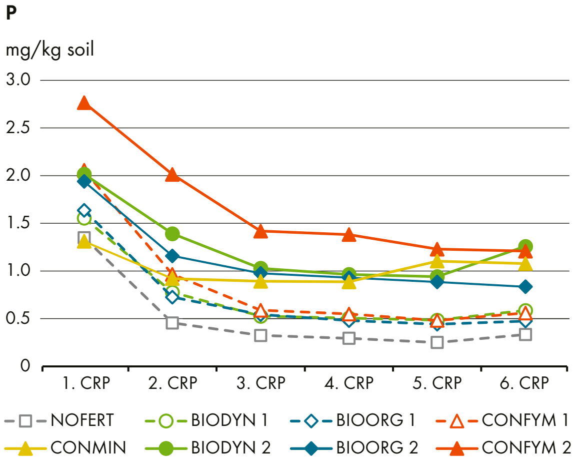


Phosphorus balance: the difference between the phosphorus supplied through fertilisation and seed and the phosphorus removed when harvesting the crop. Average value from the five crop rotation periods between 1985 and 2019

The CONFYM 2 system shows a higher P availability than BIODYN 2 and BIOORG 2 due to fertilisation with readily available mineral fertiliser. Based on current fertilisation GRUD recommendations, 'sufficient' P was still available in the CONFYM 2 and BIODYN 2 cropping systems after 42 years (Figure 23).

However, the BIOORG 2 system and all systems with reduced fertilisation already showed a 'moderate' supply from the fourth CRP at the latest. In agricultural practice, a possible reduction in yield is usually compensated for by additional fertilisation. The causes of the decrease in soluble phosphorus are the negative P balances, rapid fixation and leaching into deeper soil layers.

Figure 23: Soluble phosphorus



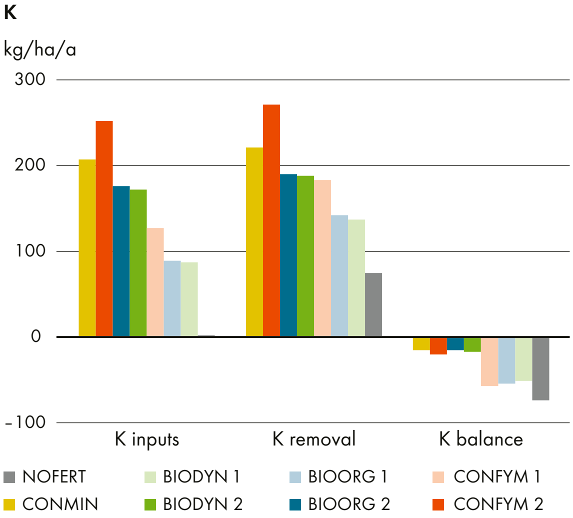
Soluble phosphorus content of the soil in soil samples after harvest. Mean values from annual (1978–2006, 2008–2010) and biennial (2010–2018) surveys per plot, CO_2 method.

Due to the cool weather after sowing, P deficiency symptoms were visible in maize in the organic systems with reduced fertilisation.

Potassium

The potassium balance is also determined by the difference between the potassium supplied through fertilisation and seed and the potassium taken up by the harvested crop. The CONFYM 2 cropping system had the highest K supply with 251 kg K per hectare per year. The amount removed was higher than the amount supplied in all cropping systems, resulting in a negative balance in all systems (Figure 24).

Figure 24: Potassium balance

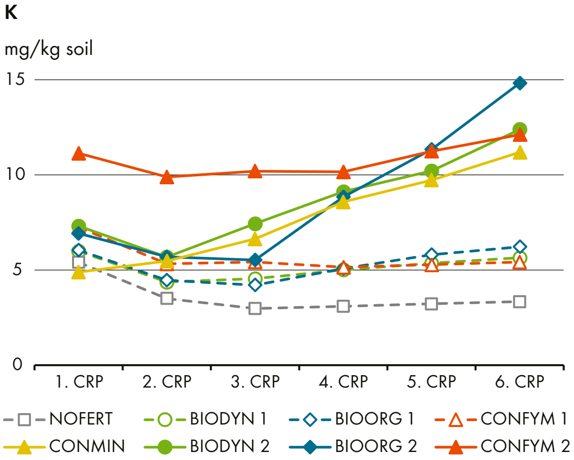


Potassium balance: the difference between the potassium supplied through fertilisation and seed and the potassium removed when harvesting the crop. Average value from the five crop rotation periods between 1985 and 2019.

The availability of potassium shows a clear differentiation between the cropping systems and fertilisation levels (Figure 25). What is particularly striking is the increase in K availability in all cropping systems with the normal level 2 of fertilisation and in the CONMIN system, in which fertilisation amounts have been precisely calculated since the 1990s. During this period, the potassium supply in the organic systems increased noticeably in some cases, but the amount removed did not increase to the same extent.

Despite this, all cropping systems currently fall into the 'moderate' supply class. The agricultural advisors would recommend increasing K fertilisation. Studies have shown that the NOFERT system impairs plant growth due to the reduced availability of potassium.

Figure 25: Soluble potassium



Soluble potassium content. Mean values from annual (1978–2006, 2008–2010) and biennial (2010–2018) surveys per plot, CO_2 method.

Nutrient inputs via roots and nitrogen transfer

Carbon and nitrogen inputs via roots are the main source for maintaining and building up soil organic matter, also called humus. Root inputs to the soil consist of the roots and the substances released by the roots (rhizodeposition) while the plant is growing. These include substances such as soluble root exudates and mucilage (layer on the surface of roots), as well as detached root cells, root hairs and fine roots, which are quickly decomposed by microorganisms in the soil. Here we show the carbon and nitrogen transferred belowground by roots.

Carbon inputs

Scientific models, which estimate carbon (C) inputs in soils and form the basis for international climate reports, have so far assumed that below-ground C inputs are proportional to above-ground biomass: the higher the yield of a crop, the more C is introduced into the soil below ground. Conversely, this would mean that more C is introduced into the soil in conventional cropping systems than in organic systems. Results from the DOK trial disproved this assumption for winter wheat and maize.

The study has shown that below-ground inputs are largely independent of above-ground biomass production and that organic systems even tend to have slightly higher below-ground C inputs despite having lower yields. Below-ground C inputs accounted for between 18 and 26 % of total C assimilation. Rhizodeposition was of fundamental importance for below-ground C inputs and in turn accounted for 57 to 63 % of below-ground C inputs in maize and 54 to 58 % of below-ground C inputs in winter wheat (Figure 26).

Nitrogen transfer in the grass-clover meadow

C and N inputs are equally fundamental for maintaining or building up SOM. In the DOK trial, the C/N ratio of the SOM was relatively constant at around nine. This means that, per kg C, around 0.11 kg N is fixed in SOM for the long term. This is the part of soil nitrogen that may become available to the plant when SOM is decomposed.

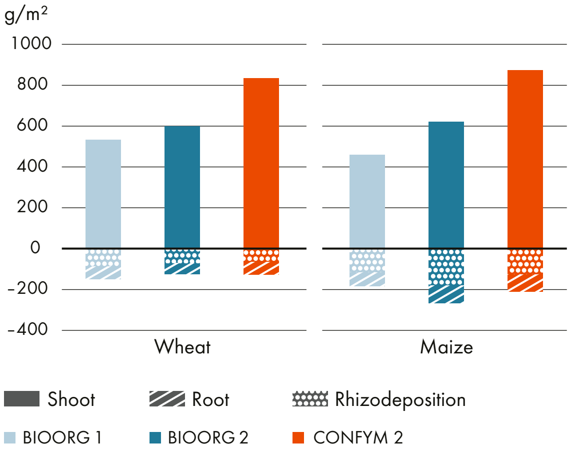
The example of the grass-clover meadow in the DOK shows how the below-ground root inputs of clover affect the biological N_2 fixation of the entire mixture. In contrast to C-transfer by maize and wheat roots, the below-ground N inputs of clover were proportional to the above-ground N assimilation. It should also be noted that, in the first harvest year, the N bound in the roots and the N rhizodeposition increase over the vegetation period. In the second harvest year, the root N decreases again, but the inputs via rhizodeposition increase significantly. This indicates a very high root turnover, due to the frequent mowing and ageing of the clover.

The DOK systems differed significantly in terms of N assimilation, however, the proportion of below-ground N was always constant and amounted to around 29 % of the total N. The proportion of rhizodeposition in the below-ground N increased from around 35 % to 75 % from the end of the first harvest year to the end of the second harvest year.

The grass part of the grass-clover mixture benefited directly from the N inputs via the rhizodeposition of the clover. Two independent DOK studies showed that, in organic systems, around 40 % of the N taken up by the grass originates from the clover and, therefore, mainly from biological N_2 fixation.

The consideration of below-ground N inputs and the N transfer from clover to grass has a significant influence on the estimation of the quantity of fixed N in grass clover meadows. This is significantly lower when based only on the above-ground growth. This is why, when compared to conventional estimation systems, we calculated 1.8 times more fixed atmospheric nitrogen in BIOORG 2 in 2007.

Figure 26: Distribution of assimilates in shoots, roots and rhizodeposition in wheat and maize



Comparison of the BIOORG 1, BIOORG 2 and CONFYM 2 systems.

In short: Nutrient dynamics

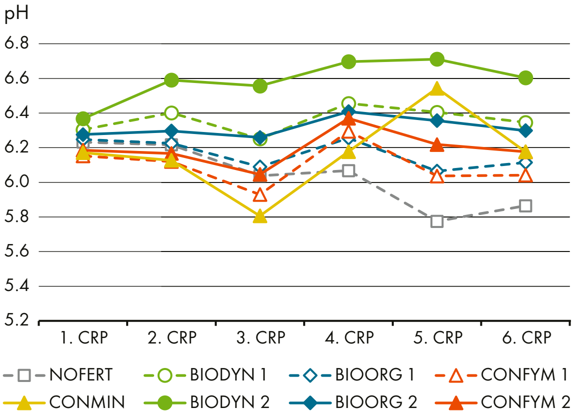
The nitrogen stock in the upper 20 cm increased only in the BIODYN 2 system (see page 32 "Soil carbon"). In BIOORG 2 and CONFYM 2, the stocks were constant. Nitrogen stocks decreased in systems that received no or reduced rates of organic fertilisers. The fixation of atmospheric nitrogen through the symbiosis of legumes with rhizobia accounted for a very high proportion of the total nitrogen supply in all systems, but it was significantly reduced in the systems without farmyard manure (CONMIN and NOFERT). Phosphorus stocks decreased in all systems, but more so in the organic systems, due to their limited fertilisation, compared with the conventional ones. So far, with the exception of NOFERT, deficiency symptoms of plants have rarely occurred, which indicates that organic systems use phosphorus efficiently. The potassium supply shows a negative balance in all systems, but the potassium availability shows a positive trend in the last three crop rotation periods.

Soil quality

pH value

In the organic systems, the pH value of the soil remained at a stable level, between 6.6 and 6.3, for the entire duration of the trial. In the conventional systems, the pH value decreased below 6 after 25 years, which is considered critical for this type of soil according to GRUD. This development is due to the acidifying effect of mineral fertilisers.

Figure 27: Course of the soil reaction



The CONFYM and CONMIN systems were limed in the years 1999–2005 (n = 12).

Maintaining a pH value above 6 is important for plant nutrition, biological activity and soil structure. In order to raise the pH value again in the conventional systems, the soils were limed with five metric tonnes of CaO equivalents per hectare and fertilised with basic calcium ammonium nitrate (CAN) at the beginning of the fourth CRP in 1999. The success of this measure can be seen in the pH increase in the conventional systems (Figure 27). CONMIN received an additional liming because the pH value was still lower than in CONFYM. However, the trend towards acidification appears to continue after liming.

Soil structure

Soil aggregates

Soil aggregates are formed by the accumulation and assemblage of mineral clay particles and organic particles. They are stabilised by soil organisms with hyphae and biofilms. This results in the formation of relatively solid structures that do not dissolve in water. The shape of the aggregates is an indicator of the structural stability of the soil.

Soil with more water-stable soil aggregates is crumbly, less silted up and better protected against erosion thanks to improved water infiltration. It allows for better aeration and a better oxygen supply to the roots. The structurally relatively weak loess soil of the DOK trial tends to silt up. In the organic systems, the soils tend to silt up less.

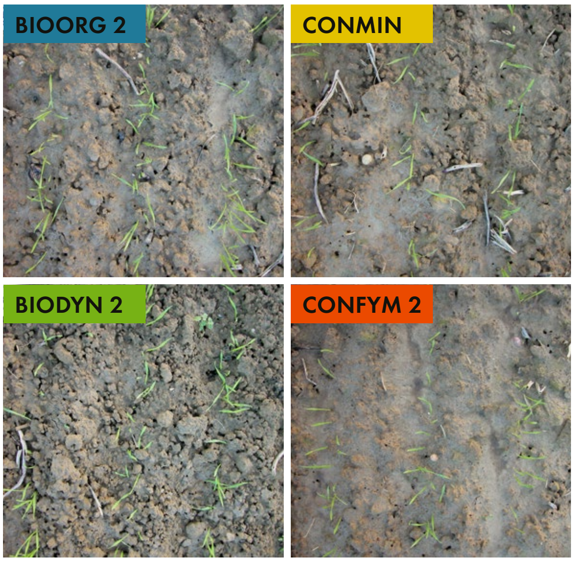
Interestingly, the aggregate stability shows a strong seasonality (Table 11). Especially in summer, when the soil was dry, the aggregate stability in the loess soil was low across all systems. The two organic systems still had the highest proportion of stable aggregates. This might be connected to an increased microbial biomass, and in the case of BIODYN more humus, which promote aggregate formation. The differences were smaller in spring. Under humid conditions, the fungal hyphae and bacterial biofilms remain effective as ‘adhesives.’

Table 11: Proportion of water-stable aggregates in soils of the DOK trial

	Proportion of stable aggregates	Significance
BIODYN 2	50.1 %	a
BIOORG 2	44.2 %	ab
CONFYM 2	38.4 %	b
CONMIN	38.4 %	b
Overall average across all systems		
March 2000	55.3 %	a
March 2003	48.2 %	b
July 2003	24.8 %	c

Bulk density

The bulk density of the soil in the DOK trial is high, as the loess soil consists mainly of finer silt particles. Through biological measures, for example with the help of earthworms and fine roots, this soil can nevertheless form a system of fine and coarse pores. It can be temporarily loosened with tillage. Due to the influence of crop rotation and tillage, the bulk density changes over the course of a vegetation period. The bulk densities differed only slightly between the cropping systems, yet a change of more than a tenth in this parameter can be relevant. Ultimately, due to the parent material, the soil remains poor in coarse pores, tends to become waterlogged and warms up slowly.



Aggregate stability influences the tendency of soils to silt up.

Table 12: Bulk density in the soils of the DOK trial (in kg/dm^3)

Level	Bulk density, 1st CRP	SD	Bulk density, 3rd CRP	SD
NOFERT	1.32	0.046	1.26	0.035
BIODYN 1	1.33	0.043	1.20	0.039
BIOORG 1	1.32	0.039	1.23	0.029
CONFYM 1	1.33	0.023	1.22	0.070
BIODYN 2	1.31	0.047	1.20	0.044
BIOORG 2	1.32	0.040	1.22	0.046
CONFYM 2	1.32	0.039	1.22	0.027
CONMIN	1.31	0.057	1.25	0.066
Mean value	1.32		1.22	

Soil carbon

More carbon is stored in the world's soils compared to the sum of its plant biomass and atmospheric carbon dioxide (CO_2). They, therefore, play an important role in the discussion on climate change, as arable soils in particular are often depleted of humus and have great potential to build up humus and thus store CO_2 from the atmosphere.

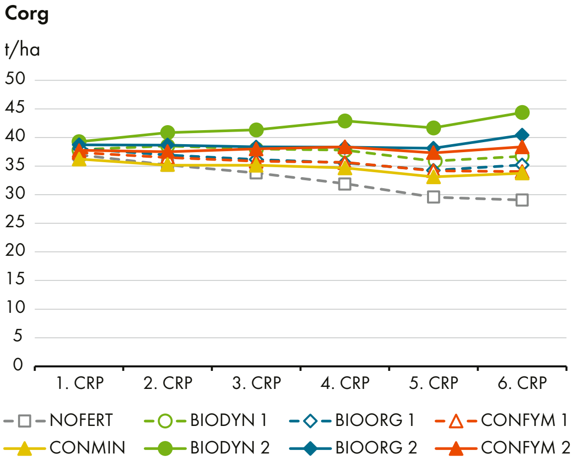
Organic carbon

Soil organic matter (humus) is formed from the residues of plant and animal biomass that have been decomposed in the soil. On average, it consists of 58 % C. Thus, SOM is usually quantified by measuring the organic carbon content (Corg), where SOM = 1.725 × Corg. SOM is the most commonly used indicator to analyse the quality of a soil for cropping.

In the DOK trial, annual soil samples were taken after the harvest from a depth of 0–20 cm and archived. The majority of these samples from the entire trial period were analysed uniformly at the end of the sixth CRP. This made it possible to exclude influencing factors such as changing laboratory personnel, new equipment and methods and to visualise the actual development.

The new analyses yielded the following results: Organic carbon (Corg) is clearly highest in the BIODYN 2 system (Figure 28). A positive trend was also statistically confirmed in this system. In the BIOORG 2 and CONFYM 2 systems, the contents remained constant – the slight increase here could not be statistically substantiated. Corg levels decreased in all systems with reduced fertilisation as well as in CONMIN. As expected, the most significant decrease was recorded in NOFERT.

Figure 28: Soil carbon stock



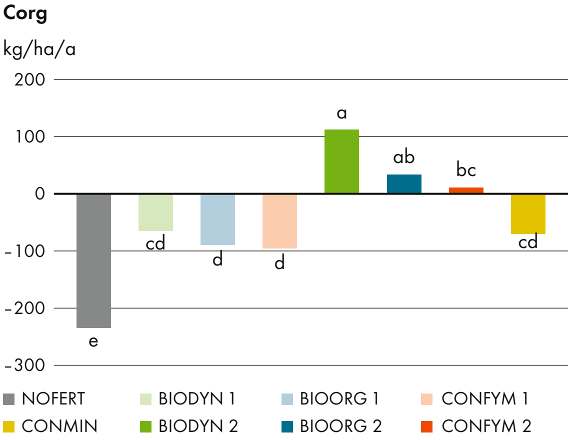
Carbon stock in the top 20 cm of the soil of the eight cropping systems (n = 12). These data were calculated from the Corg content and the bulk density of the soil in the first CRP.

Changes in the carbon stock

The carbon stock refers to the amount of carbon present in the soil of a defined area. For the DOK trial, it was calculated for the uppermost soil layer to a depth of 20 cm per hectare (Figure 28). The bulk density was based on a measurement from the first CRP, when this parameter was not yet influenced by the cropping systems.

Between the first and sixth CRP, there was a significant increase in Corg stocks in BIODYN 2 (12 %), while the stocks in BIOORG 2 and CONFYM 2 remained unchanged. In this comparison, the systems with reduced fertilisation lost 4 % (BIODYN 1) to 9 % (BIOORG 1, CONFYM 1 and CONMIN) of their Corg stocks. The unfertilised NOFERT system lost 22 % relative to the first CRP.

Figure 29: Change in soil carbon stock



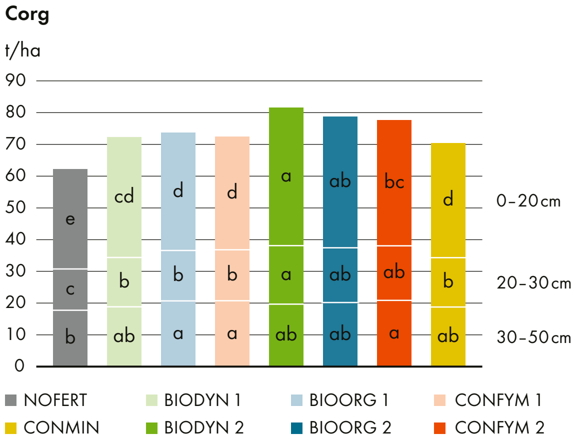
Mean annual increase or decrease in organic carbon.

The average annual growth or loss rates can be derived from the temporal dynamics of the C stocks (Figure 29). Only the level 2 cropping systems were able to increase or maintain the Corg stocks. All systems with reduced fertilisation and CONMIN had losses of up to 100 kg per hectare per year. With NOFERT, the losses amounted to 234 kg Corg per year.

The differences between the systems with regard to Corg were most pronounced in the uppermost soil layer of 0–20 cm. The main root mass is located in this layer, and farmyard manure, green manures and crop residues are mixed in. The most intensive decomposition processes of soil organic matter take place here. They can be stimulated by tillage, but also by mineral fertilisers and root exudates. Another part of Corg is stored in deeper soil layers. The Corg content decreases with depth because less fresh organic matter is supplied via roots or farmyard manure. With increasing depth, the influence of the cropping system also decreases. At a depth of 30 to 50 cm, it is only recognisable in the NOFERT system.

At 81 metric tonnes per hectare down to a depth of 50 cm, the BIODYN 2 system achieved the highest Corg stock in the 2019/20 measurement. In BIOORG 2, it was 80.25, and in CONFYM 2, 78.9 metric tonnes/ha. CONMIN, on the other hand, had almost nine metric tonnes less Corg than CONFYM 2. These two systems received the standard fertilisation and also produced similar amounts of crop residues, so the difference of nine metric tonnes can be interpreted as the effect of organic fertilisation over 35 years (CONMIN was unfertilised for the first seven years).

Figure 30: Organic carbon stock



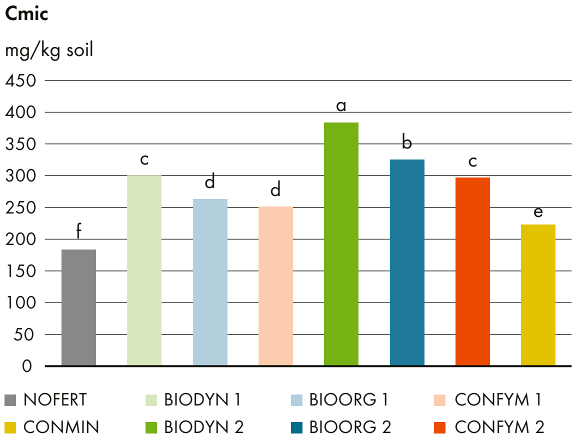
Carbon stock in soil layers up to 50 cm deep after 42 years of differentiated management. The differences between the systems decrease with depth. Samples from 2019 after winter wheat and under grass clover and from 2020 after winter wheat; n = 12.

In summary, only systems with manure from 1.4 LU were able to maintain the Corg (humus content) in the soil, and the composting of manure in BIODYN 2 even resulted in an increase in humus over 42 years. Despite high yields, the mineral-fertilised, conventional CONMIN system lost Corg, which is remarkable in view of the humus-increasing grass clover meadows and the green manures grown. However, the systems with manure from 0.7 LU also lost Corg over time. Reduced tillage and the use of green waste compost are additional measures to build up humus.

Microbial biomass

Microbial biomass is made up of microscopic organisms in the soil, including bacteria, archaea, microalgae and some fungi. It is the living part of soil organic matter. Microbial carbon makes up 1 to 3 % of soil carbon. In this section, microbial biomass is represented as microbially bound carbon (Cmic) (Figure 31) and in the chapter on nutrients as microbial nitrogen (Nmic) (Figure 20).

Figure 31: Microbial biomass



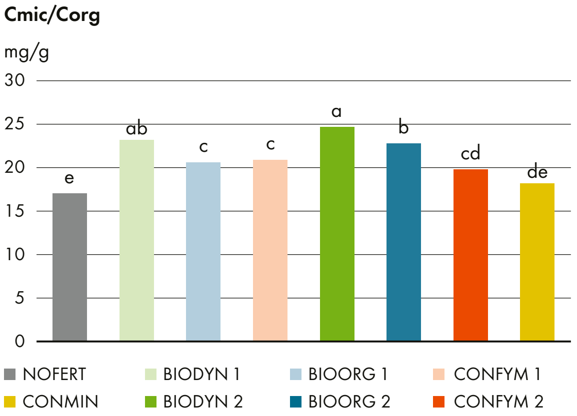
Microbially bound carbon in the eight systems of the DOK trial. Mean value from analyses of all plots in spring 1998, 2006, 2012 and 2019.

The BIODYN system had the highest microbial biomass at both fertilisation levels. CONMIN and NOFERT, on the other hand, had the lowest microbial biomass levels.

Ratio of Cmic to Corg

The proportion of microbial carbon to soil organic carbon is used as an indicator of the quality of the organic matter. This quotient shows how good the conditions are for microbial growth in the soil and is also an early indicator of an increasing humus content after a change in soil management (Figure 32).

Figure 32: Cmic/Corg ratio

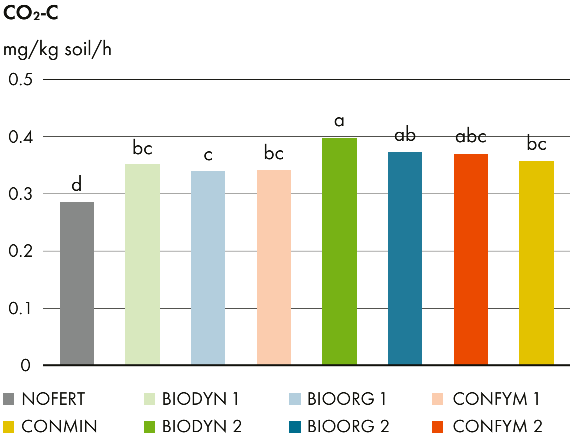


Proportion of Cmic to Corg. This quotient indicates how suitable soil with a high organic matter content is as a habitat for microorganisms.

Soil respiration

Soil microorganisms feed on dead organic material and break it down to its mineral components and CO_2. This process is of central importance for the nutrient cycle. Alongside microbial biomass, soil respiration is one of the most significant biological soil parameters. When measured under standardised laboratory conditions, it is referred to as basal respiration. CO_2 development is a measure of the activity of soil organisms, which also depends on the amount of readily available C sources (Figure 33).

Figure 33: Soil respiration

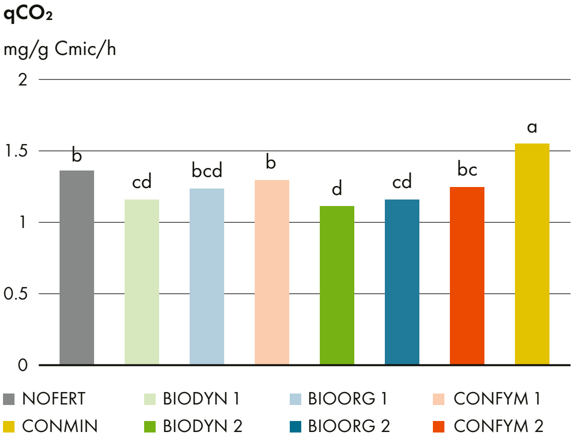


Basal respiration in the soils of the DOK trial. Data from the analysis of soil samples from 2019. A high value indicates high soil organism activity.

Metabolic quotient

The amount of CO_2 required by microorganisms in the soil to maintain their biomass provides an indication of how good their living conditions are. The corresponding measure is the metabolic quotient qCO_2. The more the microorganisms breathe, the more energy they consume to maintain their metabolism. A low value indicates that the microbial community is efficiently converting the available energy.

Figure 34: Metabolic quotient



Metabolic quotient for CO_2 in the soils of the DOK trial. Data from the analysis of soil samples from 2019.

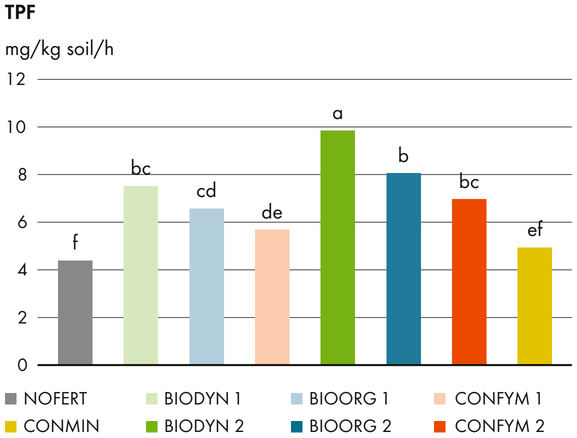
Despite its high basal respiration (Figure 33), the soil microbial community in BIODYN converts available energy more effectively. BIODYN consumes 16 % less energy per unit of biomass for its maintenance requirements than the microbial community in CONFYM (Figure 34). The CONMIN system has the highest metabolic quotient. This means that the microorganisms find the best living conditions in the BIODYN system and are most stressed in CONMIN.

Soil enzymes

Dehydrogenases

Enzymes from the group of dehydrogenases play an important role in the energy metabolism of microorganisms. They are active within the cell and serve as an indicator of its metabolic activity.

Figure 35:
Activity of the dehydrogenase



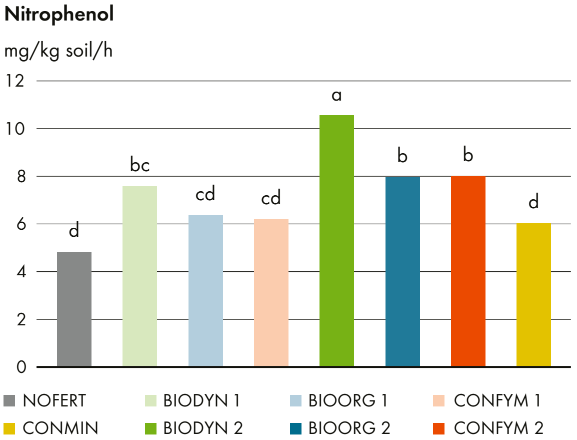
Dehydrogenase activity in the soils of the DOK trial. Data from the analysis of soil samples in 2016. The higher the value, the more dehydrogenase enzymes are active in the soil.

The high activity of dehydrogenase in the BIODYN system shows that there are significantly more microorganisms in the soil than in the soils of the other systems. It may also indicate that the activity per unit of microorganisms is higher.

Phosphatases

Enzymes from the class of phosphatases are secreted by plants and microorganisms to break down organic phosphorus compounds. Because the concentration of dissolved P in soil water is very low, the enzymatic degradation of organic P compounds can contribute to plant nutrition.

Figure 36: Alkaline phosphomonoesterase activity



Activity of alkaline phosphomonoesterase in the DOK trial. Data from the analysis of soil samples in 2019. The higher the value, the more phosphatase enzymes are active in the soil.

Phosphatase activity is highly dependent on the cropping system. The high activity of phosphatases in the BIODYN system shows a high potential to break down organic phosphorus compounds, which makes released P available to the plants.

In short: Soil quality
After 20 years, the pH value of the soils of conventional cropping systems had fallen to such an extent that it had to be corrected by liming. The soils in the organic systems showed less of a tendency towards silting and better structural stability than those in the conventional systems. In the systems that use farmyard manure from 1.4 LU, the organic carbon content and stocks were constant. Without organic fertiliser or with reduced fertilisation, the soils lost organic carbon. With the application of manure compost, the BIODYN 2 system achieved significantly higher organic carbon contents than all other systems. The microbial biomass as well as its activity and efficiency were significantly higher in the organic systems than in the conventional ones. All indicators for soil fertility showed better values in the organic systems and especially in the BIODYN system. The soil fertility of BIODYN with reduced fertilisation reached or exceeded that of CONFYM with typical fertilisation.

Biodiversity

Humanity has overstepped planetary boundaries through many human practices and economic activities. This is especially apparent when considering biodiversity loss.

With its 100 m² plots, the DOK trial only allows statements to be made about the frequency and activity of species that are present in this area. Depending on the size and mobility of the organisms, they are active over a larger area than the dimensions of a single plot.

For this reason, research in the DOK trial focussed on earthworms, microorganisms and weeds. Surprisingly, however, soil animals that live mainly on the soil surface (epigeic arthropods) were also greatly effected by cropping system, even though these organisms can cover considerable distances daily.

When analysing segetal flora, an influence on the neighbouring plots can also be expected due to seed dispersal.

Weed seed bank

The population of segetal flora has changed as a result of the specific management involved in the DOK systems. Each crop has its own particular segetal flora, and each season brings different plants in the field to the fore. Analysing the seed stock is, therefore, an interesting method, as it provides information about the emergence of segetal flora from seed over longer periods of time.

Table 13: Number of seeds and of plant species

	Seed stock			
	Species		Seeds/m²	
BIODYN 2	42	114 %	14 413	233 %
BIOORG 2	40	108 %	19 622	317 %
CONFYM 2	37	100 %	6195	100 %
CONMIN	33	89 %	8404	136 %
NOFERT	44	119 %	69 468	1121 %

Weed flora fulfils important tasks in the ecosystem: It provides shelter and food for beneficial organisms, protects the soil from silting and erosion and serves to absorb mineralised nitrogen after the harvest, thus protecting against leaching. In addition, its root exudates and roots also release carbon compounds into the soil.

Field poppies in the winter wheat plots of the DOK trial.

Weeds are an important component of biodiversity in the often uniform arable landscapes, and they act as important intermediate hosts for root symbiotic fungi (mycorrhiza).

However, the high seed stock also poses a considerable risk of weed infestation to the crops. As part of the crop rotation, which suppresses many weeds with two years of grass clover, competition from weed flora in the organic systems could be limited by hoeing and harrowing. Soya is an exception: weeds are regularly weeded by hand in organic soya plots (approx. 25 h/ha).

Due to the absence of herbicides and less dense crop stands, more weed species were found in the organically farmed plots than in the conventionally farmed plots. In terms of the number of germinable seeds per unit area, organic plots have two to three times more stock in the soil than conventional plots. This means that a seed stock has built up in the organic systems that needs to be monitored.

Soil animals

Earthworms

Earthworms are the best-known invertebrates that live in the soil. The habitat of the deep-burrowing species extends to a depth of around one metre in the deep loess soils of the DOK trial. There, earthworms find burrows into which they retreat when the surface becomes too dry or too cold.

Earthworms can be categorised into ecological groups based on their preferred habitat:

- Epigeic species live below the soil surface, where they feed mainly on animal excrement and dead plant material. They are dark in colour to protect themselves from UV radiation.
- Endogeic species live in the upper part of the mineral soil. They are pale and almost transparent, as they rarely come to the surface.
- Anecic species dig vertically and seek out deeper soil layers at a depth of one metre or greater. These species promote the mixing of the mineral soil with the humus and draw plant residues and manure into the soil.

The collection of earthworms by hand sorting or extraction is time-consuming and only makes sense in spring or autumn when the worms are active.

The biomass of earthworms in the DOK experiment is dominated by anecic species, which are relatively large and are, therefore, smaller in number than the relatively small, endogeic species.

The methodology for data collection, which involves the removal by hand sorting and extraction and identification of the animals, is very time-consuming. In addition, the DOK plots are heavily disturbed as a result. For this reason, such data could only be carried out for some of the systems. Earthworm dynamics varied largely over the course of the year and day and are strongly dependent on humidity and temperature.

Table 14: Number and biomass of earthworms in the DOK plots: 1990–1991 and 2001–2005

	Earthworms 1990–1991				Earthworms 2001–2005			
	Number (ind. /m²)		Biomass (g/m²)		Number (ind. /m²)		Biomass (g/m²)	
BIODYN 2	302	138 %	192	124 %	234	90 %	183	89 %
BIOORG 2	463	211 %	228	148 %	247	95 %	180	88 %
CONFYM 2	219	100 %	154	100 %	259	100 %	205	100 %
CONMIN	145	66 %	118	77 %	190	73 %	166	81 %
NOFERT	208	95 %	137	89 %	164	63 %	142	69 %

The earthworm studies in 2001–2005 using a simplified method, which is less effective at detecting anecic earthworms, took place after the crop rotation phase with 3 years of clover-grass. Studies from 2024 reconfirm the data from 1990–1991 using the same methodology and with 2 years of clover-grass: significantly more earthworms in the organic soils than in the conventional ones.

Until 1998, conventional systems used plant protection products (carbendazim, dinoseb, methiocarb) that were very toxic to earthworms. The early analyses, therefore, show a significantly lower number and biomass of earthworms in these systems. The switch to integrated production with the start of the third crop rotation and the phasing out of many of the old, very toxic products is the most likely explanation for the recovery of the earthworm populations in CONFYM and CONMIN. On the other hand, liming between 1999 and 2005 and the switch to alkaline nitrogen fertilisers may also have had a positive influence on the earthworm habitat.

Ground beetles and rove beetles

Ground beetles and rove beetles are two families within the Coleoptera (beetle) order. Many of their species have not yet been studied in detail, but more is known about the autecology of ground beetles than that of rove beetles. The activity density of these animals is determined with the help of pitfall traps in the field soil. As the animals are very mobile, they cannot be directly assigned to a small area. However, the frequency with which they visit a plot can be easily estimated from the trap numbers.

Large ground beetles are voracious and eat up to 2.5 times their body weight per day.

Table 15: Abundance of ground beetles and rove beetles in winter wheat plots

	Ground beetle individuals						Rove beetle individuals					
	1988		1990		1991		1988		1990		1991	
BIODYN 2	208	a	72	a	60	a	42	a	58	a	20	a
BIOORG 2	156	ab	75	a	57	a	44	a	50	a	17	a
CONFYM 2	89	b	46	b	31	a	20	b	33	b	15	a

On average over the entire year, the abundance of these two groups of animals in the organic plots is around two times higher than in the conventional plots. Ground beetles, which prefer warmth and dryness, and those that feed mainly on seeds were found more frequently in organic plots. The predatory beetles are important in the field for controlling pests such as aphids. They are already active in spring, when ladybirds are less effective at controlling pests at lower temperatures.

Table 16: Density of spiders in individuals per m²

	Web-building spiders		Predatory spiders	
BIODYN 2	2.5	a	7.4	a
BIOORG 2	1.8	ab	7.3	a
CONFYM 2	1.2	b	3.4	b
CONMIN	1.0	b	4.5	b

The organic systems have a significantly higher density of spiders. Predatory spiders occur almost twice as frequently in the organic plots as in the conventionally farmed plots.

A web spider in a DOK wheat plot.

Nematodes

Nematodes are one of the most species-rich and widespread animal phyla. Due to the morphological specialisations of individual nematode species, they are able to occupy a wide variety of ecological niches. They play a key role in the regulation of biogeochemical cycles and ecosystem processes. Examples of this are mineralisation and the build-up of soil organic matter.

However, individual species can cause damage to crops, partly due to their parasitic lifestyle. Due to their high diversity, the composition of the nematode community can serve as an important indicator of the ecological environmental conditions.

Nematodes are easy to recognise only under a microscope.

Table 17: Number of nematodes in individuals per m²

	Bacterivore		Herbivore		Fungivore		Omnivore	
BIODYN 2	17.5	a	27.2	a	0.4	b	4.5	a
BIOORG 2	16.2	ab	28.1	a	0.5	ab	5.2	a
CONFYM 2	19.3	a	24.8	a	0.9	a	4.8	a
CONMIN	9.5	bc	16.8	b	0.9	a	2.3	b

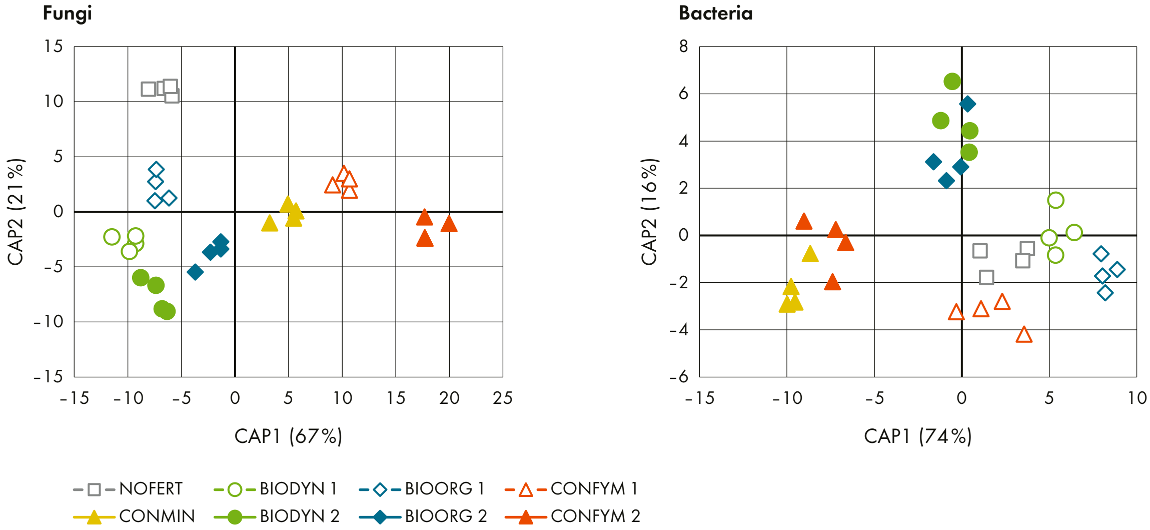
Studies in the DOK trial show that both the number of species and the biomass of nematodes are strongly dependent on organic fertilisation. Nematodes whose preferred food source is bacteria and plant residues are significantly more common in the organically fertilised systems. Nematodes that live on fungi are more common in the mineral-fertilised systems. Hardly any difference was found between the systems with organic fertilisers.

Microbial diversity

Bacteria and fungi are extremely adaptable organisms that exhibit great diversity in the soil and colonise even the smallest habitats in the pore space of the soil. They can be described on the basis of their genetics, their appearance and their functionality. Many of the fungi and bacteria live in interaction with other microorganisms and form communities where the various metabolic pathways and lifestyles are mutually supported.

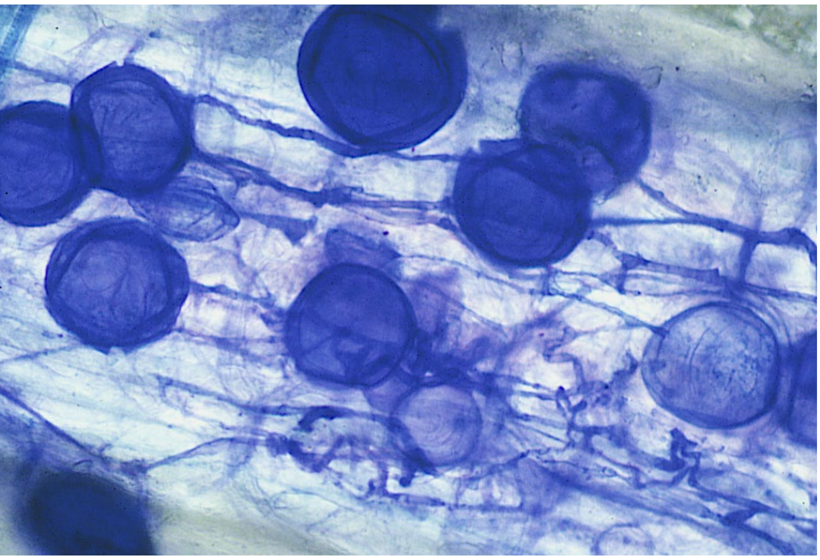
Important soil properties that affect microbial diversity in the soil include the pH value, soil carbon and soil texture. In the DOK trial, each system exhibits its own unique community structure of soil fungi and bacteria (Figure 37). The soil fungi show a higher sensitivity to the agricultural cropping system. This can be seen in the close grouping of the two intensity levels of the three systems BIODYN, BIOORG and CONFYM (Figure 37). The bacteria, in turn, are primarily influenced by the fertilisation intensity, as shown by the close grouping of the semi-fertilised systems and the non-fertilised control.

Figure 37: Community structure of soil fungi and soil bacteria



Community structure of soil fungi (left) and soil bacteria (right) in the DOK trial. The graph shows the similarities between soil microbes identified by marker genes. Each dot corresponds to the community structure of a subplot (plot C). The closer the dots, the more similar the structure. The further apart the dots are, the more different the community structure.

Flowering weeds attract insects, and are also shaping the landscape.



Symbiosis between mycorrhizal fungus and legumes: reserve organs of the fungus (vesicles) and hyphae within the root cortex can be seen.

The metabolic activity of fungi and bacteria is crucial for many ecosystem services provided by the soil. Conversely, fungi and bacteria ensure fertile soils with a high storage capacity.

Symbiotic fungi, the mycorrhiza, enable cultivated plants to expand the catchment radius for nutrients and water in the soil many times over and thus secure their supply. The so-called endomycorrhiza in the root cortex is relatively unspecific and can colonise several plant families and genera. This also makes them bridges between the root networks of different plant species in the soil; even herbaceous and woody plants are connected via fungal threads (hyphae) and thus exchange carbohydrates and minerals.

The DOK trial, particularly in the organic and unfertilised systems, demonstrated a high level of mycorrhizal fungi colonisation of the cultivated plants. The systems with mineral fertilisation showed a clear decline in symbiotic activity between the fungi and cultivated plants. This may be related to the decline in the diversity of the mycorrhizal communities.

In an experiment to simulate drought in the DOK trial, an increase in the occurrence of mycorrhizae was demonstrated in an organic system as compared to a conventional system, whereas other biological indicators in the soil remained unaffected. In the BIODYN system, mycorrhizal fungi were three times more frequent during drought than in the conventional CONMIN system. Effects on the water balance of plants are currently being investigated. Not all crops are dependent on symbiotic fungi. However, in the absence of mycorrhiza, the crop is more dependent on soluble fertilisers and plant protection. In the long term, reduced soil microbial activity leads to a loss of soil structure and soil quality.

In short: Biodiversity

The size of the trial plots in the DOK trial restricts the selection of species and biodiversity indicators.
The plant diversity in the organic systems showed more species and two to three times as many germinable seeds than in the conventional systems. Ground beetles, rove beetles and spiders were around twice as common in the organic plots as in the conventional ones. Organic fertilisation promotes the number and species composition of nematodes that eat bacteria and plants. Nematodes that feed primarily on fungi were more prevalent in the CONMIN system. Soil fungi and bacteria develop very differently in the individual systems: bacteria were more strongly influenced by the intensity of the fertiliser, while fungi were more influenced by the differences of the system. Mycorrhizal fungi on cultivated plants were detected more frequently in the organic and non-fertilised systems. Their abundance increased under drought stress, most strongly in BIODYN.

Climate change

The agricultural sector is responsible for around 14 % of Switzerland's greenhouse gas emissions and, therefore, makes significantly contributes to climate change. At the same time, agriculture is also strongly affected by climate change. Global greenhouse gas emissions are rising, and the likelihood of summer droughts coupled with severe storms is predicted to increase significantly in Central Europe. Agriculture must, therefore, develop climate mitigation strategies to reduce greenhouse gases as well as climate adaptation strategies to increase resilience in the face of unstable weather conditions.

Climate adaptation through humus build-up

Measures that lead to improved adaptation of agriculture to the consequences of climate change often also serve to improve soil quality and biodiversity.

One example are management practices for building up humus. By building up and stabilising humus, carbon is removed from the atmosphere and soil quality is improved. In the DOK trial, the development of humus content has been monitored for over 40 years. It was found that the humus content could only be increased or kept stable with organic fertilisation. The build-up of humus is particularly pronounced in the biodynamic system, although the amount of organic fertiliser applied as manure compost was the lowest (see chapter “The trial”). Despite the loss of carbon and nitrogen during the composting process, the quality of the fertiliser applied appears to be the decisive factor for the stability of carbon in the soil. Through the build-up of soil carbon, the use of organic cropping systems can be a strategy for climate change mitigation and adaptation. However, the increase in soil carbon is very slow.

Comparison of greenhouse gas emissions

The most important greenhouse gases from agriculture are carbon dioxide CO_2, nitrous oxide N_2O and methane CH_4. These three gases are converted into CO_2 equivalents in order to assess their climate impact: nitrous oxide has a factor of 300 and methane a factor of 28. Nitrous oxide remains in the atmosphere longer and has a climate impact that is 300 times greater.

Due to the high climate impact of N_2O, nitrogen-related greenhouse gas emissions play the decisive role for climate assessment in arable farming with well-aerated soils. Starting in 2012, N_2O and CH_4 emissions were measured under grass clover, maize and green manure over the course of 571 days and compared with the average rate of change in soil carbon stocks (Figure 38). The highest N_2O emissions were measured in the conventional system with farmyard manure and mineral fertilisation. The high nitrogen application in maize was probably the decisive factor in the high-climate impact of the system during the measurement period.

Hail damage in the maize plots of the DOK trial in 2022.

The avoidance of mineral nitrogen, a stable soil pH and a good soil structure are important factors for minimising N_2O emissions in the organic systems.

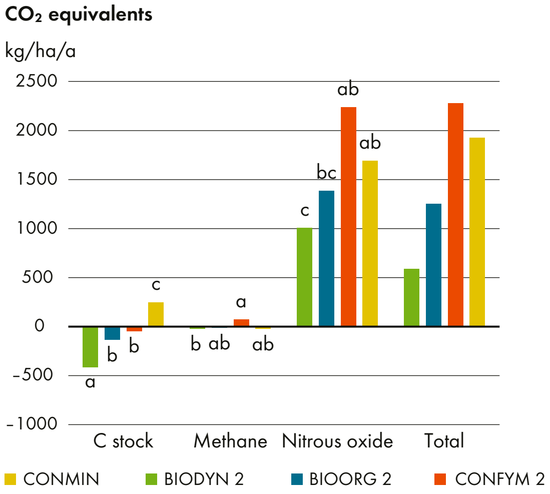
It is noteworthy that, in the biodynamic system, an increase in carbon stocks was observed together with the lowest N_2O emissions. This result shows that increasing soil carbon content when using a customised fertilisation strategy does not necessarily lead to increased N_2O emissions. Relative to the area, 44% less greenhouse gas emissions were measured in BIOORG 2 and 63 % less in BIODYN 2 compared to the conventional system, each case using typical fertilisation practices.

Resilience against drought stress

How cropping systems act under drought stress is an important question for the ability to adapt to climate change. In the experimental comparison, the more diverse bacterial community in the soil of BIOORG 2 meant that drought stress had less of an impact on protease activity and N mineralisation than in CONMIN. As a result, the plants in BIOORG 2 developed significantly better under drought stress.

Current studies from the DOK trials show that soil water evaporation is almost the same in all cropping systems, as is the depth from which the plants draw their water. However, the soil moisture in the root zone was significantly higher in the organic systems, and the plants were able to utilise the water more efficiently. The results suggest that organic farming systems have advantages in terms of agronomic water utilisation efficiency and are more resilient to drought stress. Two large, ongoing projects are currently investigating this in greater depth.

Figure 38: Climate impact of the soils of the DOK trial



CO_2 equivalents from the fully fertilised cropping systems, shown for the changes in soil organic matter (SOM, humus) over all 42 years and the nitrous oxide and methane emissions from an almost two-year measurement campaign under grass clover, maize and green manure in the sixth CRP.

In short: Climate change

Of the various cropping systems, only the biodynamic system using typical fertilisation intensities stored additional organic carbon in the soil. The lowest nitrous oxide emissions were also measured in the BIODYN system. The high emission rates in CONFYM 2 and CONMIN are due to high rates of nitrogen fertilisation. Overall, greenhouse gas emissions per area unit were 63 % lower in BIODYN and 44 % lower in BIOORG than in CONFYM. During moderate droughts, the more diverse bacterial community in organically farmed plots remains active for longer, which can have a positive effect on nitrogen mineralisation and thus on plant growth.

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Publications from the DOK trial (peer reviewed)

Scientific publications

1. Arncken, C. M., Mäder, P., Mayer, J., & Weibel, F. P. (2012). Sensory, yield and quality differences between organically and conventionally grown winter wheat. Journal of the Science of Food and Agriculture 92, 2819-2825.
2. Autret, B., Mary, B., Strullu, L., Chlebowski, F., Mäder, P., Mayer, J., Olesen, J. E., & Beaudoin, N. (2020). Long-term modelling of crop yield, nitrogen losses and GHG balance in organic cropping systems. Science of the Total Environment 710, 134597.
3. Bai, Z., Caspari, T., Gonzalez, M. R., Batjes, N. H., Mäder, P., Bünemann, E. K., De Goede, R., Brussaard, L., Xu, M., Ferreira, C. S. S., Reintam, E., Fan, H., Mihelič, R., Glavan, M.,& Tóth, Z. (2018). Effects of agricultural management practices on soil quality: A review of long-term experiments for Europe and China. Agriculture, Ecosystems & Environment 265, 1-7.
4. Berchtold, A., Besson, J. M., & Feller, U. (1993). Effects of fertilization levels in two farming systems on senescence and nutrient contents in potato leaves. Plant and Soil 154(1), 81-88.
5. Besson, J. M., Spiess, E., & Niggli, U. (1995). N uptake in relation to N application during two crop rotations in the DOC field trial. Biological agriculture & horticulture11(1-4), 69-75.
6. Birkhofer, K., Bezemer, T. M., Bloem, J., Bonkowski, M., Christensen, S., Dubois, D., Ekelund, F., Fliessbach, A., Gunst, L., Hedlund, K., Mader, P., Mikola, J., Robin, C., Setala, H., Tatin-Froux, F., Van Der Putten, W. H., & Scheu, S. (2008). Long-term organic farming fosters below and aboveground biota: Implications for soil quality, biological control and productivity. Soil Biology & Biochemistry 40(9), 2297-2308.
7. Birkhofer, K., Fliessbach, A., Wise, D. H., & Scheu, S. (2008). Generalist predators in organically and conventionally managed grass-clover fields: implications for conservation biological control. Annals of Applied Biology 153(2), 271-280.
8. Birkhofer, K., Fliessbach, A., Wise, D. H., & Scheu, S. (2011). Arthropod food webs in organic and conventional wheat farming systems of an agricultural long-term experiment: a stable isotope approach. Agricultural and Forest Entomology 13(2), 197-204.
9. Birkhofer, K., Fliessbach, A., Gavín-Centol, M. P., Hedlund, K., Ingimarsdóttir, M., Jørgensen, H. B., Kozjek, K., Meyer, S., Montserrat, M., Moreno, S. S., Laraño, J. M., Scheu, S., Serrano-Carnero, D., Truu, J., & Kundel, D. (2021). Conventional agriculture and not drought alters relationships between soil biota and functions. Scientific Reports 11(1), 23975.
10. Bongiorno, G., Bünemann, E. K., Oguejiofor, C. U., Meier, J., Gort, G., Comans, R., Mäder, P., Brussaard, L., & De Goede, R. (2019). Sensitivity of labile carbon fractions to tillage and organic matter management and their potential as comprehensive soil quality indicators across pedoclimatic conditions in Europe. Ecological Indicators 99, 38-50.
11. Bongiorno, G., Postma, J., Bünemann, E. K., Brussaard, L., De Goede, R. G. M., Mäder, P., Tamm, L., & Thuerig, B. (2019). Soil suppressiveness to *Pythium ultimum* in ten European long-term field experiments and its relation with soil parameters. Soil Biology & Biochemistry 133, 174-187.
12. Bongiorno, G., Bodenhausen, N., Bünemann, E. K., Brussaard, L., Geisen, S., Mäder, P., Quist, C. W., Walser, J.-C., & De Goede, R. G. M. (2019). Reduced tillage, but not organic matter input, increased nematode diversity and food web stability in European long-term field experiments. Molecular Ecology 28(22), 4987-5005.
13. Bongiorno, G., Bünemann, E. K., Brussaard, L., Mäder, P., Oguejiofor, C. U., & De Goede, R. G. M. (2020). Soil management intensity shifts microbial catabolic profiles across a range of European long-term field experiments. Applied Soil Ecology 154, 103596.
14. Bonte, A., Neuweger, H., Goesmann, A., Thonar, C., Mäder, P., Langenkämper, G., & Niehaus, K. (2014). Metabolite profiling on wheat grain to enable a distinction of samples from organic and conventional farming systems. Journal of the Science of Food and Agriculture 94(13), 2605-2612.
15. Bosshard, C., Frossard, E., Dubois, D., Mäder, P., Manolov, I., & Oberson, A. (2008). Incorporation of nitrogen-15-labeled amendments into physically separated soil organic matter fractions. Soil Science Society of America Journal 72(4), 949-959.
16. Bosshard, C., Sørensen, P., Frossard, E., Dubois, D., Mäder, P., Nanzer, S., & Oberson, A. (2009). Nitrogen use efficiency of 15 N-labelled sheep manure and mineral fertiliser applied to microplots in long-term organic and conventional cropping systems. Nutrient Cycling in Agroecosystems 83(3), 271-287.
17. Brock, C., Fliessbach, A., Oberholzer, H.-R., Schulz, F., Wiesinger, K., Reinicke, F., Koch, W., Pallutt, B., Dittman, B., Zimmer, J., Hülsbergen, K.-J., & Leithold, G. (2011). Relation between soil organic matter and yield levels of nonlegume crops in organic and conventional farming systems. Journal of Plant Nutrition and Soil Science 174(4), 568–575.
18. Brock, C., Hoyer, U., Leithold, G., & Hülsbergen, K.-J. (2012). The humus balance model (HU-MOD): a simple tool for the assessment of management change impact on soil organic matter levels in arable soils. Nutrient Cycling in Agroecosystems 92(3), 239-254.
19. Chalker-Scott, L. (2013). The science behind biodynamic preparations: A literature review. Horttechnology 23(6), 814-819.
20. Chowdhury, S. P., Babin, D., Sandmann, M., Jacquiod, S., Sommermann, L., Sørensen, S. J., Fliessbach, A., Mäder, P., Geistlinger, J., Smalla, K., Rothballer, M., & Grosch, R. (2019). Effect of long-term organic and mineral fertilization strategies on rhizosphere microbiota assemblage and performance of lettuce. Environmental Microbiology.
21. Dubois, D., Scherrer, C., Gunst, L., Jossi, W., & Stauffer, W. (1998). Effect of different farming systems on the weed seed bank in the long term-trials Chaiblen and DOK. Journal of Plant Diseases and Protection (Special issue XVI), 67-74.
22. Dos Reis Martins, M., Necpalova, M., Ammann, C., Buchmann, N., Calanca, P., Flechard, C. R., Hartman, M. D., Krauss, M., Le Roy, P., Mäder, P., Maier, R., Morvan, T., Nicolardot, B., Skinner, C., Six, J., & Keel, S. G. (2022). Modeling N_2O emissions of complex cropland management in Western Europe using DayCent: Performance and scope for improvement. European Journal of Agronomy 141, 126613.
23. Esperschütz, J., Gattinger, A., Mäder, P., Schloter, M., & Fliessbach, A. (2007). Response of soil microbial biomass and community structures to conventional and organic farming systems under identical crop rotations. FEMS Microbiology Ecology 61(1), 26-37.
24. Fliessbach, A., & Mäder, P. (2000). Microbial biomass and size-density fractions differ between soils of organic and conventional agricultural systems. Soil Biology & Biochemistry 32(6), 757-768.

25. Fliessbach, A., & Mäder, P. (2004). Short- and long-term effects on soil microorganisms of two potato pesticide spraying sequences with either glufosinate or dinoseb as defoliants. Biology and Fertility of Soils 40(4), 268-276.

26. Fliessbach, A., Imhof, D., Brunner, T., & Wüthrich, C. (1999). Tiefenverteilung und zeitliche Dynamik der mikrobiellen Biomasse in biologisch und konventionell bewirtschafteten Böden. Regio Basiliensis 3(40), 253-263.

27. Fliessbach, A., Mäder, P., & Niggli, U. (2000). Mineralization and microbial assimilation of 14 C-labeled straw in soils of organic and conventional agricultural systems. Soil Biology & Biochemistry 32(8-9), 1131-1139.

28. Fliessbach, A., Messmer, M., Nietlispach, B., Infante, V., & Mäder, P. (2012). Effects of conventionally bred and *Bacillus thuringiensis* (Bt) maize varieties on soil microbial biomass and activity. Biology and Fertility of Soils 48(3), 315-324.

29. Fliessbach, A., Nietlispach, B., Messmer, M., Rodríguez-Romero, A.-S., & Mäder, P. (2013). Microbial response of soils with organic and conventional management history to the cultivation of *Bacillus thuringiensis* (Bt)-maize under climate chamber conditions. Biology and Fertility of Soils 49(7), 829-837.

30. Fliessbach, A., Oberholzer, H.-R., Gunst, L., & Mäder, P. (2007). Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. Agriculture, Ecosystems & Environment 118, 273-284.

31. Fliessbach, A., Winkler, M., Lutz, M. P., Oberholzer, H.-R., & Mäder, P. (2009). Soil amendment with Pseudomonas fluorescens CHA0: lasting effects on soil biological properties in soils low in microbial biomass and activity. Microbial Ecology 57(4), 611-623.

32. Frossard, E., Buchmann, N., Bünemann, E. K., Kiba, D. I., Lompo, F., Oberson, A., Tamburini, F., Traore, O.Y.A. (2016). Soil properties and not inputs control carbon : nitrogen : phosphorus ratios in cropped soils in the long term. SOIL 2, 83-99

33. Fuchs, J. G., Fliessbach, A., Mäder, P., Weibel, F. P., Tamm, L., Mayer, J., & Schleiss, K. (2014). Effects of compost on soil fertility parameters in short-, mid- and long-term field experiments. Acta Horticulturae 1018, 39-46.

34. García-Palacios, P., Gattinger, A., Bracht-Jørgensen, H., Brussaard, L., Carvalho, F., Castro, H., Clément, J.-C., De Deyn, G., D'Hertefeldt, T., Foulquier, A., Hedlund, K., Lavorel, S., Legay, N., Lori, M., Mäder, P., Martínez-García, L. B., Martins Da Silva, P., Muller, A., Nascimento, E., Reis, F., Symanczik, S., Paulo Sousa, J., & Milla, R. (2018). Crop traits drive soil carbon sequestration under organic farming. Journal of Applied Ecology 55(5), 2496-2505.

35. Gasser, M., Hammelehle, A., Oberson, A., Frossard, E., & Mayer, J. (2015). Quantitative evidence of overestimated rhizodeposition using N-15 leaf-labelling. Soil Biology & Biochemistry 85, 10-20.

36. Gattinger, A., Muller, A., Haeni, M., Skinner, C., Fliessbach, A., Buchmann, N., Mäder, P., Stolze, M., Smith, P., Scialabba, N. E.-H., & Niggli, U. (2012). Enhanced top soil carbon stocks under organic farming. Proceedings of the National Academy of Sciences 109(44), 18226-18231.

37. Grüter, R., Costerousse, B., Mayer, J., Mäder, P., Thonar, C., Frossard, E., Schulin, R., & Tandy, S. (2019). Long-term organic matter application reduces cadmium but not zinc concentrations in wheat. Science of the Total Environment 669, 608-620.

38. Hammelehle, A., Oberson, A., Lüscher, A., Mäder, P., & Mayer, J. (2018). Above- and belowground nitrogen distribution of a red clover-perennial ryegrass sward along a soil nutrient availability gradient established by organic and conventional cropping systems. Plant and Soil 425(1), 507-525.

39. Hartmann, M., & Widmer, F., (2006). Community structure analyses are more sensitive to differences in soil bacterial communities than anonymous diversity indices. Applied and Environmental Microbiology 72(12), 7804-7812.

40. Hartmann, M., Fliessbach, A., Oberholzer, H.-R., & Widmer, F. (2006). Ranking the magnitude of crop and farming system effects on soil microbial biomass and genetic structure of bacterial communities. FEMS Microbiology Ecology 57, 378-388.

41. Hartmann, M., Frey, B., Kölliker, R., & Widmer, F. (2005). Semi-automated genetic analyses of soil microbial communities: comparison of T-RFLP and RISA based on descriptive and discriminative statistical approaches. Journal of Microbiological Methods 61, 349– 360.

42. Hartmann, M., Frey, B., Mayer, J., Mäder, P., & Widmer, F. (2015). Distinct soil microbial diversity under long-term organic and conventional farming. The ISME Journal 9, 1177.

43. Haubert, D., Birkhofer, K., Fliessbach, A., Gehre, M., Scheu, S., & Ruess, L. (2009). Trophic structure and major trophic links in conventional versus organic farming systems as indicated by carbon stable isotope ratios of fatty acids. Oikos 118(10), 1579-1589.

44. Heger, T. J., Straub, F., & Mitchell, E. A. D. (2012). Impact of farming practices on soil diatoms and testate amoebae: A pilot study in the DOK-trial at Therwil, Switzerland. European Journal of Soil Biology 49(0), 31-36.

45. Hijri, I., Sykorova, Z., Oehl, F., Ineichen, K., Mäder, P., Wiemken, A., & Redecker, D. (2006). Communities of arbuscular mycorrhizal fungi in arable soils are not necessarily low in diversity. Molecular Ecology 15, 2277-2289.

46. Hildermann, I., Messmer, M., Dubois, D., Boller, T., Wiemken, A., & Mäder, P. (2010). Nutrient use efficiency and arbuscular mycorrhizal root colonisation of winter wheat cultivars in different farming systems of the DOK long-term trial. Journal of the Science of Food and Agriculture 90(12), 2027-2038.

47. Hildermann, I., Thommen, A., Dubois, D., Boller, T., Wiemken, A., & Mäder, P. (2009). Yield and baking quality of winter wheat cultivars in different farming systems of the DOK long-term trial. Journal of the Science of Food and Agriculture 89(14), 2477-2491.

48. Hirte, J., Leifeld, J., Abiven, S., & Mayer, J. (2018). Maize and wheat root biomass, vertical distribution, and size class as affected by fertilization intensity in two long-term field trials. Field Crops Research 216, 197-208.

49. Hirte, J., Leifeld, J., Abiven, S., Oberholzer, H.-R., Hammelehle, A., & Mayer, J. (2017). Overestimation of crop root biomass in field experiments due to extraneous organic matter. Frontiers in Plant Science 8(284).

50. Jaffuel, G., Mäder, P., Blanco-Perez, R., Chiriboga, X., Fliessbach, A., Turlings, T. C. J., & Campos-Herrera, R. (2016). Prevalence and activity of entomopathogenic nematodes and their antagonists in soils that are subject to different agricultural practices. Agriculture, Ecosystems & Environment 230, 329-340.

51. Joergensen, R., Mäder, P., & Fliessbach, A. (2010). Long-term effects of organic farming on fungal and bacterial residues in relation to microbial energy metabolism. Biology and Fertility of Soils 46, 303-307.

52. Kahl, J., Busscher, N., Mergardt, G., Mäder, P., Torp, T., & Ploeger, A. (2015). Differentiation of organic and non-organic winter wheat cultivars from a controlled field trial by crystallization patterns. Journal of the Science of Food and Agriculture 95(1), 53-58.

53. Keel, S. G., Anken, T., Büchi, L., Chervet, A., Fliessbach, A., Flisch, R., Huguenin-Elie, O., Mäder, P., Mayer, J., Sinaj, S., Sturny, W., Wüst-Galley, C., Zihlmann, U., & Leifeld, J. (2019). Loss of soil organic carbon in Swiss long-term agricultural experiments over a wide range of management practices. Agriculture, Ecosystems & Environment 286, 106654.

54. Keller, M., Oberson, A., Annaheim, K. E., Tamburini, F., Mäder, P., Mayer, J., Frossard, E., & Bünemann, E. K. (2012). Phosphorus forms and enzymatic hydrolyzability of organic phosphorus in soils after 30 years of organic and conventional farming. Journal of Plant Nutrition and Soil Science 175(3), 385-393.

55. Kessler, N., Bonte, A., Albaum, S. P., Mäder, P., Messmer, M., Goesmann, A., Niehaus, K., Langenkämper, G., & Nattkemper, T. W. (2015). Learning to classify organic and conventional wheat – a machine learning driven approach using the MeltDB 2.0 metabolomics analysis platform. Frontiers in Bioengineering and Biotechnology 3, 35.

56. Knapp, S., Gunst, L., Mäder, P., Ghiasi, S., & Mayer, J. (2023). Organic cropping systems maintain yields but have lower yield levels and yield stability than conventional systems – Results from the DOK trial in Switzerland. Field Crops Research 302, 109072.

57. Kozjek, K., Kundel, D., Kushwaha, S. K., Olsson, P. A., Ahrén, D., Fliessbach, A., Birkhofer, K., & Hedlund, K. (2021). Long-term agricultural management impacts arbuscular mycorrhizal fungi more than short-term experimental drought. Applied Soil Ecology 168, 104140.

58. Krause, H. M., Thonar, C., Eschenbach, W., Well, R., Mader, P., Behrens, S., Kappler, A., & Gattinger, A. (2017). Long term farming systems affect soils potential for N_2O production and reduction processes under denitrifying conditions. Soil Biology & Biochemistry 114, 31-41.

59. Krause, H.-M., Stehle, B., Mayer, J., Mayer, M., Steffens, M., Mäder, P., & Fliessbach, A. (2022). Biological soil quality and soil organic carbon change in biodynamic, organic, and conventional farming systems after 42 years. Agronomy for Sustainable Development 42(6), 117.

60. Krause, H.-M., Stehle, B., Mayer, J., Mayer, M., Steffens, M., Mäder, P., & Fliessbach, A. (2022). Soil organic carbon over 42 years of organic and conventional farming and biological soil quality in year 42 of the DOK long-term field experiment. PANGAEA. DOI 10.1594/PANGAEA.948567

61. Kundel, D., Bodenhausen, N., Jørgensen, H. B., Truu, J., Birkhofer, K., Hedlund, K., Mäder, P., & Fliessbach, A. (2020). Effects of simulated drought on biological soil quality, microbial diversity and yields under long-term conventional and organic agriculture. FEMS Microbiology Ecology 96(12).

62. Kundel, D., Lori, M., Fliessbach, A., Van Kleunen, M., Meyer, S., & Mäder, P. (2021). Drought Effects on Nitrogen Provisioning in Different Agricultural Systems: Insights Gained and Lessons Learned from a Field Experiment. Nitrogen 2(1), 1-17.

63. Kundel, D., Meyer, S., Birkhofer, H., Fliessbach, A., Mäder, P., Scheu, S., Van Kleunen, M., & Birkhofer, K. (2018). Design and manual to construct rainout-shelters for climate change experiments in agroecosystems. Frontiers in Environmental Science 6(14).

64. Langenkämper, G., Zörb, C., Seifert, M., Mäder, P., Fretzdorff, B., & Betsche, T. (2006). Nutritional quality of organic and conventional wheat. Journal of Applied Botany and Food Quality 80, 150-154.

65. Langmeier, M., Frossard, E., Kreuzer, M., Mäder, P., Dubois, D., & Oberson, A. (2002). Nitrogen fertilizer value of cattle manure applied on soils originating from organic and conventional farming systems. Agronomie 22, 789-800.

66. Leifeld, J., Reiser, R., & Oberholzer, H. R. (2009). Consequences of conventional versus organic farming on soil carbon: Results from a 27-year field experiment. Agronomy Journal 101(5), 1204-1218.

67. Lori, M., Piton, G., Symanczik, S., Legay, N., Brussaard, L., Jaenicke, S., Nascimento, E., Reis, F., Sousa, J. P., Mäder, P., Gattinger, A., Clément, J.-C., & Foulquier, A. (2020). Compared to conventional, ecological intensive management promotes beneficial proteolytic soil microbial communities for agro-ecosystem functioning under climate change-induced rain regimes. Scientific Reports 10(1), 7296.

68. Lori, M., Symanczik, S., Mäder, P., Efosa, N., Jaenicke, S., Buegger, F., Tresch, S., Goesmann, A., & Gattinger, A. (2018). Distinct nitrogen provisioning from organic amendments in soil as influenced by farming system and water regime. Frontiers in Environmental Science 6(40).

69. Lori, M., Symnaczik, S., Mäder, P., De Deyn, G., & Gattinger, A. (2017). Organic farming enhances soil microbial abundance and activity – A meta-analysis and meta-regression. PLOS ONE 12(7), e0180442.

70. Lori, M., Hartmann, M., Kundel, D., Mayer, J., Mueller, R.C., Mäder, P., Krause H-M. (2023). Soil microbial communities are sensitive to differences in fertilization intensity in organic and conventional farming systems. FEMS Microbiology Ecology 99 (6).

71. Mäder, P., & Berner, A. (2012). Development of reduced tillage systems in organic farming in Europe. Renewable Agriculture and Food Systems 27(Special Issue 01), 7-11.

72. Mäder, P., Alföldi, T., Niggli, U., Besson, J.-M., & Dubois, D. (1997). Der Wert des DOK-Versuches unter den Aspekten moderner agrarwissenschaftlicher Forschung. Archiv für Acker-, Pflanzenbau und Bodenkunde 42, 279-301.

73. Mäder, P., Edenhofer, S., Boller, T., Wiemken, A., & Niggli, U. (2000). Arbuscular mycorrhizae in a long-term field trial comparing low-input (organic, biological) and high-input (conventional) farming systems in a crop rotation. Biology and Fertility of Soils 31, 150-156.

74. Mäder, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P., & Niggli, U. (2002). Soil fertility and biodiversity in organic farming. Science 296, 1694-1697.

75. Mäder, P., Hahn, D., Dubois, D., Gunst, L., Alföldi, T., Bergmann, H., Oehme, M., Amadô, R., Schneider, H., Graf, U., Velimirov, A., Fliessbach, A., & Niggli, U. (2007). Wheat quality in organic and conventional farming: Results of a 21-year old field experiment. Journal of the Science of Food and Agriculture 87(10), 1826-1835.

76. Mäder, P., Kaiser, F., Adholeya, A., Singh, R., Uppal, H. S., Sharma, A. K., Srivastava, R., Sahai, V., Aragno, M., Wiemken, A., Johri, B. N., & Fried, P. M. (2011). Inoculation of root microorganisms for sustainable wheat-rice and wheat-black gram rotations in India. Soil Biology and Biochemistry 43(3), 609-619.

77. Mäder, P., Pfiffner, L., Niggli, U., Balzer, U., Balzer, F., Plochberger, K., Velimirov, A., & Besson, J.-M. (1993). Effect of three farming systems (bio-dynamic, bio-organic, conventional) on yield and quality of beetroot (*Beta vulgaris L. var. esculenta L.*) in a seven year crop rotation. Acta Horticulturae 339, 11-31.

78. Mäder, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P., & Niggli, U. (2002). The Ins and Outs of Organic Farming. FiBL response to the letter of Goklany in Science Vol 298. Science 298(5600), 1889-1890.

79. Mäder, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P., & Niggli, U. (2002). Organic Farming and Energy Efficiency. FiBL response to the letter of Zoebl in Science Vol 298. Science Science 298(5600), 1891-1891.

80. Marinari, S., Liburdi, K., Fliessbach, A., & Kalbitz, K. (2010). Effects of organic management on water-extractable organic matter and C mineralization in European arable soils. Soil & Tillage Research 106(2), 211-217.

81. Mayer, J., Gunst, L., Mäder, P., Samson, M.-F., Carcea, M., Narducci, V., Thomsen, I. K., & Dubois, D. (2015). Productivity, quality and sustainability of winter wheat under long-term conventional and organic management in Switzerland. European Journal of Agronomy 65(0), 27-39.

82. Mayer, M., Krause, H.-M., Fliessbach, A., Mäder, P., & Steffens, M. (2022). Fertilizer quality and labile soil organic matter fractions are vital for organic carbon sequestration in temperate arable soils within a long-term trial in Switzerland. Geoderma 426, 116080.

83. Mosimann, C., Oberhansli, T., Ziegler, D., Nassal, D., Kandeler, E., Boller, T., Mader, P., & Thonar, C. (2017). Tracing of two Pseudomonas strains in the root and rhizoplane of maize, as related to their plant growth-promoting effect in contrasting soils. Frontiers in Microbiology 7, 14.

84. Necpalova, M., Lee, J., Skinner, C., Büchi, L., Wittwer, R., Gattinger, A., Van Der Heijden, M., Mäder, P., Charles, R., Berner, A., Mayer, J., & Six, J. (2018). Potentials to mitigate greenhouse gas emissions from Swiss agriculture. Agriculture, Ecosystems & Environment 265, 84-102.

85. Nemecek, T., Dubois, D., Huguenin-Elie, O., & Gaillard, G. (2006). Life cycle assessment of Swiss organic farming systems. Aspects of Applied Biology 79, 15-18.

86. Nemecek, T., Dubois, D., Huguenin-Elie, O., & Gaillard, G. (2011). Life cycle assessment of Swiss farming systems: I. Integrated and organic farming. Agricultural Systems 104(3), 217-232.

87. Nemecek, T., Huguenin-Elie, O., Dubois, D., Gaillard, G., Schaller, B., & Chervet, A. (2011). Life cycle assessment of Swiss farming systems: II. Extensive and intensive production. Agricultural Systems 104(3), 233-245.

88. Oberson, A., Besson, J. M., Maire, N., & Sticher, H. (1996). Microbiological processes in soil organic phosphorus transformations in conventional and biological cropping systems. Biology and Fertility of Soils 21(3), 138-148.

89. Oberson, A., Fardeau, J.-C., Besson, J.-M., & Sticher, H. (1993). Soil phosphorus dynamics in cropping systems managed according to conventional and biological methods. Biology and Fertility of Soils 16, 111-117.

90. Oberson, A., Frossard, E., Bühlmann, C., Mayer, J., Mäder, P., & Lüscher, A. (2013). Nitrogen fixation and transfer in grass-clover leys under organic and conventional cropping systems. Plant and Soil 371(1), 237-255.

91. Oberson, A., Nanzer, S., Bosshard, C., Dubois, D., Mäder, P., & Frossard, E. (2007). Symbiotic N-2 fixation by soybean in organic and conventional cropping systems estimated by N-15 dilution and N-15 natural abundance. Plant and Soil 290(1-2), 69-83.

92. Oberson, A., Tagmann, H., Langmeier, M., Dubois, D., Mäder, P., & Frossard, E. (2010). Fresh and residual phosphorus uptake by ryegrass from soils with different fertilization histories. Plant and Soil 334(1), 391-407.

93. Oberson, A., Jarosch, K. A., Frossard, E., Hammelehle, A., Fliessbach, A., Mäder, P., Mayer J. (2024): Higher than expected: Nitrogen flows, budgets, and use efficiencies over 35 years of organic and conventional cropping. Agriculture, Ecosystems and Environment 362,108802.

94. Oehl, F., Frossard, E., Fliessbach, A., Dubois, D., & Oberson, A. (2004). Basal organic phosphorus mineralization in soils under different farming systems. Soil Biology & Biochemistry 36, 667-675.

95. Oehl, F., Oberson, A., Probst, M., Fliessbach, A., Roth, H. R., & Frossard, E. (2001). Kinetics of microbial phosphorus uptake in cultivated soils. Biology and Fertility of Soils 34(1), 31-41.

96. Oehl, F., Oberson, A., Sinaj, S., & Frossard, E. (2001). Organic phosphorus mineralization studies using isotopic dilution techniques. Soil Science Society of America Journal 65, 780-787.

97. Oehl, F., Oberson, A., Tagmann, H. U., Besson, J.-M., Dubois, D., Mäder, P., Roth, H.-R., & Frossard, E. (2002). Phosphorus budget and phosphorus availability in soils under organic and conventional farming. Nutrient Cycling in Agroecosystems 62, 25-35.

98. Oehl, F., Sieverding, E., Ineichen, K., Mäder, P., Boller, T., & Wiemken, A. (2003). Impact of land use intensity on the species diversity of arbuscular mycorrhizal fungi in agrooecosystems of central Europe. Applied and Environmental Microbiology 69(5), 2816-2824.

99. Oehl, F., Sieverding, E., Ineichen, K., Mäder, P., Wiemken, A., & Boller, T. (2009). Distinct sporulation dynamics of arbuscular mycorrhizal fungal communities from different agroecosystems in long-term microcosms. Agriculture, Ecosystems & Environment 134, 257–268.

100. Oehl, F., Sieverding, E., Mäder, P., Dubois, D., Ineichen, K., Boller, T., & Wiemken, A. (2004). Impact of long-term conventional and organic farming on the diversity of arbuscular mycorrhizal fungi. Oecologia 138, 574-583.

101. Pesaro, M., & Widmer, F. (2006). Identification and specific detection of a novel Pseudomonadaceae cluster associated with soils from winter wheat plots of a long-term agricultural field experiment. Applied and Environmental Microbiology 72(1), 37-43.

102. Pfiffner, L., & Luka, H. (2007). Earthworm populations in two low-input cereal farming systems. Applied Soil Ecology 37(3), 184-191.

103. Pfiffner, L., & Luka, H. (2000). Overwintering of arthropods in soils of arable fields and adjacent semi-natural habitats. Agriculture, Ecosystems & Environment 78, 215-222.

104. Pfiffner, L., & Mäder, P. (1997). Effects of biodynamic, organic and conventional production systems on earthworm populations. Biological Agriculture and Horticulture – Entomological Research in Organic Agriculture 15, 3-10.

105. Pfiffner, L., Besson, J., & Niggli, U. (1995). DOK-Versuch: Vergleichende Langzeituntersuchungen in den drei Anbausystemen biologisch-dynamisch, organisch-biologisch und konventionell. III. Boden: Untersuchungen über die epigäischen Nutzarthropoden, insbesondere auf die Laufkäfer (Col. Carabidae), in Winterweizenparzellen. Schweiz. Landw. Forsch. Sonderheft 1: 1-15.

106. Pfiffner, L., & Niggli, U. (1996). Effects of bio-dynamic, organic and conventional farming on ground beetles (Col. Carabidae) and other epigaeic arthropods in winter wheat. Biological Agriculture and Horticulture 12: 353-364.

107. Pfiffner, L. (1993). Long-term effects of biological and conventional farming on earthworm populations. Zeitschrift für Pflanzenernährung und Bodenkunde 156(3), 259-265.

108. Rotches-Ribalta, R., Armengot, L., Mäder, P., Mayer, J., & Sans, F. X. (2017). Long-term management affects the community composition of arable soil seedbanks. Weed Science 65(1), 73-82.

109. Schärer, M.-L., Dietrich, L., Kundel, D., Mäder, P., & Kahmen, A. (2022). Reduced plant water use can explain higher soil moisture in organic compared to conventional farming systems. Agriculture, Ecosystems & Environment 332, 107915.

110. Scheifele, M., Hobi, A., Buegger, F., Gattinger, A., Schulin, R., Boller, T., & Mäder, P. (2017). Impact of pyrochar and hydrochar on soybean (*Glycine max L.*) root nodulation and biological nitrogen fixation. Journal of Plant Nutrition and Soil Science 180(2), 199-211.

111. Schneider, S., Hartmann, M., Enkerli, J., & Widmer, F. (2010). Fungal community structure in soils of conventional and organic farming systems. Fungal Ecology 3(3), 215-224.
112. Siegrist, S., Schaub, D., Pfiffner, L., & Mäder, P. (1998). Does organic agriculture reduce soil erodibility? The results of a long-term field study on loess in Switzerland. Agriculture, Ecosystems & Environment 69, 253-264.
113. Simpson, R.J., Oberson, A., Culvenor, R.A., Ryan, M.H., Veneklaas, E.J., Lambers, H., Lynch, J.P., Ryan, P.R., Delhaize, E., Smith, F.A., Smith, S.E., Harvey, P.R., Richardson, A.E. 2011. Strategies and agronomic interventions to improve the phosphorus-use efficiency of farming systems. Plant Soil 349, 89-120.
114. Skinner, C., Gattinger, A., Krauss, M., Krause, H.-M., Mayer, J., Van Der Heijden, M. G. A., & Mäder, P. (2019). The impact of long-term organic farming on soil-derived greenhouse gas emissions. Scientific Reports 9(1), 1702.
115. Skinner, C., Gattinger, A., Muller, A., Mäder, P., Fliessbach, A., Stolze, M., Ruser, R., & Niggli, U. (2014). Greenhouse gas fluxes from agricultural soils under organic and non-organic management – A global meta-analysis. Science of The Total Environment 468–469, 553-563.
116. Stracke, B. A., Eitel, J., Watzl, B., Mäder, P., & Rüfer, C. E. (2009). Influence of the production method on phytochemical concentrations in whole wheat (*triticum aestivum l.*): A comparative study. Journal of Agricultural and Food Chemistry 57(21), 10116-10121.
117. Schwalb, S. A., Li, S., Hemkemeyer, M., Heinze, S., Joergensen, R. G., Mayer, J., Mäder, P., & Wichern, F. (2023). Long-term differences in fertilisation type change the bacteria:archaea:fungi ratios and reveal a heterogeneous response of the soil microbial ionome in a Haplic Luvisol. Soil Biology and Biochemistry 177, 108892.
118. Tamm, L., Thürig, B., Bruns, C., Fuchs, J. G., Köpke, U., Laustela, M., Leifert, C., Mahlberg, N., Nietlispach, B., Schmidt, C., Weber, F., & Fliessbach, A. (2010). Soil type, management history, and soil amendments influence the development of soil-borne (*Rhizoctonia solani, Pythium ultimum*) and air-borne (*Phytophthora infestans, Hyaloperonospora parasitica*) diseases. European Journal of Plant Pathology 127(4), 465-481.
119. Tamm, L., Thürig, B., Fliessbach, A., Goltlieb, A. E., Karavani, S., & Cohen, Y. (2011). Elicitors and soil management to induce resistance against fungal plant diseases. NJAS - Wageningen Journal of Life Sciences 58(3-4), 131-137.
120. Thuerig, B., Fliessbach, A., Berger, N., Fuchs, J. G., Kraus, N., Mahlberg, N., Nietlispach, B., & Tamm, L. (2009). Re-establishment of suppressiveness to soil- and air-borne diseases by re-inoculation of soil microbial communities. Soil Biology and Biochemistry 41(10), 2153-2161.
121. Widmer, F., Rasche, F., Hartmann, M., & Fliessbach, A. (2006). Community structures and substrate utilization of bacteria in soils from organic and conventional farming systems of the DOK long-term field experiment. Applied Soil Ecology 33(3), 294-307.
122. Woese, K., Lange, D., Boess, C., & Bogl, K. W. (1997). A comparison of organically and conventionally grown foods – Results of a review of the relevant literature. Journal of the Science of Food and Agriculture 74(3), 281-293.
123. Zörb, C., Langenkämper, G., Betsche, T., Neehaus, K., & Barsch, A. (2006). Metabolite profiling of wheat grains (Triticum aestivum L.) from organic and conventional agriculture. Journal of Agricultural and Food Chemistry 54(21), 8301-8306.
124. Zörb, C., Niehaus, K., Barsch, A., Betsche, T., & Langenkämper, G. (2009). Levels of compounds and metabolites in wheat ears and grains in organic and conventional agriculture. Journal of Agricultural and Food Chemistry 57(20), 9555-9562.

Book chapters

1. FAC, & FiBL,. (Eds) (1995). DOK-Versuch: vergleichende Langzeit-Untersuchungen in den drei Anbausystemen biologisch-Dynamisch, Organisch-biologisch und Konventionell. Bern: Bundesamt für Landwirtschaft (BLW).
2. Fliessbach, A., Eyhorn, F., Mäder, P., Rentsch, D., & Hany, R. (2001). DOK long-term farming systems trial: Microbial biomass, activity and diversity affect the decomposition of plant residues. In Sustainable Management of Soil Organic Matter Eds R. M. Rees, B. C. Ball, C. D. Campbell & C. A. Watson, pp. 363-369. London: CABI.
3. Fliessbach, A., & Mäder, P. (1997). Carbon source utilization by microbial communities in soils under organic and conventional farming practice. In Microbial Communities — Functional versus Structural Approaches Eds H. Insam & A. Rangger), pp. 109-120. Berlin: Springer.
4. Frey, B., Brunner, I., Christie, P., Wiemken, A., & Mäder, P. (1998). The use of polytetrafluoroethylene (PTFE) hydrophobic membranes to study transport of 15N by mycorrhizal hyphae. In Mycorrhiza Manual (Ed A. Varma), pp. 151-158. Heidelberg: Springer.
5. Frossard, E., Bünemann, E.K., Gunst, L., Oberson, A., Schärer, M., Tamburini, F. (2016). Fate of fertilizer P in soils the organic pathway. In: Schnug, E., De Kok, L.J. (Eds.), Phosphorus in agriculture: 100% zero. Springer Dordrecht, pp. 41-61.
6. Fuchs, J. G., Fliessbach, A., Mäder, P., Weibel, F. P., Tamm, L., Mayer, J., & Schleiss, K. (2014). Effects of compost on soil fertility parameters in short-, mid- and long-term field experiments. In I International Symposium on Organic Matter Management and Compost Use in Horticulture Eds J. Biala, R. Prange & M. Raviv), pp. 39-46.
7. Krause, H.-M., Fliessbach, A., Mayer, J., & Mäder, P. (2020). Chapter 2 - Implementation and management of the DOK long-term system comparison trial. In Long-Term Farming Systems Research Eds G. S. Bhullar & A. Riar), pp. 37-51. Academic Press.
8. Mayer, J., & Mäder, P. (2016). Langzeitversuche – Eine Analyse der Ertragsentwicklung.In Forschung im Ökologischen Landbau Eds. B. Freyer) pp.421-445 Stuttgart VTB.
9. Mäder, P. (1997). Erhöhte bodenmikrobiologische Aktivität durch ökologischen Landbau. In Naturschutz durch ökologischen Landbau. Ökologische Konzepte 95 Eds H. Weiger & H. Willer), pp. 49-72. Bad Dürkheim: Deukalion, Stiftung Ökologie und Landbau.
10. Mäder, P., Alföldi, T., Fliessbach, A., Pfiffner, L., & Niggli, U. (1999). Agricultural and ecological performance of cropping systems compared in a long-term field trial. In Nutrient Disequilibria in Agroecosystems Eds E. M. A. Smaling, O. Oenema & L. O. Fesco), pp. 247-264. London, Amsterdam: CABI.
11. Mäder, P., Fliessbach, A., Dubois, D., Gunst, L., Jossi, W., Widmer, F., Oberson, A., Frossard, E., Oehl, F., Wiemken, A., Gattinger, A., & Niggli, U. (2006). The DOK experiment (Switzerland). In Long-term field experiments in organic farming Eds J. Raupp, C. Pekrun, M. Oltmanns & U. Köpke), pp. 41-58. Bonn: Koester.
12. Oberson, A., Pypers, P., Bünemann, E., Frossard, E. (2011). Management impacts on biological phosphorus cycling in cropped soils In: Bünemann, E., Oberson, A., Frossard , E. (Eds.), Phosphorus in action - Biological processes in soil phosphorus cycling. Springer Soil Biology Series, pp. 431-458.
13. Pfiffner, L., & Armengot L. (2019). Biodiversity as a prerequisite of sustainable organic farming. In : Köpke, U. (Ed.), Improving organic crop cultivation , Chapter 16 : 401-433. Burleigh Dodds Science Publishing, Cambridge, UK (ISBN: 978-1-78676-184-2; www.bdspublishing.com).

Abbreviations and glossary

a	annum / year
arthropod	insects, millipedes, crustaceans, arachnids
bacterivore	feeds on bacteria
basal respiration	soil respiration under standard conditions
BIODYN	DOK cropping system using biodynamic principles
BIOORG	DOK cropping system using bio-organic principles
BT	*Bacillus thuringiensis*. BT preparations contain spores or toxins of the bacterium
C	carbon
CaO	quicklime, chemically calcium oxide
CH_4	methane
Cmic	microbially bound carbon
Cmic/Corg	ratio of microbial carbon to organic carbon
C/N	ratio of carbon to nitrogen
CO_2	Carbon dioxide
Corg	organic carbon
CONFYM	DOK system using conventional cropping with farmyard manure
CONMIN	DOK system using conventional cropping with mineral fertiliser only
CRP	Crop rotation period, in the DOK trial CRP 1: 1978–84; CRP 2: 1985–91; CRP 3: 1992–98; CRP 4: 1999–2005; CRP 5: 2006–12; CRP 6: 2013–19
dehydrogenases	enzyme group in the respiratory chain of microorganisms
DM	dry matter
DOK	dynamic, organic, conventional ('konventionell' in German). Abbreviated for the DOK trial of (bio) dynamic, organic and conventional cropping systems
DON	deoxynivalenol, a mycotoxin
fertilisation	farmyard manure in the DOK trial reduced = 1 = 0.7 LU standard practice = 2 = 1.4 LU
field	in the DOK trial, crops are grown at staggered intervals in three fields (A, B, C)
fungivore	feeds on fungi
GRUD	Principles of Fertilisation of Agricultural Crops in Switzerland (2017)
herbivore	feeds on plants
IP	integrated production (integrated farming)
K	potassium
LU	fertiliser livestock unit. 1 LU corresponds to the annual production of 105 kg N and 15 kg P_2O_5 (the empirical formula for diphosphorus pentoxide)
metabolite	products from enzyme-catalysed reactions
metagenomics	genetic material is extracted directly from environmental samples, sequenced and analysed
n	sample size
N	nitrogen
N_2	molecular atmospheric nitrogen
N_2O	nitrous oxide (laughing gas)
NRP	Swiss National Research Programme
NIR	near-infrared spectroscopy
NIV	nivalenol, a mycotoxin
Nmic	microbially bound nitrogen
Nmin	mineral nitrogen from ammonium and nitrate
NMR	nuclear magnetic resonance spectroscopy
Ntotal	total nitrogen
NOFERT	DOK cropping system without fertilisation
NUE	nitrogen utilisation efficiency
omnivore	feeds on both plants and animals
OS	organic substance
P	phosphorus
P_2O_5	empirical formula for diphosphorus pentoxide
PLFA	phospholipid fatty acid and ether lipid pattern
plot	individual area of a cropping system in the DOK trial facility
PPP	plant protection products
qCO_2	metabolic quotient: A low value indicates that the microorganism community is efficiently converting the available energy
replicate	repetitions of the test units
RFLP	restriction fragment length polymorphism
rhizodeposition	root inputs from roots and substances released into the soil by roots
SD	standard deviation
SIMS	secondary ion mass spectrometry
SNSF	Swiss National Science Foundation
soil respiration	CO_2 emitted by microorganisms
SOM	soil organic matter = humus = 1.725 × Corg
t	metric tonnes
TPF	Triphenylformazan (indicator dye)
15N	stable isotope of nitrogen
32P, 33P	radioactive isotopes of phosphorus

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Research Institute of Organic Agriculture FiBL
Ackerstrasse 113, P.O. Box 219, 5070 Frick, Switzerland
Tel. +41 (0)62 865 72 72
info.suisse@fibl.org, fibl.org

In collaboration with Agroscope and ETH Zurich

Authors: Andreas Fliessbach, Hans-Martin Krause (both FiBL Switzerland),
Klaus Jarosch, Jochen Mayer (both Agroscope), Astrid Oberson (ETH Zurich), Paul Mäder (FiBL Switzerland)

Review: Lukas Pfiffner, Else Bünemann-König (both FiBL Switzerland)

Editors: Vanessa Gabel, Simona Moosmann (both FiBL Switzerland)

Translation: Jennifer Bartmess, Aron Alber (Bartmess Editing)

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