ASK THE CARROT

The fundamentals of modern plant research

Agriculture: Basics · History

Inhalt

Further information can be found at:

http://www.mpimpgolm.mpg.de/22409/Frag_die_Erbse_Booklet

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What is agriculture?

The core of all things

Agriculture describes the **targeted cultivation** of an area for the production of food. Plants are able to form organic substances like sugars, fats, and proteins with the use of solar energy in the process of photosynthesis ➥ **ASK THE PEA.** Therefore, all of our chops or steaks as well as other animal products like cheese, eggs, and milk are based on the cultivation of plants just as much as fruit, vegetables, muesli, or bread.

Besides the production of **food**, plants also have been and still are used for the productionof **industrial products**, such as flax and cotton for the production of fibers or potatoes for the production of pastes and glues. Further, plants are increasingly being used as sources of energy. This leads to a competition between the production of food and the cultivation of plants for energy production in the form of biogas, biopetrol or biodiesel.

Is there such a thing as “natural agriculture”?
Cultivated landscapes and the production of food

The cultivation of landscapes requires the natural vegetation to be pushed back. Therefore, agriculture always means interference with the environment, regardless of whether it is organic or whether is practiced particularly intensively. This was already the case when landscapes first began to be used for agricultural purposes more than 7,000 years ago. The large forested areas of Europe were cleared and little by little made space for cultivated agricultural and forest landscapes. Areas like the Lüneburg Heath, which are today regarded as unspoiled nature that needs to be protected, arose as a result of human activity – through the overgrazing of the previously existing forests. Still today, this unique cultivated landscape is being rid of bushes and trees through ongoing grazing and in this way “artificially preserved”.

Do plants in the field need protection?

Securing yields through plant protection

The clearing of forests and the subsequent cultivation of crops allowed other plant species to settle and grow, as they were no longer overshadowed by trees and did not have to compete with them for light, water, and nutrients. The beginning of agricultural cultivation in this way led to a larger diversity in the plants but also animal kingdoms. This diversity of plants brought animal, fungal, and bacterial pests as well as viruses with it, which jeopardized yields for humans. While in natural ecosystems, the composition of plants in a location is determined by the climate and soil as well as by competition and resistance to pests and diseases ➥ **ASK THE PLUM**, arable farming generally involves only one species of plant being cultivated on an area at a time. Like foxes in the henhouse, pests (mostly insects) and pathogens (viruses, bacteria or fungi) find optimal conditions in these monocultures for their nutrition and Vreproduction. They can even adjust their development and life cycle to the crop in the field, which becomes easier the more often the same plant is cultivated.

Photo: istockphoto © Meinzahn

Kulturlandschaft

Fungal disease in maize:
corn smut

Pest in maize:
European corn borer

Photos: JKI/Hommel

Pest in potato:
potato beetle larva

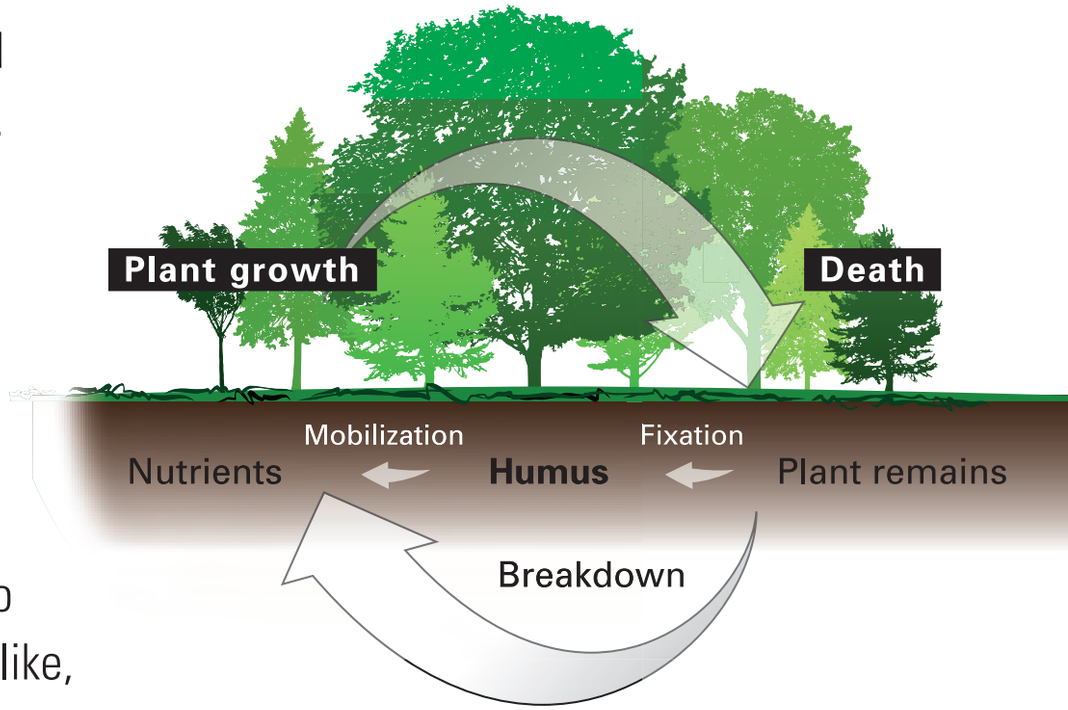
The same holds true for the wild plants that compete with the cultivated plants for nutrients, water, and light, and that are known as **weeds**.

The lack of appropriate countermeasures can lead to substantial loss of yields or even to the complete loss of the harvest. To prevent this, different measures can be taken and combined with each other. Potential measures range from a healthy and diverse crop rotation – so that the same plant species does not grow on the field every year – to the selection of the cultivated species and variety up to techniques of soil cultivation, the application of agents that protect and strengthen plants, and the cultivation of genetically modified plants. The more effective a method is in fighting disease and weeds, the lower is the incidence of disease and the less weeds and therefore species diversity is found on the field. However, pathogens and weeds can also resist these attacks by developing resistance to the agents applied for the protection of the cultivated plants. The process of developing resistance in the form of adaptation and counteradaptations is constantly running in natural ecosystems ➥ **ASK THE PLUM**.

Do plants need fertilizer?

Plants also need food

In addition to sunlight, carbon dioxide, and water, plants also need nutrients to grow. They take these up in mineral form with the water from the soil. On areas that are not cultivated, new plants grow and old ones die off.

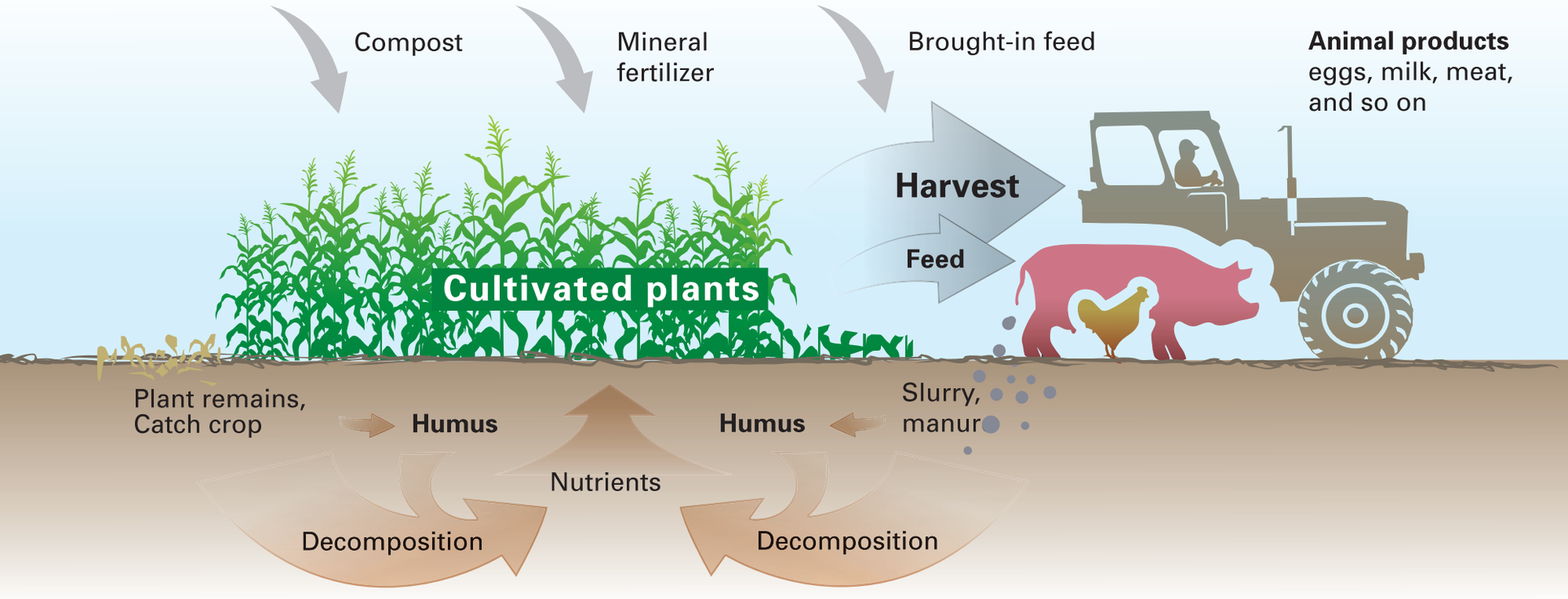


Bacteria decompose the dead plants through many intermediate stages down to their elementary and mineral components like, for example, carbon dioxide, water, nitrogen and phosphorus compounds, and others. This degradation process is called mineralization.
The substances released by the microorganisms serve as food for the newly growing plants. Thus, a **cycle of dying**, breakdown, conversion of substances, and growth is played out on areas that are not cultivated.

Things work differently on agricultural land:

Nutrients are removed from the soil along with the harvesting of the crop.
Similar to a bank account from which money is always withdrawn but which is never replenished, the amount of nutrients would be reduced, the yield would fall, and the soil would be drained. Fertilization is practiced so that this does not occur.

Fertilizers can be **organic**, e.g., animal dungs like manure or slurry, green manure in the form of plant residues, or **mineral**. In nitrogen-containing mineral fertilizers, nitrogen is supplied in the form that is taken up by plants. Thus, it does not have to be first released from the organic material and is therefore more readily available for the plant. The possibility of treating cultivated plants with these fast-acting fertilizers enables the provision of an appropriate supply of nitrogen during the different phases of growth. Fertilization becomes a problem when the quantity and time of application are not adjusted to the nutrient needs of the plant – this holds true not only for mineral, but above all for organic fertilization. An exclusively mineral fertilization of the plants is not sensible and is also not practiced. A purely organic fertilization, on the other hand, can lead to plants being undersupplied with nutrients which can bring yield losses in its wake.

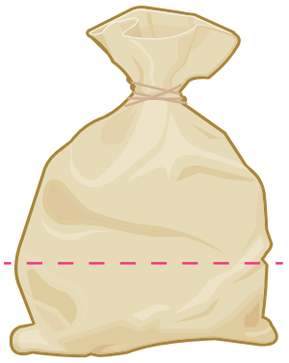


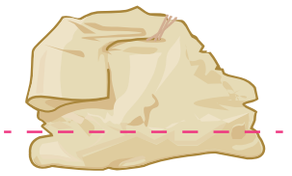
Are plant protection and fertilization modern inventions?

Plant protection and fertilization from the very beginning

The history of plant protection and fertilization began together with that of agriculture itself. The Babylonians already used stable manure, and the Egyptians sludge from the Nile, as fertilizer. Attempts were also made to fight against animal pests like locusts, moths, beetles, and worms. The first seed treatments were carried out already several hundred years before Christ. Soil pests were fought by spraying the ground with oil or arsenic-containing substances, and rings of glue were used.

Nevertheless, through agriculture and hard work humans could, over thousands of years, scrape together only small yields. In the early Middle Ages, harvests were only about twice as high as the amount of sown grains. In the late Middle Ages, at least three or four times the amount of sown grain could be harvested on average. Many of the relationships important for the yield were not yet known. Because of the scarcity of food – especially in winter – only small numbers of animals could be kept, and there was a lack of manure for fertilization. Those measures against harmful insects and plant diseases known at the time were not adequate and, not least, together with unfavorable weather, led again and again to large famines. Badharvests did not only lead to starvation in the year of the harvest, but also endangered the harvests in the following years due to the lack of seeds.





As the harvests were meagre, minor losses in yield were already enough to lead to food shortages. Nevertheless, a portion of the harvest had to be kept back as seed. No seed meant no harvest in the next year.

Why do yields have to be increased?

A changing world

After the fall of the Roman Empire, wars, epidemics, and poor harvests had brought farmers to a state of dependency. They could not acquire any land, they had landlords to whom they had responsibilities and who possessed among others, jurisdiction, the right to determine the place of residence and permission to get married. Parts of their harvest had to be paid to the landlords, the church, and the tax collector. The yields were barely large enough to feed their own families.

In the 16th century, 9/10 of the German population was made up of dependent farmers. Despite the first attempts at reform in the middle of the 18th century, farmers were only liberated in Germany at the start of the 19th century. However, because the landlords had to be compensated, the farmers incurred debts. Many farmers lost a part of or even the whole of their land. The landless farmers crowded to the towns and cities where they found work in factories. While death rates and birth rates were very close to one another in pre-industrial times, birth rates now increased, while at the same time the life expectancy grew as a result of improved hygienic measures. Between 1800 und 1910 the populations grew markedly. On the area of what was later the German Empire, the population grew almost three-fold (an increase from 23 to 65 million.). A science-based agriculture with increased yields therefore assumed huge importance.

Changes in Germany in the 19th century

around 1800		around 1900
 rural population 75% urban population 25%	**rural exodus** industrialization and urbanization	 rural population 40% urban population 60%
 23 million people	**population growth** progresses in medicine	 56 million 1900, 65 million 1910
 Yields: wheat 10 dt/ha rye 9 dt/ha	**increase in yields** increases in productivity through agricultural innovations	 Yields: wheat 20 dt/ha Rye 18 dt/ha

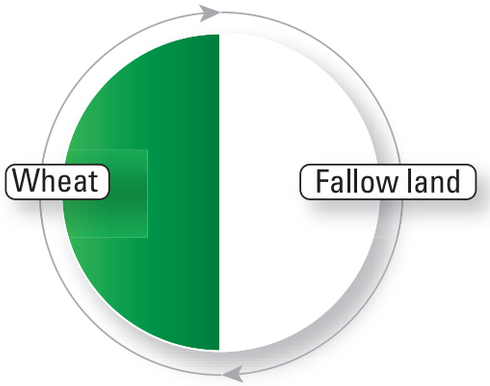
Source:http://www.digitalis.uni-koeln.de/Brentano/brentano7-14.pdf

How has agriculture developed?

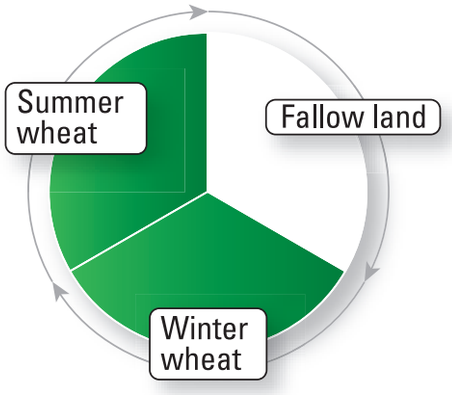
New insights lead to higher yields

The modern era brought with it many new insights in the fields of chemistry and physics ➥ **ASK THE PLUM**. These not only exerted effects on plant research, but also had an impact on practical agriculture. In the 19th century Julius Kühn and Anton de Bary founded the discipline of the study of plant pathogens (phytopathology), after the development of the microscope allowed the investigation of sick cells and tissues.

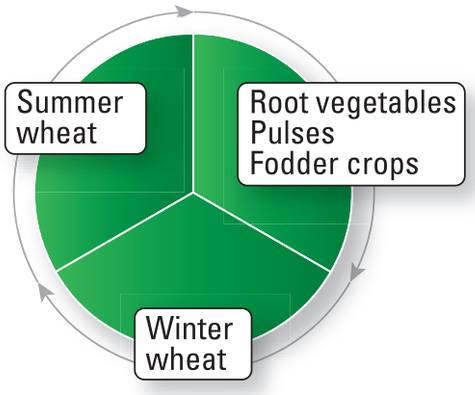
Among the scientists of the 18th and 19th centuries that gave important impetus to agriculture, Albrecht Thaer, who at the beginning of the 19th century developed an agricultural science based on theories and experiments, is particularly worthy of mention. He suggested, among other things, that fields should not be left fallow in the third year of crop rotation, but should rather be cultivated with root vegetables like potatoes, pulses, or fodder crops. In this way, the number of livestock could be increased, which not only led to an increase in the supply of animal products, but also in manure that could be used as fertilizer.



Two-field rotation
in the early Middle Ages



Three-field rotation
in the Middle Ages (from about 1100)



Crop rotation
(end of the 18th/beginning of the 19th century)

In the middle of the 19th century, **Hermann Hellriegel and Hermann Wilfarth** discovered why the cultivation of pulses and forage **legumes** had a positive impact on the nitrogen supply of a field. The reason for this are particular bacteria that enter into a partnership with the legumes (symbiosis). The bacteria absorb nitrogen from the soil and convert it into a form that is available for plants; in return, the plants provide the bacteria with the energy required for this process. At the end of the vegetative period, nitrogen that can be used by plants remains in the field and can be used by the succeeding crop.

Johann Heinrich von Thünen founded the teachings of agricultural business operations, which allow farmers to make the right decisions on the basis of profit and loss calculations.

Rhizobiaceae on the roots of legumes

photo: MPI-MP, Josef Bergstein

The foundations for targeted fertilization were laid by **Carl Sprengel and Justus von Liebig**. Carl Sprengel could prove that the fertilizing effect of humus is due to the nutrients that it contains and he formulated the **"law of the minimum"**.

Liebig's aim was to prevent in the future the devastating famines of past times. He expanded on the law of the minimum in a work on agricultural chemistry written in 1840 and advocated mineral fertilization and its importance for the quality and yield of plants. On the basis of his work, phosphate fertilizer (super-phosphate) has been produced in Germany since 1855. To improve the supply of nitrogen, saltpeter was imported from Chile and guano from Peru. Only since the beginning of the 20th century has it been possible to use atmospheric nitrogen for the production of fertilizer with the Haber-Bosch process.

Gesetz vom Minimum
If one of the substances required for the growth of the plant does not meet the demand, then this nutrient deficiency acts to limit the yield. The absence of a given nutrient cannot be compensated for by any other nutrient.

From the middle of the 18th century onwards plant fungal infections were combated with metal salts or organic mercury compounds. Attempts were also made to tackle weeds with chemical agents. The cultivation of new crops with high nutritional value (e.g., the potato) enhanced knowledge of the connections between soil, plants, and their nutrition. Improvements and the introduction of new techniques and devices as well as the cultivation of "waste land" all led to higher yields. This resulted in a doubling of yields between 1800 and 1900 – for wheat from 10 to 20, for rye from 9 to 18, and for oats even from 7 to 18 quintals or decitons (1 dz or 1dt = 100 kg). The cattle population doubled together with the milk yield of the cows.

Plants affected by blight

Is “industrial agriculture” a new term?

From the enlightenment to romanticism: “Back to nature”

Industrialization, urbanization, and changes in agricultural practices have also attracted criticism. In the middle of the 19th century, a reform movement developed in Germany and Switzerland. The proponents of this “life reform” saw the changes not as progress but rather as a symptom of decline and the feared “destruction of civilization” and “diseases of civilization” caused by individualism. Only through the return to a “more natural” way of life could these be avoided and healed. They advocated, among other things, a life close to nature, ecological agriculture, vegetarianism, and natural medicine. Reform houses were founded in this time. A “pastoral hostility to the city” developed within the educated middle-classes together with a longing for the rural idyll. Some created allotments, while others founded communes in the countryside with the aspiration of largely producing their own food.

Photo: iStockphoto © 97

In the course of the reform movement, reform houses were founded. They were characterized by an alternative range of products, e.g., medicinal herbs, plant products as a replacement for meat, natural clothing, natural cosmetics, etc. urrently, a large number of organic products are offered for sale in reform houses, although non-organic products also remain on sale.

How has agriculture changed?
Inexpensive food in abundance

Yields were already increased in the 19th century as a result of enhanced scientific knowledge and newly-developed methods in agricultural technology. However, the decisive steps towards supplying the growing population with sufficient food of good quality have only been taken in the last century.

The development and application of so-called “artificial fertilizers” (in particular, nitrogen fertilizers produced in the Haber-Bosch process) and of chemicals that are effective against insects (insecticides), fungi (fungicides), or weeds (herbicides), as well as improved breeding and cultivation methods led, after the Second World War, to a rapid increase in agricultural outputs.

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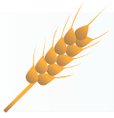
Increases in yield

	1950		2015
Wheat yield	27 dt/ha*		78 dt/ha +
Potato yield	224 dt/ha*		436 dt/ha +
Sugar beet yield	345 dt/ha*		717 dt/ha +

*Mean yields from 1950 to 1954. Federal Statistical Office, BML, Institute for Agricultural Market Research Völkenrode, + Mean yields from 2010 to 2015, Federal Statistical Office, BMEL

In 1949, one farmer fed only 10 people; that number is now 147. Food products are now cheaper than they ever have been before. While in 1960 consumers still had to spend 55% of their incomes on food, today food accounts for only barely 12%. Instead of three- to four-fold, like in the late Middle Ages, or 10-fold like in the 19th century, harvests today come to 40- to 50-fold of the sown seeds.

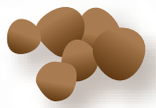
The high wages that were paid outside of agriculture in the 1950s during the "economic miracle" and the high fixed costs for buildings, equipment, and instrumentation in agricultural enterprises contributed to a profound change in agriculture. The number of people engaged in agricultural activity sank in the space of 60 years from 4.8 million in 1949 to about 1 million today.

Manpower was replaced by mechanization. Manure management began to be practiced in stalls, so that the more expensive mucking out was dropped. Electrical milking systems helped to reduce the amount of human work needed. As a result of the easily mechanizable cultivation of grains, the proportion of grain in crop rotation increased from 55 to 70%. In order to reach an adequate operating income, production volume had to be increased. The number of agricultural operations fell from 1.65 million in 1949 to barely 300,000 in 2010.

Food products are becoming cheaper – farmers revenues smaller

Working time
The time needed to earn one's food

Sales revenue
How much money reaches the farmer in %

1960/1970		2011
96 min	**Meat**  1 kg pork chop	22 min
72 min	 1 kg beef for cooking	28 min
60 %		**24 %**
16 min	**Bread**  1 kg dark multigrain bread	11 min
30 %		**5 %**
9 min	**Milk**  1 L milk, 3.5% fat	3 min
60 %		**33 %**
6 min	**Potatoes**  2.5 kg potatoes	3 min
58 %		**13 %**
55 %	**Average of all products**	**23 %**

Data sources: Federal Statistical Office, AMI, BMELV (123) and from the Thünen Institute, DBV

What were the effects of agricultural change?

Of mountains of butter, seas of milk, and other consequences

Such profound structural and management changes were not without their consequences for the environment. As a result of economic constraints or a lack of experience in the application of fertilizers and plant protection products, the motto "the more the better" described a widespread attitude. Consequences of this approach included not only overproduction (seas of milk, mountains of butter, the destruction of fruit to stabilize prices), but also the discovery of nitrate and/or plant protection products (mostly atrazine) in drinking water and the detection of DDT, that was enriched in the food chain, in the adipose tissue of animals and humans. The larger numbers of livestock in turn led to a manure problem. The new achievements of the herbicides led, in the 70s and at the beginning of the 80s, to the spraying of field margins to prevent the seeds of wild herbs reaching farmland. Orchards or vineyards were kept free of any vegetation in order to avoid fungal infections, and ploughed wastelands were the rule in winter. The threshold value for nitrate in drinking water was reduced from 100 mg/l to 50 mg/l, which caused problems for some water suppliers, and threshold values were introduced for plant protection products and the sum of their degradation products in drinking water. Then, in the middle of the 1980s the first cases of BSE occurred in England. Agriculture and its methods were brought into disrepute. Consumers were unsettled.

As a consequence of these developments, a change was initiated in agricultural policies. Programs aimed at the extensification of agricultural production and at the protection of natural and cultivated landscapes were launched. As part of these extensification programs, farmers received money for setting aside land and for making the changeover to organic farming, as the smaller yields of this form of land management contributed among other things to easing the strain on the market.

What is organic farming?

The slightly different way to run a farm

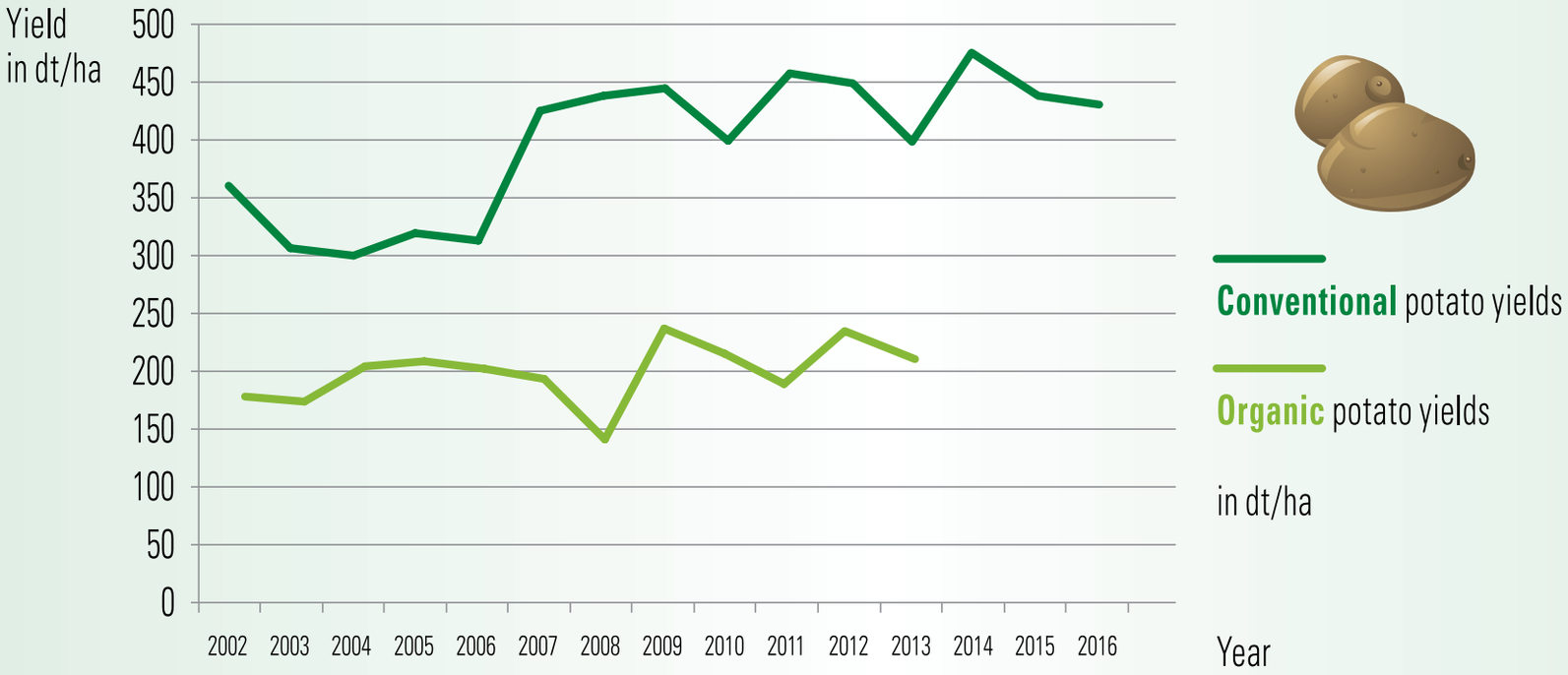
In organic farming the aim is for operational cycles to be as closed as possible. The nutrients removed from the soil in the harvest should be returned to the fields in the form of organic fertilization. The animal feed must be ecologically produced and, if possible, be produced on-site. The number of livestock per hectare is in most cases lower than in conventional operations. Varied crop rotations have the aim of reducing diseases and pests. Synthetically-produced fertilizers and plant protection products as well as the cultivation of genetically modified plants are not allowed.

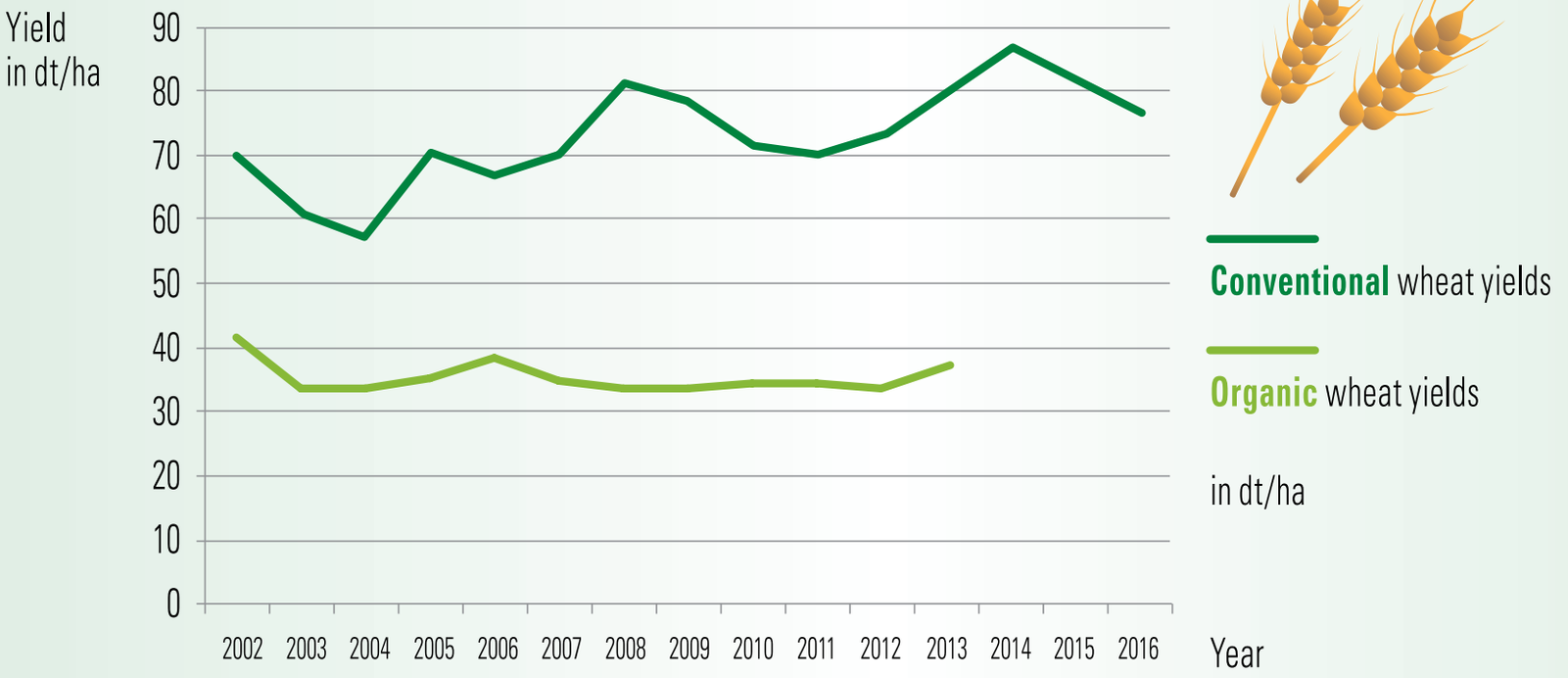
Nevertheless, organic farming does not get by without plant protection. Weeds are combated by hoeing or burning. The application of preparations of *Bacillus thuringiensis* (Bt) against insects is also permitted as are attempts to combat pests with beneficial parasites (parasitic wasps against moths, ladybird larvae against aphids, etc.). The application of constituents of chrysanthemum

with insecticidal activity is allowed. However, the same substance, synthetically produced, is prohibited. Fungal infections in potatoes caused by Phytophthora infestans (late blight) can be combated using copper preparations, but, again, synthetic fungicides are not permitted. Further, plant fortifiers that increase the resistance of plants to pests and non-parasitic damage can be applied.

This form of management does come at a price – not only in the supermarket: for staple goods such as wheat or potatoes yields are only half as big as for conventional farming, and at the same time the workload is higher. Rape or sugar beet are only grown on a very limited basis, as rape numbers among those cultures that particularly sap the nutrients from the soil und besides there is a lack of "natural" control methods for harmful insects that affect rape. The cultivation of sugar beet is also problematic in organic farming, because weed control is very difficult. As organic farming does not have the goal of reaching the highest possible yield with the available resources, but rather strives to be extensive, the economic efficiency of this kind of management can only be ensured by the marketing of the products at higher prices and by state subsidies that particularly support this mode of production. Organic farming has now managed to develop an "organic" brand for their products, that consumers associate with positive attributes. For that reason, they are willing to dig deeper into their pockets.

Yields in comparisony





Source data: BMEL, Statista
Unfortunately, no yield data could be determined for organic farming from 2014 to 2016.

Only organic from now on?

Is conventional agriculture being made into a scapegoat?

Since the experiences of the 70s and 80s, a great deal has happened in modern agriculture. Instead of "the more the better", the motto of modern integrated farming is now **"as much as is necessary, as little as is possible"**. This is demonstrated by the reduced application of (mineral) fertilizers and the amount of plant protection products that are spread per hectare. New procedures for determining the nutritional requirements and status of plants were developed as were improvements in the targeted application of fertilizers. New plant protection products were developed, the approval of which was determined in large part by environmental considerations, e.g., for insecticides the impact on non-target organisms or the rate of degradation in soil. Modern agricultural crop breeding and the development of new varieties ➥ **ASK THE BARRLEY** contributed further.

Although nationwide on average 94% of operations practice conventional management and ensure the supply of sufficient quantities of reasonably-priced food, and despite the fact that the proportion of organically-produced food on the whole food market amounts to less than 4%, conventional land management is met with high levels of mistrust.

With arguments and slogans comparable to those from the 19th century (life reform movement) it is criticized as "industrial agriculture". The size of a conventionally managed operation is often taken as a criterion for the label of "industrial agriculture", even though the area structures of these operations do not differ from those of organic operations. In the end, it is not the size of the operation that determines how environmentally and

animal friendly an operation is, but it is much more a question of the dedication and know-how of the management and their financial abilities to invest in new, more environmentally friendly technologies.

Operation sizes and areas of conventional and organically run operations (2013)

Operation size	Proportion of the operations in %	Proportion of the area in %
Less than 10 ha	25,4 % 17,1 %	2,2 % 1,9 %
10 – 50 ha	46,1 % 53,4 %	19,5 % 23,0 %
50 – 100 ha	17,3 % 16,7 %	21,2 % 20,2 %
100 – 200 ha	7,6 % 8,4 %	19,2 % 19,6 %
More than 200 ha	3,6 % 4,5 %	37,8 % 35,2 %

durchschnittliche Betriebsgröße

Conv. 58,6 ha

Bio 58,0 ha

Source data: Federal Statistical Office, BMEL

Whether large or small, it is a fact that yields can be increased in conventionally-run operations. Without the increased yields of the 19th and 20th centuries, we would be faced with even greater levels of world hunger than is the case today. Having said that no all-clear can be given for the future, as the world's population is increasing and the land available for agricultural use is being lost, e.g., through increased urbanization, climate change will most probably change the cultivation conditions, and energy and food production are already in competition with each other. In these conditions, it is inappropriate to gamble away our perspectives for the future through conflicts that are often ideological in basis. It is much more sensible to sift through the knowledge and insights from different methods of cultivation, to evaluate, and to renounce dogmas. The aim of agricultural practices must be, depending on the circumstances at the respective location, to make production as effective as possible, while simultaneously protecting the environment and maintaining the largest possible diversity of species. Optimally developed **plant and agricultural research** will make a decisive contribution to attaining this goal.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IMPORTANT QUESTIONS:

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- What is agriculture?
- Is there such a thing as natural agriculture?
- Why to plants need protection and fertilizers?
- Is the idea of plant protection and fertilization a new one?
- Why do yields have to be increased?
- Is the term “industrial agriculture” new?
- How has agriculture changed?
- What were the consequences of this change?
- What is organic farming?

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