Chapter 1
Introduction

1.1 Basic Terms and Overview of Contents

The term "agroecology" is composed of three roots, derived from the Latin *agrarius* (pertaining to the field), the Greek *oikos* (the home or the household), and the Greek *logos* (study).

The term **ecology**, defined as *the science of the overall relations of organisms to both their living and non-living environment*, was first introduced by the German zoologist Ernst Haeckel (1866). Based on this, **agroecology** can be defined as *the science of the relationships of organisms in an environment purposely transformed by man for crop or livestock production*. However, the term agroecology is currently used with quite different meanings (Sect. 1.1.3).

The **organisms** include various **species** and **populations** (Box 1.1) of crops, wild plants, animals and microorganisms. Domesticated crops and animals originate from wild species and have subsequently evolved through the selection of particular traits by man (Sect. 2.2.1).

Box 1.1 Species and Population

Groups of individuals are members of the same **biological species** and form a genetic unit when they can produce offspring capable of reproduction. This applies to both the cultivated forms of plants (varieties) and animals (breeds) that were derived from wild species, although the common descent is often difficult to discern because of marked differences in their habit. Only when individuals no longer form a reproductive community, i.e. are isolated from each other in terms of reproduction, can they be regarded as separate species. A **population** is defined as a reproductive community that is composed of individuals of a species in a particular geographic area or in a particular habitat.

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The **environment** consists of all factors affecting the living conditions of organisms. The different physical and chemical effects that originate from the non-living environment represent the **abiotic factors**. In terrestrial habitats, they essentially include the properties of the soil, specific geographic factors (e.g. topography and altitude), and climatic conditions. The latter primarily include factors related to insolation (thermal energy and light), precipitation, and the water balance.

The affects of **biotic factors** originate from organisms and can be exerted on other individuals of the same species (intraspecific), on individuals of a different species (interspecific), or on the abiotic environment (e.g. on specific soil properties). From the perspective of a species, the biotic environment essentially consists of other species, to which it can have different forms of relationship. These include feeding relationships, competition, and mutualism (Sect. 3.1).

Specific environmental factors are termed **resources**, defined as essential components of the environment that are used by the individuals and species. They can be of biotic or abiotic origin and differ by species, depending on their specific requirements. Basically, three categories of resource are of importance for all species: food, energy, and specific spatial structures. Important resources for plants include light (energy source), carbon dioxide, mineral nutrients, and, for species that form roots, a suitable soil structure to anchor and support the plant. Animals draw their food and energy from organic compounds that originate from either living organisms or their dead remains. Specific bacteria use chemical compounds (e.g. hydrogen sulfide or methane) as energy sources. Most living organisms also require oxygen for respiration. Spatial resources for animals can include shelter or hiding places and suitable locations to raise their offspring (e.g. nesting sites).

The **ecological niche** of a species comprises the total range of abiotic and biotic factors under which a species or population exists, maintaining itself by reproduction and reaching a specific density of individuals per spatial unit (abundance).

Organisms obtain their food directly from the natural environment in which they live and reproduce. There are few but notable exceptions to this general fact. One exception is the leaf-cutter ants (*Atta* and *Acromyrmex* species) in tropical America, which harvest leaf pieces from plants and carry them to their subterranean nests. There, the leaf material is chewed to a pulp and then used as a substrate for cultivation of fungi which, in turn, serve as food for the ant colony. Humans are also able to produce their own food by cultivation of crops. However, this strategy has not been used by humans during all their 150,000 years of existence as the so-called modern human (*Homo sapiens sapiens*) but was, instead, only adopted approximately 10,000 years ago. Therefore, important aspects of agroecology also concern the ecology of humans. This not only refers to the question of why and how there was this change in the use of natural resources (Chap. 2) but also to its future development, which is essentially determined by the growing world population. These questions concern human food supply and changes in the global environment (Chap. 8).

1.1.1 Ecosystems

Network structures involving organisms and their environment, in which a variety of abiotic and biotic factors are at work, are called **ecosystems**. They form structural and functional units that are both spatially related and involved in the exchange of materials, energy, and organisms, thus affecting each other. This characterization also applies to **agroecosystems** which differ from natural ecosystems in that they are managed by humans.

The most important patterns and processes describing natural and agricultural ecosystems include the relationships between species, species diversity, temporal changes of communities, and flows of materials and energy (Chap. 3).

There are no objective criteria with which to determine the spatial and functional boundaries of an ecosystem. However, on the basis of abiotic and biotic properties, some structural sections can be defined on the basis of different scales and used for description of patterns and for analysis of processes. For example, the Earth's surface can be divided into different ecological zones on the basis of climate, which broadly corresponds to specific vegetation and soil types (Chap. 7). Within the climate and vegetation zones, different landscapes and landscape elements continuing down to individual biotopes and habitats (Box 1.2) can be defined. Criteria for this include the respective temperature and precipitation conditions, geological and hydrological characteristics, topography and altitude, and the plant and animal communities affected by these factors. Corresponding to this, energy and material flows can be examined on different scales, ranging from global material cycles (Sect. 3.7) to small-scale translocations in the soil (Sect. 4.3).

Box 1.2 Biotope and Habitat

Originally, a **biotope** was understood to be the environment of an ecological community (biocoenosis; Sect. 3.2) characterized by abiotic factors whereby the biotope and the biocoenosis together form the ecosystem. However, in the broader, and currently most common form, the term is used mostly without separation of abiotic and biotic properties. In this case, the term generally refers to specific structures within a landscape (e.g. ponds, meadows, fields, woodlands etc.).

The term **habitat** was defined to characterize the space inhabited by a specific species. Today the term is also used for communities of species and, similar to biotope, includes abiotic and biotic characteristics.

Overall, biotopes, habitats and ecosystems do not represent hierarchically ordered and separable structures. They can be defined as spatial units only by more detailed characterization (e.g. on the basis of the vegetation).

1.1.2 Agroecosystems

Agroecosystems are ecosystems established for the production of useful plants and animals. They differ from natural ecosystems in that they are shaped by humans whose regular intervention manipulates the composition of their organisms and their function. They are characterized by regular cultivation measures, primarily sowing, harvest, and soil cultivation, but also by other types of management, for example mowing, grazing, and burning.

A classification of the different kinds of agroecosystem is presented in Sect. 2.4. The crops used in the different systems can be classified on the basis of their use:

- **Food crops** that serve as part of the human diet. These include cereals, root and tuber crops, legumes, oil crops, leaf vegetables, and fruit.
- **Beverages and stimulants, medicinal and spice plants**. Examples are coffee (*Coffea* species), tea (*Camellia sinensis*), chamomile (*Matricaria recuitita*), lavender (*Lavandula augustifolia*), and pepper (*Piper nigrum*).
- **Fodder plants** for animal production. These include a wide range of species and production types, depending on their use (Chap. 6). Food for livestock can be produced from different types of grassland, for example regularly mown hay meadows or pastures for livestock grazing. Field forage crops include a variety of cereals identical to human food plants, legumes, and other herbaceous species, for example fodder beet (*Beta vulgaris*).
- **Raw materials**, which can serve in the production of fibres and fuels. Fibre plants include cotton (*Gossypium* species), hemp (*Cannabis sativa*), and abaca (*Musa textilis*). For fuel, crops such as rapeseed (biodiesel), and alcohol (ethanol) are used; the latter is produced from a variety of crops, for example sugar cane (*Saccharum officinarum*).

Many crop species can be grown for different purposes and different uses, and so can be assigned to more than one of the categories listed.

One approach to description and analysis of agroecosystems is to focus on the crop plant. From the perspective of the plant, the agroecosystem is the environment where its growth, development, and physiological processes are directly or indirectly affected (Fig. 1.1). Each site is characterized by its own natural conditions, to which the crop plant is exposed (Chap. 4). Some of these conditions can be modified by the farmer to create the most suitable conditions for crop development. Specific measures include, e.g., fertilization and irrigation, and control of organisms, for example pests and weeds, that negatively effect the crop plants or cause yield losses (Chap. 5).

Another approach addresses analysis of matter and energy flows in agroecosystems at different spatial and temporal scales. Understanding and integration of ecological processes in farm production and land management can be used to improve resource use efficiency and to reduce external inputs. Overall, consideration of ecological principles, for example nutrient cycling, can contribute to sustainable crop and food production by minimizing both use of non-renewable

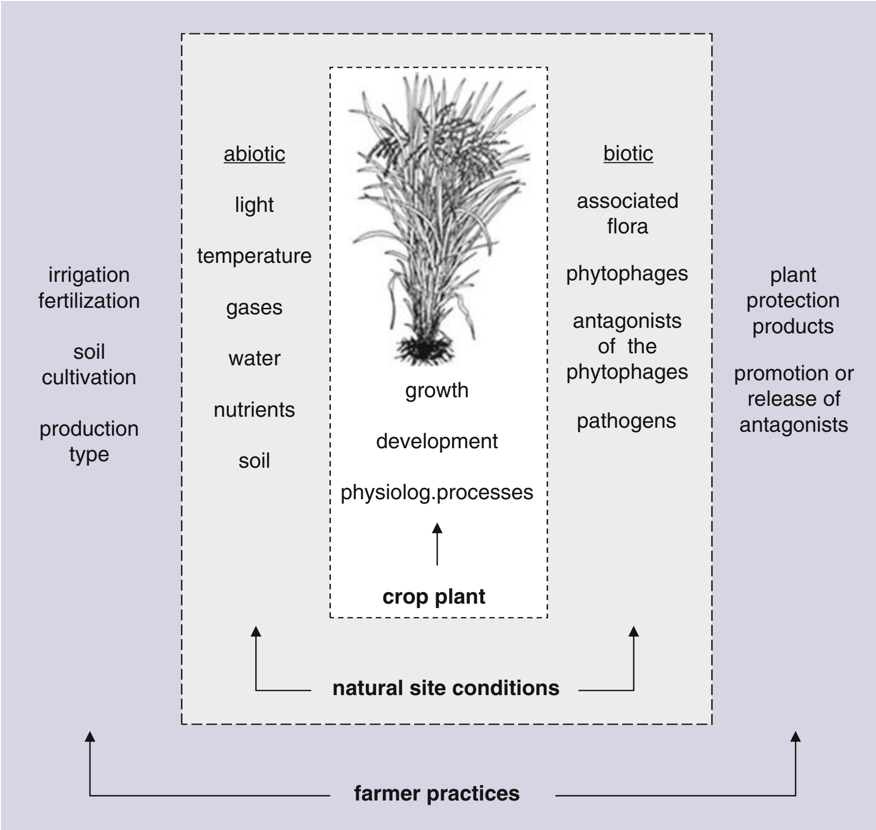

Fig. 1.1 The agroecosystem as the environment of the crop

inputs and detrimental effects on the environment. Concepts to achieve this include the combination and alternation of crops to enhance nutrient use efficiency, in particular the use of legumes for nitrogen fixation. In addition, incorporation of livestock in the system will increase the range of crops, including grassland, and provide nutrients in manure which can be used to fertilize annual crops and forage land (Chap. 6).

1.1.3 *Agroecology: History and Concepts*

Other than the generally accepted concept of ecology, the term "agroecology" is not clearly defined and can have quite different meanings. Wezel et al. (2009) reviewed the use and history of the term and found that it can imply a scientific discipline, an agricultural practice, or a social or political movement. Although agroecology

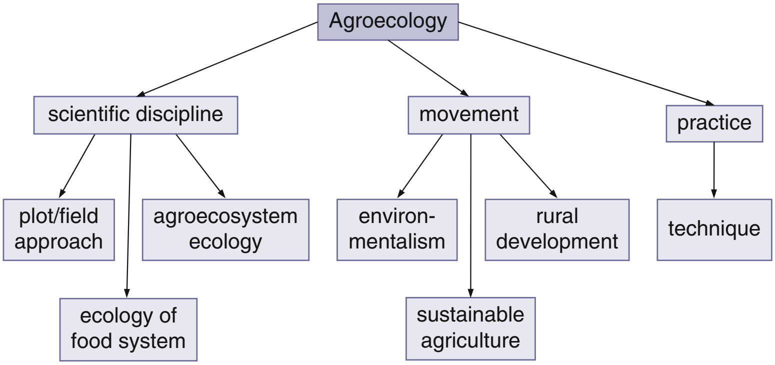

Fig. 1.2 Diversity of current meanings of agroecology (Based on Wezel et al. 2009)

initially dealt primarily with aspects of crop production and crop protection, in recent decades new dimensions, for example environmental, social, economic, ethical and development issues have become relevant.

According to Wezel et al. (2009), the term agroecology was used for the first time by the Russian agronomist Bensin in the 1930s to describe the use of ecological methods in research on commercial crop plants. By this, agroecology is primarily defined as the application of ecology to agriculture. Another important tenet of agroecology as a biological science was established by the German zoologist Tischler in the 1950s. He analyzed the different components of agroecosystems, for example plants, animals, soils, and climate, and their different relationships with the surrounding landscape, and the effect of agricultural management on these components.

As a consequence of different adverse effects of industrialized agriculture on the environment and on human welfare, agroecology emerged as both a movement and a set of practices from the 1970s onwards (Fig. 1.2).

Instead of narrow focus on short-term yields and economic returns, researchers increasingly considered the environmental and social factors of food production. From an ecological perspective, agroecology became defined as "*the scientific basis of alternative agriculture*" (Altieri 1987) and as "*the application of ecological concepts and principles to the design and management of sustainable agro-ecosystems*" (Gliessman 1997). Finally, agroecoecology as a scientific discipline went through a major change, moving beyond field or agroecosystem scales toward a larger focus on the whole food system, leading to a new and broader definition of agroecology as "*the integrative study of the ecology of the entire food systems, encompassing ecological, economic and social dimensions, or more simply the ecology of food systems*" (Francis et al. 2003). Therefore, according to Wezel et al. (2009), there are actually three approaches to agroecology, different aspects of which are also considered in this book: (1) investigations at plot and field scales, (2) investigations at agroecosystem and farm scales, and (3) investigations covering the whole food system.

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Chapter 2
Origin and Development of Agriculture

2.1 The First Humans

The savannas of Africa are believed to be the cradle of mankind. All members of *Homo sapiens sapiens* living today descended from populations that lived there approximately 150,000–200,000 years ago. Just as two earlier representatives of the genus *Homo* (*H. erectus* and the ancestors of the *H. neanderthalensis*) had done before, groups of modern humans left their homeland to colonize other continents. This occurred between 50,000 and 70,000 years ago. The reasons for this migration, which only began 100,000 years after the emergence of *H. sapiens*, are subject to speculation. It is possible that the first migrations coincided with changes in climate that also affected resource availability and the living conditions of humans. However, little is known about the diet of early *H. sapiens* in Africa. He was already a hunter of wild animals, which placed him in competition with large cats and other predators. Humans not only had to defend their prey against these predators, but also to protect themselves. The hunt for large animals for example gazelles, buffalo, or even elephants was of little importance for early humans partially because of their still primitive weapons. Presumably, they used a broad range of food sources including plant products (roots, seeds, and fruit), small animals (e.g. small mammals, reptiles, insects), wild honey, and eggs from birds and reptiles. They probably also ate the remains of large animals, for example bone marrow, which was accessed with the help of stone tools (Fig. 2.1). With the help of fire, it was possible to roast meat and to cook many plant species that were otherwise inedible or even poisonous.

According to today's knowledge, the first groups of *H. sapiens* left Africa via the Middle East and had reached Australia by at least 40,000 years ago (Fig. 2.2).

Because a land bridge has never existed between Asia and Australia, this continent could only be settled with the help of boats or rafts. Approximately 35,000 years ago the first humans reached Europe where the Neanderthal (*H. neanderthalensis*) was already living. The first modern Europeans were the Cro-Magnons, named after the first location in which they were found in France. After spreading into Asia, humans

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Fig. 2.1 Hand axe made of flint

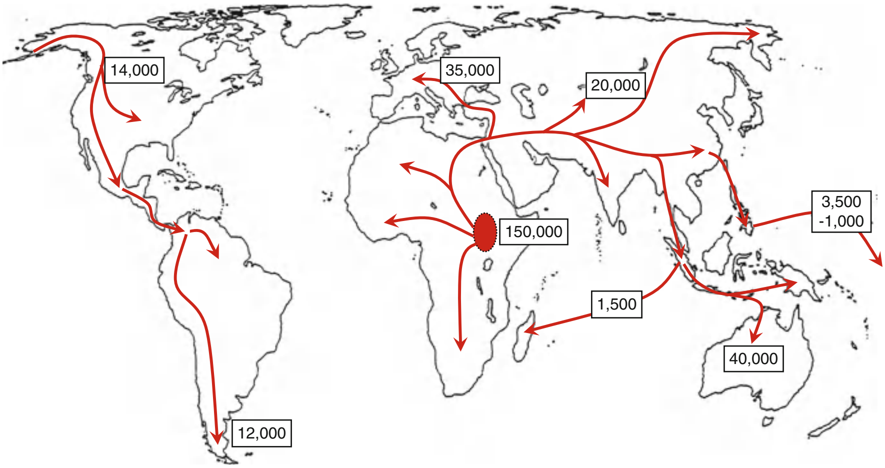

Fig. 2.2 The spread of *Homo sapiens* from Africa around the world (dates are years before present)

were able to settle the Americas via the Bering Strait, at least 14,000 years ago. During the ice age (i.e. the period before approx. 11,000 years ago), humans in Europe and North America were primarily hunters. With the development of effective weapons (Fig. 2.3) and other hunting techniques it became possible to successfully hunt large animals of the open steppe or tundra (for example mammoth, woolly rhinoceros, horse, Irish elk, giant deer, and European bison). Such species were not only of importance for food, but also provided fur and skin for the production of clothing and shelter. Use of plant resources may have been of minor importance because of the sparse vegetation in these areas during the ice age.

Humans reached the southern tip of South America within approximately 2,000 years of their initial colonization of North America. However, the history of

Fig. 2.3 Arrowhead made of flint

colonization of the Americas is subject to debate because there is also evidence of much earlier appearance of humans on this continent. The last large areas reached by humans, except for the polar regions, were the islands of the South Pacific (approx. 3,000–1,000 years ago) and Madagascar (approx. 1,500 years ago), both of which were colonized from Asia (Fig. 2.2).

2.2 The Origins of Agriculture

With the end of the last ice age, approximately 11,000 years ago, the climatic conditions fundamentally changed in many regions of the world. Temperature increases and altered precipitation patterns led to changes in vegetation. Forests became established in Central Europe and some other regions, replacing the treeless tundra or steppe that existed during the ice age. Distinct changes in the distribution of different vegetation zones also occurred in many regions of the tropics and subtropics. In addition, toward the end of the ice age most of the large animal species that existed in the ice age environments of Europe, North America, and parts of Asia became extinct. However, it is unlikely that changes in climate were the sole cause for the disappearance of this fauna. Their habitat did not completely disappear, but shifted toward the north, so migration into today's tundra regions was, in principle, possible and was achieved by a few species. Thus, musk oxen and reindeer still exist today, and the last dwarf mammoths became extinct 4,000 years ago on the Wrangel Islands in north-eastern Siberia. Another factor that probably contributed to the extinction of species among the large fauna of the ice age was hunting by humans.

In various regions of the world, the origin of agriculture dates back 11,000–10,000 years, during a phase in the climate that was accompanied by fundamental changes in the living conditions of organisms, including humans.

Why and how did the transition from hunting and gathering to farming occur? Numerous theories and models attempt to provide an answer to this. From these, two main groups of hypotheses can be distinguished:

1. According to the first hypothesis, agriculture is an innovation that enabled a way of life that is advantageous compared with the hunter-gatherer existence. Some groups of humans discovered the potential of producing plants in fields, whereby these earliest farmers not only acquired a secure source of food, but also became sedentary. This also initiated cultural progress and, overall, a higher standard of living. Such groups served as examples for the hunter-and-gatherer groups, which subsequently also began to practise agriculture.
2. According to the second hypothesis, a shortage of food resources (primarily the lack of wild animals for the hunters) was the precondition for the development of agriculture. Reasons for this include an increase in human population density in combination with decreases in big-game species because of overhunting. According to this view, the transition to agriculture was not a voluntary act, but rather occurred as a result of the need to find alternative sources of food. By no means does this have advantages over hunting and gathering, but is more labour and time-intensive and is, in addition, associated with the risk of crop failures and thus with hunger.

The emergence of agriculture was not a sudden event or a genius invention by individuals, but rather a far more gradual process. There is evidence from different regions of the world that the intended production of plants is generally associated with decreased use of, or a decline in, wild animal populations, which supports the second of the hypothesis stated above. In the earliest phases of crop production, the cultivated plants probably served as a kind of food reserve or alternative, in case of failure in hunting. Subsequently, crop production gained in importance as the hunted animals became increasingly scarce.

However, the development of agriculture in the different regions of the world in which it emerged (Sect. 2.2.2) did not always follow exactly the same pattern. There were, probably, corresponding to the given conditions, all imaginable kinds of transition between the nomadic hunter-and-gatherer existence and the sedentary farmer, in which both wild natural resources and crop production contributed to the food supply.

Complete dependence of humans on agriculture only emerged after wild animals and plants could no longer make a significant contribution to the food supply of the growing population.

2.2.1 Adapting Wild Plants and Animals for Agriculture

Both agricultural crop varieties and domestic livestock breeds originate from wild species, many of which were already gathered or hunted, respectively, by humans before the emergence of agriculture. In contrast with the wild forms, the cultivated plants and animals have altered characteristics that developed via selection (Box 2.1).

Box 2.1 Genetic Diversity and Selection

Individual differences are often already visible among members of the same population and species that reproduce by sexual reproduction. These are primarily morphological, physiological, and biochemical properties that together make up the **phenotype** of an individual. The phenotype is the sum of the interactions between the genes (which together represent the **genotype**) and the environment during the ontogenesis of an individual. A specific genotype can produce different phenotypes, depending on environmental conditions. For example, plants that are sufficiently supplied with water and nutrients form large individuals and produce more biomass than those that lack these resources. The range of variation of the phenotype, which the same genotype produces in relation to dominant environmental conditions, is termed the **reaction norm**. The second cause of phenotypic variation among members of a population are differences in their genotype. Individuals that are the product of sexual reproduction are never genetically identical, because each is a new and unique combination of the parental genes. The diversity of the genes of a population (the so-called **gene pool**) constantly changes because of the incidence of **mutations**. Mutations are random changes in the genotype of an individual which usually result from mistakes in the doubling of the genome during cell division (cytokinesis) and may be harmful, useful, or irrelevant to the individual.

On the basis of their unique genetic endowment, individuals of a population also have different probabilities of survival and reproduction (Fitness; Box 3.1), which means they are not all equally well-adapted to the given environmental conditions. This becomes particularly evident when the effect of individual factors changes drastically. This can include the effects of the abiotic environment (e.g. weather conditions) or effects that originate from other organisms (e.g. pathogens, predators, or competitors). Depending on the

(continued)

Box 2.1 (continued)

situation, some properties prove advantageous and others disadvantageous regarding survival under the given conditions. Individuals with unsuitable genotypes and phenotypes sometimes become eliminated from the population. This process is called **natural selection**.

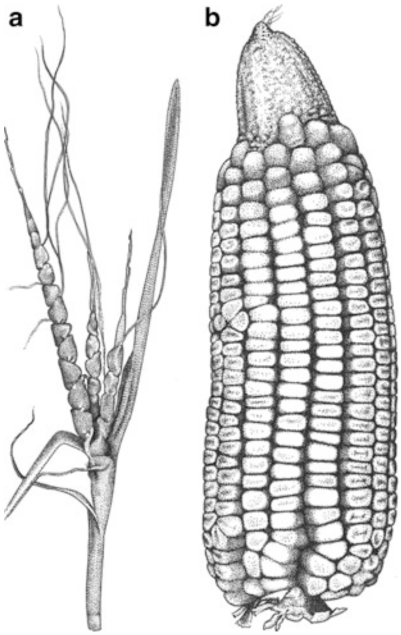

Fig. 2.4 Teosinte (**a**), a grass species from Central America, is regarded as the wild form of maize (**b**)

For cultivated species, however, selection is not based on natural processes alone, but also originates from humans, and probably happened unconsciously at the beginning. It can hardly be assumed that all wild seeds or fruits of a species were gathered randomly, instead the largest individuals were probably preferred. Of this yield, some was accidentally lost near the resting and settlement areas and thus inadvertently sown. In these plants, which were later harvested from such locations, the preferred characteristics already occurred more frequently than in the natural population. From here it was only a small step to conscious selection or selective breeding, through which, as a result of propagation and repeated selection of individuals, the desired traits were further improved. Over hundreds and thousands of years, crops and domestic livestock gradually emerged from wild ancestors via directed selection of the respective wild species (Fig. 2.4). Overall, conscious and unconscious changes in plant and animal species as a result of artificial selection, to make them more useful for humans than the original wild form, is called **domestication**.

2.2.1.1 Characteristics of Domesticated Crops

The altered characteristics of food crops are, primarily, the size of the utilized plant parts (for example seeds, fruit, leaves, or roots). For example, cabbage (*Brassica oleracea*) was variously selected for its leaves (cabbage and kale), stems (kohlrabi), flower shoots (broccoli and cauliflower), and buds (Brussels sprouts). Characteristics may also include altered concentrations of specific ingredients (especially secondary plant metabolites, Sect. 4.5.5.2) that determine edibility and taste. There are, in addition, other traits of importance for cultivation which became characteristic of domesticated crops. These include:

- **Dispersal mechanisms** of seeds of crop species (primarily cereals and legumes): the wild species have mechanisms that cause the release of ripe seeds from the plant and thus enable effective dispersal. The seed heads of wild grasses break apart ("shatter") at maturity to scatter the seed. The pods of legumes split explosively at maturity to scatter seed. These characteristics are undesirable in a crop plant because they lead to reduced yield when the seed falls off the plant before or during harvest. For many species, however, mutants appear that cannot drop their seeds. In mutated individuals of bean and pea, for example, the pod remains closed after ripening, and in the respective grass or cereal species, breaking of the spike is impeded. In the harvest of wild stands or in the field, these mutants are automatically preferred. Eventually, their characteristics establish themselves in the crop, which thus become entirely dependent on the farmer in its reproduction.
- **Synchronous germination**: The seeds of many annual plant species do not all germinate simultaneously in one season, but instead germinate over the course of several years. This mechanism prevents all the offspring of a population dying with the occurrence of unfavourable conditions (especially drought). When sown in fields, only individuals without this delay in germination emerge in the first year. They are harvested and utilized for a later sowing. Thus selection of plants that all germinate at once and ripen simultaneously occurs, and thus a higher yield is achieved. Lack of germination delay is, therefore, a characteristic of many domestic crops.

2.2.1.2 Characteristics of Domesticated Animals

Similar to useful plants, some wild animal species were domesticated as sources of food and clothing and/or for labour or transportation (called livestock or farm animals). In general, domestication of livestock species occurred somewhat later than crop domestication.

Because of the behaviour of animals, domestication of livestock is a more complex process than domestication of plants. Different from taming, animal domestication can be defined as a process which includes removal of the species from its natural habitat, adaptation to man and to a captive environment, control of its movements (keeping) and its food supply, and, finally, controlled breeding by practising artificial selection. Animals subject to less than complete mastery can be regarded as partially domesticated. Tameness, or lack of avoidance responses when approached by humans, is a desirable behavioural characteristic of captive animals, because it facilitates handling.

The transition from nature to captivity is accompanied by many changes in biological and physical environments. Providing animals with food and medical care, protecting them from predators, and assisting in the care of offspring are functions served by humans that may increase the genetic and phenotypic variability characterizing captive animal populations. Man's control including the selection of livestock for high fertility, docility, and early maturity often improves viability and reproductive success compared with their free-living counterparts (Price 1984).

The history of animal domestication shows that relatively few wild animal species have been successfully domesticated as farm animals. They are mainly large mammalian herbivores or omnivores and a small number of bird species (chicken, turkey, goose, duck), which are relatively convenient and economical to breed and to maintain in captivity. Diamond (2002) identified six main obstacles to domestication of wild mammal species:

- difficulty fulfilling specific food requirements;
- slow growth rate and long birth spacing;
- nasty disposition;
- reluctance to breed in captivity;
- lack of follow-the-leader dominance hierarchies; and
- tendency to panic in enclosures or when faced with predators.

For one or more of these reasons, such wild mammals as bears, elephants, antelopes, and gazelles were never domesticated. In contrast, behavioural characteristics that facilitate the domestication process include social organization in large groups of hierarchical structure, intensive mother–young interactions and precocial young, and low reactivity to man or sudden changes in the environment. Therefore all important livestock species, including poultry, are herd animals.

2.2.2 Centres of Origin of Agriculture

Worldwide, approximately 11 regions are believed to be centres of the origin of agriculture, identified as the locations in which native plant and some animal species were domesticated independently of each other (Fig. 2.5). In contrast, in other regions the origin of agriculture is based, at least in large part, on crops and livestock that were introduced to those regions and originally come from the centres of origin.

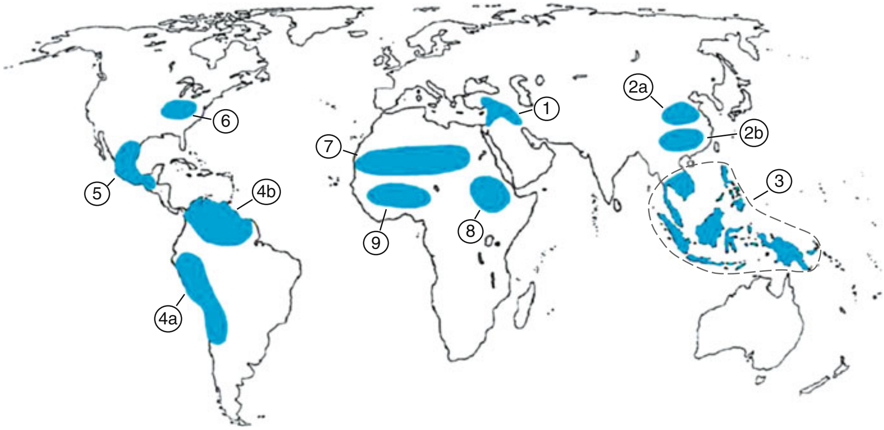

Fig. 2.5 Centres of origin of agriculture. **1** = Middle East (Fertile Crescent), **2a** = northern China, **2b** = southern China, **3** = Southeast Asia, **4a** = South American highlands, **4b** = South American lowlands, **5** = Central America, **6** = arid savannas of northern Africa, **7** = eastern North America, **8** = highlands of Ethiopia, **9** = humid savannas of West Africa (Based on Diamond 1998)

The most important regions in which plants and, sometimes, animals were domesticated are:

2.2.2.1 The Middle East

The Middle Eastern centre of origin, also known as the "Fertile Crescent", covers an area ranging from Jordan and Syria over the eastern part of Turkey to the valleys of the Euphrates and Tigris Rivers (Mesopotamia, today Iraq). The beginnings of agriculture in these regions date back at least 11,000 years. The oldest crop species that were domesticated there are the wheat species emmer (*Triticum dioccum*) and einkorn (*Triticum monococcum*; Fig. 2.6), barley (*Hordeum vulgare*), pea (*Pisum sativum*; Fig. 2.7), lentil (*Lens esculenta*), chickpea (*Cicer arietinum*), and flax (= linseed; *Linum usitatissimum*).

The first animal species domesticated in this region were sheep (*Ovis ammon*) and goat (*Capra hircus*), approximately 11,000 years ago, and subsequently pig (*Sus scrofa*) and cattle (*Bos taurus*). Agricultural economies reliant on a mixture of domesticated crops and livestock became established in this region approximately 9,500–9,000 years ago (Zeder 2008).

2.2.2.2 Northern and Southern China

It was, presumably, somewhat later than in the Middle East that the development of agriculture began in China, with at least two centres of origin. The first of these was the tropical/subtropical south, where rice (*Oryza sativa*) was domesticated

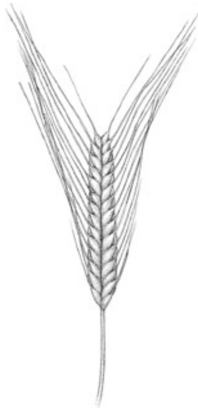

Fig. 2.6 Einkorn (*Triticum monococcum*)

Fig. 2.7 Pea (*Pisum sativum*)

approximately 10,000 years ago. The domestic chicken (*Gallus gallus*) is also assumed to originate from this region. The pig is also counted among the earliest livestock of China and was probably domesticated there independently of the Middle Eastern centre of domestication. The oldest crops of the cooler and dryer north include foxtail millet (*Setaria italica*), which was domesticated approximately 6,000 years ago, and soybean (*Glycine max*).

2.2.2.3 Southeast Asia

Banana (*Musa* species), sugar cane (*Saccharum officinarum*), taro (*Colocasia esculenta*; Fig. 2.8) and yam (*Dioscorea* species) originate from tropical Southeast

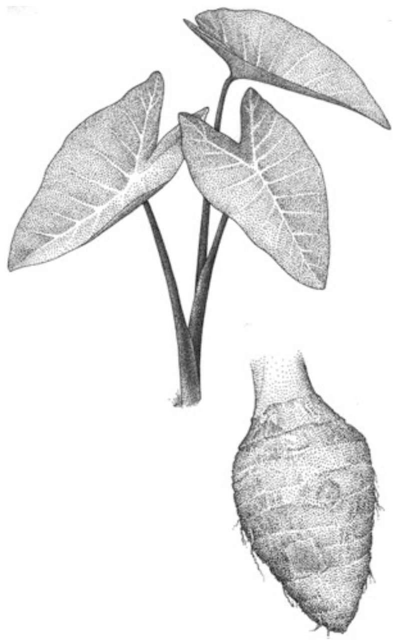

Fig. 2.8 Taro (*Colocasia esculenta*), habitus of the plant and rhizome

Asia. The agriculture of this region probably has its origins in the highlands of Papua New Guinea and began there, according to recent discoveries, approximately 10,000 years ago (Denham et al. 2003).

2.2.2.4 Tropical South America

Agriculture in South America also began at least 10,000 years ago, with evidence of the domestication of *Cucurbita* species (Piperno and Stothert 2003). In South America, depending on altitude, three regions can be identified from which specific crop species originate. The potato (*Solanum tuberuosum*) originates from the highlands of the Peruvian and Bolivian Andes. Peanut (*Arachis hypogaea*) and common bean (*Phaseolus vulgaris*) were domesticated in the mid-altitudes of the Andes. The tropical lowlands of South America were the centre of origin of squash and pumpkins (*Cucurbita*), peppers and chili (*Capsicum* species), pineapple (*Ananas comosus*), sweet potato (*Ipomoea batatas*), cassava (*Manihot esculenta*), avocado (*Persea americana*), and the cotton species *Gossypium barbadense*. The only animal species domesticated in South America were guanaco (*Llama guanicoe*; the wild form of llamas and alpacas) and guinea pig (*Cavia aperea*).

Fig. 2.9 Cotton (*Gossypium hirstum*), twig with open seed pod

2.2.2.5 Central America

In Mexico, the domestication of pumpkins or winter squash (*Cucurbita pepo*) dates back approximately 10,000 years (Smith 1997), and occurred independent of the process of domestication of the *Cucurbita* species in South America. Domestication of *Phaseolus* and *Capsicum* species, avocado and the cotton species *Gossypium hirstum* (Fig. 2.9) also occurred in Mexico independently of South America.

The most important crop species originating from Central America is maize (*Zea mays*). The potato only reached Central America thousands of years after its domestication in the Andes. This can be regarded as further evidence that the two regions developed independently of each other over long periods of time. The turkey (*Meleagris gallopavo*) was domesticated in Central America approximately 2,000 years ago.

2.2.2.6 North America

Approximately 4,000 years ago, an independent centre of origin of agricultural development emerged in eastern North America. There, several crops were cultivated that are of little importance today, for example sumpweed or marshelder (*Iva annua*) and pigweed or lambsquarters (*Chenopodium berlandieri*). The only important crop that originates from North America is the sunflower (*Helianthus annus*), which was probably grown as an oil crop.

Fig. 2.10 Coffee (*Coffea arabica*), twig with leaves and fruits

2.2.2.7 African Regions

In Africa, three climatically different regions that are believed to be centres of origin of agriculture have been identified. Agriculture developed in the **highlands of Ethiopia** approximately 6,000 years ago. Several domesticated species, for example coffee (*Coffea arabica*; Fig. 2.10), finger millet (*Eleusine coracana*), and the cereal species teff (*Eragrostis tef*), originate from this region.

In the **dry savannas of northern Africa**, sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*), and African rice (*Oryza glaberrima*) were domesticated. The **humid savannas of West Africa** are the centre of origin of oil palm (*Elaies guineensis*), cowpea (*Vigna unguiculata*), and the African yam (*Dioscorea* species).

2.2.3 Spread of Agriculture and Crops

In most regions in which agriculture developed, the cultivated plant species can be divided into four main groups, each of which meets specific nutritional requirements of humans. These are:

- starch-yielding crops (primarily cereals and tuber crops),
- crops rich in protein (primarily legumes),
- oil-producing crops, and
- fibre crops that primarily serve in the production of textiles.

In cases in which wild plants from these groups were not available for domestication, the respective crops could, under specific conditions, be acquired from other regions. The possibilities of this were primarily determined by

- the distance to another region and the existence of contact with the resident people, and
- the climatic suitability of the region for the production of crops that originate from other climate zones.

The agriculture that developed in the Middle East sooner or later spread into neighbouring regions. Recent evidence suggests that the expansion of domesticated species and agricultural economies across the Mediterranean was accomplished by several waves of colonists who established coastal farming enclaves around the Mediterranean Basin within approximately 3,000 years of the first farming activities. This process also involved the adoption of domesticated species and technology by indigenous populations and the local domestication of additional species. Likewise, agriculture spread in an easterly direction reaching the Indus Valley (today's Pakistan). The spread of agriculture to Central, Western, and Northern Europe proceeded over a period of thousands of years. Approximately 7,000 years ago, most Middle Eastern crops were known in Central Europe, but in some regions (e.g. coastal regions of the North and the Baltic Sea) they were only cultivated between 6,000 and 4,500 years ago. In some regions, for example northern Germany and the Alps, it was mainly animal husbandry that was adopted at that time. Already by pre-Roman times, crops of regions other than the Middle East had reached Central Europe. Examples include proso or common millet (*Panicum miliaceum*), which was an important crop well into the Middle Ages and probably originates from Central Asia, and the faba bean (*Vicia faba*), the wild form and centre of origin of which are not precisely known.

Among farm animals, the domestic chicken (*Gallus gallus*), originating from Southeast Asia, became known in Southern Europe approximately 3,500 years ago and in Central Europe 2,600 years ago. The first use of the domesticated horse (*Equus ferus caballus*) as a working animal in Europe dates back approximately 4,000 years.

Over the course of time, additional crop and animal species were domesticated, both in the original centres of agricultural development and in the regions of agricultural expansion. The wild forms of oats (*Avena sativa*; Fig. 2.11) were, presumably, the wild or animated oat (*Avena sterilis*) or the common wild oat (*A. fatua*), which reached Central Europe from the Middle East as weeds and were domesticated there approximately 4,000 years ago.

Other wild plants that became established in Europe were domesticated as late as the nineteenth century, and include lamb's lettuce (*Valerianella locusta*) and the witloof (*Cichorium intybus*), the domestic form of which is used as chicory.

Only several thousand years after the first food crops were domesticated did the domestic forms of most of the agriculturally utilized woody plants become established. These include many of the species typical of the Mediterranean region today, for example the grape vine (*Vitis vinifera*), olive tree (*Olea europaea*), fig tree (*Ficus carica*), and almond (*Prunus dulcis*), the wild forms of which originate from the Middle East to Central Asia, and the orange (*Citrus sinensis*), lemon (*C. limon*), peach (*Prunus persica*), and apricot (*P. armeniaca*), the centre of origin of which is China. The wild forms of the apple (*Malus* species) and pear (*Pyrus* species), and other fruit trees, originated in the deciduous forest zone of the mountainous regions of Central Asia.

After the re-discovery of America by Columbus in 1492, transcontinental exchange of domestic crops and livestock began. In Europe, Africa, and Asia,

Fig. 2.11 Oats (*Avena sativa*)

nothing was previously known about the plant species domesticated in America, for example maize, potato, peppers, tomato (*Solanum lycopersicum*; Fig. 2.12), cotton, and squash.

Over the course of hundreds of years, the most important crops and livestock species spread throughout the world, which means that today they are cultivated almost everywhere climatic conditions allow. In most regions, agriculture today is based on species that are exotic to the area. Europe, North America, and Australia are almost completely dependent on wheat and barley (from the Middle East), maize (from Central America), potatoes (from South America), and soybeans (from China). The same is true for Africa, where almost 80% of agricultural production is of species that originate from Central America (maize), South America (cassava, sweet potato), and Southeast Asia (banana).

The development of agriculture progressed independently in different regions of the world and was defined by gradual processes that sometimes stretched over thousands of years. These were essentially determined by the supply of prey for hunting, the availability of plant and animal species that could be domesticated, and the possibility of acquiring species from other regions.

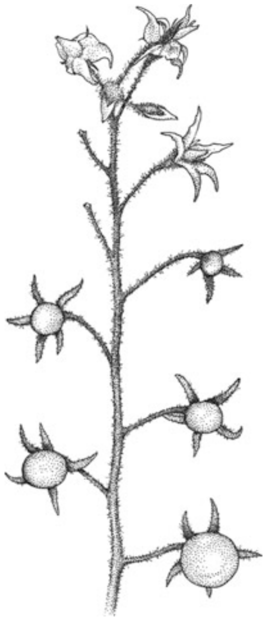

Fig. 2.12 Tomato (*Solanum lycopersicum*; synonym: *Lycopersicon esculentum*), inflorescence

2.3 Progress and Effects of Agriculture

The development of agriculture with the sedentary lifestyle initiated a chain of processes that strongly affected the living conditions of humans, their social and cultural contexts, and technical development. As a consequence of this, agricultural methods of production also changed, which was associated with a significant increase in yields over the course of time. Two developments that were dependent on each other provided the necessary conditions for this. First, sedentary living and the increased production of aliments beyond the needs of subsistence, led to an increase in population density and, second, agriculture enabled an increase in the size of settlements and division of labour. While farmers were responsible for the production of food, specialists for example blacksmiths, wagon makers, and carpenters could deal with other activities, which also included production of implements for agriculture. This altered social and material living conditions within societies and was the basis for the development of cities, states, and civilization in its entirety. Over the course of this development, the proportion of people working in agriculture declined. This enabled progress in technology and science, which contributed to the raising of living standards.

Worldwide, today, more than a billion farmers produce food for seven billion people. In Germany, the average farmer provides 137 people with food (Fig. 2.13). Today, the residents of industrial countries use no more than a few minutes per day for acquisition of food; for most people in developing countries this time is much longer.

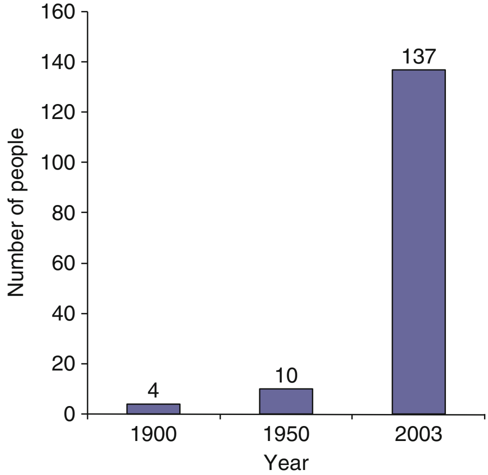

Fig. 2.13 Number of people supplied with food by a single farmer in Germany (Based on Bayerische Landesanstalt für Landwirtschaft 2000)

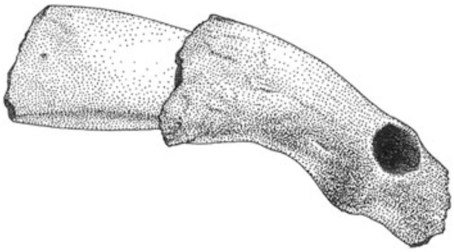

Fig. 2.14 Stone Age flat adze, used as a hoe or to fell small trees

2.3.1 Technical Development and Mechanization

With the discovery and invention of new tools which made it easier to cultivate the soil and to harvest crops, it was possible to increase agricultural production. In the Neolithic (approx. 7,000–4,000 years ago), the first implements for agriculture were made of wood and stone. At this time, digging sticks for sowing of plants, hoes to loosen the soil (Fig. 2.14), and stone scythes to harvest cereals already existed. The first primitive ploughs were used at least 5,000 years ago. They had a hook which was usually made of wood and served to create furrows in the field for the seed (ard or scratch plough; Fig. 2.15).

Later, from the Bronze Age (approx. 4,200–2,800 years ago), there is evidence of the first animal-drawn plough. Starting in the pre-Roman Iron Age (from 2,800 to 2,000 years ago), the ploughshare was reinforced with iron to prevent it wearing down as quickly as the purely wooden implement. In South, Central and North America, no animals that could be used for field work existed before the arrival of the Europeans in the sixteenth century.

With the Industrial Revolution, which originated in the middle of the eighteenth century in England, the development of modern agriculture began. Until then, agricultural implements had remained largely unchanged for hundreds of years

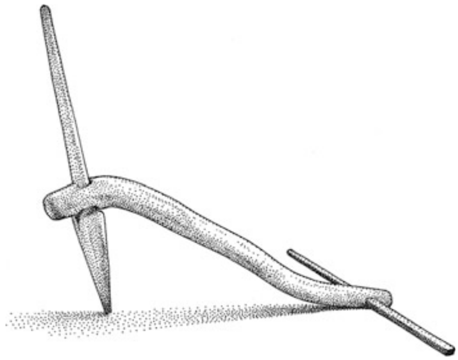

Fig. 2.15 Ard or scratch plough made of wood

and were constructed by the village blacksmith or wagon maker. At the beginning of the nineteenth century, improved ploughs were constructed that enabled more effective soil cultivation with less draught power. Further innovations included machines that made the sowing, harvesting, and threshing of cereals substantially easier and faster. The first German factory for agricultural implements and machines was founded in 1819 in Stuttgart-Hohenheim. Already by the 1860s, the first steam-powered ploughs were being used in Germany; however these could only replace the draught animals on large farms.

2.3.2 Irrigation

The availability of water determines the possibility of growing crops, and the security of the yield. In rain-fed agriculture, there is total dependence on the quantity and distribution of precipitation; this is insufficient to supply the plants over the entire vegetation period in some regions of the earth and/or in some years. The beginning and the duration of the rainy season is variable in many parts of the tropics and subtropics, which is why plant production there is associated with risk. The development of artificial irrigation systems, often associated with terracing of the landscape, was a substantial innovation from which agriculture benefited substantially (Sect. 4.2.2). With this, more land in arid areas, and even on steep slopes, could be put under cultivation. The first irrigated landscape was created approximately 7,000 years ago in Egypt in the fields along the Nile. The Sumerians began to construct irrigation and drainage canals 5,000 years ago in Mesopotamia (Euphrates and Tigris region), on which their entire agricultural production was dependent.

2.3.3 Fertilizers and Pesticides

Since the beginning of arable plant production, one problem is that the fertility of cultivated soil declines over time, because with each harvest the agroecosystem is deprived of nutrients. This situation requires restoration of these losses; this can be achieved by means of prolonged fallow periods or by fertilization. Among fertilizers, a basic differentiation can be made between

- **organic fertilizers**, or example manure, liquid manure, harvest residues, compost, green manure (Sect. 2.3.3), and human excrement, which are usually produced within an agricultural enterprise and thus called farmyard manure, and
- **inorganic fertilizers** or **mineral fertilizers**, which are either mined from natural reserves (primarily rock deposits), for example phosphorus (Sect. 3.7.5) and potassium, or produced synthetically, for example mineral nitrogen fertilizers (Sect. 3.7.4). Because mineral fertilizers are usually purchased by agricultural enterprises, they are termed commercial fertilizers.

Long past the medieval period, different types of rotation system, including fallow land (Sect. 2.4.1), were dominant in Europe. This method served to regenerate soil fertility, and fertilizers were available in very limited quantities only. In the nineteenth century, production and trade in fertilizers began, for example guano (excrement of sea birds harvested from large deposits, particularly on the islands off the coast of Peru), sodium nitrate (mainly from Chile), or bone meal. A further improvement in the situation was achieved as a result of the Haber–Bosch process for production of ammonia in 1910 (Sect. 3.7.4.2). Industrially produced nitrogen fertilizer could now, at least in the industrialized countries, completely provide for the needs of agriculture. This solution of the fertilization problem led to substantial increases in yields.

Since the mid-twentieth century, use of synthetic pesticides (Box 2.2) has contributed to the security of yields. In 1939, the insecticide DDT was developed and was used in agriculture after the end of the Second World War. Shortly thereafter the development of numerous other substances began (Sect. 5.2.1). The first synthetic herbicides (Sect. 5.1.1) also became commercially available at this time.

Box 2.2 Pesticides

Pesticides are natural or synthetic compounds that protect plants or plant products from damaging organisms (pests and diseases) and substances that kill undesired plants (weeds) or that affect the life processes of plants (e.g. growth regulators, germination inhibitors). “Plant protection” therefore only refers to protection of domestic plants and crops or the harvest products.

Pesticides are primarily classified with reference to the target organisms. Pesticides (Sect. 5.2) can be targeted against animal pests, primarily insects (insecticides), mites (acaricides), and nematodes (nematicides), but also against other pests, for example snails (molluscicides) or rodents (rodenticides). The substances that protect plants against phytopathogens (Sect. 5.3) primarily include fungicides and bactericides. Substances used to control weeds are called herbicides (Sect. 5.1.1).

2.3.4 Plant Breeding

Plant breeding has the objective of changing the genetic properties of plants and adapting them to the requirements of humans. The first domestic plants were developed by **selective breeding** practised by farmers over thousands of years (Sect. 2.2.1). The Austrian monk Gregor Mendel (1822–1884) recognized the regularity of inheritance in his breeding experiments with peas and thus formed the foundation of the modern science of genetics. In contrast with selective breeding, which primarily served for improvement of the properties of individual varieties, it now became possible to purposefully combine the genomes of two different varieties and thus to obtain varieties with new properties. In addition to selective breeding, this **cross breeding** is the basis of every plant-breeding program since the beginning of the twentieth century.

Another development of cross breeding is **hybrid breeding**. By repeated, artificial self-fertilization, inbred lines with particular properties are developed, which usually produce low yields themselves as a result of the in-breeding depression. Such inbred lines are then crossed with each other, whereby the so-called hybrids are created. In comparison with the parent lines, growth and yields of these hybrids are usually substantially higher. This phenomenon is called **heterosis** or **hybrid vigour** and is the opposite of the in-breeding depression. The increased yields are almost exclusively achieved by the first generation and decline in subsequent generations. When using hybrid varieties, the farmer must therefore purchase new seed for every growing season. Hybrid breeding is important in cross-pollinated crops, for example maize (Fig. 2.16), rye, sugar beet, sunflower, and many vegetable species.

The development of molecular genetics and cell biotechnology in the 1980s resulted in new perspectives in plant breeding as a result of genetic engineering. It became possible to transfer genes across species boundaries and thus bestow new traits on plants. The introduction of foreign DNA into the genome of an organism is called transformation, resulting in **genetically modified organisms (GMO)** or, for crops, **GM crops** (Box 2.3).

Box 2.3 Genetically Modified (GM) Crops

Depending on the purpose of a particular genetic modification, GM crops can be categorized as having either first, second or third-generation characteristics:

- First-generation transgenic crops were created to improve the agronomic properties of the plant, but not the quality of its product. First-generation GM crops include plants with greater resistance to pests or herbicides, or to environmental (abiotic) stressors, for example salinity, drought, or extremes of temperature.
- Second-generation plants were modified to obtain new food or feed properties, including crops with substances that are beneficial to human

(continued)

Box 2.3 (continued)

health (functional food). Characteristics include increased nutrition or enhanced quality, for example improved omega-3 fatty acid production in oil seeds, starch modification, or improved mineral or vitamin content. An example of this is "golden rice" which is engineered to produce beta-carotene (pro-vitamin A).

- Third-generation plants are expected to be used in the future for industrial production of non-plant products. This involves the creation and cultivation of transgenic plants that can produce biofuels, biodegradable plastics, enzymes, lubricant oils, or pharmaceutical substances, for example hormones and vaccines. Future approaches will also include the development of crops with reduced dependency on fertilizers and water, promoting the environmental sustainability of agricultural production systems (Sect. 8.1.2.3).

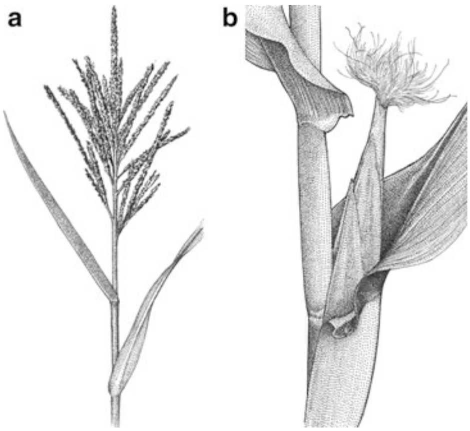

Fig. 2.16 In contrast with most other grass species, maize (*Zea mays*) has unisexual flowers that are located on separate inflorescences. The male flowers (**a**) are combined with the terminal panicle. The female flowers (**b**) are axillary and wrapped in bracts. Because maize is cross pollinated, fertilization does not occur within the same plant, but rather with pollen from another plant

The most economically important commercially produced transgenic crop varieties are currently soybean, maize, cotton, and rapeseed. Most of the transgenic varieties currently cultivated are resistant to herbicides (Sect. 5.1.2) and/or to specific phytophagous insects (Chap. 5.2.2). Since the beginning of the cultivation of transgenic crops in 1996, global production area has increased from 2 million ha to 148 million ha in 2010 (Fig. 2.17).

2.3.5 *Livestock Breeding*

The principle, methods and objectives in animal or livestock breeding are basically the same as in plant breeding, but differ in their use of terms. Domestic animals

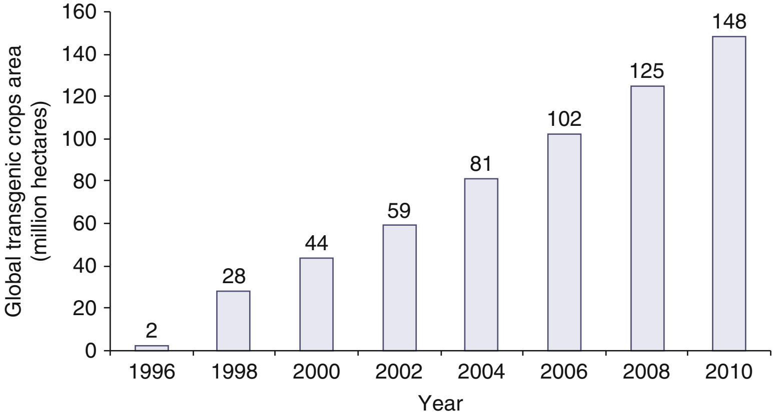

Fig. 2.17 Increase in the global area of transgenic crops between 1996 and 2010 (Based on James 2010)

originate from controlled selective breeding (artificial selection) for desirable traits from the human perspective, for example increased meat, milk, or egg production.

The concentration and maintenance of desired characteristics through several successive generations is called **line breeding**. This process increases genetic uniformity and is based on the mating of related animals. The relationship is normally less close than first degree, and therefore line breeding is a mild form of inbreeding. Consequently, a line represents a trait that is uniquely expressed by that population of a species, which is called **purebred** (or purebreed). The ancestors of a purebred animal are usually recorded over a number of generations, and the animal is then recorded as being pedigreed.

Cross breeding, the biological opposite of line breeding, is also a common method in livestock breeding applied to all important species. Similar to plants, crossbreeding of animals is conducted with purebred parents of two different breeds. Crossbreeding has two distinct advantages over purebreeding. The first is the possibility of creating offspring that shares or combines desirable traits of both parent lineages (**complementarity**). The second is the creation of offspring with hybrid vigour (heterosis), which are therefore superior to their purebred parents. They perform at a level above the average of their parents with regard to such characteristics as disease resistance, fertility, growth rate, etc. In general use, such animals are termed “crossbreeds”, whereas the term “hybrid” is used in plant breeding. However, the term hybrid is also used to describe crosses between animals of different species, for example the mule (female horse × male donkey).

As a breeding practice, crossbreeding does not denote the indiscriminate mixing of breeds. Rather, it is the systematic and selective process of identifying breeding

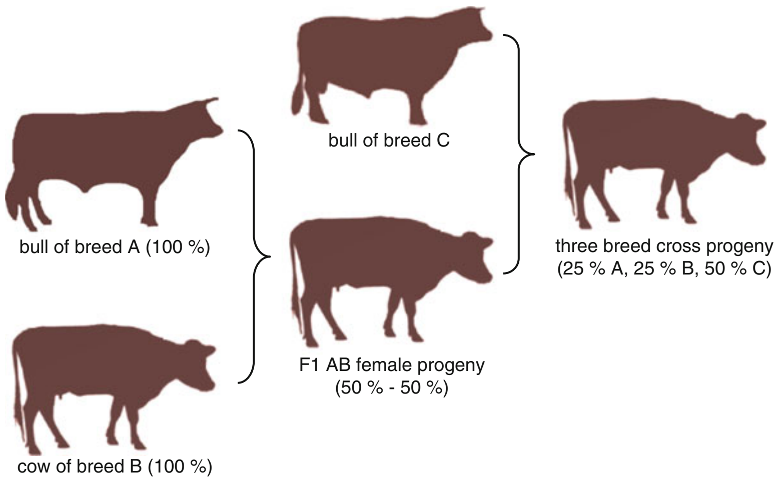

Fig. 2.18 Three-breed cross in cattle. It is obtained when all the females of a two breed cross are mated to a bull of a third, unrelated breed

animals with superior genetic merit for heritable, economically important traits. Depending on the breeding objective, there is a variety of crossbreeding systems, which include:

- **two-breed cross** (production of first cross offspring)
- **three-breed cross** (females from a two-breed cross are mated with a male of a third, unrelated breed; Fig. 2.18)
- **backcross** (females from a two-breed cross are mated with a purebred male of either of the original breeds)
- **rotational cross** (males of two or more breeds are mated with crossbred females)
- **composite breed** (matings among crossbred animals resulting from crosses of two or more breeds, used to form new or "composite" breeds designed to retain heterosis in future generations).

In addition to breeding, reproductive techniques for improvement of livestock traits have been developed in recent decades. **Reproductive cloning** became established in livestock production since this method was first successfully applied to a mammal (Dolly the sheep) in 1996. Reproductive cloning is used to produce identical genetic copies of whole animals. The most common cloning technique is somatic cell nuclear transfer (SCNT). For this, the nucleus of a somatic cell (a cell from the body) from the donor organism to be cloned is inserted into an egg cell from which the nucleus has been removed. As a result of chemical or electrical stimulation in an artificial environment, the egg cell develops into an early-stage embryo which then is implanted into the uterus of a female animal in which the clone grows before being born.

Reproductive cloning is a mechanism by which superior animals can be produced. It is usually used to improve the breeding stock with highly valuable sires, but not to produce animals for human consumption directly, because it is too expensive and too inefficient. Cloning success is very low and often results in a high incidence of death after birth or in severe physical deformities which violate animal welfare.

Although cloning itself is not a method of genetic engineering, it is a basis for the creation of **transgenic animals**, by introduction of alien genes into target animal embryos to alter the production characteristics of the animal (e.g. disease resistance, growth rate) or the quality of its products. With exception of some fish species, however, no genetically modified farm animals are commercially available at present.

2.3.6 Conventional Agriculture and Alternative Concepts

The objectives of the so-called **conventional** or **industrial agriculture** that developed in the second half of the twentieth century were intensification of production, essentially on the basis of products of the agrochemical industry (mineral fertilizers, synthetic pesticides), the use of uniform high-yield hybrid crops (including genetically modified crops), and the application of modern technology for cultivation of the land.

This has a variety of effects on the environment, which are not limited to agroecosystems but also affect the landscape and its structural and species diversity. Fertilizers, primarily nitrate and phosphate, pollute waters and soil (Sect. 3.7.4.2), and pesticides enter the food chain. The use of machinery in agriculture necessitates large and, preferably, homogeneous fields. As a consequence of mechanization, habitats such as hedgerows, ridges, and wetlands are increasingly lost from the landscape, and heavy machinery also leads to compaction of the soil.

Furthermore, most livestock species, for example chicken, turkeys, pigs, and cows in conventional agriculture are raised indoors at high densities and with little space to produce as much meat, eggs, or milk as possible at the lowest cost. These **factory farms** contribute substantially to the environmental impact of agriculture. Large amounts of manure are produced, stored, and released to the environment in slurry form (a liquid mixture of urine and faeces), causing nitrogen pollution of land, water, and air and greenhouse gas emissions. In addition, factory farming increases risk to human health as a result of excessive use of antibiotics to mitigate the spread of disease and to stimulate the growth of animals. This leads to the development of virulent, antibiotic-resistant pathogens which render antibiotics useless for treatment of human diseases. Overall, factory farming contributes substantially, and in different ways, to the most significant global environmental problems (Chap. 8).