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

K. Martin and J. Sauerborn, *Agroecology*, DOI 10.1007/978-94-007-5917-6_2,

Fig. 2.1 Hand axe made of flint

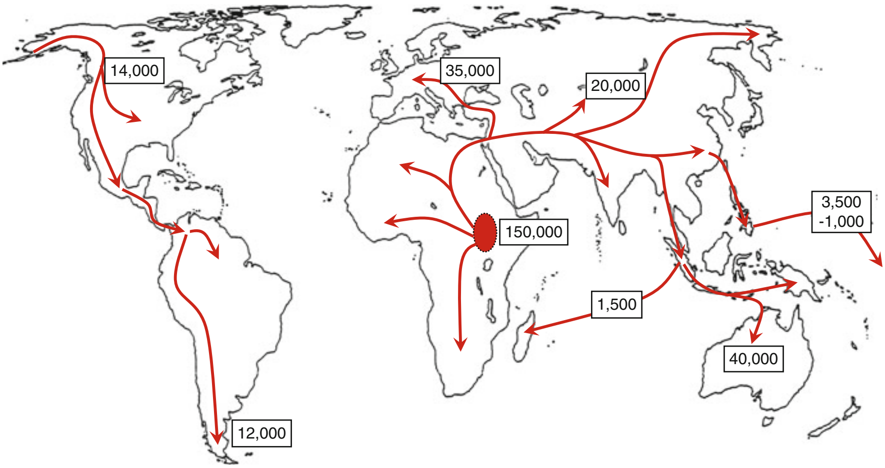

Fig. 2.2 The spread of *Homo sapiens* from Africa around the world (dates are years before present)

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**.

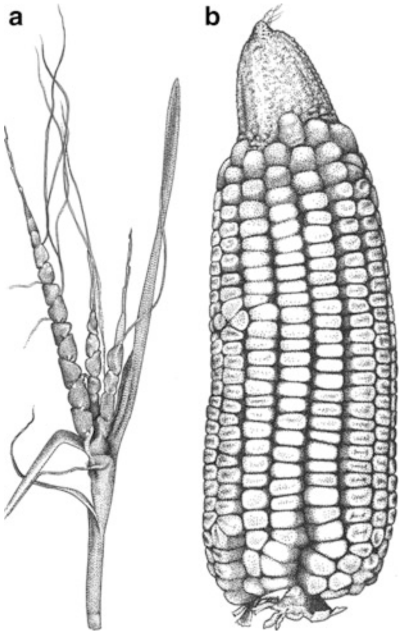

Fig. 2.4 Teosinte (**a**), a grass species from Central America, is regarded as the wild form of maize (**b**)

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.

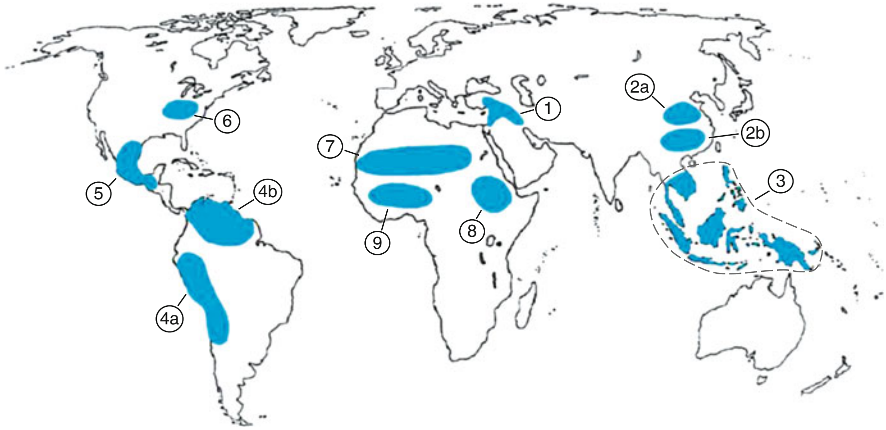

Fig. 2.5 Centres of origin of agriculture. **1** = Middle East (Fertile Crescent), **2a** = northern China, **2b** = southern China, **3** = Southeast Asia, **4a** = South American highlands, **4b** = South American lowlands, **5** = Central America, **6** = arid savannas of northern Africa, **7** = 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

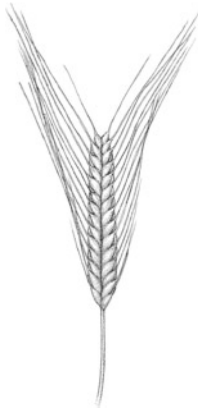

Fig. 2.6 Einkorn (*Triticum monococcum*)

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

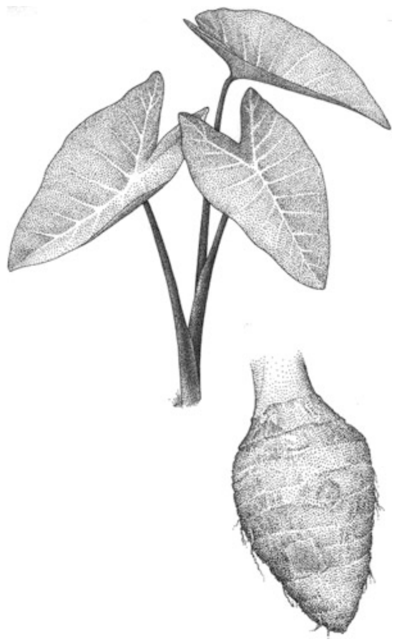

Fig. 2.8 Taro (*Colocasia esculenta*), habitus of the plant and rhizome

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.

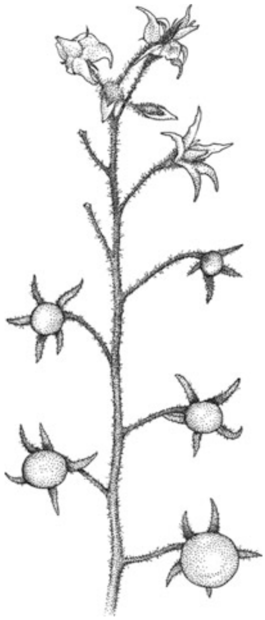

Fig. 2.12 Tomato (*Solanum lycopersicum*; synonym: *Lycopersicon esculentum*), inflorescence

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.

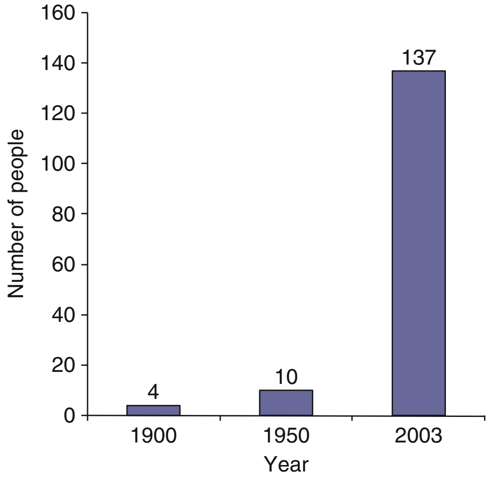

Fig. 2.13 Number of people supplied with food by a single farmer in Germany (Based on Bayerische Landesanstalt für Landwirtschaft 2000)

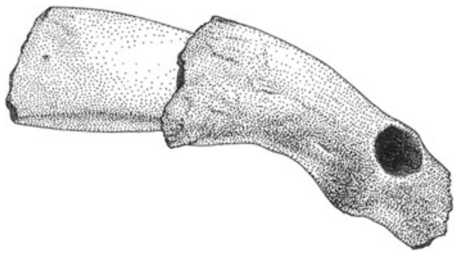

Fig. 2.14 Stone Age flat adze, used as a hoe or to fell small trees

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

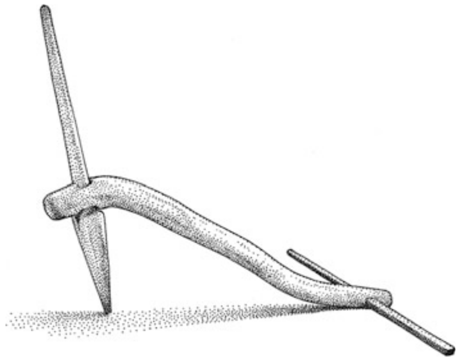

Fig. 2.15 Ard or scratch plough made of wood

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).

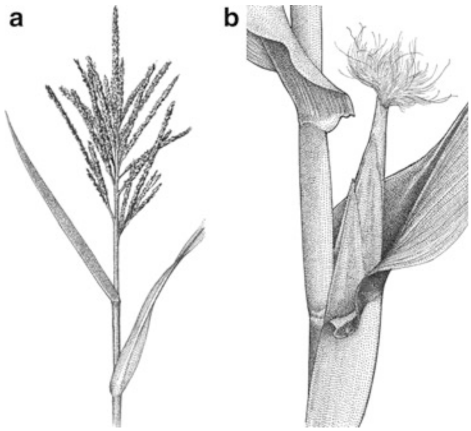

Fig. 2.16 In contrast with most other grass species, maize (*Zea mays*) has unisexual flowers that are located on separate inflorescences. The male flowers (**a**) are combined with the terminal panicle. The female flowers (**b**) are axillary and wrapped in bracts. Because maize is cross pollinated, 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

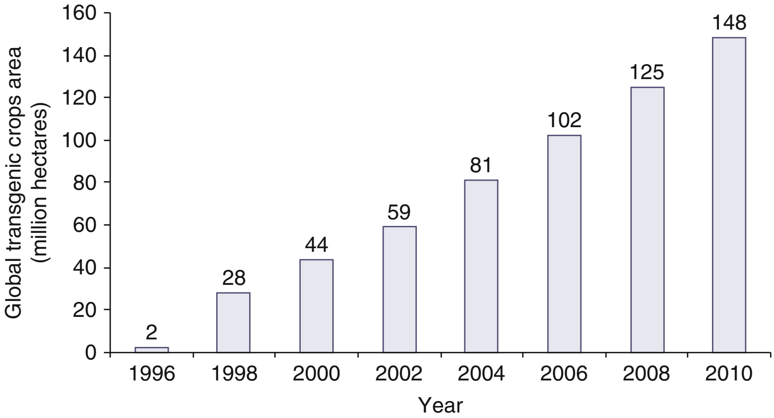

Fig. 2.17 Increase in the global area of transgenic crops between 1996 and 2010 (Based on James 2010)

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

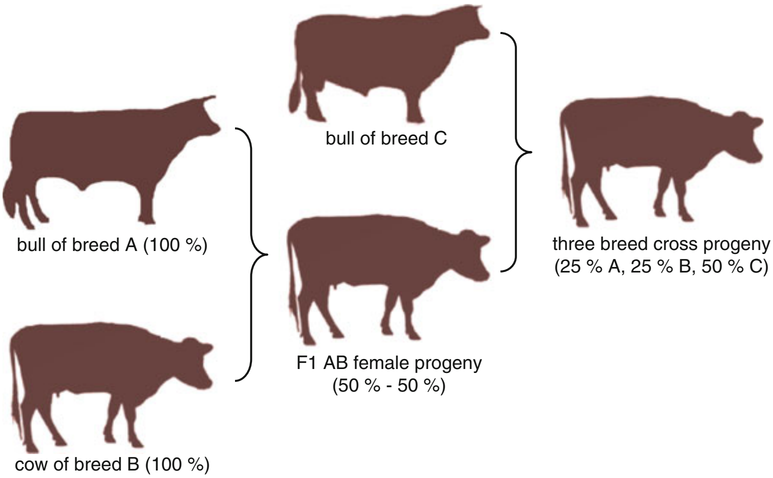

Fig. 2.18 Three-breed cross in cattle. It is obtained when all the females of a two breed cross are mated to a bull of a third, unrelated breed

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).

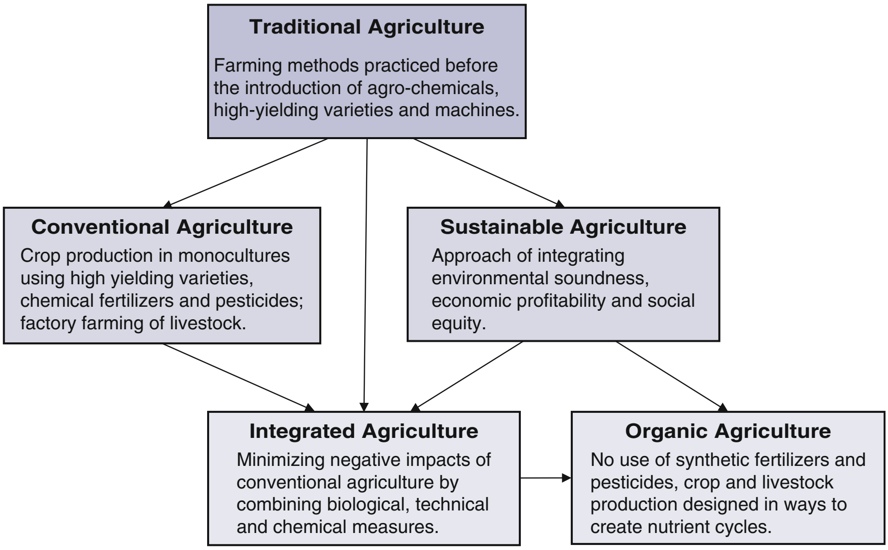

Fig. 2.19 Main concepts of agricultural production

To minimize the adverse effects of conventional agriculture, different alternative concepts of production have been developed (Fig. 2.19).

The overall idea of such alternatives is **sustainable agriculture**, which is based on the principle that agricultural production must meet the needs of the present without compromising the ability of future generations to meet their own needs. A variety of philosophies and perspectives from scientists to farmers and consumers have contributed to this vision, but there is no overall consensus on how to define and achieve sustainability in agriculture. However, most views agree that it integrates three main objectives: environmental soundness, economic profitability, and social equity. It does not, however, mean a return to traditional agriculture with the practices and low yields that characterized the nineteenth century. More closely, sustainable agriculture can be defined as an integrated system of plant and animal production practices that will, over the long term, satisfy human food and fibre needs, conserve environmental quality and natural resources, and enhance the quality of life for farmers and society as a whole by considering and integrating ecological cycles and controls.

In practice, there are two main approaches to achieving the objectives of sustainable agriculture:

1. **Integrated agriculture** principally makes use of the techniques of conventional agriculture, but tries to minimize its negative effects by combining biological, technical, and chemical measures that enable production of a high-quality harvest

while conserving natural resources. Integrated agriculture can therefore be regarded as a method between conventional and organic agriculture and includes:

- site-adapted design of the production area by use of suitable species and varieties of crops and livestock;
- crop rotation that mitigates weed, disease, and pest problems and provide alternatives sources of soil nitrogen;
- careful soil cultivation that avoids soil compaction and erosion;
- fertilization based on need, ideally with a combination of organic and mineral fertilizers, and which reduces the risk of water contamination;
- application of mechanical methods of weed control to reduce herbicide input; and
- use of pest-control strategies that reduce the need for pesticides by integration and promotion of natural enemies; synthetic pesticides should be used only when other methods of control cannot prevent a threshold of damage being crossed.

2. **Organic agriculture** is a way of farming that entirely avoids the application of synthetic fertilizers and pesticides. Its objective is to create nutrient cycles within the farm that are as closed as possible, which means that crop and animal production are designed such that fertilizers and feed are mostly produced and utilized on the farm. Of major importance is the conservation and promotion of soil fertility (Sect. 4.3.5.3). This is achieved by means of site-adapted crop rotation (Sect. 2.4.1.1) in which the use of legumes for fixation of nitrogen (Sect. 3.7.4.1) is important, as also is the utilization of organic fertilizers (compost, manure). For compensation of nutrient losses, purchased organic fertilizers, untreated rock meal, and bone meal, may be used. To avoid an excess of nutrients, the number of animals and the use of feedstuffs from outside the farm are limited. Overall, organic agriculture aims at using ecological principles to create synergies among the system components and to improve sustainability. Other principles of organic agriculture include:

- a ban on the use of genetically modified crops and other applications linked to genetic engineering;
- species-appropriate animal husbandry and a ban on the addition of hormones and antibiotics to feed; and
- the conservation and improvement of the structure and biodiversity of the landscape.

In contrast with integrated agriculture and integrated plant protection, organic agriculture is subject to government regulations which are defined in an EU regulation and in other national regulations around the world. These rules address, among other aspects, the application of fertilizers and pesticides. Plant or animal products of organic agriculture are identified by the legally protected terms "eco", "bio", or "organic". Other declarations regarding such concepts as integrated, inspected, or environmentally friendly production, do not guarantee that the product was produced without synthetic fertilizers and pesticides.

2.4 Classification of Agroecosystems

Depending of the objectives of the farmer, the availability of capital, energy, and technology, and the institutional and infrastructural context, a great diversity of crop and livestock production systems exist. In addition, there are also differences related to historical and geographic factors. The latter primarily result from the climate, the natural vegetation, and the soils of different zones of the world (Chap. 7).

2.4.1 Cropping Systems

Cropping systems can be classified on the basis of a combination of three key characteristics, each of which can be subdivided into two groups:

1. **Life-form of the crop**
   Crops, similar to other plants, can usually be classified into two groups according to their life-form:
   (a) **Annual crops**, for example cereals, require one vegetation period to complete their development and have, accordingly, a short life span. They must, therefore, be sown again every growing season. However, depending on the species and region, more than one harvest per year is possible. For example, in the humid tropics, rice, with a vegetation period of 120 days, can be cultivated three times per year.
   (b) **Perennial crops** have a lifespan of several years and deliver, depending on the species, a harvest in one or more of these years.
2. **Intensity of production**
   (a) In agroecosystems that are subject to **extensive** management, production is essentially based on the natural site conditions, which means that only a limited quantity of materials are imported into the system, and these usually consist of limited quantities of farmyard manure.
   (b) Agroecosystems that are subject to **intensive** management are characterized by the application of technology which includes the use of machines, mineral fertilizers, and pesticides. In such systems, plant production is not based solely on solar energy but also on fossil energy, which is required for operation of machines and for production and transport of fertilizers and pesticides.

   These two forms of land use are not absolute opposites, but are instead connected by a wide range of production intensity. On the one hand, the different transition forms imply the gradual improvement of production methods that has occurred during the development of agriculture over the course of thousands of years. On the other hand, they show the existing differences between production conditions and the potential of farming in the industrial and developing nations.

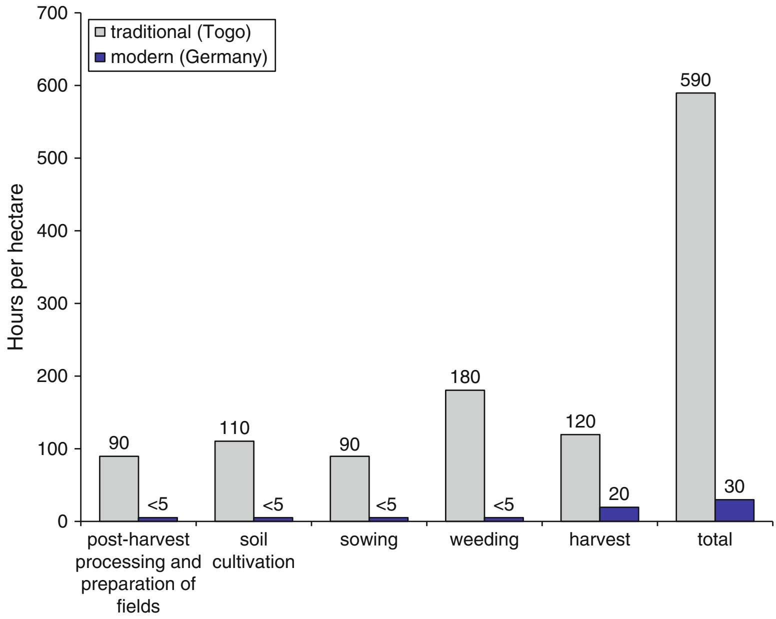

Fig. 2.20 Labour requirements for maize production in Togo and Germany (Based on Koch 1994)

With increasing intensification of agricultural production, the input of human labour usually decreases as the need for manual labour for activities such as soil cultivation, sowing, weeding, and harvesting, decreases. This results in significant differences between the labour required for extensively and intensively managed agroecosystems (Fig. 2.20).

3. **Cropping period**

(a) In extensive land use, production of crops on the same area is possible for a limited period of time only (usually between 2 and 4 years). Then, the nutrient reserves in the soil no longer deliver satisfactory yields. For regeneration of the soil fertility, an extended fallow period (several years to decades) is therefore necessary, before crop production can start again. Systems in which crop production is interrupted by such a phase are called **rotation systems**.

(b) By intensification of production, not only an increase in crop yield per field area but also a longer duration of use of the same field, up to permanent use, becomes possible. Thus, in such **permanent systems**, there are no multi-year fallow periods but, at most, seasonally dependent interruptions to production.

A more detailed description of rotation and permanent systems is presented in the following sections. An overview is given in Fig. 2.21.

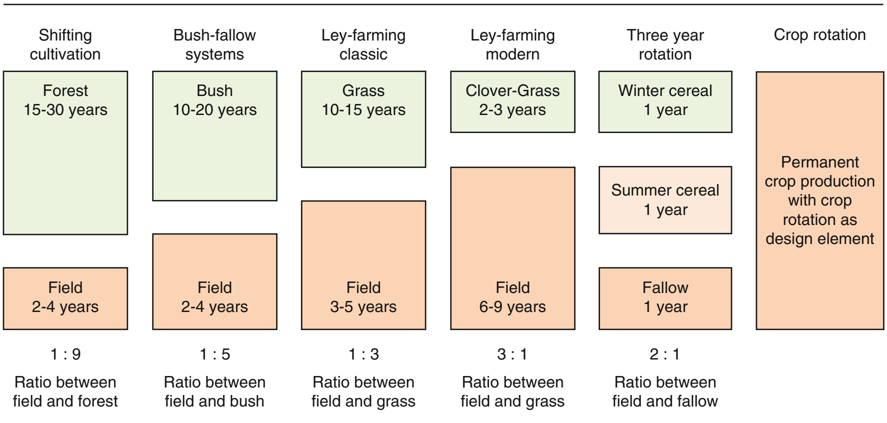

Fig. 2.21 Overview of agricultural rotation and permanent systems

2.4.1.1 Rotation Systems

Production systems with long fallow periods mark not only the beginning of agriculture but are still an important form of crop production in many regions.

Shifting Cultivation

Production systems in which short phases of field use alternate with long forest phases are called shifting cultivation or slash-and-burn farming. To establish a 1–4 year phase of crop production, the trees are felled and often burnt. Because the tree roots generally remain in the soil, cultivation of the fields between the remains of the forest vegetation is conducted in the simplest manner, for example with a digging stick. With declining soil fertility, the land is abandoned and left to natural succession, to be used again at a later date. In forested Europe, this form of production was the start of agriculture and was predominant into the early medieval period.

In the tropics, shifting cultivation is still performed by more than 250 million people (Metzger 2003). With increasing population density and the corresponding increasing demand for agricultural products, the forest phases between those of agricultural land use will become shorter. Finally, this leads to overexploitation or nutrient mining of the site, through which the growth of the trees is limited and the forest eventually disappears completely. Often, a cleared site can no longer be used for production because the fertile upper soil layers have been eroded by heavy tropical rainfall (Sect. 4.3.6).

Bush-Fallow Systems

Rotation systems in the form of bush-fallow systems primarily exist in the savanna regions. After a short period of agricultural land use, bush vegetation often becomes

Table 2.1 Types of ley-farming

Unregulated	Irregular alternation between crops and grassland
Regulated	Regular alternation between crops and grassland
Classic	Establishment of grassland after the crop phase by natural succession
Modern	Establishment of grassland after the crop phase by sowing of seed mixtures

established on fallow fields, which serves to regenerate the soil as in shifting cultivation, and is cleared again after a specific period of time.

Ley-Farming

Alternating use of an area as crop field and as grassland (meadow or pasture) is called ley-farming, whereby the grassland serves for soil regeneration. As in many other production systems, a broad range of historical and regional types exist (Table 2.1).

In the early medieval period, from approximately the sixth century onward, ley-farming became established in Central Europe and, in contrast with shifting cultivation, had the advantage that cultivation was not hindered by tree roots. Reforestation of the grassland was generally prevented by grazing.

Basically, one can distinguish between regulated and unregulated ley-farming. In the regulated type, the change in use occurs after a defined number of years. This type of system was usually found in the vicinity of the homestead; crop production was performed for 3–5 consecutive years and then alternated with at least 10 years of grassland use. In the unregulated type, the transition between crop field and grassland occurs irregularly and was typically practised on land distant from the homestead. In this case, grassland use extended from 10 to 40 years and was interrupted by a 1–2-year phase of cereal production.

In many regions of Europe, ley-farming was replaced in the ninth century by three-year rotation (see below), but was continued in marginal regions of production (e.g. the Black Forest, northern Germany, the Alps, and Scandinavia) until today. Whereas in classic ley-farming natural establishment of grasses occurred, the modern type includes sowing (usually of a clover–grass mixture) for production of animal feed. Different types of ley-farming are often among the predominant land-use systems today in the wet–dry tropics, but also in many regions of the temperate latitudes.

2.4.1.2 Permanent Cropping Systems

The population density of Europe increased substantially since approximately the eighth century. This process not only required expansion of agricultural land but also intensification of crop production on existing fields. This occurred through the introduction of a **3-year rotation**, which can be seen as intermediate between

Fig. 2.22 Spelt (*Triticum spelta*)

rotation and permanent systems. In its original form, this system consisted of 2 years of crop production (winter cereals in the 1st year, summer cereals in the 2nd year) and fallow in the 3rd year. The most important cereal crops were barley, rye, and oats. In southwestern Germany, spelt (*Triticum spelta*; Fig. 2.22) was also important. In the nineteenth century, an improved form of the 3-year rotation emerged in which the fallow year was used for the production of feed legumes (primarily clover) or root and tuber crops (primarily potato). The development of permanent cropping without fallow years was also promoted by the increasing availability of fertilizers (compare Sect. 2.3.3).

Because of the need to feed a growing population, permanent systems are also gaining increasing importance in the densely populated regions of the tropics. However, production there often occurs without the possibility of compensating for nutrient losses by sufficient fertilization. As a consequence of this, yields decline. For the savanna regions of West Africa, annual nutrient deficits are estimated to be between 15 and 25 kg nitrogen, up to 2 kg phosphorus, 15–20 kg potassium, and 5 kg magnesium per hectare (Buerkert and Hiernaux 1998).

Permanent Arable Cropping

Worldwide, permanent crop production is predominantly performed in the form of **one-crop systems**, which means the exclusive production of a single crop species in a field. In agricultural land use that is increasingly oriented toward intensification and yield maximization, specific crop species are also grown on the same field for several years in a row. Such **monocultures** are only possible with autotolerant plants. These are plants for which repeated, consecutive production in the same field does not lead to declines in yield. This is true for maize and many other important food plants, including rye and potatoes. In contrast, autointolerant species cannot be repeatedly grown on the same field without interruption, because otherwise yield losses result. This also often happens when an adequate supply of nutrients is not ensured. Species that are autointolerant include sugar beet, oats, wheat, pea, and rapeseed. The causes of this phenomenon, which is also termed soil sickness, are unknown in many cases. For some species (e.g. rapeseed) the reduction in yield is primarily the result of an increased incidence of plant diseases.

For other species, for example alfalfa and some rice varieties, allelopathic effects have been demonstrated (Sect. 4.4.2).

A proved and tested principle of permanent crop production is **crop rotation**, which means a temporal sequence of production of different crop species (mostly one-crop cultivation) in the same field. Crop rotation not only contributes to conservation or improvement of soil fertility (Sect. 4.3.5.3) but are also to a measure of weed management (Sect. 5.1.3) and pest management (Sect. 5.2.3.1), because the population development of weeds or pests can be affected by the change in crop species. In crop rotation, a distinction is made between cereals and leaf crops. The latter are all species other than cereals, for example rapeseed, root and tuber crops (potato, beet, field vegetables), and legumes, but also green and silage maize and fodder grasses. Production of cereals (C) and leaf crops (L) can be designed in different ways. Common systems include simple rotation (C – L – C – L) and double rotation (L – L – C – C). The seasonally dependent temporal gaps between the respective main crops can be filled with the production of **cover crops** which can serve as green manure or animal fodder. Green manure plants are grown to biologically bind nutrients (primarily nitrogen) left in the soil by previous crops, thus protecting them from leaching. Examples of cover crops include legumes, for example lupines and clover species, grasses, and different Brassicaceae (mustard family), for example white/yellow mustard (*Sinapis alba*), radish (*Raphanus sativus*), and field mustard or turnip (*Brassica rapa*). Another cover crop species is the lacy phacelia (*Phacelia tanacetifolia*), which is a member of the Hydrophyllaceae (waterleaf family). It was introduced to Europe from California and also serves as a feeding resource for bees. Summer and winter cover crops are distinguished, depending on the sowing date. In contrast with one-crop systems, **intercropping** involves at least two crop species grown simultaneously in the same field. They are grown in alternate rows or wide strips but often also without a planned order. A particular type of intercropping is the establishment of underseeds (undersown crops). This is done by sowing a plant species into the stand of a main crop. Underseeds used in cereals include clover and grass species which serve as animal fodder.

Whereas in the industrialized nations large one-crop systems predominate, intercropping is a traditional type of land use in many regions of the tropics and continues to be of importance today. Examples include the mixed cropping of maize, beans (*Phaseolus* species), and squash in Central America and the mixed cropping of cereals (sorghum, pearl millet) and legumes, for example cowpea, pigeon pea (*Cajanus cajan*), and/or peanuts in the savanna regions of Africa.

Intercropping enables a better utilization of nutrients and water from the soil, e.g., by growing shallow and deep-rooted crops together. In addition, intercropping can contribute to the suppression of weed growth and to reduced pest incidence (Sect. 5.2.4.5). Overall, intercropping serves to minimize the risk of losing the entire harvest. Even when one of the cultivated crops fails, the other may still produce a yield.

Because of improved resource utilization in intercropping, the yield per unit area is often higher than that from the same area with only one crop. Whether, and to what extent, intercropping furnishes better yields than one-crop cultivation can be

Table 2.2 Example of calculation of the land equivalent ratio (*LER*)

Crop	Yield (t/ha)		LER partial
	Intercropping (E_M)	Sole cropping (E_R)	
A	5.1	8.9	5.1/8.9 = 0.57
B	1.9	3.9	1.9/3.9 = 0.49
C	0.6	2.8	0.6/2.8 = 0.21
LER total	–	–	$\sum \frac{E_{Mi}}{E_{Ri}} = 1.27$

evaluated with the **Land Equivalent Ratio (LER)**. This ratio is calculated by comparing the yields of two or more crop species from intercropping with the yields produced with the same species in sole cultivation. LER is calculated by use of formula:

$$\mathrm{LER} = \sum E_{\mathrm{Mi}}/E_{\mathrm{Ri}}$$

where E_M is the yield of one crop from intercropping and E_R is the yield of the same species from the one-crop system. For every crop, i, represented in the intercropping, the relationship between E_M and E_R is calculated. The resulting partial LER values are summed to produce the total LER value. A value >1.0 means there is a yield advantage from intercropping. In the example given in Table 2.2, the LER total value is 1.27, which means the area required in sole cropping to achieve the same yield of the three crops as is produced by intercropping would have to be 27% larger than in intercropping.

Perennial Crops

Permanent agricultural crops include all crop species with more than one year periods of use. These are perennial field crops, for example asparagus (*Asparagus officinalis*), hops (*Humulus lupulus*), and artichoke (*Cynara scolymus*), and the variety of shrub and tree crops used in agricultural production, for example grapes (*Vitis vinifera*) and tree fruit species.

Plantations (from Latin *plantare* = to plant) are typical permanent cropping systems. In the original sense this term referred to large scale agricultural enterprises in the tropics and subtropics in which plant products were usually grown in monocultures and produced for the world market (Table 2.3).

This type of operation was first established by the Europeans in their colonies and was inseparably connected with slavery from the beginning of the seventeenth century to the end of the nineteenth century.

Plantations are used in the production of:

- perennial field crops, for example sugar cane, sisal (*Agave sisalana*; Fig. 2.23), and pineapple;

Table 2.3 Important crop species of the tropics that are primarily produced in plantations for the world market

Species	Length of economic use period (years)	Main producers
Sugar cane	6–8	Brazil, India
Oil palm	50	Indonesia, Malaysia
Banana	20	India, Brazil
Coconut	80	Philippines, Indonesia
Pineapple	6–13	Thailand, Philippines
Rubber tree	30–40	Thailand, Indonesia
Coffee	30–100	Brazil, Columbia
Tea	50	India, China
Sisal	6–20	Brazil, Tanzania

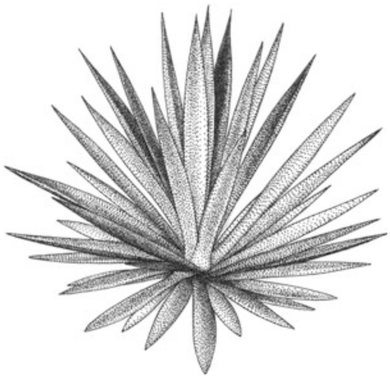

Fig. 2.23 Sisal (*Agave sisalana*)

- shrub crops, for example coffee, tea (*Camellia sinensis*; Fig. 2.24), and cacao (*Theobroma cacao*; Fig. 2.25);
- herbaceous perennials, for example the banana (*Musa* × *paradisiaca*); and
- tree crops, for example oil palm, coconut palm (*Cocos nucifera*), and rubber tree (*Hevea brasiliensis*), and various fruit and spice trees, e.g. cloves (*Syzygium aromaticum*) and nutmeg (*Myristica fragans*).

Agroforestry systems are also permanent systems producing trees or other woody plants and agricultural crops together on the same plot. By combining such species, the diversity of products gained from the system can be increased and, in addition, various ecological functions are better fulfilled than in sole arable cropping systems. Woody plants provide better protection of the soil from wind and water erosion (Sect. 4.3.6) than annual plants and increase the biodiversity of the system. Their root systems reach greater depths than those of most arable crop species, which means that water and nutrients from deeper soil layers can be used. The organic material in tree litter reaches the soil's surface where it is decomposed by soil organisms, so the inorganic components of this "nutrient pump" become available to plants. Overall, the need for external fertilizers is thus reduced. The

Fig. 2.24 Tea (*Camellia sinensis*)

Fig. 2.25 Cacao (*Theobroma cacao*) is a cauliflorous tree species. Cauliflory refers to woody plants which flower and fruit from their main stems or branches as opposed to the ends of the twigs

root systems of woody plants also affect the soil structure and, thus, the rate of infiltration of precipitation and the water balance of the soil.

In addition to the positive effects mentioned above, woody plants can also have negative effects on the other plants of an agroforestry system, primarily as a result of competition for light, nutrients, and/or water. Therefore, for every system it is necessary to investigate which perennial and annual species are best suited for cultivation together, to achieve complementary effects. Factors such as sowing and planting dates of the species also affect the ecological interactions.

A particular form of agroforestry are **home gardens**, in which crops are integrated in natural tree stands. They are primarily found in Southeast Asia and serve to produce fruit trees, rattan palms, medicinal plants, and vegetables. Another type is the so-called agro-silvopastoral system (Latin *silva* = forest, and *pastor* = shepherd), in which forestry and agricultural uses are complemented by a livestock component.

2.5 Livestock Systems

In addition to, and sometimes in combination with cropping systems, a large variety of livestock production systems exist around the globe. Important factors involved in livestock production include the animal species and the type of product, the climatic conditions in the region of production, the type of land use, and the type and origin of feeding resources.

In consideration of these and with additional criteria, for example socio-economic conditions, several system classifications have been proposed. Among these, the classification scheme based on Seré and Steinfeld (1996) has become most widely accepted and is also used in the following discussion. Further information is provided by Steinfeld et al. (2006) and Robinson et al. (2011).

As shown in Fig. 2.26, this classification first distinguishes two main categories, i.e., solely livestock systems and mixed farming systems. These groups are then broken down into different categories considering animal type, land use, and climate.

2.5.1 Solely Livestock Production Systems

This group includes the two most extreme types of livestock production, ranging from old traditional systems using large areas of natural grassland to systems of intensive livestock production with high animal densities in factory farming systems with low space requirements.

2.5.1.1 Landless Livestock Systems

These systems are largely independent of climate and are defined as livestock systems in which more than 90% of the dry matter fed to animals is introduced from outside the farm, and in which annual average stocking is above ten livestock units (LU) per hectare of agricultural land. (In this context, a livestock unit is one individual for cattle or eight individuals for sheep or goats.)

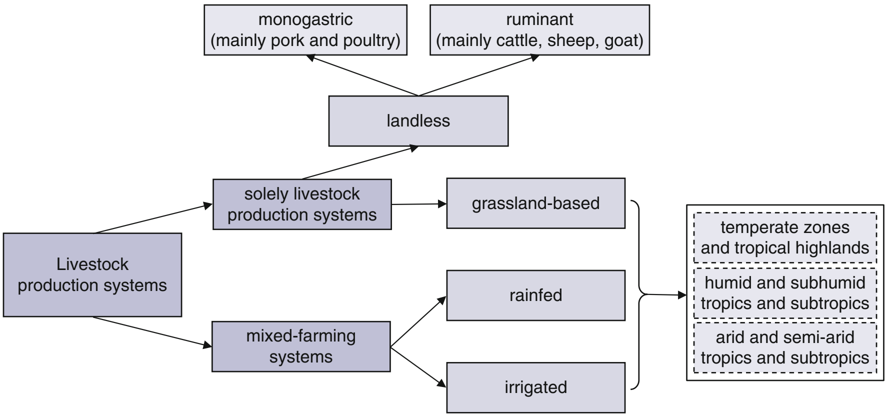

Fig. 2.26 Classification of world livestock production systems (Based on Seré and Steinfeld 1996)

Landless livestock systems can further be subdivided into:

- **Landless monogastric systems** (mainly pigs and poultry) are found predominantly in the industrialized countries of Europe and North America, with approximately half of global landless pork production and landless poultry production each. In pig production, Asia is second, with nearly one third of the world total. The predominant producer of pigs and poultry in Asia is China.
- **Landless ruminant systems** (mainly cattle, sheep, goats) exist in only a few regions of the world. For cattle, they are concentrated in eastern Europe; landless sheep production systems are found in western Asia and northern Africa only.

2.5.1.2 Grassland-Based Systems

Areas used for livestock grazing cover more than a quarter of the global land surface but are inhabited by approximately 4% of the world's human population only. Grassland-based livestock systems produce more than 10% of the dry matter fed to animals and have annual average stocking rates less than ten livestock units per hectare of agricultural land.

Overall, livestock grazing covers a wide range of systems which are defined as follows:

- **Total nomadism**: herders have no permanent place of residence; they move with their animals in a way that normally avoids depleting pastures without regular cultivation.
- **Semi-nomadism**: a permanent place of residence exists; supplementary cultivation is practised, but for long periods of time animal owners travel to distant grazing areas.

- **Transhumance**: herders have a permanent home, and their herds are sent to distant grazing areas, usually on seasonal cycles, e.g. in montane regions the movement between higher pastures in summer and valleys in winter.
- **Partial nomadism**: characterized by farmers who live continuously in permanent settlements and have herds at their disposal that graze in the vicinity.
- **Stationary animal husbandry**: animals remain on the farm or in the village throughout the year.

Solely livestock production on grasslands is of different importance in different climatic regions. Most of the world's large natural grasslands of the temperate zones have conditions suitable for crop production and, therefore, have been developed for arable farming, especially in the North American Prairie, the South American Pampas, and the East European Steppe. The largest areas of natural grassland used for grazing in the temperate zone are found in Central Asia including Mongolia, where 80% of the country is used for extensive grazing.

In the humid and sub-humid tropics, the grassland-based livestock production system is found mostly in the tropical and subtropical lowlands of South America, including the llanos of Colombia and Venezuela and the cattle-ranching lands of the Amazon basin which have developed from cleared and burned rainforest.

In many regions of the arid and semi-arid tropics, extensive grazing systems, usually known as **rangelands**, are the dominant form of land use. Extensive grazing of rangelands for livestock production is called **pastoralism**. In northern Africa and in western Asia, pastoralism is a traditional way of subsistence for an important part of the population. In dry regions, especially, fuel wood is often scarce, leading to an increased role for animals as providers of manure for fuel, in addition to their provision of meat and milk and as a means of transport. In Australia, parts of western United States, and southern Africa, commercial rangeland enterprises are the modern form of land use in dry regions.

2.5.2 Mixed-Farming Systems

Mixed-farming systems are agricultural production systems in which the waste products of one enterprise (residues from crop production) are used by the other enterprise (livestock production) which returns its own waste products (manure) to the first enterprise. In these types of system, more than 10% of the dry matter fed to animals comes from crop by-products or stubble, or more than 10% of the total value of production comes from non-livestock farming activities.

Globally, mixed-farming systems contribute more than half of total meat production, compared with approximately one-third by landless systems and less than 10% by grazing systems.

Mixed systems can combine crops and livestock to different extents, which include on-farm systems with more or less closed ecological cycles, spatially separated systems of between-farm mixing (exchanging resources between different farms within a region), or temporally changing activities and crop–livestock interactions related to seasonal differences (winter/summer or rainy/dry season). In smallholder systems, livestock, in addition to crop production, may provide food and income, draught power for crop production, manure to improve soil fertility, and financial insurance in times of scarcity.

Depending on the water resources available for crop production, mixed systems can be further subdivided into rain-fed and irrigated systems. Most mixed farming systems are rain-fed, and are widespread in semi-arid and sub-humid areas of the tropics and in temperate zones.

Overall, if the land area used for grazing and that used for feed crop production for landless livestock systems are added together, livestock production is the world's largest agricultural sector with the highest proportion of land use.

Driven by human population growth, urbanization, and increased income, the demand for animal-source food products is increasing, especially in the developing countries. In the future, production will increasingly be affected by competition for natural resources, particularly land and water, and competition between human food and animal feed production. Environmental problems of livestock production and potential solutions are raised in Sect. 6.2.2.

References

Bayerische Landesanstalt für Landwirtschaft (2000) Integrierter Pflanzenschutz. Rapsschädlinge. www.Lfl.Bayern.de/Publikationen

Buerkert A, Hiernaux P (1998) Nutrients in the West African Sudano-Sahelian zone: losses, transfers and role of external inputs. J Plant Nutr Soil Sci 161:365–383

Denham TP, Haberle SG, Lentfer C, Fullagar R, Field J, Therin M, Porch N, Winsborough B (2003) Origins of agriculture at Kuk swamp in the highlands of New Guinea. Science 301:189–193

Diamond J (1998) Guns, germs and steel: a short history of everybody for the last 13,000 years. Vintage, London

Diamond J (2002) Evolution, consequences and future of plant and animal domestication. Nature 418:700–707

James C (2010) Global status of commercialized biotech/GM crops. ISAAA (International Service for the Acquisition of Agri-biotech Applications) Report 2010, www.isaaa.org

Koch W (1994) Grundzüge des Pflanzenschutzes mit dem Versuch einer Bewertung. PLITS 12(4), W. & S. Koch Verlag, Stuttgart

Metzger JP (2003) Effects of slash-and-burn fallow periods on landscape structure. Environ Conserv 30:325–333

Piperno DR, Stothert KE (2003) Phytolith evidence for early Holocene *Cucurbita* domestication in Southwest Ecuador. Science 299:1054–1057

Price EO (1984) Behavioral aspects of animal domestication. Q Rev Biol 59:1–32

Robinson TP, Thornton PK, Franceschini G, Kruska RL, Chiozza F, Notenbaert A, Cecchi G, Herrero M, Epprecht M, Fritz S, You L, Conchedda G, See L (2011) Global livestock production systems. FAO/ILRI, Rome/Nairobi
Seré C, Steinfeld H (1996) World livestock production systems: current status, issues and trends. Animal production and health paper 127. FAO, Rome
Smith BD (1997) The initial domestication of *Cucurbita pepo* in the Americas 10,000 years ago. Science 276:932–934
Steinfeld H, Wassenaar T, Jutzi S (2006) Livestock production systems in developing countries: status, drivers, trends. Revue Scientifique et Technique de l'Office International des Epizooties 25:505–516
Zeder MA (2008) Domestication and early agriculture in the Mediterranean Basin: origins, diffusion, and impact. Proc Natl Acad Sci 105:11597–11604

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Agroecology
Martin, K.; Sauerborn, J.
2013, X, 330 p., Hardcover
ISBN: 978-94-007-5916-9