Handbook of

Agronomy and Agricultural Engineering

Guillermina Salyer

Roslyn Eubanks

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Email: info@wtbooks.com

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Chapter- 1

Agronomy

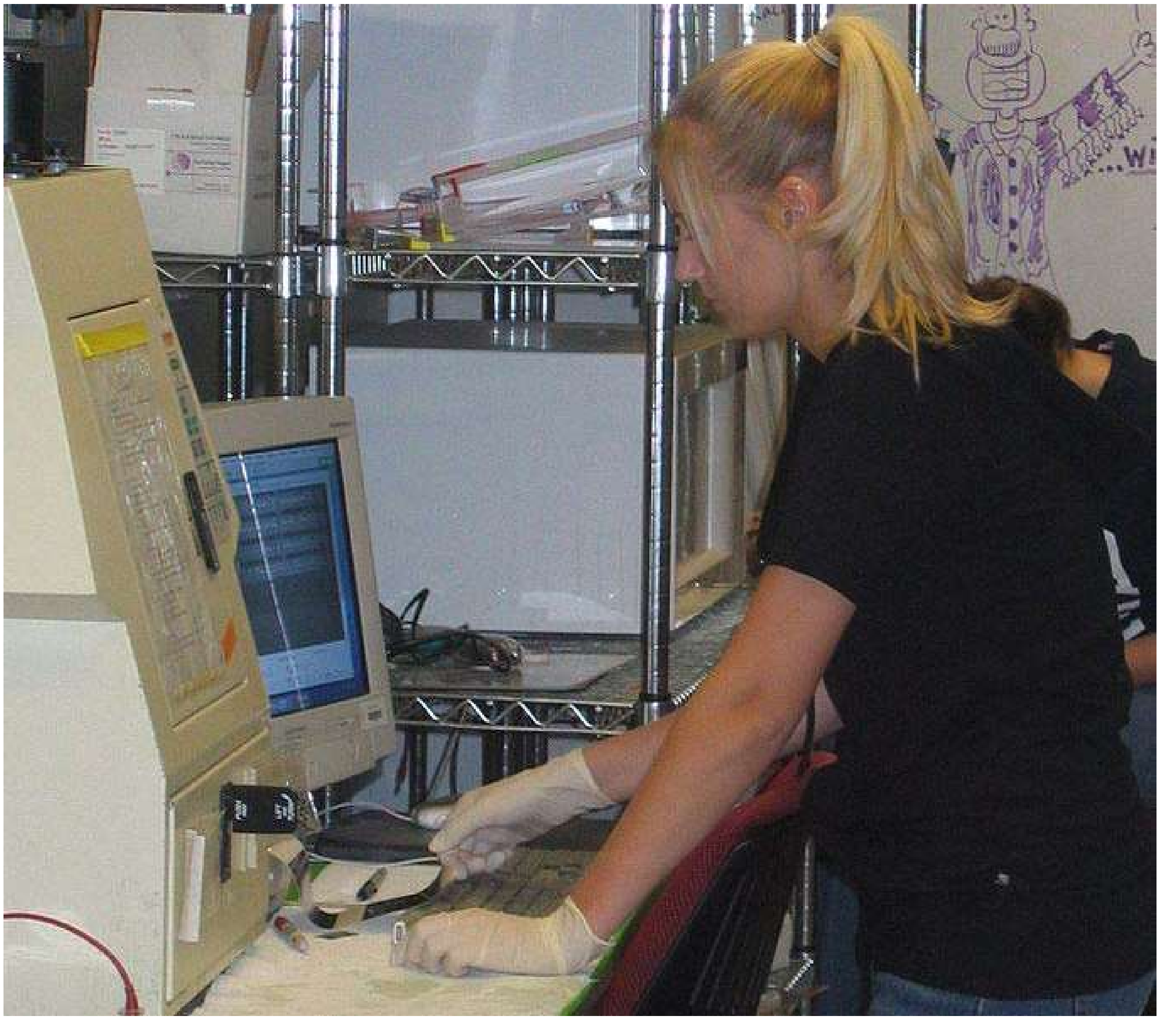
An agronomist field sampling a trial plot of flax.

Agronomy is the science and technology of producing and using plants for food, fuel, feed, fiber, and reclamation. Agronomy encompasses work in the areas of plant genetics, plant physiology, meteorology, and soil science. Agronomy is the application of a combination of sciences like biology, chemistry, ecology, earth science, and genetics. Agronomists today are involved with many issues including producing food, creating healthier food, managing environmental impact of agriculture, and creating energy from plants. Agronomists often specialize in areas such as crop rotation, irrigation and drainage, plant breeding, plant physiology, soil classification, soil fertility, weed control, insect and pest control.

Plant breeding

This area of agronomy involves selective breeding of plants to produce the best crops under various conditions. Plant breeding has increased crop yields and has improved the nutritional value of numerous crops, including corn, soybeans, and wheat. It also has led to the development of new types of plants. For example, a hybrid grain called triticale was produced by crossbreeding rye and wheat. Triticale contains more usable protein than does either rye or wheat. Agronomy has also been instrumental in fruit and vegetable production research. It is understood that the role of agronomist includes seeing whether produce from a field of 'x' meets the following conditions: 1. Land and water access, 2. Commercialization (market), 3. Quality and quantity of inputs, 4. Risk protection (insurance), 5. Agricultural credit.

Biotechnology



An agronomist mapping a plant genome.

Agronomists use biotechnology to extend and expedite the development of desired characteristics listed in the Plant Breeding section. Biotechnology is often a lab activity requiring field testing of the new crop varieties that are developed.

In addition to increasing crop yields agronomic biotechnology is increasingly being applied for novel uses other than food. For example, oilseed is at present used mainly for margarine and other food oils, but it can be modified to produce fatty acids for detergents, substitute fuels and petrochemicals.

Soil science

Agronomists describing a soil sample in Uganda, Africa.

Agronomists study sustainable ways to make soils more productive and profitable. They classify soils and reproduce them to determine whether they contain substances vital to plant growth such as compounds of nitrogen, phosphorus, and potassium. If a certain soil is deficient in these substances, fertilizers may provide them. Soil science also involves investigation of the movement of nutrients through the soil, the amount of nutrients absorbed by a plant's roots, and the development of roots and their relation to the soil.

Soil conservation

In addition, agronomists develop methods to preserve the soil and to decrease the effects of erosion by wind and water. For example, a technique called contour plowing may be used to prevent soil erosion and conserve rainfall. Researchers in agronomy also seek ways to use the soil more effectively in solving other problems. Such problems include the disposal of human and animal wastes; water pollution; and the build-up in the soil of pesticides. No-tilling crops is a technique now used to help prevent erosion. Planting of soil binding grasses along contours can be tried in steep slopes. For better effect, contour drains of depths up to 1 metre may help retain the soil and prevent permanent wash off.

Agroecology

Agroecology is the management of agricultural systems with an emphasis on ecological and environmental perspectives. This area is closely associated with work in the areas of sustainable agriculture, organic farming, alternative food systems and the development of alternative cropping systems.

Agronomy schools

Agronomy programs are offered at colleges, universities, and specialized agricultural schools. Agronomy programs often involve classes across a range of departments including agriculture, biology, chemistry, and physiology. They can usually take from four to twelve years. Many companies will pay an agronomist-in-training's way through college if they agree to work for them when they graduate.

Career outlook

Due to the continued growth of the global population—and the consequent expanding need for study of food crops and agriculture in general—the outlook for agronomy and agronomists is excellent. Past agricultural research has created higher yielding crops, crops with better resistance to pests and plant pathogens, and more effective fertilizers and pesticides. Research is still necessary, however, particularly as insects and diseases continue to adapt to pesticides and as soil fertility and water quality continue to need improvement.

Emerging biotechnologies will play an ever larger role in agricultural research. Scientists will be needed to apply these technologies to the creation of new food products and other advances. Moreover, increasing demand is expected for biofuels and other agricultural products used in industrial processes. Agricultural scientists will be needed to find ways to increase the output of crops used in these products.

Agronomists will also be needed to balance increased agricultural output with protection and preservation of soil, water, and ecosystems. They increasingly encourage the practice of sustainable agriculture by developing and implementing plans to manage pests, crops, soil fertility and erosion, and animal waste in ways that reduce the use of harmful chemicals and do little damage to farms and the natural environment.

Most agronomists are consultants, researchers, or teachers. Many work for agricultural experiment stations, federal or state government agencies, industrial firms, or universities. Agronomists also serve in such international organizations as the Agency for International Development, The United States Department of Agriculture, and the Food and Agriculture Organization of the United Nations.

Agronomists career options are expanding rapidly with possible ties with golf landscaping including topsoil analysis and drainage conditions. They often work in conjunction with landscape architects and engineers to determine the best soil qualities/conditions to suit the site specifications.

Chapter- 2

Plant Breeding

Plant breeding is the art and science of changing the genetics of plants for the benefit of mankind. Plant breeding can be accomplished through many different techniques ranging from simply selecting plants with desirable characteristics for propagation, to more complex molecular techniques.

Plant breeding has been practiced for thousands of years, since near the beginning of human civilization. It is now practiced worldwide by individuals such as gardeners and farmers, or by professional plant breeders employed by organizations such as government institutions, universities, crop-specific industry associations or research centers.

International development agencies believe that breeding new crops is important for ensuring food security by developing new varieties that are higher-yielding, resistant to pests and diseases, drought-resistant or regionally adapted to different environments and growing conditions.

Domestication

Centers of origin of selected crops

Note: The pointer locations indicate general regions where crops are believed to have first been domesticated. In some cases, the center of origin is uncertain. Other geographic regions also harbor important genetic diversity for these crops.

Source: This map was developed by the General Accounting Office using data provided by the National Plant Germplasm System's Plant Exchange Office.

This map shows the sites of domestication for a number of crops. Places where crops were initially domesticated are called centers of origin

Plant breeding in certain situations may lead to the domestication of wild plants. Domestication of plants is an artificial selection process conducted by humans to produce plants that have more desirable traits than wild plants, and which renders them dependent on artificial (usually enhanced) environments for their continued existence. The practice is estimated to date back 9,000-11,000 years. Many crops in present day cultivation are the result of domestication in ancient times, about 5,000 years ago in the Old World and 3,000 years ago in the New World. In the Neolithic period, domestication took a minimum of 1,000 years and a maximum of 7,000 years. Today, all of our principal food crops come from domesticated varieties. Almost all the domesticated plants used today for food and agriculture were domesticated in the centers of origin. In these centers there is still a great diversity of closely related wild plants, so-called crop wild relatives, that can also be used for improving modern cultivars by plant breeding.

A plant whose origin or selection is due primarily to intentional human activity is called a cultigen, and a cultivated crop species that has evolved from wild populations due to selective pressures from traditional farmers is called a landrace. Landraces, which can be the result of natural forces or domestication, are plants (or animals) that are ideally suited to a particular region or environment. An example are the landraces of rice, *Oryza sativa* subspecies *indica*, which was developed in South Asia, and *Oryza sativa* subspecies *japonica*, which was developed in China.

Classical plant breeding

Classical plant breeding uses deliberate interbreeding (**crossing**) of closely or distantly related individuals to produce new crop varieties or lines with desirable properties. Plants are crossbred to introduce traits/genes from one variety or line into a new genetic background. For example, a mildew-resistant pea may be crossed with a high-yielding but susceptible pea, the goal of the cross being to introduce mildew resistance without losing the high-yield characteristics. Progeny from the cross would then be crossed with the high-yielding parent to ensure that the progeny were most like the high-yielding parent, (**backcrossing**). The progeny from that cross would then be tested for yield and mildew resistance and high-yielding resistant plants would be further developed. Plants may also be crossed with themselves to produce **inbred** varieties for breeding.

Classical breeding relies largely on homologous recombination between chromosomes to generate genetic diversity. The classical plant breeder may also makes use of a number of *in vitro* techniques such as protoplast fusion, embryo rescue or mutagenesis (see below) to generate diversity and produce hybrid plants that would not exist in nature.

The Yecoro wheat (right) cultivar is sensitive to salinity, plants resulting from a hybrid cross with cultivar W4910 (left) show greater tolerance to high salinity

Traits that breeders have tried to incorporate into crop plants in the last 100 years include:

1. Increased quality and yield of the crop
2. Increased tolerance of environmental pressures (salinity, extreme temperature, drought)
3. Resistance to viruses, fungi and bacteria
4. Increased tolerance to insect pests
5. Increased tolerance of herbicides

Before World War II

Intraspecific hybridization within a plant species was demonstrated by Charles Darwin and Gregor Mendel, and was further developed by geneticists and plant breeders. In the United Kingdom in the 1880s, it was the pioneering work of Gartons Agricultural Plant Breeders. In the early 20th century, plant breeders realized that Mendel's findings on the non-random nature of inheritance could be applied to seedling populations produced through deliberate pollinations to predict the frequencies of different types.

From 1904 to the World War II in Italy Nazareno Strampelli created a number of wheat hybrids. His work allowed Italy to increase hugely crop production during the so called "Battle for Grain" (1925–1940) and some varieties was exported in foreign countries, as Argentina, Mexico, China and others. After the war, the work of Strampelli was quickly forgotten, but thanks to the hybrids he created, Norman Borlaug was able to move the very first steps of the Green Revolution.

In 1908, George Harrison Shull described heterosis, also known as hybrid vigor. Heterosis describes the tendency of the progeny of a specific cross to outperform both parents. The detection of the usefulness of heterosis for plant breeding has led to the development of inbred lines that reveal a heterotic yield advantage when they are crossed. Maize was the first species where heterosis was widely used to produce hybrids.

By the 1920s, statistical methods were developed to analyze gene action and distinguish heritable variation from variation caused by environment. In 1933, another important breeding technique, cytoplasmic male sterility (CMS), developed in maize, was described by Marcus Morton Rhoades. CMS is a maternally inherited trait that makes the plant produce sterile pollen. This enables the production of hybrids without the need for labor intensive detasseling.

These early breeding techniques resulted in large yield increase in the United States in the early 20th century. Similar yield increases were not produced elsewhere until after World War II, the Green Revolution increased crop production in the developing world in the 1960s.

After World War II

Following World War II a number of techniques were developed that allowed plant breeders to hybridize distantly related species, and artificially induce genetic diversity.

When distantly related species are crossed, plant breeders make use of a number of plant tissue culture techniques to produce progeny from otherwise fruitless mating. Interspecific and intergeneric hybrids are produced from a cross of related species or genera that do not normally sexually reproduce with each other. These crosses are referred to as *Wide crosses*. For example, the cereal triticale is a wheat and rye hybrid. The cells in the plants derived from the first generation created from the cross contained an uneven number of chromosomes and as result was sterile. The cell division inhibitor colchicine was used to double the number of chromosomes in the cell and thus allow the production of a fertile line.

Failure to produce a hybrid may be due to pre- or post-fertilization incompatibility. If fertilization is possible between two species or genera, the hybrid embryo may abort before maturation. If this does occur the embryo resulting from an interspecific or intergeneric cross can sometimes be rescued and cultured to produce a whole plant. Such a method is referred to as *Embryo Rescue*. This technique has been used to produce new rice for Africa, an interspecific cross of Asian rice *(Oryza sativa)* and African rice *(Oryza glaberrima)*.

Hybrids may also be produced by a technique called protoplast fusion. In this case protoplasts are fused, usually in an electric field. Viable recombinants can be regenerated in culture.

Chemical mutagens like EMS and DMS, radiation and transposons are used to generate mutants with desirable traits to be bred with other cultivars - a process known as *Mutation Breeding*. Classical plant breeders also generate genetic diversity within a species by exploiting a process called somaclonal variation, which occurs in plants produced from tissue culture, particularly plants derived from callus. Induced polyploidy, and the addition or removal of chromosomes using a technique called chromosome engineering may also be used.

When a desirable trait has been bred into a species, a number of crosses to the favored parent are made to make the new plant as similar to the favored parent as possible. Returning to the example of the mildew resistant pea being crossed with a high-yielding but susceptible pea, to make the mildew resistant progeny of the cross most like the high-yielding parent, the progeny will be crossed back to that parent for several generations. This process removes most of the genetic contribution of the mildew resistant parent. Classical breeding is therefore a cyclical process.

With classical breeding techniques, the breeder does not know exactly what genes have been introduced to the new cultivars. Some scientists therefore argue that plants produced by classical breeding methods should undergo the same safety testing regime as genetically modified plants. There have been instances where plants bred using classical techniques have been unsuitable for human consumption, for example the poison solanine was unintentionally increased to unacceptable levels in certain varieties of potato through plant breeding. New potato varieties are often screened for solanine levels before reaching the marketplace.

Modern plant breeding

Modern plant breeding uses techniques of molecular biology to select, or in the case of genetic modification, to insert, desirable traits into plants.

Modern facilities in molecular biology has converted classical plant breeding to molecular plant breeding

Steps of Plant Breeding

The following are the major activities of plant breeding;

1. Creation of variation
2. Selection
3. Evaluation
4. Release
5. Multiplication
6. Distribution of the new variety

Marker assisted selection

Sometimes many different genes can influence a desirable trait in plant breeding. The use of tools such as molecular markers or DNA fingerprinting can map thousands of genes. This allows plant breeders to screen large populations of plants for those that possess the trait of interest. The screening is based on the presence or absence of a certain gene as determined by laboratory procedures, rather than on the visual identification of the expressed trait in the plant.

Reverse Breeding and Doubled Haploids (DH)

A method for efficiently producing homozygous plants from a heterozygous starting plant, which has all desirable traits. This starting plant is induced to produce doubled haploid from haploid cells, and later on creating homozygous/doubled haploid plants from those cells. While in natural offspring genetic recombination occurs and traits can be unlinked from each other, in doubled haploid cells and in the resulting DH plants recombination is no longer an issue. There, a recombination between two corresponding chromosomes does not lead to un-linkage of alleles or traits, since it just leads to recombination with its identical copy. Thus, traits on one chromosome stay linked. Selecting those offspring having the desired set of chromosomes and crossing them will result in a final F1 hybrid plant, having exactly the same set of chromosomes, genes and traits as the starting hybrid plant. The homozygous parental lines can reconstitute the original heterozygous plant by crossing, if desired even in a large quantity. An individual heterozygous plant can be converted into a heterozygous variety (F1 hybrid) without the necessity of vegetative propagation but as the result of the cross of two homozygous/doubled haploid lines derived from the originally selected plant. patent

Genetic modification

Genetic modification of plants is achieved by adding a specific gene or genes to a plant, or by knocking down a gene with RNAi, to produce a desirable phenotype. The plants resulting from adding a gene are often referred to as transgenic plants. If for genetic modification genes of the species or of a crossable plant are used under control of their native promoter, then they are called cisgenic plants. Genetic modification can produce a plant with the desired trait or traits faster than classical breeding because the majority of the plant's genome is not altered.

To genetically modify a plant, a genetic construct must be designed so that the gene to be added or removed will be expressed by the plant. To do this, a promoter to drive transcription and a termination sequence to stop transcription of the new gene, and the gene or genes of interest must be introduced to the plant. A marker for the selection of transformed plants is also included. In the laboratory, antibiotic resistance is a commonly used marker: Plants that have been successfully transformed will grow on media containing antibiotics; plants that have not been transformed will die. In some instances markers for selection are removed by backcrossing with the parent plant prior to commercial release.

The construct can be inserted in the plant genome by genetic recombination using the bacteria *Agrobacterium tumefaciens* or *A. rhizogenes*, or by direct methods like the gene gun or microinjection. Using plant viruses to insert genetic constructs into plants is also a possibility, but the technique is limited by the host range of the virus. For example, Cauliflower mosaic virus (CaMV) only infects cauliflower and related species. Another limitation of viral vectors is that the virus is not usually passed on the progeny, so every plant has to be inoculated.

The majority of commercially released transgenic plants are currently limited to plants that have introduced resistance to insect pests and herbicides. Insect resistance is achieved through incorporation of a gene from *Bacillus thuringiensis* (Bt) that encodes a protein that is toxic to some insects. For example, the cotton bollworm, a common cotton pest, feeds on Bt cotton it will ingest the toxin and die. Herbicides usually work by binding to certain plant enzymes and inhibiting their action. The enzymes that the herbicide inhibits are known as the herbicides *target site*. Herbicide resistance can be engineered into crops by expressing a version of *target site* protein that is not inhibited by the herbicide. This is the method used to produce glyphosate resistant crop plants.

Genetic modification of plants that can produce pharmaceuticals (and industrial chemicals), sometimes called *pharmacrops*, is a rather radical new area of plant breeding.

Issues and concerns

Modern plant breeding, whether classical or through genetic engineering, comes with issues of concern, particularly with regard to food crops. The question of whether breeding can have a negative effect on nutritional value is central in this respect. Although relatively little direct research in this area has been done, there are scientific indications that, by favoring certain aspects of a plant's development, other aspects may be retarded. A study published in the *Journal of the American College of Nutrition* in 2004, entitled *Changes in USDA Food Composition Data for 43 Garden Crops, 1950 to 1999*, compared nutritional analysis of vegetables done in 1950 and in 1999, and found substantial decreases in six of 13 nutrients measured, including 6% of protein and 38% of riboflavin. Reductions in calcium, phosphorus, iron and ascorbic acid were also found. The study, conducted at the Biochemical Institute, University of Texas at Austin, concluded in summary: *"We suggest that any real declines are generally most easily explained by changes in cultivated varieties between 1950 and 1999, in which there may be trade-offs between yield and nutrient content."*

The debate surrounding genetically modified food during the 1990s peaked in 1999 in terms of media coverage and risk perception, and continues today - for example, "*Germany has thrown its weight behind a growing European mutiny over genetically modified crops by banning the planting of a widely grown pest-resistant corn variety.*". The debate encompasses the ecological impact of genetically modified plants, the safety of genetically modified food and concepts used for safety evaluation like substantial equivalence. Such concerns are not new to plant breeding. Most countries have regulatory processes in place to help ensure that new crop varieties entering the marketplace are both safe and meet farmers' needs. Examples include variety registration, seed schemes, regulatory authorizations for GM plants, etc.

Plant breeders' rights is also a major and controversial issue. Today, production of new varieties is dominated by commercial plant breeders, who seek to protect their work and collect royalties through national and international agreements based in intellectual property rights. The range of related issues is complex. In the simplest terms, critics of the increasingly restrictive regulations argue that, through a combination of technical and economic pressures, commercial breeders are reducing biodiversity and significantly constraining individuals (such as farmers) from developing and trading seed on a regional level. Efforts to strengthen breeders' rights, for example, by lengthening periods of variety protection, are ongoing.

When new plant breeds or cultivars are bred, they must be maintained and propagated. Some plants are propagated by asexual means while others are propagated by seeds. Seed propagated cultivars require specific control over seed source and production procedures to maintain the integrity of the plant breeds results. Isolation is necessary to prevent cross contamination with related plants or the mixing of seeds after harvesting. Isolation is normally accomplished by planting distance but in certain crops, plants are enclosed in greenhouses or cages (most commonly used when producing F1 hybrids.)

Participatory Plant Breeding

The development of agricultural science, with phenomenon like the Green Revolution arising, have left millions of farmers in developing countries, most of whom operate small farms under unstable and difficult growing conditions, in a precarious situation. The adoption of new plant varieties by this group has been hampered by the constraints of poverty and the international policies promoting an industrialized model of agriculture. Their response has been the creation of a novel and promising set of research methods collectively known as participatory plant breeding. Participatory means that farmers are more involved in the breeding process and breeding goals are defined by farmers instead of international seed companies with their large-scale breeding programs. Farmers' groups and NGOs, for example, may wish to affirm local people's rights over genetic resources, produce seeds themselves, build farmers' technical expertise, or develop new products for niche markets, like organically grown food.

List of notable plant breeders

- Gartons Agricultural Plant Breeders
- Norman Borlaug
- Nazareno Strampelli
- Luther Burbank
- Roger Doucet
- Keith Downey
- Niels Ebbesen Hansen
- Gregor Mendel
- Colin Wyatt

Chapter- 3

Theoretical Production Ecology

Theoretical production ecology tries to quantitively study the growth of crops. The plant is treated as a kind of biological factory, which processes light, carbon dioxide, water and nutrients into harvestable parts. Main parameters kept into consideration are temperature, sunlight, standing crop biomass, plant production distribution, nutrient and water supply.

Modelling

Modelling is essential in theoretical production ecology. Unit of modelling usually is the crop, the assembly of plants per standard surface unit. Analysis results for an individual plant are generalised to the standard surface, e.g. the Leaf Area Index is the generalised surface of all crop leaves per surface unit.

Processes

The usual system of describing plant production divides the plant production process into at least five separate processes, which are influenced by several external parameters.

Two cycles of biochemical reactions constitute the basis of plant production, the light reaction and the dark reaction.

- In the light reaction, sunlight photons are absorbed by chloroplasts which split water into an electron, proton and oxygen radical which is recombined with another radical and released as molecular oxygen. The recombination of the electron with the proton yields the energy carriers NADH and ATP. The rate of this reaction often depends on sunlight intensity, leaf area index, leaf angle and amount of chloroplasts per leaf surface unit. The maximum theoretical gross production rate under optimum growth conditions is approximately 250 kg per hectare per day.
- The dark reaction or **Calvin cycle** ties atmospheric carbon dioxide and uses NADH and ATP to convert it into sucrose. The available NADH and ATP, as well as temperature and carbon dioxide levels determine the rate of this reaction. Together those two reactions are termed photosynthesis. The rate of photosynthesis is determined by the interaction of a number of factors including temperature, light intensity and carbon dioxide.

- The produced carbohydrates are transported to other plant parts, such as storage organs and converted into secondary products, such as amino acids, lipids, cellulose and other chemicals needed by the plant or used for respiration. Lipids, sugars, cellulose and starch can be produced without extra elements. The conversion of carbohydrates into amino acids and nucleic acids requires nitrogen, phosphorus and sulfur. Chlorophyll production requires magnesium, while several enzymes and coenzymes require trace elements. This means, nutrient supply influences this part of the production chain. Water supply is essential for transport, hence limits this too.
- The production centers, i.e. the leaves, are sources, the storage organs, growth tips or other destinations for the photosynthetic production are sinks. The lack of sinks can be a limiting factor for production too, as happens e.g. in apple orchards where insects or night frost have destroyed the blossoms and the produced assimilates cannot be converted into apples. Biennial and perennial plants employ the stored starch and fats in their storage organs to produce new leafs and shoots the next year.
- The amount of crop biomass and the relative distribution of biomass over leafs, stems, roots and storage organs determines the respiration rate. The amount of biomass in leafs determines the leaf area index, which is important in calculating the gross photosynthetic production.
- extensions to this basic model can include insect and pest damage, intercropping, climatical changes, etc.

Parameters

Important parameters in theoretical production models thus are:

Climate

- **Temperature** - The temperature determines the speed of respiration and the dark reaction. A high temperature combined with a low intensity of sunlight means a high loss by respiration. A low temperature combined with a high intensity of sunlight means that NADH and ATP heap up but cannot be converted into glucose because the dark reaction cannot process them swiftly enough.

- **Light** - Light, also called photosynthetic Active Radiation (PAR) is the energy source for green plant growth. PAR powers the light reaction, which provides ATP and NADPH for the conversion of carbon dioxide and water into carbohydrates and molecular oxygen. When temperature, moisture, carbon dioxide and nutrient levels are optimal, light intensity determines maximum production level.

- **Carbon dioxide levels** - Atmospheric carbon dioxide is the sole carbon source for plants. About half of all proteins in green leaves have the sole purpose of capturing carbon dioxide.

Although CO_2 levels are constant under natural circumstances, CO_2 fertilization is common in greenhouses and is known to increase yields by on average 24% . C_4 plants like maize and sorghum can achieve a higher yield at high solar radiation intensities, because they prevent the leaking of captured carbon dioxide due of the spatial separation of carbon dioxide capture and carbon dioxide use in the dark reaction. This means that their photorespiration is almost zero. This advantage is sometimes offset by a higher rate of maintenance respiration. In most models for natural crops, carbon dioxide levels are assumed to be constant.

Crop

- **Standing crop biomass** - Unlimited growth is an exponential process, which means that the amount of biomass determines the production. Because an increased biomass implies higher respiration per surface unit and a limited increase in intercepted light, crop growth is a sigmoid function of crop biomass.

- **Plant production distribution** - Usually only a fraction of the total plant biomass consists of useful products, e.g. the seeds in pulses and cereals, the tubers in potato and cassava, the leafs in sisal and spinach etc. The yield of usable plant portions will increase when the plant allocates more nutrients to this parts, e.g. the high-yielding varieties of wheat and rice allocate 40% of their biomass into wheat and rice grains, while the traditional varieties achieve only 20%, thus doubling the effective yield.

  Different plant organs have a different respiration rate, e.g. a young leaf has a much higher respiration rate than roots, storage tissues or stems do. There is a distinction between "growth respiration" and "maintenance respiration". Sinks, such as developing fruits, need to be present. They are usually represented by a discrete switch, which is turned on after a certain condition, e.g. critical daylength has been met.

Care

- **Water supply** - Because plants use passive transport to transfer water and nutrients from their roots to the leafs, water supply is essential to growth, even so that water efficiency rates are known for different crops, e.g. 5000 for sugar cane, meaning that each kilogram of produced sugar requires up to 5000 liters of water.

- **Nutrient supply** - Nutrient supply has a twofold effect on plant growth. A limitation in nutrient supply will limit biomass production as per Liebig's Law of the Minimum. With some crops, several nutrients influence the distribution of plant products in the plants. A nitrogen gift is known to stimulate leaf growth and therefore can work adversely on the yield of crops which are accumulating photosynthesis products in storage organs, such as ripening cereals or fruit-bearing fruit trees.

Phases in crop growth

Theoretical production ecology assumes that the growth of common agricultural crops, such as cereals and tubers, usually consists of four (or five) phases:

- **Germination** - Agronomical research has indicated a temperature dependence of germination time (GT, in days). Each crop has a unique critical temperature (CT, dimension temperature) and temperature sum (dimensions temperature times time), which are related as follows.

  $$GT = \frac{TS}{\sum_{k=1}^{N}(T - T_{\text{crit}})}$$

  When a crop has a temperature sum of e.g. 150 °C·d and a critical temperature of 10 °C, it will germinate in 15 days when temperature is 20 °C, but in 10 days when temperature is 25 °C. When the temperature sum exceeds the threshold value, the germination process is complete.

- **Initial spread** - In this phase, the crop does not cover the field yet. The growth of the crop is linearly dependent on leaf area index, which in its turn is linearly dependent on crop biomass. As a result, crop growth in this phase is exponential.
- **Total coverage of field** - in this phase, growth is assumed to be linearly dependent on incident light and respiration rate, as nearly 100% of all incident light is intercepted. Typically, LAI is above two to three in this phase. This phase of vegetative growth ends when the plant gets a certain environmental or internal signal and starts generative growth (as in cereals and pulses) or the storage phase (as in tubers).
- **Allocation to storage organs** - in this phase, up to 100% of all production is directed to the storage organs. Generally, the leafs are still intact and as a result, gross primary production stays the same. Prolonging this phase, e.g. by careful fertilization, water and pest management results directly in a higher harvest.
- **Ripening** - in this phase, leafs and other production structures slowly die off. Their carbohydrates and proteins are transported to the storage organs. As a result, the LAI and, hence, the primary production decreases.

Existing plant production models

Plant production models exist in varying levels of scope (cell, physiological, individual plant, crop, geographical region, global) and of generality: the model can be crop-specific or be more generally applicable. Here the emphasis will be on crop-level based models as the crop is the main area of interest from an agronomical point of view.

As of 2005, several crop production models are in use. The crop growth model **SUCROS** has been developed during more than 20 years and is based on earlier models. Its latest revision known dates from 1997. The IRRI and Wageningen University more recently developed the rice growth model **ORYZA2000**. This model is used for modeling rice growth. Both crop growth models are open source. Other more crop-specific plant growth models exist as well.

SUCROS

SUCROS is programmed in the Fortran computer programming language. The model can and has been applied to a variety of weather regimes and crops. Because the source code of Sucros is open source, the model is open to modifications of users with FORTRAN programming experience. The official maintained version of SUCROS comes into two flavours: SUCROS I, which has non-inhibited unlimited crop growth (which means that only solar radiation and temperature determine growth) and SUCROS II, in which crop growth is limited only by water shortage.

ORYZA2000

The ORYZA2000 rice growth model has been developed at the IRRI in cooperation with Wageningen University. This model, too, is programmed in FORTRAN. The scope of this model is limited to rice, which is the main food crop for Asia.

Other models

The United States Department of Agriculture has sponsored a number of applicable crop growth models for various major US crops, such as cotton, soy bean, wheat and rice. Other widely-used models are the precursor of SUCROS (**SWATR**), **CERES**, several incarnations of **PLANTGRO**, **SUBSTOR**, the FAO-sponsored **CROPWAT**, **AGWATER** and the erosion-specific model **EPIC**.

A less mechanistic growth and competition model, called the Conductance Model, has been developed, mainly at Warwick-HRI, Wellesbourne, UK. This model simulates light interception and growth of individual plants based on the lateral expansion of their crown zone areas. Competition between plants is simulated by a set algorithms related to competition for space and resultant light intercept as the canopy closes. Some versions of the model assume overtopping of some species by others. Although the model cannot take account of water or mineral nutrients, it can simulate individual plant growth, variability in growth within plant communities and inter-species competition. This model was written in Matlab.

Chapter- 4

Agroecology

A community-supported agriculture share of vegetables

Agroecology is the application of ecological principles to the production of food, fuel, fiber, and pharmaceuticals. The term encompasses a broad range of approaches, and is considered "a science, a movement, [and] a practice."

Ecological strategy

Agroecologists study a variety of agroecosystems, and the field of agroecology is not associated with any one particular method of farming, whether it be organic, conventional, intensive or extensive. Furthermore, it is not defined by certain management practices, such as the use of natural enemies in place of insecticides, or polyculture in place of monoculture.

Additionally, agroecologists do not unanimously oppose technology or inputs in agriculture but instead assess how, when, and if technology can be used in conjunction with natural, social and human assets. Agroecology proposes a context- or site-specific manner of studying agroecosystems, and as such, it recognizes that there is no universal formula or recipe for the success and maximum well-being of an agroecosystem.

Instead, agroecologists may study questions related to the four system properties of agroecosystems: productivity, stability, sustainability and equitability. As opposed to disciplines that are concerned with only one or some of these properties, agroecologists see all four properties as interconnected and integral to the success of an agroecosystem. Recognizing that these properties are found on varying spatial scales, agroecologists do not limit themselves to the study of agroecosystems at any one scale: farm, community, or global.

Agroecologists study these four properties through an interdisciplinary lens, using natural sciences to understand elements of agroecosystems such as soil properties and plant-insect interactions, as well as using social sciences to understand the effects of farming practices on rural communities, economic constraints to developing new production methods, or cultural factors determining farming practices.

Various approaches to agroecology

Agroecologists do not always agree about what agroecology is or should be in the long-term. Different definitions of the term agroecology can be distinguished largely by the specificity with which one defines the term "ecology," as well as the term's potential political connotations. Definitions of agroecology, therefore, may be first grouped according to the specific contexts within which they situate agriculture. Agroecology is defined by the OECD as "the study of the relation of agricultural crops and environment." This definition refers to the "-ecology" part of "agroecology" narrowly as the natural environment. Following this definition, an agroecologist would study agriculture's various relationships with soil health, water quality, air quality, meso- and micro-fauna, surrounding flora, environmental toxins, and other envirnomental contexts.

A more common definition of the word can be taken from Dalgaard et al., who refer to agroecology as the study of the interactions between plants, animals, humans and the environment within agricultural systems. Consequently, agroecology is inherently multidisciplinary, including factors from agronomy, ecology, sociology and economics . In this case, the "-ecology" portion of "agroecology is defined broadly to include social, cultural, and economic contexts as well.

Agroecology is also defined differently according to geographic location. In the global south, the term often carries overtly political connotations. Such political definitions of the term usually ascribe to it the goals of social and economic justice; special attention, in this case, is often paid to the traditional farming knowledge of indigenous populations . North American and European uses of the term sometimes avoid the inclusion of such overtly political goals. In these cases, agroecology is seen more strictly as a scientific discipline with less specific social goals.

Fred Buttel makes a more academic distinction of the various approaches within the field, separating it into five broad categories:

Ecosystems agroecology

This approach is driven by the ecosystems biology of Eugene Odum. This approach is based in the hypotheses that the natural systems, with its stability and resilience, provide the best model to mimic if sustainability is the goal. Normally, ecosystems agroecology is not actively involved in social science; however, this school is essentially based on the belief that large-scale agriculture is inappropriate. The work of Steve Gliessman is prototypical of this approach.

Agronomic ecology

The basic approach in this branch is derived mostly from agronomy, including the traditional agricultural production sciences. This approach also does not actively involve social sciences in the agroecological analysis, but uses social sciences to understand the processes by which agriculture became unsustainable. Chuck Francis, Richard Hardwood, Ricardo Salvador, and Matt Liebman are exemplars of this approach.

Ecological political economy

The driving force behind this form of agroecology is a political-economical critique of modern agriculture. The school believes that only radical changes in political economy and the moral economy of research will reduce the negative costs of modern agriculture. The works of Miguel Altieri (ecosystem biologist), John Vandermeer (population ecologist), Richard Lewontin, and Richard Levins provide examples of this politically charged and socially-oriented version of agroecology.

Agro-population ecology

This approach is derived from the science of ecology primarily based on population ecology, which over the past three decades has been displacing the ecosystems biology of Odum. Buttel explains the main difference between the two categories, saying that “the application of population ecology to agroecology involves the primacy not only of analyzing agroecosystems from the perspective of the population dynamics of their constituent species, and their relationships to climate and biogeochemistry, but also there is a major emphasis placed on the role of genetics.” David Andow and Alison Power are cited as examples of professionals espousing this view.

Integrated assessment of multifunctional agricultural systems

This approach focuses on the multifunctionality of the landscape, instead of focusing solely on the agricultural enterprise. Agriculture and the food system are considered parts of an institutional complex that relates to and integrates with other social institutions. Scholars adopting this highly integrated approach, mostly Europeans, do not consider any one discipline the leader of agroecology.

Holon agroecology

First introduced in 2007 by the soil scientist William T. Bland and the environmental sociologist Michael M. Bell of the University of Wisconsin–Madison, holon agroecology draws on Koestler's notion of a "holon" which is both part and whole and develops it with ideas of narrative, intentionality, and incompleteness or unfinalizability, within an ever-changing "ecology of contexts". In contrast to systems thinking, holon agroecology stresses seeing the agricultural endeavor as an unfinished accomplishment that is constantly adjusting itself to its many contexts and their conflicts and incommensurabilities. The farm holon represents a kind of "holding together" in order to persist through change, but a holding together that is never fully unified and worked out.

History of agroecology

Pre-WWII

The notions and ideas relating to crop ecology have been around since at least 1911 when F.H. King released *Farmers of Forty Centuries*. King was one of the pioneers as a proponent of more quantitative methods for characterization of water relations and physical properties of soils. In the late 1920s the attempt to merge agronomy and ecology was born with the development of the field of crop ecology. Crop ecology's main concern was where crops would be best grown. Actually, it was only in 1928 that agronomy and ecology were formally linked by Klages.

1928 was the first mention of the term agroecology, with the publication of the term by Bensin in 1928 . The book of Tischler (1965), was probably the first to be actually titled 'agroecology'. He analysed the different components (plants, animals, soils and climate) and their interactions within an agroecosystem as well as the impact of human agricultural management on these components. Other books dealing with agroecology, but without using the term explicitly were published by the German zoologist Friederichs (1930) with his book on agricultural zoology and related ecological/environmental factors for plant protection and by American crop physiologist Hansen in 1939 when both used the word as a synonym for the application of ecology within agriculture.

Post-WWII

Gliessman mentions that post-WWII, groups of scientists with ecologists gave more focus to experiments in the natural environment, while agronomists dedicated their attention to the cultivated systems in agriculture. According to Gliessman, the two groups kept their research and interest apart until books and articles using the concept of agroecosystems and the word agroecology started to appear in 1970. Dalgaard explains the different points of view in ecology schools, and the fundamental differences, which set the basis for the development of agroecology. The early ecology school of Henry Gleason investigated plant populations focusing in the hierarchical levels of the organism under study.

Friederich Clement's ecology school, however included the organism in question as well as the higher hierarchical levels in its investigations, a "landscape perspective". However, the ecological schools where the roots of agroecology lie are even broader in nature. The ecology school of Tansley , whose view included both the biotic organism and their environment, is the one from which the concept of agroecosystems emerged in 1974 with Harper.

In the 1960s and 70's the increasing awareness of how humans manage the landscape and its consequences set the stage for the necessary cross between agronomy and ecology. Even though, in many ways the environmental movement in the US was a product of the times, the Green Decade spread an environmental awareness of the unintended consequences of changing ecological processes. Works such as *Silent Spring*, and *The Limits to Growth*, and changes in legislation such as the Clean Air Act, Clean Water Act, and the National Environmental Policy Act caused the public to be aware of societal growth patterns, agricultural production, and the overall capacity of the system.

Fusion of agronomy and ecology

After the 1970s, when agronomists saw the value of ecology and ecologists began to use the agricultural systems as study plots, studies in agroecology grew more rapidly. Gliessman describes that the innovative work of Prof. Efraim Hernandez X., who developed research based on indigenous systems of knowledge in Mexico, led to education programs in agroecology. In 1977 Prof. Efraim Hernandez X. explained that modern agricultural systems had lost their ecological foundation when socio-economic factors became the only driving force in the food system . The acknowledgement that the socio-economic interactions are indeed one of the fundamental components of any agroecosystems came to light in 1982, with the article Agroecologia del Tropico Americano by Montaldo. The author argues that the socio-economic context cannot be separated from the agricultural systems when designing agricultural practices .

In 1995 Edens et al. in Sustainable Agriculture and Integrated Farming Systems solidified this idea proving his point by devoting special sections to economics of the systems, ecological impacts, and ethics and values in agriculture . Actually, 1985 ended up being a fertile and creative year for the new discipline. For instance in the same year, Miguel

Altieri integrated how consolidation of the farms, and cropping systems impact pest populations. In addition, Gliessman highlighted that socio-economic, technological, and ecological components give rise to producer choices of food production systems . These pioneering agroecologists have helped to frame the foundation of what we today consider the interdisciplinary field of agroecology.

Applications of agroecology

To emit a point of view about a particular way of farming, an agroecologist would first seek to understand the contexts in which the farm(s) is(are) involved. Each farm may be inserted in a unique combination of factors or contexts. Each farmer may have their own premises about the meanings of an agricultural endeavor, and these meanings might be different than those of agroecologists. Generally, farmers seek a configuration that is viable in multiple contexts, such as family, financial, technical, political, logistical, market, environmental, spiritual. Agroecologists want to understand the behavior of those who seek livelihoods from plant and animal increase, acknowledging the organization and planning that is required to run a farm.

How agroecologists might see organic and non-organic milk production

Because organic agriculture proclaims to sustain the health of soils, ecosystems and people , it has much in common with Agroecology; this doesn't mean that Agroecology is the same as organic agriculture or that Agroecology sees organic farming as the right way of farming, though. Also, it is important to point out that there are large differences in organic standards among countries and certifying agencies.

Three of the main areas that agroecologists would look at in farms, would be: the environmental impacts, animal welfare issues, and the social aspects.

Environmental impacts caused by organic and non-organic milk production can vary significantly. For both cases, there are positive and negative environmental consequences.

Compared to conventional milk production, organic milk production tends to have lower eutrophication potential per ton of milk or per hectare of farmland, because it potentially reduces leaching of nitrates (NO_3^-) and phosphates (PO_4^-) due to lower fertilizer application rates. Because organic milk production reduces pesticides utilization, it increases land use per ton of milk due to decreased crop yields per hectare. Mainly due to the lower level of concentrates given to cows in organic herds, organic dairy farms generally produce less milk per cow than conventional dairy farms. Because of the increased use of roughage and the, on-average, lower milk production level per cow, some research has connected organic milk production with increases in the emission of methane.

Animal welfare issues vary among dairy farms and are not necessarily related to the way of producing milk (organically or conventionally).

A key component of animal welfare is freedom to perform their innate (natural) behavior, and this is stated in one of the basic principles of organic agriculture. Also, there are other aspects of animal welfare to be considered - such as freedom from hunger, thirst, discomfort, injury, fear, distress, disease and pain. Because organic standards require loose housing systems, adequate bedding, restrictions on the area of slatted floors, a minimum forage proportion in the ruminant diets, and tend to limit stocking densities both on pasture and in housing for dairy cows, they potentially promote good foot and hoof health. Some studies show lower incidence of placenta retention, milk fever, abomasums displacement and other diseases in organic than in conventional dairy herds . However, the level of infections by parasites in organically managed herds is generally higher than in conventional herds .

Social aspects of dairy enterprises include life quality of farmers, of farm labor, of rural and urban communities, and also includes public health.

Both organic and non-organic farms can have good and bad implications for the life quality of all the different people involved in that food chain. Issues like labor conditions, labor hours and labor rights, for instance, do not depend on the organic/non-organic characteristic of the farm; they can be more related to the socio-economical and cultural situations in which the farm is inserted, instead.

As for the public health or food safety concern, organic foods are intended to be healthy, free of contaminations and free from agents that could cause human diseases. Organic milk is meant to have no chemical residues to consumers, and the restrictions on the use of antibiotics and chemicals in organic food production has the purpose to accomplish this goal. But dairy cows in organic farms, as in conventional farms, indeed do get exposed to virus, parasites and bacteria that can contaminate milk and hence humans, so the risks of transmitting diseases are not eliminated just because the production is organic.

In an organic dairy farm, an agroecologist could evaluate the following:

1. can the farm minimize environmental impacts and increase its level of sustainability, for instance by efficiently increasing the productivity of the animals to minimize waste of feed and of land use?

2. are there ways to improve the health status of the herd (in the case of organics, by using biological controls, for instance)?

3. does this way of farming sustain good quality of life for the farmers, their families, rural labor and communities involved?

Agroecologists' view of no-till farming

No-tillage is one of the components of conservation agriculture practices and is considered more environmental friendly than complete tillage . Due to this belief, it could be expected that agroecologists would not recommend the use of complete tillage and would rather recommend no-till farming, but this is not always the case. In fact, there is a general consensus that no-till can increase soils capacity of acting as a carbon sink, especially when combined with cover crops.

No-till can contribute to higher soil organic matter and organic carbon content in soils , though reports of no-effects of no-tillage in organic matter and organic carbon soil contents also exist, depending on environmental and crop conditions . In addition, no-till can indirectly reduce CO_2 emissions by decreasing the use of fossil fuels .

Most crops can benefit from the practice of no-till, but not all crops are suitable for complete no-till agriculture . Crops that do not perform well when competing with other plants that grow in no-tilled soil in their early stages can be best grown by using other conservation tillage practices, like a combination of strip-till with no-till areas . Also, crops which harvestable portion grows underground can have better results with strip-tillage, mainly in soils which are hard for plant roots to penetrate into deeper layers to access water and nutrients.

The benefits provided by no-tillage to predators may lead to larger predator populations , which is a good way to control pests (biological control), but also can facilitate predation of the crop itself. In corn crops, for instance, predation by caterpillars can be higher in no-till than in conventional tillage fields.

In places with rigorous winter, no-tilled soil can take longer to warm and dry in spring, which may delay planting to less ideal dates. Another factor to be considered is that organic residue from the previous years crops laying on the surface of no-tilled fields can provide a favorable environment to pathogens, helping to increase the risk of transmitting diseases to the future crop. And because no-till farming provides good environment for pathogens, insects and weeds, it can lead farmers to a more intensive use of chemicals for pest control. Other disadvantages of no-till include underground rot, low soil temperatures and high moisture.

Based on the balance of these factors, and because each farm has different problems, agroecologists will not atest that only no-till or complete tillage is the right way of farming. In fact, these are not the only possible choices regarding soils preparation, since there are intermediate practices such as strip-till, mulch-till and ridge-till, all of them - just as no-till - categorized as conservation tillage. Agroecologists, then, will evaluate the need of different practices for the contexts in which each farm is inserted.

In a no-till system, an agroecologist could ask the following:

1. Can the farm minimize environmental impacts and increase its level of sustainability; for instance by efficiently increasing the productivity of the crops to minimize land use?

2. Does this way of farming sustain good quality of life for the farmers, their families, rural labor and rural communities involved?

Agroecology by region

The principles of agroecology are expressed differently depending on local ecological and social contexts.

Latin America and agroecology

Latin America's experiences with North American Green Revolution agricultural techniques have opened space for agroecologists. Traditional or indigenous knowledge represents a wealth of possibility for agroecologists, including "exchange of wisdoms."

Madagascar and agroecology

Most of the historical farming in Madagascar has been conducted by indigenous peoples. The French colonial period disturbed a very small percentage of land area, and even included some useful experiments in sustainable forestry. Slash-and-burn techniques, a component of some shifting cultivation systems have been practised by natives in Madagascar for centuries. As of 2006 some of the major agricultural products from slash-and-burn methods are wood, charcoal and grass for Zebu grazing. These practices have taken perhaps the greatest toll on land fertility since the end of French rule, mainly due to overpopulation pressures.

Chapter- 5

Crop Rotation

Satellite image of circular crop fields in Haskell County, Kansas in late June 2001. Healthy, growing crops are green. Corn would be growing into leafy stalks by then. Sorghum, which resembles corn, grows more slowly and would be much smaller and therefore, (possibly) paler. Wheat is a brilliant gold as harvest occurs in June. Fields of brown have been recently harvested and plowed under or lie fallow for the year.

Crop rotation is the practice of growing a series of dissimilar types of crops in the same area in sequential seasons for various benefits such as to avoid the build up of pathogens and pests that often occurs when one species is continuously cropped. Crop rotation also seeks to balance the fertility demands of various crops to avoid excessive depletion of soil nutrients. A traditional element of crop rotation is the replenishment of nitrogen through the use of green manure in sequence with cereals and other crops. It is one component of polyculture. Crop rotation can also improve soil structure and fertility by alternating deep-rooted and shallow-rooted plants.

Method and purpose

Effects of crop rotation and monoculture: On the left field, the "Norfolk" crop rotation sequence (potatoes, oats, peas, rye) is being applied; on the right field, rye has been grown for 45 years in a row.

Crop rotation avoids a decrease in soil fertility, as growing the same crop in the same place for many years in a row disproportionately depletes the soil of certain nutrients. With rotation, a crop that leaches the soil of one kind of nutrient is followed during the next growing season by a dissimilar crop that returns that nutrient to the soil or draws a different ratio of nutrients, for example, rice followed by cotton. By crop rotation farmers can keep their fields under continuous production, without the need to let them lie fallow, and reducing the need for artificial fertilizers, both of which can be expensive. Rotating crops adds nutrients to the soil. Legumes, plants of the family Fabaceae, for instance, have nodules on their roots which contain nitrogen-fixing bacteria. It therefore makes good sense agriculturally to alternate them with cereals (family Poaceae) and other plants that require nitrates. An extremely common modern crop rotation is alternating soybeans and maize (corn). In subsistence farming, it also makes good nutritional sense to grow beans and grain at the same time in different fields.

Crop rotation is a type of cultural control that is also used to control pests and diseases that can become established in the soil over time. The changing of crops in a sequence tends to decrease the population level of pests. Plants within the same taxonomic family tend to have similar pests and pathogens. By regularly changing the planting location, the pest cycles can be broken or limited. For example, root-knot nematode is a serious problem for some plants in warm climates and sandy soils, where it slowly builds up to high levels in the soil, and can severely damage plant productivity by cutting off circulation from the plant roots. Growing a crop that is not a host for root-knot nematode for one season greatly reduces the level of the nematode in the soil, thus making it possible to grow a susceptible crop the following season without needing soil fumigation.

It is also difficult to control weeds similar to the crop which may contaminate the final produce. For instance, ergot in weed grasses is difficult to separate from harvested grain. A different crop allows the weeds to be eliminated, breaking the ergot cycle.

This principle is of particular use in organic farming, where pest control may be achieved without synthetic pesticides.

A general effect of crop rotation is that there is a geographic mixing of crops, which can slow the spread of pests and diseases during the growing season. The different crops can also reduce the effects of adverse weather for the individual farmer and, by requiring planting and harvest at different times, allow more land to be farmed with the same amount of machinery and labor.

The choice and sequence of rotation crops depends on the nature of the soil, the climate, and precipitation which together determine the type of plants that may be cultivated. Other important aspects of farming such as crop marketing and economic variables must also be considered when crop rotation

History

Historic crop rotation methods are mentioned in Roman literature, and referred to by several civilizations in Asia and on three major elements: sophisticated systems of crop rotation, highly developed irrigation techniques and the introduction of a large variety of crops which were studied and catalogued according to the season, type of land and amount of water they require. Numerous farming encyclopaedias were produced.

In Europe, since the times Charlemagne, there was a transition from a two-field crop rotation to a three-field crop rotation. Under a two-field rotation, half the land was planted in a year while the other half lay fallow. Then, in the next year, the two fields were reversed. Under three-field rotation, the land was divided into three parts. One section was planted in the Autumn with winter wheat or rye. The next Spring, the second field was planted with other crops such as peas, lentils, or beans and the third field was left fallow. The three fields were rotated in this manner so that every three years, a field would rest and be unplanted. Under the two field system, if one has a total of 600 fertile acres of land, one would only plant 300 acres. Under the new three-field rotation system, one would plant (and thereby harvest) 400 acres. But, the additional crops had a more significant effect than mere productivity. Since the Spring crops were mostly legumes, they increased the overall nutrition of the people of Northern Europe.

From the end of the Middle Ages until the 20th century, the three-year rotation was practiced by farmers in Europe with a rotation of rye or winter wheat, followed by spring oats or barley, then letting the soil rest (leaving it fallow) during the third stage. The fact that suitable rotations made it possible to restore or to maintain a productive soil has long been recognized by planting spring crops for livestock in place of grains for human consumption.

A four-field rotation was pioneered by farmers, namely in the region Waasland in the early 16th century and popularised by the British agriculturist Charles Townshend in the 18th century. The system (wheat, turnips, barley and clover), opened up a fodder crop and grazing crop allowing livestock to be bred year-round. The four-field crop rotation was a key development in the British Agricultural Revolution.

George Washington Carver pioneered crop rotation methods in the United States by teaching southern farmers to rotate soil depleting crops like cotton with soil enriching crops like peanuts and peas.

In the Green Revolution, the traditional practice of crop rotation gave way in some parts of the world to the practice of supplementing the chemical inputs to the soil through top dressing with fertilizers, e.g., adding ammonium nitrate or urea and restoring soil pH with lime in the search for increased yields, preparing soil for specialist crops, and seeking to reduce waste and inefficiency by simplifying planting and harvesting. Some disadvantages of this type of monoculture have since become apparent, notably from the perspective of sustainable agriculture and the risk of catastrophic crop failure.

Effects on soil erosion

Crop rotation can greatly affect the amount of soil lost from erosion by water. In areas that are highly susceptible to erosion, farm management practices such as zero and reduced tillage can be supplemented with specific crop rotation methods to reduce raindrop impact, sediment detachment, sediment transport, surface runoff, and soil loss.

Protection against soil loss is maximized with rotation methods that leave the greatest mass of crop stubble (plant residue left after harvest) on top of the soil. Stubble cover in contact with the soil minimizes erosion from water by reducing overland flow velocity, stream power, and thus the ability of the water to detach and transport sediment Soil Erosion and Cill prevent the disruption and detachment of soil aggregates that cause macrospores to block, infiltration to decline, and runoff to increase. This significantly improves the resilience of soils when subjected to periods of erosion and stress.

The effect of crop rotation on erosion control varies by climate. In regions under relatively consistent climate conditions, where annual rainfall and temperature levels are assumed, rigid crop rotations can produce sufficient plant growth and soil cover. In regions where climate conditions are less predictable, and unexpected periods of rain and drought may occur, a more flexible approach for soil cover by crop rotation is necessary. An opportunity cropping system promotes adequate soil cover under these erratic climate conditions. In an opportunity cropping system, crops are grown when soil water is adequate and there is a reliable sowing window. This form of cropping system is likely to produce better soil cover than a rigid crop rotation because crops are only sown under optimal conditions, whereas rigid systems are sown in the best conditions available.

Crop rotations also affect the timing and length of when a field is subject to fallow. This is very important because depending on a particular region's climate, a field could be the most vulnerable to erosion when it is under fallow. Efficient fallow management is an essential part of reducing erosion in a crop rotation system. Zero tillage is a fundamental management practice that promotes crop stubble retention under longer unplanned fallows when crops cannot be planted. Such management practices that succeed in retaining suitable soil cover in areas under fallow will ultimately reduce soil loss.

Chapter- 6

Crop Diversity

Crop diversity is the variance in genetic and phenotypic characteristics of plants used in agriculture. Crops may vary in seed size, branching pattern, in height, flower color, fruiting time, or flavor. They may also vary in less obvious characteristics such as their response to heat, cold or drought, or their ability to resist specific diseases and pests. It is possible to discover variation in almost every conceivable trait, including nutritional qualities, preparation and cooking techniques, and of course how a crop tastes. And if a trait cannot be found in the crop itself, it can often be found in a wild relative of the crop; a plant that has similar species that have not been farmed or used in agriculture, but exist in the wild.

Diversity in a crop can also result from different growing conditions: a crop growing in nutrient poor soil is likely to be shorter than a crop growing in more fertile soil. In addition, and perhaps most importantly, diversity of a harvested plant can be the result of genetic differences: a crop may have genes conferring early maturity or disease resistance. It is these heritable traits that are of special interest as they are passed on from generation to generation and collectively determine a crop's overall characteristics and future potential. Through combining genes for different traits in desired combinations, plant breeders are able to develop new crop varieties to meet specific conditions. A new variety might, for example, be higher yielding, more disease resistant and have a longer shelf life than the varieties from which it was bred. The practical use of crop diversity goes back to early agricultural methods of crop rotation and fallow fields, planting and harvesting one type of crop on a plot of land one year, and using a different crop the next based on differences in a plant's nutrient needs. Both farmers and scientists must continually draw on the irreplaceable resource of genetic diversity to ensure productive harvests, as genetic variability provides farmers resilience to pests and diseases and allows scientists access to a more diverse genetic bank. Diversification of harvests and maintaining wild biodiversity in crop relatives influence many aspects of human and global interaction, being important for environmental and species sustainability.

Benefits to the environment

The loss of biodiversity is considered one of today's most serious environmental concerns by the Food and Agriculture Organization of the United Nations. According to some estimates, if current trends persist as many as half of all plant species could face extinction. Among the many threatened species are wild relatives of our crops – species that could contribute invaluable traits to future crop varieties. It has been estimated that 6% of wild relatives of cereal crops (wheat, maize, rice, sorghum etc.) are under threat as are 18% of legume species (the wild relatives of beans, peas and lentils) and 13% of species within the botanical family that includes potato, tomato, eggplant, and pepper. The wise use of crop genetic diversity in plant breeding can contribute significantly to protecting the environment. Crop varieties that are resistant to pests and diseases can reduce the need for application of harmful pesticides more vigorous varieties can better compete with weeds; reducing the need for applying herbicides as in the case study at Aarhus University in Denmark using more robust maize; drought resistant plants can help save water through reducing the need for irrigation; deeper rooting varieties can help stabilize soils; and varieties that are more efficient in their use of nutrients require less fertilizer. Most importantly, perhaps, productive agricultural systems reduce or eliminate the need to cut down forest or clear fragile lands to create more farmland for food production.

Crop diversity and the economy

Agriculture is the economic foundation of most countries, and for developing countries the most likely source of economic growth. Growth is most rapid where agricultural productivity has risen the most, and the reverse is also true. Growth in agriculture, although beneficial for the wider economy, benefits the poor most, and by providing affordable food these benefits extend beyond the 70% of the world's poorest people who live in rural areas and for whose livelihoods agriculture remains central. Ensuring agriculture is able to play this fundamental role requires a range of improvements including: the growing of higher value crops, promoting value-adding activities through, for example, improved processing, expanding access to markets, and lowering food prices through increasing production, processing and marketing efficiency, particularly for subsistence and very low income farming families. Fundamental to all of these potential solutions is crop diversity – the diversity that enables farmers and plant breeders to develop higher yielding, more productive varieties having improved quality characteristics required by farmers and desired by consumers. They can breed varieties better suited to particular processing methods or that store longer or that can be transported with less loss. They can produce varieties that resist pests and diseases and are drought tolerant, providing more protection against crop failure and better insulating poor farmers from risk. Agriculture's part in fighting poverty is complex, but without the genetic diversity found within crops, it cannot fulfill its potential.

Disease threats to crops with low genetic diversity

One particular threat to mass producing plants for harvest is their susceptibility to diseases. Generally speaking, a species has a range of genetic variability that allows for individuals and/or populations within that species to survive should a stressor or disturbance occur. In the case of agriculture, this is a tricky business to ensure, as seeds are planted under uniform conditions. For example, monocultural agriculture potentially elicits low crop diversity (especially if the seeds were mass produced or cloned). It is possible that a single pest or disease could wipe out entire areas of a crop due to this uniformity. One of the more historically known examples of harvests that suffered from low crop diversity was the Irish Potato Famine of 1845-1847.

One growing danger to present day agriculture is something called wheat rust: the name given from the reddish spores, it is a fungus that attaches to plants and breaks them down for food. A new form of the wheat disease - stem rust, strain Ug99 - has spread from Africa across to the Arabian Peninsula. This development was summarized on the January 16th 2007 by the international research centers Borlaug Global Rust Initiative and the Agricultural Research Service of the United States Department of Agriculture over 2 years of observation after its initial outbreak. The Ug99 stem rust has recently proven to be even more virulent than other forms. Observations from field trials in Kenya showed that more than 85% of wheat samples, including cultivars from the major wheat producing regions in the world, have succumbed to the pest. This is a serious pest alert for one of the major food crops of the world. The key to overcome the threat is genetic resistance found in certain wheat varieties. As Nobel laureate Norman Borlaug puts it: "We know what to do and how to do it. All we need are the financial resources, scientific cooperation and political will to contain this threat to world food security."

Reports from Burundi and Angola warn of another looming food crisis partly caused by outbreaks of the African Cassava Mosaic Virus (ACMD). Creating a "mosaic" of decay on the plants leaves, ACMD is responsible for the loss of a million tons of food each year. The Famine Early Warning Network of USAID reports from Angola that pockets of food insecurity exist in a number of districts partly due to the impacts of mosaic virus on the cassava crop. Likewise FAO (Food and Agriculture Organization of the United Nations) has warned about food insecurity in north and east central Burundi and one of the factors causing the precarious situation is declining yam harvests and the losses of cassava crops to the mosaic virus. CMD also affects people already exposed to malnutrition and with limited coping mechanisms. CMD continues to be prevalent in all the main cassava-growing areas in the Great Lakes region of east Africa, causing between 20 and 90 percent crop losses in the Congo. Breeders and relief agencies work together to fight the disease, and the FAO emergency relief and rehabilitation program is engaged in a project to assist vulnerable returnee populations in the African Great Lakes Region through mass propagation and distribution of CMD resistant or highly tolerant cassava planting materials.

A well known occurrence of disease susceptibility in crops lacking diversity concerns the Gros Michel, a seedless banana that saw world marketing in the 1940s. As the market demand became high for this particular species, growers and farmers of the Gros Michel banana began to use this species almost exclusively. Genetically, these bananas are duplicates of every other in their species due to its self-pollinating reproductive style, and because of this lack of genetic diversity, are now virtually extinct due to a single fungus; Panama Disease. This fungus (also known as Fusarium wilt), which infected Gros Michel banana crops in the 1950s, completely wiped out the Gros Michel as the predecessor to the current, and most popular, banana on the market: the Cavendish.

Organizations, technology and solutions

The implications of crop diversity are at both the local and world level, and numerous organizations are emerging with great global backing in response to this ideology. International Plant Genetic Resources Institute (IPGRI – now known as Bioversity International), the International Institute of Tropical Agriculture (ITTA), the Borlaug Global Rust Initiative, and the International Network for Improvement of Banana and Plantain (INIBAP) are a few of the most prominent. Members of the United Nations, at the World Summit on Sustainable Development 2002 at Johannesburg, said that crop diversity is in danger of being lost if measures are not taken. One such step taken in the action against the loss of biodiversity among crops is called gene banking. There are a number of organizations that enlist teams of local farmers to grow native varieties, particularly those that are threatened by extinction due to lack of modern-day use. There are also local, national and international efforts to preserve agricultural genetic resources through ex situ (off-site) methods such as seed and sperm banks for further research and/or crop breeding. Some of the major germplasm storage efforts include:

- The Global Crop Diversity Trust is an independent international organisation which exists to ensure the conservation and availability of crop diversity for food security worldwide. It was established through a partnership between the United Nations Food and Agriculture Organisation (FAO) and the Consultative Group on International Agricultural Research (CGIAR) acting through Bioversity International.

- The Consultative Group on International Agricultural Research (CGIAR) is a consortium of International Agriculture Research Centers (IARC) and others that each conduct research on and preserve germplasm from a particular crop or animal species. The CGIAR holds one of the world's largest off site collections of plant genetic resources in trust for the world community. It contains over 500,000 accessions of more than 3,000 crop, forage, and agro-forestry species. The collection includes farmers' varieties and improved varieties and, in substantial measure, the wild species from which those varieties were created.

- National germplasm storage centers including the U.S. Department of Agriculture's National Center for Genetic Resources Preservation, India's National Bureau of Animal Genetic Resources (NBAGR), the Taiwan Livestock Research Institute, and the Australian Network of Plant Genetic Resource Centers.

- Organizations such as the World Resources Institute (WRI) and the World Conservation Union (IUCN) are non-profit organizations that provide funding and other support to off site and on site conservation efforts. The wise use of crop genetic diversity in plant breeding and genetic modification can also contribute significantly to protecting the biodiversity in crops. Crop varieties with specifically modified genes grow resistances to pests and diseases. One successful example of this is the insertion of the gene from the soil bacterium Bacillus thuringiensis.

- Bacillus thuringiensis (Bt) is a soil bacterium that produces a natural insecticide toxin.

- Genes from Bt can be inserted into crop plants to make them capable of producing an insecticidal toxin and therefore a resistance to certain pests.

- There are no known adverse human health effects associated with Bt corn.

- Bt corn can adversely affect non-target insects if they are closely related to the target pest, as is the case with Monarch butterfly. These adverse effects are considered minor, relative to those associated with the alternative of blanket insecticide applications.

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Chapter- 7

Grafting

Grafted apple tree *Malus* sp., consolidated 'V' graft

Newly grafted cherry tree, tape has been used to bind the rootstock and scion at the graft and tar paint to protect the cut end of the scion from desiccation. The buds will burst within the next few weeks to produce leaves and shoots

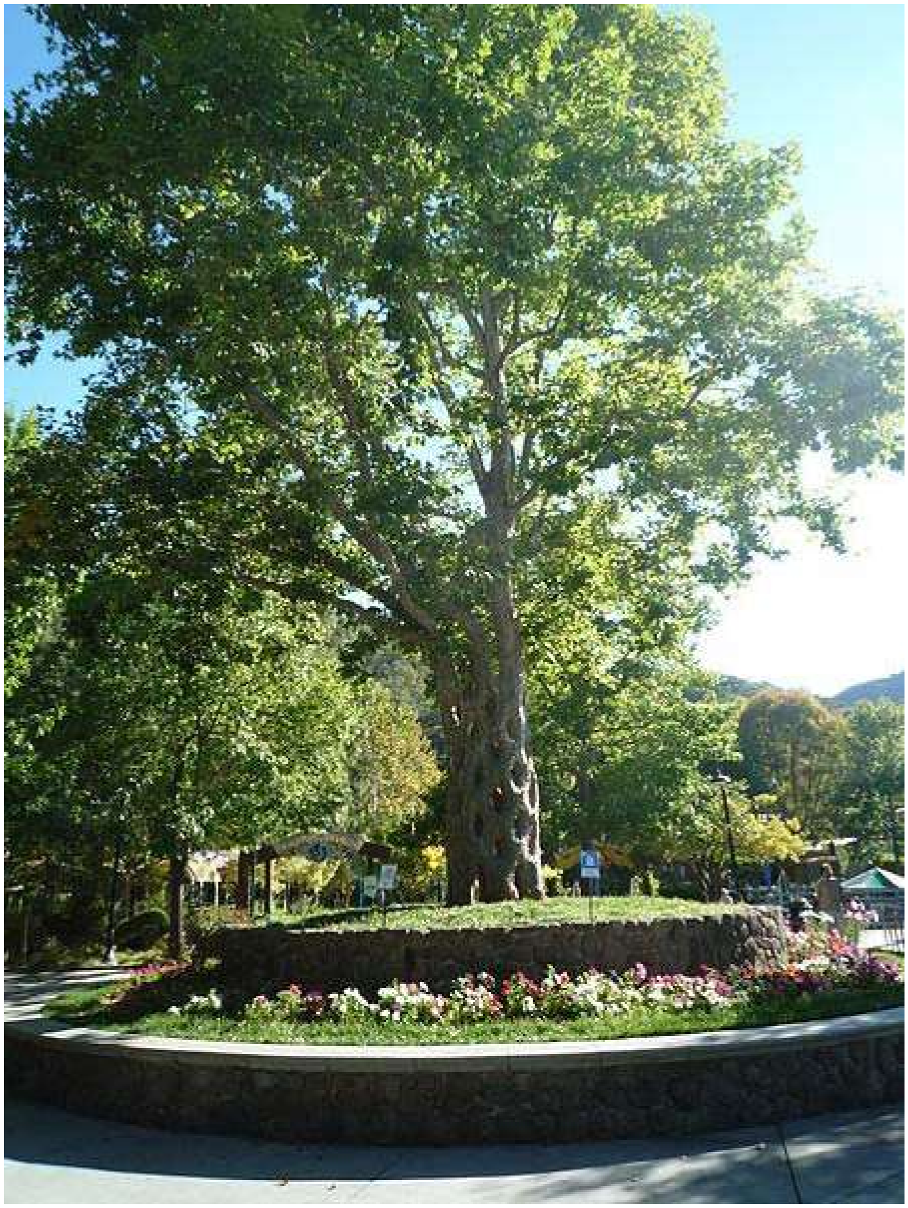
A grafted tree showing two different color blossoms

Grafting is a method of asexual plant propagation widely used in agriculture and horticulture where the tissues of one plant are encouraged to fuse with those of another. It is most commonly used for the propagation of trees and shrubs grown commercially.

In most cases, one plant is selected for its roots, and this is called the **stock** or rootstock. The other plant is selected for its stems, leaves, flowers, or fruits and is called the **scion**. The scion contains the desired genes to be duplicated in future production by the stock/scion plant.

In stem grafting, a common grafting method, a shoot of a selected, desired plant cultivar is grafted onto the stock of another type. In another common form called budding, a dormant side bud is grafted on the stem of another stock plant, and when it has fused successfully, it is encouraged to grow by cutting out the stem above the new bud.

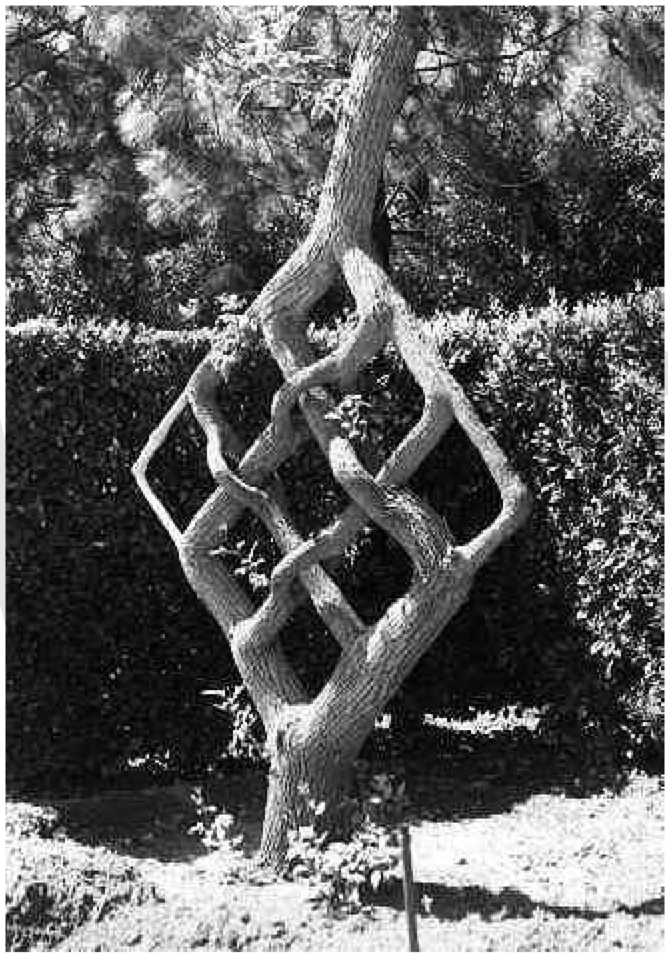
For successful grafting to take place, the vascular cambium tissues of the stock and scion plants must be placed in contact with each other. Both tissues must be kept alive until the graft has taken, usually a period of a few weeks. Successful grafting only requires that a vascular connection take place between the two tissues. A physical weak point often still occurs at the graft, because the structural tissue of the two distinct plants, such as wood, may not fuse.



Advantages

- **Precocity**: The ability to induce fruitfulness without the need for completing the juvenile phase. Juvenility is the natural state through which a seedling plant must pass before it can become reproductive. In most fruiting trees, juvenility may last between 5 and 9 years, but in some tropical fruits e.g. Mangosteen, juvenility may be prolonged for up to 15 years. Grafting of mature scions onto rootstocks can result in fruiting in as little as two years.
- **Dwarfing**: To induce dwarfing or cold tolerance or other characteristics to the scion. Most apple trees in modern orchards are grafted on to dwarf or semi-dwarf trees planted at high density. They provide more fruit per unit of land, higher quality fruit, and reduce the danger of accidents by harvest crews working on ladders.
- **Ease of propagation**: Because the scion is difficult to propagate vegetatively by other means, such as by cuttings. In this case, cuttings of an easily rooted plant are used to provide a rootstock. In some cases, the scion may be easily propagated, but grafting may still be used because it is commercially the most cost-effective way of raising a particular type of plant.
- **Hybrid breeding**: To speed maturity of hybrids in fruit tree breeding programs. Hybrid seedlings may take ten or more years to flower and fruit on their own roots. Grafting can reduce the time to flowering and shorten the breeding program.
- **Hardiness**: Because the scion has weak roots or the roots of the stock plants have roots tolerant of difficult conditions. e.g. many showy Western Australian plants are sensitive to dieback on heavy soils, common in urban gardens, and are grafted onto hardier eastern Australian relatives. Grevilleas and eucalypts are examples.
- **Sturdiness**: To provide a strong, tall trunk for certain ornamental shrubs and trees. In these cases, a graft is made at a desired height on a stock plant with a strong stem. This is used to raise 'standard' roses, which are rose bushes on a high stem, and it is also used for some ornamental trees, such as certain weeping cherries.
- **Pollen source**: To provide pollenizers. For example, in tightly planted or badly planned apple orchards of a single variety, limbs of crab apple may be grafted at regularly spaced intervals onto trees down rows, say every fourth tree. This takes care of pollen needs at blossom time, yet does not confuse pickers who might otherwise mix varieties while harvesting, as the mature crab apples are so distinct from other apple varieties.
- **Repair**: To repair damage to the trunk of a tree that would prohibit nutrient flow, such as stripping of the bark by rodents that completely girdles the trunk. In this case a bridge graft may be used to connect tissues receiving flow from the roots to tissues above the damage that have been severed from the flow. Where a watershoot, basal shoot or sapling of the same species is growing nearby, any of these can be grafted to the area above the damage by a method called inarch grafting. These alternatives to scions must be of the correct length to span the gap of the wound.

- **Changing cultivars**: To change the cultivar in a fruit orchard to a more profitable cultivar, called *topworking*. It may be faster to graft a new cultivar onto existing limbs of established trees than to replant an entire orchard.
- **Maintain consistency**: Apples are notorious for their genetic variability, even differing in multiple characteristics, such as, size, color, and flavor, of fruits located on the same tree. In the commercial farming industry, consistency is maintained by grafting a scion with desired fruit traits onto a hardy stock.



An example of approach grafting by Axel Erlandson.

- **Curiosities**
  - A practice sometimes carried out by gardeners is to graft related potatoes and tomatoes so that both are produced on the same plant, one above ground and one underground.
  - Cacti of widely different forms are sometimes grafted on to each other.
  - Multiple cultivars of fruits such as apples are sometimes grafted on a single tree. This so-called "family tree" provides more fruit variety for small spaces such as a suburban backyard, and also takes care of the need for pollenizers. The drawback is that the gardener must be sufficiently

trained to prune them correctly, or one strong variety will usually "take over".

- Ornamental and functional, tree shaping uses grafting techniques to join separate trees or parts of the same tree to itself. Furniture, hearts, entry archways are examples. Axel Erlandson was a prolific tree shaper who grew over 75 mature specimens.

Techniques

Approach

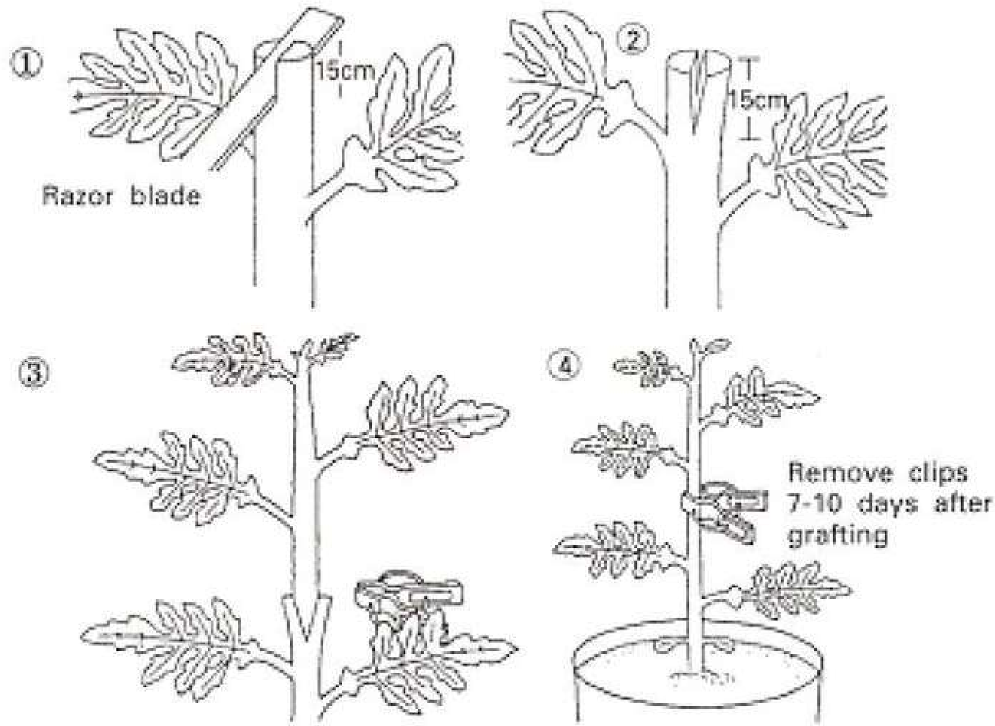
Approach grafting or inarching is used to join together plants that are otherwise difficult to join. The plants are grown close together, and then joined so that each plant has roots below and growth above the point of union. Both scion and stock retain their respective parents that may or may not be removed after joining. Also used in pleaching. The graft can be successfully accomplished any time of year.

Budding

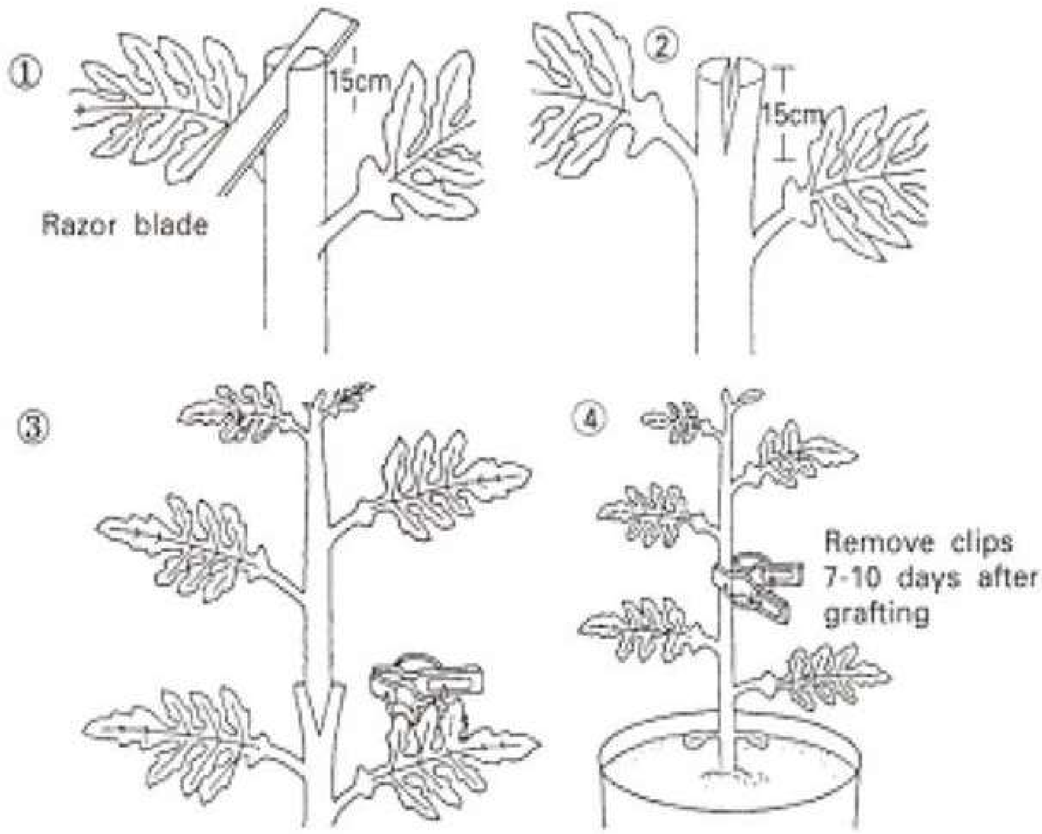
T budding

Grafting with a single eye or bud. Normally performed at the height of the growing season by inserting a dormant bud into a shallow slice under the rind of the tree. The bud is sealed from drying and bound in place. There are many styles of budding depending on the cutting and fitting methods, the most popular being shield budding.

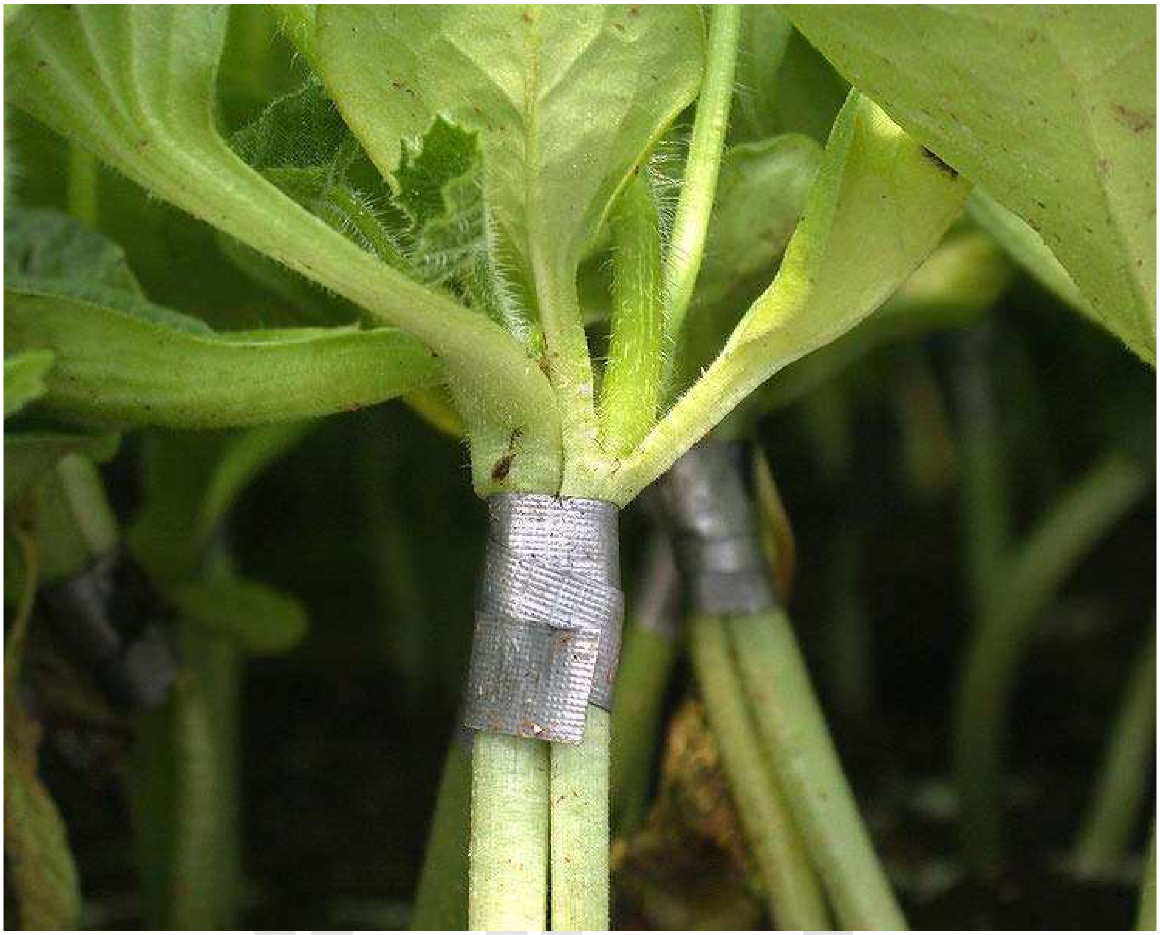
Other budding styles include the inverted T, patch budding, double shield, flute budding and chip budding.



Cleft Grafting – (Source: Oda, 1999)



Cleft Grafting (Source: Oda, 1999)



Cleft

The most common form of grafting is cleft grafting. This is best done in the spring and is useful for joining a thin scion about 1 cm (0.39 in) diameter to a thicker branch or stock. It is best if the latter is 2–7 cm (0.79–2.8 in) in diameter and has 3-5 buds. The branch or stock should be split carefully down the middle to form a cleft about 3 cm (1.2 in) deep. If it is a branch that is not vertical then the cleft should be cut horizontally. The end of the scion should be cut cleanly to a long shallow wedge, preferably with a single cut for each wedge surface, and not whittled. A third cut may be made across the end of the wedge to make it straight across.

Slide the wedge into the cleft so that it is at the edge of the stock and the centre of the wedge faces are against the cambium layer between the bark and the wood. It is preferable if a second scion is inserted in a similar way into the other side of the cleft. This helps to seal off the cleft. Tape around the top of the stock to hold the scion/s in place and cover with grafting wax or sealing compound. This stops the cambium layers from drying out and also prevents the ingress of water into the cleft.

Successful cleft graft after 2 years' growth

Whip

Also known as the whip and tongue graft, this is considered the most difficult to master but has the highest rate of success as it offers the most cambium contact between the 2 species. It is the most common graft used in top-dressing commercial fruit trees. It is generally used with stock less than $\frac{1}{2}$ in (1.3 cm) diameter, with the ideal diameter closer to $\frac{3}{8}$ in (0.95 cm) and the scion should be of roughly the same diameter as the stock.

The stock is cut through on one side only at a shallow angle with a sharp knife. (If the stock is a branch and not the main trunk of the rootstock then the cut surface should face outward from the centre of the tree.) The scion is similarly sliced through at an equal angle starting just below a bud, so that the bud is at the top of the cut and on the other side than the cut face.

Quelle: Deutsche Fotothek

A notch is cut downwards into the sliced face of the stock and a similar cut upwards into the face of the scion cut. These act as the tongues and it requires some skill to make the cuts so that the scion and the stock marry up neatly. The join is then taped around and treated with tree sealing compound or grafting wax.

The elongated "Z" shape adds strength, removing the need for a companion rod in the first season.

Successful whip graft

Successful whip graft needing additional pruning the following season

Stub

Stub grafting is a technique that requires less stock than cleft grafting, and retains the shape of a tree. Also scions are generally of 6-8 buds in this process.

An incision is made into the branch 1 cm (0.39 in) long, then the scion is wedged and forced into the branch. The scion should be at an angle of at most 35° to the parent tree so that the crotch remains strong. The graft is covered with grafting compound.

After the graft has taken, the branch is removed and treated a few cm above the graft, to be fully removed when the graft is strong.

Successful stub graft, healed

Awl

Awl grafting takes the least resources and the least time. It is best done by an experienced grafter, as it is possible to accidentally drive the tool too far into the stock, reducing the scion's chance of survival. Awl grafting can be done by using a screwdriver to make a slit in the bark, not penetrating the cambium layer completely. Then inset the wedged scion into the incision.

Veneer

Veneer grafting, or inlay grafting, is a method used for stocks larger than three centimeters in diameter. The scion is recommended to be about as thick as a pencil. Clefts are made of the same size as the scion on the side of the branch, not on top. The scion end is shaped as a wedge, inserted, and wrapped with tape to the scaffolding branches to give it more strength.

Natural grafting

Possible deliberate grafts on a Sessile Oak in Ayrshire, Scotland

A Husband and Wife tree - Natural grafting in blackthorn Prunus spinosa

Tree branches and more often roots of the same species will sometimes naturally graft, this is called inosculation. When roots make physical contact with each other they often grow together. A group of trees can share water and mineral nutrients via root grafts, which may be advantageous to weaker trees, and may also form a larger rootmass as an adaptation to promote fire resistance and regeneration as exemplified by the California Black Oak (*Quercus kelloggii*).

A problem with root grafts is that they allow transmission of certain pathogens, such as Dutch elm disease. Inosculation also sometimes occurs where two stems on the same tree, shrub or vine make contact with each other. This is common in plants such as strawberries and potatoes.

Graft hybrids

Occasionally, a so-called "graft hybrid" can occur where the tissues of the stock continue to grow within the scion. Such a plant can produce flowers and foliage typical of both plants as well as shoots intermediate between the two. The best-known example this is probably +*Laburnocytisus* 'Adamii', a graft hybrid between laburnum and broom, which originated in a nursery near Paris, France in 1825. This small tree bears yellow flowers typical of *Laburnum anagyroides*, purple flowers typical of *Chamaecytisus purpureus* and curious coppery-pink flowers that show characteristics of both "parents".

Scientific uses

Grafting has been important in flowering research. Leaves or shoots from plants induced to flower can be grafted onto uninduced plants and transmit a floral stimulus that induces them to flower.

The transmission of plant viruses has been studied using grafting. Virus indexing involves grafting a symptom-less plant that is suspected of carrying a virus onto an indicator plant that is very susceptible to the virus.

Herbaceous grafting

Grafting is often done for non-woody and vegetable plants (tomato, cucumber, eggplant and watermelon). Tomato grafting is very popular in Asia and Europe, and is gaining popularity in the United States. The main advantage of grafting is for disease-resistant rootstocks. Researchers in Japan developed automated processes using grafting robots as early as 1987.

Tube Grafting (Source: Rivard and Louws, 2006)

History

Grafting with detached scions has been practiced for thousands of years. It was in use by the Chinese before 2000 B.C and spread to the rest of Eurasia. The practice was almost commonplace in ancient Greece. Without the development of grafting, heterosexual fruit trees such as apples and cherries would never have been domesticated, as their natural sexual reproductive method prevents useful genes from being passed on consistently.

Chapter- 8

Agricultural Machinery

A German combine harvester

Agricultural machinery is machinery used in the operation of an agricultural area or farm.

History

The Industrial Revolution

With the coming of the Industrial Revolution and the development of more complicated machines, farming methods took a great leap forward. Instead of harvesting grain by hand with a sharp blade, wheeled machines cut a continuous swath. Instead of threshing the grain by beating it with sticks, threshing machines separated the seeds from the heads and stalks.

Steam power

Power for agricultural machinery was originally supplied by horses or other domesticated animals. With the invention of steam power came the portable engine, and later the traction engine, a multipurpose, mobile energy source that was the ground-crawling cousin to the steam locomotive. Agricultural steam engines took over the heavy pulling work of horses, and were also equipped with a pulley that could power stationary machines via the use of a long belt. The steam-powered machines were low-powered by today's standards but, because of their size and their low gear ratios, they could provide a large drawbar pull. Their slow speed led farmers to comment that tractors had two speeds: "slow, and darn slow."

Internal combustion engines

The internal combustion engine; first the petrol engine, and later diesel engines; became the main source of power for the next generation of tractors. These engines also contributed to the development of the self-propelled, combined harvester and thresher, or combine harvester (also shortened to 'combine'). Instead of cutting the grain stalks and transporting them to a stationary threshing machine, these combines cut, threshed, and separated the grain while moving continuously through the field.

Types

A 1963 Ford 600 farm truck

Combines might have taken the harvesting job away from tractors, but tractors still do the majority of work on a modern farm. They are used to pull implements—machines that till the ground, plant seed, and perform other tasks.

Tillage implements prepare the soil for planting by loosening the soil and killing weeds or competing plants. The best-known is the plow, the ancient implement that was upgraded in 1838 by John Deere. Plows are now used less frequently in the U.S. than formerly, with offset disks used instead to turn over the soil, and chisels used to gain the depth needed to retain moisture.

The most common type of seeder is called a planter, and spaces seeds out equally in long rows, which are usually two to three feet apart. Some crops are planted by drills, which put out much more seed in rows less than a foot apart, blanketing the field with crops. Transplanters automate the task of transplanting seedlings to the field. With the widespread use of plastic mulch, plastic mulch layers, transplanters, and seeders lay down long rows of plastic, and plant through them automatically.

After planting, other implements can be used to cultivate weeds from between rows, or to spread fertilizer and pesticides. Hay balers can be used to tightly package grass or alfalfa into a storable form for the winter months.

Modern irrigation relies on machinery. Engines, pumps and other specialized gear provide water quickly and in high volumes to large areas of land. Similar types of equipment can be used to deliver fertilizers and pesticides.

Besides the tractor, other vehicles have been adapted for use in farming, including trucks, airplanes, and helicopters, such as for transporting crops and making equipment mobile, to aerial spraying and livestock herd management.

New technology and the future

Though modern harvesters and planters will do a better job than their predecessors, the combine of today still cuts, threshes, and separates grain in essentially the same way it has always been done. However, technology is changing the way that humans operate the machines, as computer monitoring systems, GPS locators, and self-steer programs allow the most advanced tractors and implements to be more precise and less wasteful in the use of fuel, seed, or fertilizer. In the foreseeable future, some agricultural machines will be capable of driving themselves, using GPS maps and electronic sensors to become agricultural robots. Even more esoteric are the new areas of nanotechnology and genetic engineering, where submicroscopic devices and biological processes may be used as machines to perform agricultural tasks.

List of Agricultural Machinery

Traction and power

- Tractor
- Crawler tractor / Caterpillar tractor

Soil cultivation

- Rotavator
- Cultivator
- Cultipacker
- Chisel plow
- Harrow
    - Spike harrow
    - Drag harrow
    - Disk harrow
- Plough
- Power tiller / Rotary tiller / Rototiller

- Spading machine
- Subsoiler
- Two-wheel tractor
- Stone picker (rock picker)
- Rock windrower (rock rake)

Planting

A plough in action in South Africa. Notice the soil being turned over.

- Broadcast seeder (alternately: broadcast spreader or fertilizer spreader)
- Planter (farm implement)
- Plastic mulch layer
- Potato planter
- Seed drill
- Air seeder
- Precision drill
- Transplanter
    - Rice transplanter

Fertilizing & Pest Control

- Fertilizer spreader
- Terragator
- Manure spreader
- Sprayer

Irrigation

- Center pivot irrigation

Produce sorter

- Weight Sorter
- Bulleted list item
- Bulleted list item
- Color Sorter
- Blemish Sorter
- Diameter Sorter
- Shape Sorter
- Density Sorter
- Internal/Taste Sorter

Harvesting / post-harvest

Case IH Module Express 625 picks cotton and simultaneously builds cotton modules.

CTM Johnson Tomato Harvester

- Beet harvester
- Beet cleaner loader
- Bean harvester
- Cane Harvester
- Carrot Puller
- Chaser bin
- Combine harvester
- Conveyor belt
- Corn harvester
- Cotton picker
- Fanning mill
- Farm truck
- Forage harvester (or silage harvester)
- Gleaner
- Grain cleaner
- Gravity wagon
- Haulout Transporter
- Over-the-row mechanical harvester for harvesting apples
- Potato digger
- Potato harvester
- Rice huller
- Sickle
- Sugarcane harvester

- Swather
- Winnower

Hay making

Round baler in action

Loading

A "backhoe loader"
A restored JCB 3C MkII, showing the conventional arrangement of front loader and backhoe

A skid loader with its bucket replaced by backhoe attachment

- Backhoe
- Front end loader
- Skid-steer loader

Milking

- Bulk tank
- Milking machine
- Milking pipeline

Other

TOL Tree Trimmer

- Allen Scythe
- Grain auger
- Feed grinder
- Grain cart
- Conveyor Analyzer
- Chillcuring

Obsolete farm machinery

Steam-powered:

- Stationary steam engine
- Portable engine
- Traction engine
    - Agricultural engine
    - Ploughing engine
    - Steam tractor
- Binder
- Hog oiler
- Reaper
- Threshing machine
- Drag harrow

Chapter- 9

Plough

The traditional way: a farmer works the land with horses and plough

A plough in action in South Africa. This plough has five non-reversible mouldboards. The fifth, empty furrow on the left will be filled by the first furrow of the next pass.

The **plough** is a tool used in farming for initial cultivation of soil in preparation for sowing seed or planting. It has been a basic instrument for most of recorded history, and represents one of the major advances in agriculture. The primary purpose of ploughing is to turn over the upper layer of the soil, bringing fresh nutrients to the surface, while burying weeds and the remains of previous crops, allowing them to break down. It also aerates the soil, and allows it to hold moisture better. In modern use, a ploughed field is typically left to dry out, and is then harrowed before planting.

Ploughs were initially pulled by oxen, and later in many areas by horses (generally draught horses) and mules. In industrialised countries, the first mechanical means of pulling a plough used steam-powered (ploughing engines or steam tractors), but these were gradually superseded by internal-combustion-powered tractors. In the past two decades plough use has reduced in some areas (where soil damage and erosion are problems), in favour of shallower ploughing and other less invasive tillage techniques.

Ploughs are even used under the sea, for the laying of cables, as well as preparing the earth for side-scan sonar in a process used in oil exploration.

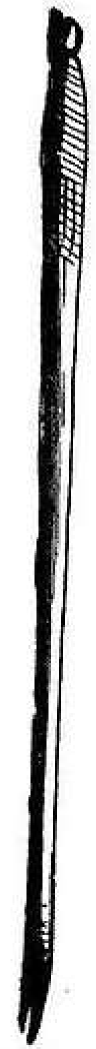
Fig. 18.—Ploughmen.—Fac-simile of a Miniature in a very ancient Anglo-Saxon Manuscript published by Shaw, with legend "God Spede ye Plough, and send us Korne enow."

Ploughing with oxen. A miniature from an early-sixteenth-century manuscript of the Middle English poem *God Spede ye Plough*, held at the British Museum

Etymology

In English, as in other Germanic languages, the plough was traditionally known by other names, e.g. Old English *sulh*, Old High German *medela*, *geiza*, or *huohili*, and Old Norse *arðr*, all presumably referring to the scratch plough.

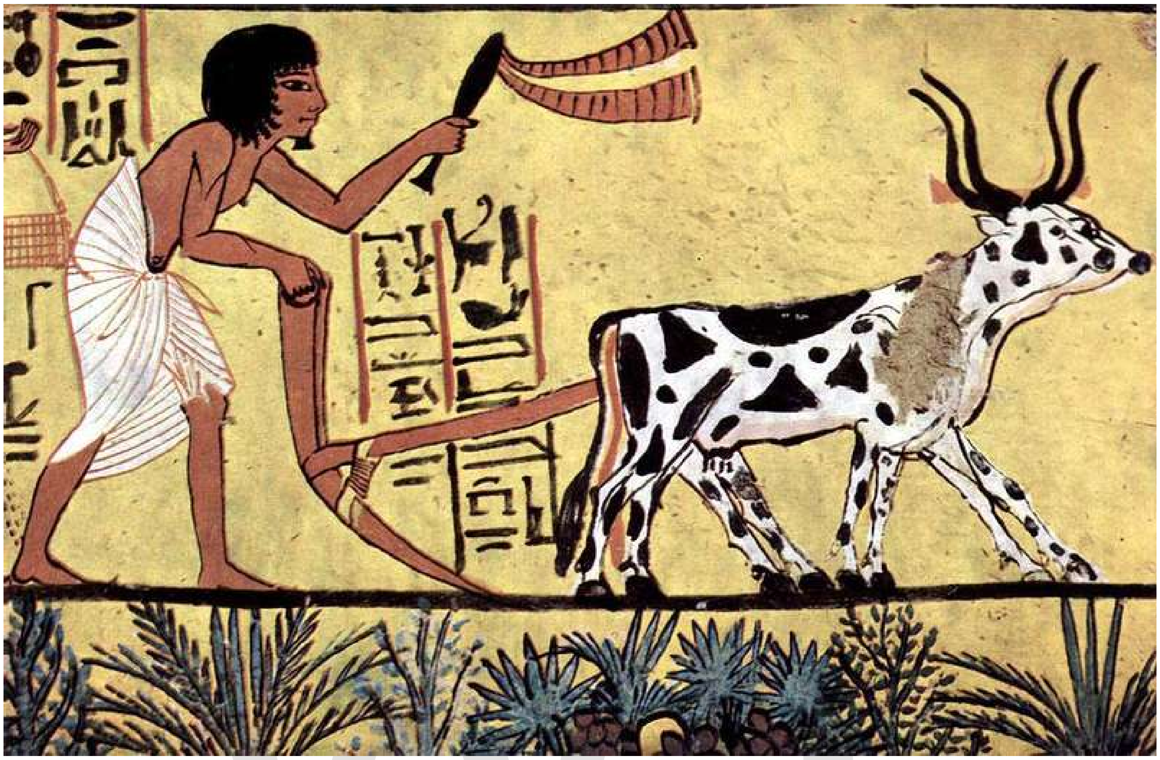
The current word *plough* also comes from English, but it appears relatively late (it is absent from Gothic), and is thought to be a loanword from one of the north Italic languages. In these it had different meanings: in Raetic *plaumorati* (Pliny), and in Latin *plaustrum* "wagon, cart", *plōstrum, plōstellum* "cart", and *plōxenum, plōximum* "cart box".



An aboriginese digging stick

The name "plough" originates from the Proto-Germanic **plōguz* ~ **plōgaz*. According to a questionable etymology, the root of that word comes from the PIE stem **blōkó-*, in which case it would be cognate to Armenian *pelem* "to dig" and Welsh *bwlch* "crack". **Plōguz* could actually be borrowed from the Proto-Slavic **plōgu* "plough", which gave *plugŭ* in Old Slavonic.

History of the plough



Ancient Egyptian plough, circa 1200 B.C.

Ploughing with buffalo in Hubei, China

Hoeing

When agriculture was first developed, simple hand-held digging sticks or hoes would have been used in highly fertile areas, such as the banks of the Nile where the annual flood rejuvenates the soil, to create furrows wherein seeds could be sown. To grow crops regularly in less fertile areas, the soil must be turned to bring nutrients to the surface.

Scratch plough

The domestication of oxen in Mesopotamia and by its contemporary Indus valley civilization, perhaps as early as the 6th millennium BC, provided mankind with the pulling power necessary to develop the plough. The very earliest plough was the simple *scratch-plough*, or *ard*, which consists of a frame holding a vertical wooden stick that was dragged through the topsoil (still used in many parts of the world). It breaks up a strip of land directly along the ploughed path, which can then be planted. Because this form of plough leaves a strip of undisturbed earth between the rows, fields are often cross-ploughed at 90 degree angles, and this tends to lead to squarish fields In the archaeology of northern Europe, such squarish fields are referred to as "Celtic fields".

Crooked ploughs

The Greeks apparently introduced the next major advance in plough design; the crooked plough, which angled the cutting surface forward, leading to the name. The cutting surface was often faced with bronze or (later) iron. Metal was expensive, so in times of war it was melted down or forged to make weapons—or the reverse in more peaceful times. This is presumably the origin of the expression found in the Bible "beat your swords to ploughshares".

Mouldboard plough

Water buffalo used for ploughing in Si Phan Don, Laos.

A major advance in plough design was the *mouldboard plough* (American spelling: *moldboard plow*), which aided the cutting blade. The *coulter*, *knife* or *skeith* cuts vertically into the ground just ahead of the *share* (or *frog*) a wedge-shaped surface to the front and bottom of the *mouldboard* with the landside of the frame supporting the below-ground components. The upper parts of the frame carries (from the front) the coupling for the motive power (horses), the coulter and the landside frame. Depending on the size of the implement, and the number of furrows it is designed to plough at one time, there is a wheel or wheels positioned to support the frame. In the case of a single-furrow plough there is only one wheel at the front and handles at the rear for the ploughman to steer and manoeuvre it.

When dragged through a field the coulter cuts down into the soil and the share cuts horizontally from the previous furrow to the vertical cut. This releases a rectangular strip of sod that is then lifted by the share and carried by the mouldboard up and over, so that the strip of sod (slice of the topsoil) that is being cut lifts and rolls over as the plough moves forward, dropping back to the ground upside down into the furrow and onto the turned soil from the previous run down the field. Each gap in the ground where the soil has been lifted and moved across (usually to the right) is called a *furrow*. The sod that has been lifted from it rests at about a 45 degree angle in the next-door furrow and lies up the back of the sod from the previous run.

In this way, a series of ploughing runs down a field leaves a row of sods that lie partly in the furrows and partly on the ground lifted earlier. Visually, across the rows, there is the land (unploughed part) on the left, a furrow (half the width of the removed strip of soil) and the removed strip almost upside-down lying on about half of the previous strip of inverted soil, and so on across the field. Each layer of soil and the gutter it came from forms the classic furrow.

The mouldboard plough greatly reduced the amount of time needed to prepare a field, and as a consequence, allowed a farmer to work a larger area of land. In addition, the resulting pattern of low (under the mouldboard) and high (beside it) ridges in the soil forms water channels, allowing the soil to drain. In areas where snow buildup is an issue, this allows the soil to be planted earlier as the snow runoff is drained away more quickly.

A reconstruction of a mould board plough.

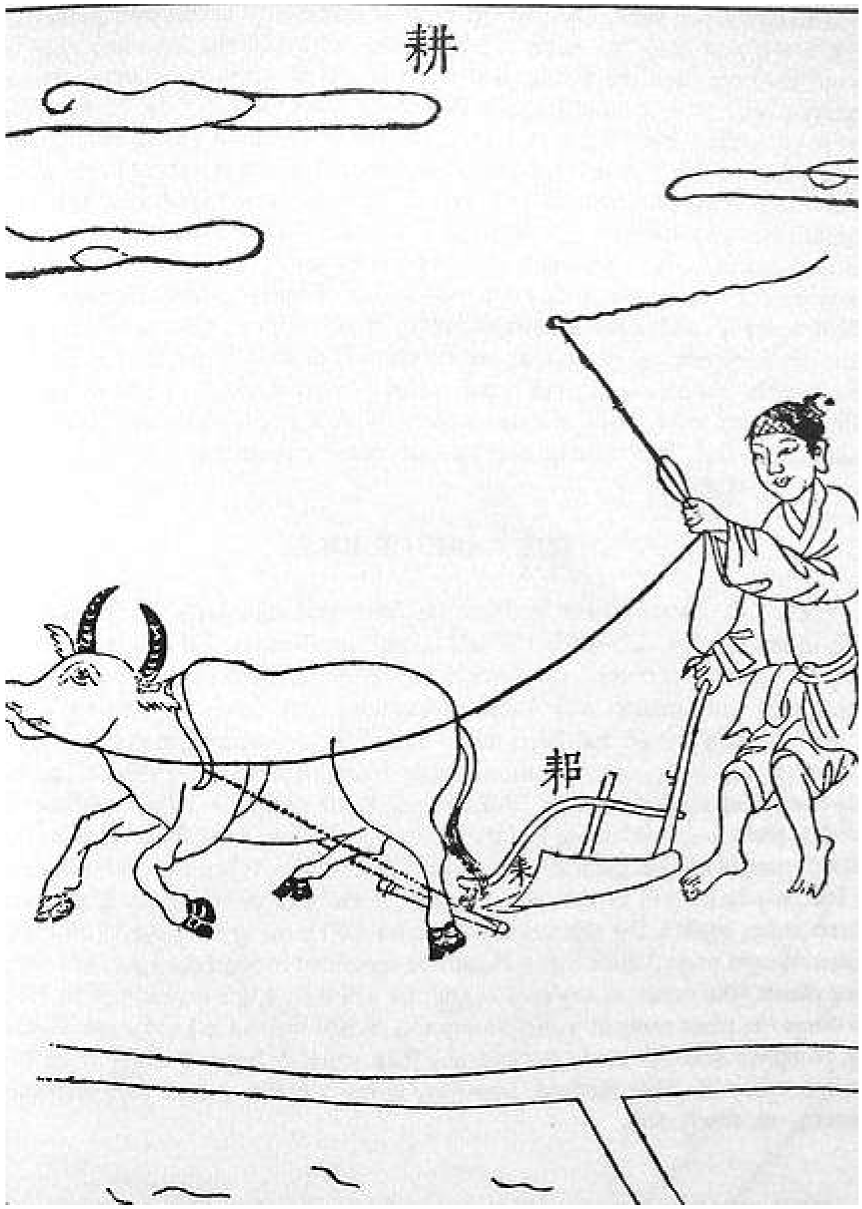
Parts of a mouldboard plough: There are 5 major parts of a mouldboard plough

1. Mouldboard
2. Share
3. Landside
4. Frog
5. Tailpiece

A *runner* extending from behind the share to the rear of the plough controls the direction of the plough, because it is held against the bottom land-side corner of the new furrow being formed. The holding force is the weight of the sod, as it is raised and rotated, on the curved surface of the mouldboard. Because of this runner, the mouldboard plough is harder to turn around than the scratch plough, and its introduction brought about a change in the shape of fields—from mostly square fields into longer rectangular "strips" (hence the introduction of the furlong).

An advance on the basic design was the *iron ploughshare*, a replaceable horizontal cutting surface mounted on the tip of the share. The earliest iron ploughshares date from around 1000 BC in the Ancient Near East, and from ca. 500 BC in China. Early mouldboards were basically wedges that sat inside the cut formed by the coulter, turning over the soil to the side. The ploughshare spread the cut horizontally below the surface, so when the mouldboard lifted it, a wider area of soil was turned over. Mouldboards are known in Britain from the late 6th century on.

Heavy ploughs



Chinese iron plough with curved mouldboard, 1637.

In the basic mouldboard plough the depth of the cut is adjusted by lifting against the runner in the furrow, which limited the weight of the plough to what the ploughman could easily lift. This limited the construction to a small amount of wood (although metal edges were possible). These ploughs were fairly fragile, and were not suitable for breaking up the heavier soils of northern Europe. The introduction of wheels to replace the runner allowed the weight of the plough to increase, and in turn allowed the use of a much larger mouldboard faced in metal. These *heavy ploughs* led to greater food production and eventually a significant population increase around 600 AD.

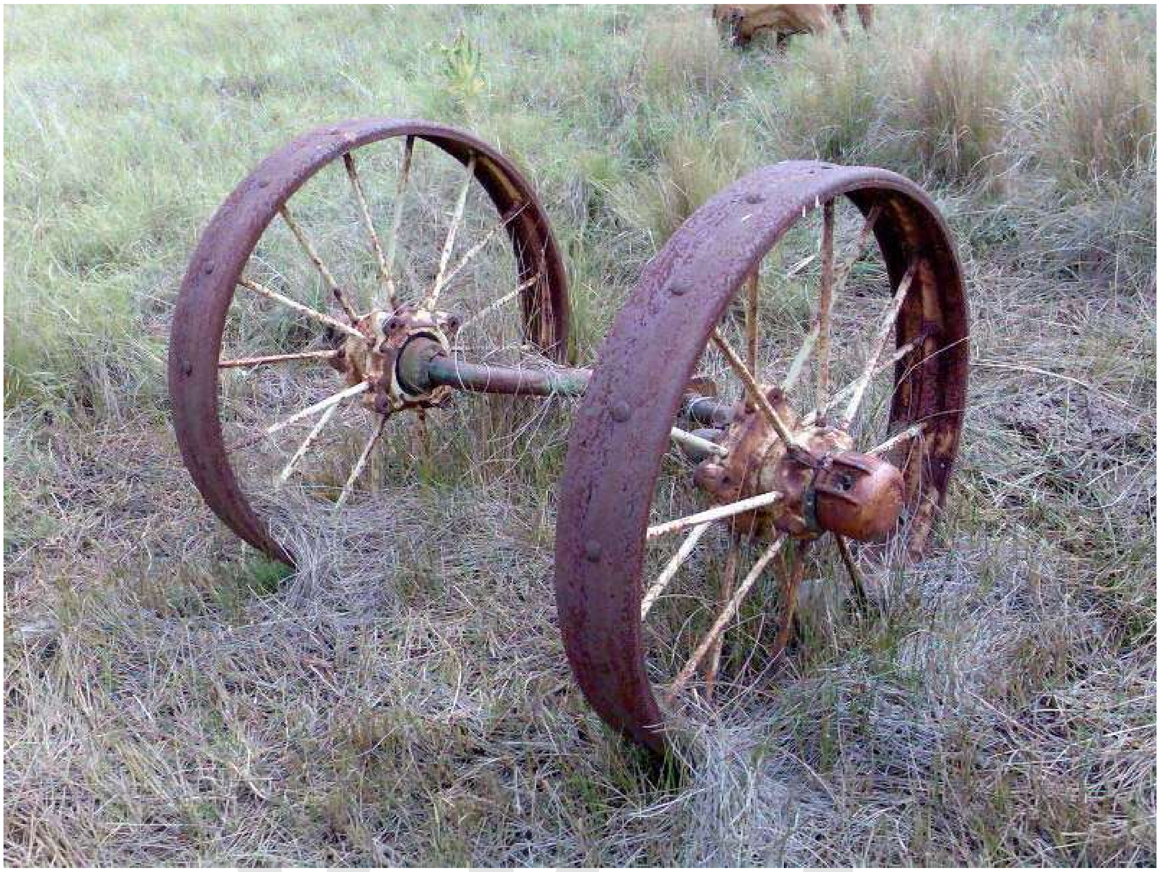
Before the Han Dynasty (202 BC–220 AD), Chinese ploughs were made almost entirely of wood, spare the iron blade of the ploughshare. By the Han period, the entire ploughshare was made of cast iron; these are the first known heavy moldboard iron ploughs.

The Romans achieved the heavy wheeled mouldboard plough in the late 3rd and 4th century AD, when archaeological evidence appears, inter alia, in Roman Britain. The first indisputable appearance after the Roman period is from 643, in a northern Italian document. Old words connected with the heavy plough and its use appear in Slavic, suggesting possible early use in this region. The general adoption of the mouldboard plough in Europe appears to have accompanied the adoption of the three-field system in the later eighth and early ninth centuries, leading to an improvement of the agricultural productivity per unit of land in northern Europe.

Research by the French historian Marc Bloch in medieval French agricultural history showed the existence of names for two different ploughs, "the *araire* was wheel-less and had to be dragged across the fields, while the *charrue* was mounted on wheels".

Improved designs

'A Champion ploughman', from Australia, circa 1900



A pair of metal wheels from a plough on a farm near Dordrecht, Eastern Cape.

The basic plough with coulter, ploughshare and mouldboard remained in use for a millennium. Major changes in design did not become common until the Age of Enlightenment, when there was rapid progress in design. Chinese ploughs, with mouldboard, were brought to Holland in the seventeenth century by Dutch sailors. And because Dutchmen were hired by the English to drain the East Anglian fens and Somerset moors at that time, they brought with them their Chinese ploughs. The English called these Chinese ploughs the 'bastard Dutch ploughs' instead of 'Chinese ploughs'. Thus, the Dutch and the English were the first to enjoy the efficient Chinese ploughs for the first time in Europe. The Chinese-style ploughs were spread to Scotland from England, and from Holland to America and France. Joseph Foljambe in Rotherham, England, in 1730 used these new shapes as the basis for the Rotherham plough, which also covered the mouldboard with iron. Unlike the heavy plough, the Rotherham (or Rotherham swing) plough consisted entirely of the coulter, mouldboard and handles. It was much lighter than conventional designs and became very popular in England. It may have been the first plough to be widely built in factories.

James Small further improved the design. Using mathematical methods he experimented with various designs until he arrived at a shape cast from a single piece of iron, the *Scots plough*. A single-piece cast iron plough was also developed and patented by Charles Newbold in the United States. This was again improved on by Jethro Wood, a blacksmith of Scipio, New York, who made a three-part Scots Plough that allowed a broken piece to be replaced. In 1837 John Deere introduced the first steel plough; it was much stronger than iron designs that it was able to work the soil in areas of the US that had earlier been considered unsuitable for farming. Improvements on this followed developments in metallurgy; steel coulters and shares with softer iron mouldboards to prevent breakage, the *chilled plough* which is an early example of surface-hardened steel, and eventually the face of the mouldboard grew strong enough to dispense with the coulter.

Single-sided ploughing

Single-sided ploughing in a ploughing match.

The first mouldboard ploughs could only turn the soil over in one direction (conventionally always to the right), as dictated by the shape of the mouldboard, and so the field had to be ploughed in long strips, or *lands*. The plough was usually worked clockwise around each land, ploughing the long sides and being dragged across the short sides without ploughing. The length of the strip was limited by the distance oxen (or later horses) could comfortably work without a rest, and their width by the distance the plough could conveniently be dragged. These distances determined the traditional size of the strips: a furlong, (or "furrow's length", 220 yards (200 m)) by a chain (22 yards (20 m))—an area of one acre (about 0.4 hectares); this is the origin of the acre. The one-sided action gradually moved soil from the sides to the centre line of the strip. If the strip was in the same place each year, the soil built up into a ridge, creating the ridge and furrow topography still seen in some ancient fields.

Turnwrest plough

The turnwrest plough allows ploughing to be done to either side. The mouldboard is removable, turning to the right for one furrow, then being moved to the other side of the plough to turn to the left (the coulter and ploughshare are fixed). In this way adjacent furrows can be ploughed in opposite directions, allowing ploughing to proceed continuously along the field and thus avoiding the ridge and furrow topography.

Reversible plough

A four-furrow reversible plough.

The reversible plough has two mouldboard ploughs mounted back-to-back, one turning to the right, the other to the left. While one is working the land, the other is carried upside-down in the air. At the end of each row, the paired ploughs are turned over, so the other can be used. This returns along the next furrow, again working the field in a consistent direction.

Riding and multiple-furrow ploughs

Horse-drawn, two-furrow plough.

Early steel ploughs, like those for thousands of years prior, were *walking ploughs*, directed by the ploughman holding onto handles on either side of the plough. The steel ploughs were so much easier to draw through the soil that the constant adjustments of the blade to react to roots or clods was no longer necessary, as the plough could easily cut through them. Consequently it was not long after that the first *riding ploughs* appeared. On these, wheels kept the plough at an adjustable level above the ground, while the ploughman sat on a seat where he would have earlier walked. Direction was now controlled mostly through the draught team, with levers allowing fine adjustments. This led very quickly to riding ploughs with multiple mouldboards, dramatically increasing ploughing performance.

A single draught horse can normally pull a single-furrow plough in clean light soil, but in heavier soils two horses are needed, one walking on the land and one in the furrow. For ploughs with two or more furrows more than two horses are needed and, usually, one or more horses have to walk on the loose ploughed sod—and that makes hard going for them, and the horse treads the newly ploughed land down. It is usual to rest such horses every half hour for about ten minutes.

Heavy volcanic loam soils, such as are found in New Zealand, require the use of four heavy draught horses to pull a double-furrow plough. Where paddocks are more square than long-rectangular it is more economical to have horses four wide in harness than two-by-two ahead, thus one horse is always on the ploughed land (the sod). The limits of strength and endurance of horses made greater than two-furrow ploughs uneconomic to use on one farm.

Amish farmers tend to use a team of about seven horses or mules when spring ploughing and as Amish farmers often help each other plough, teams are sometimes changed at noon. Using this method about 10 acres (40,000 m^2) can be ploughed per day in light soils and about 2 acres (8,100 m^2) in heavy soils.

Steam ploughing

A German balance plough. The left-turning set of shares have just completed a pass, and the right-turning shares are about to enter the ground to return across the field.

Ploughing engine *Heumar*, made by the Ottomayer company (Germany), used in pairs with a balance plough.
Built 1929, 220 PS, 21 tons.

The advent of the mobile steam engine allowed steam power to be applied to ploughing from about 1850. In Europe, soil conditions were often too soft to support the weight of heavy traction engines. Instead, counterbalanced, wheeled ploughs, known as *balance ploughs*, were drawn by cables across the fields by pairs of ploughing engines which worked along opposite field edges. The balance plough had two sets of ploughs facing each other, arranged so when one was in the ground, the other set was lifted into the air. When pulled in one direction the trailing ploughs were lowered onto the ground by the tension on the cable. When the plough reached the edge of the field, the opposite cable was pulled by the other engine, and the plough tilted (balanced), putting the other set of shares into the ground, and the plough worked back across the field.

One set of ploughs was right-handed, and the other left-handed, allowing continuous ploughing along the field, as with the turnwrest and reversible ploughs. The man credited with the invention of the ploughing engine and the associated balance plough, in the mid nineteenth century, was John Fowler, an English agricultural engineer and inventor.

In America the firm soil of the Plains allowed direct pulling with steam tractors, such as the big Case, Reeves or Sawyer Massey breaking engines. Gang ploughs of up to fourteen bottoms were used. Often these big ploughs were used in regiments of engines, so that in a single field there might be ten steam tractors each drawing a plough. In this way hundreds of acres could be turned over in a day. Only steam engines had the power to draw the big units. When internal combustion engines appeared, they had neither the strength nor the ruggedness compared to the big steam tractors. Only by reducing the number of shares could the work be completed.

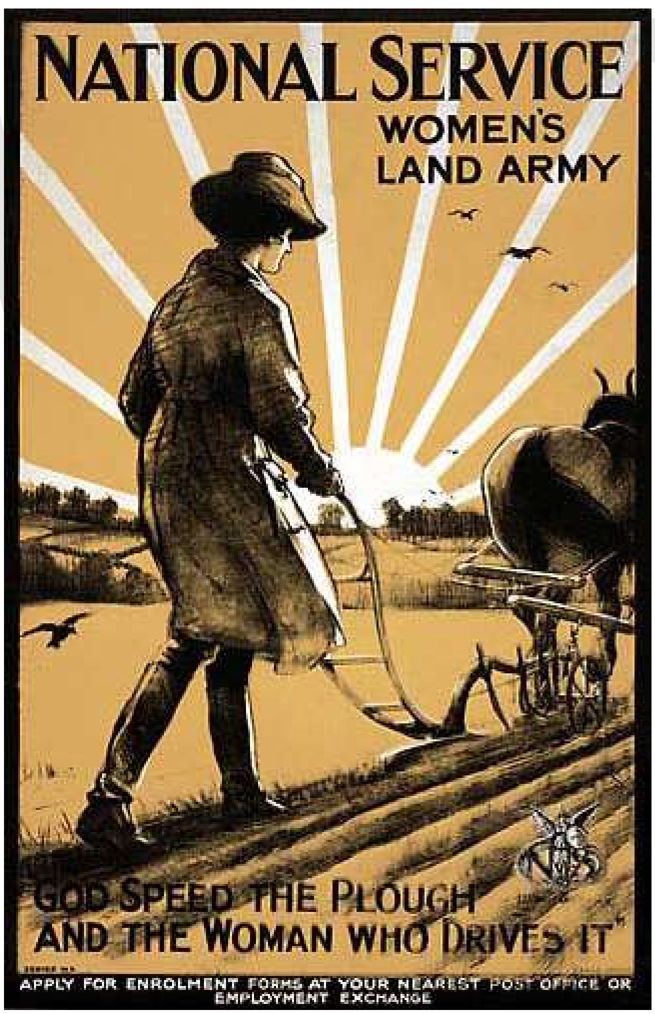
Stump-jump plough

Disc ploughs in Australia, circa 1900

The Stump-jump plough was an Australian invention of the 1870s, designed to cope with the breaking up of new farming land, that contains many tree stumps and rocks that would be very expensive to remove. The plough uses a moveable weight to hold the ploughshare in position. When a tree stump or other obstruction such as a rock is encountered, the ploughshare is thrown upwards, clear of the obstacle, to avoid breaking the plough's harness or linkage; ploughing can be continued when the weight is returned to the earth after the obstacle is passed.

A simpler system, developed later, uses a concave disc (or a pair of them) set at a large angle to the direction of progress, that uses the concave shape to hold the disc into the soil—unless something hard strikes the circumference of the disk, causing it to roll up and over the obstruction. As the arrangement is dragged forward, the sharp edge of the disc cuts the soil, and the concave surface of the rotating disc lifts and throws the soil to the side. It doesn't make as good a job as the mouldboard plough (but this is not considered a disadvantage, because it helps fight the wind erosion), but it does lift and break up the soil.

Modern ploughs



A British woman ploughing on a World War One recruitment poster for the Women's Land Army.

Modern ploughs are usually multiple reversible ploughs, mounted on a tractor via a three-point linkage. These commonly have between two and as many as seven mouldboards—and *semi-mounted* ploughs (the lifting of which is supplemented by a wheel about half-way along their length) can have as many as eighteen mouldboards. The hydraulic system of the tractor is used to lift and reverse the implement, as well as to adjust furrow width and depth. The ploughman still has to set the draughting linkage from the tractor so that the plough is carried at the proper angle in the soil. This angle and depth can be controlled automatically by modern tractors. As a complement to the rear plough a two or three mouldboards-plough can be mounted on the front of the tractor if it is equipped with front three-point linkage.

Specialist ploughs

Chisel plough

The *chisel plough* is a common tool to get deep tillage (prepared land) with limited soil disruption. The main function of this plough is to loosen and aerate the soils while leaving crop residue at the top of the soil. This plough can be used to reduce the effects of compaction and to help break up ploughpan and hardpan. Unlike many other ploughs the chisel will not invert or turn the soil. This characteristic has made it a useful addition to no-till and low-till farming practices which attempt to maximise the erosion-prevention benefits of keeping organic matter and farming residues present on the soil surface through the year. Because of these attributes, the use of a chisel plough is considered by some to be more sustainable than other types of plough, such as the mouldboard plough.

A modern John Deere 8110 Farm Tractor using a chisel plough.

Bigham Brother Tomato Tiller

The chisel plough is typically set to run up to a depth of eight to twelve inches (200 to 300 mm). However some models may run much deeper. Each of the individual ploughs, or shanks, are typically set from nine inches (229 mm) to twelve inches (305 mm) apart. Such a plough can encounter significant soil drag, consequently a tractor of sufficient power and good traction is required. When planning to plough with a chisel plough it is important to bear in mind that 10 to 15 horsepower (7 to 11 kW) per shank will be required.

Cultivators are often similar in form to chisel ploughs, but their goals are different. Cultivator teeth work near the surface, usually for weed control, whereas chisel plow shanks work deep beneath the surface. Consequently, cultivating also takes much less power per shank than does chisel plowing.

Ridging plough

A ridging plough is used for crops, such as potatoes or scallions, which are grown buried in ridges of soil using a technique called *ridging* or *hilling*. A ridging plough has two mouldboards facing away from each other, cutting a deep furrow on each pass, with high ridges either side. The same plough may be used to split the ridges to harvest the crop.

Scottish Hand Plough

A variety of ridge plough, notable in that the blade points towards the operator. This is for use solely by human effort rather than animal or machine assistance. As such it is pulled backwards by the operator, requiring great physical effort. Particularly used for second breaking of ground, and for potato planting. Found in Shetland, some western crofts and more rarely Central Scotland. The tool epitomises a small-holding too small or poor to merit use of animals.

Mole plough

The *mole plough* or *subsoiler* allows underdrainage to be installed without trenches, or it breaks up deep impermeable soil layers which impede drainage. It is a very deep plough, with a torpedo-shaped or wedge-shaped tip, and a narrow blade connecting this to the body. When dragged through the ground, it leaves a channel deep under the ground, and this acts as a drain. Modern mole ploughs may also bury a flexible perforated plastic drain pipe as they go, making a more permanent drain—or they may be used to lay pipes for water supply or other purposes.

Advantages of the mouldboard plough

Mouldboard ploughing, in cold and temperate climates, no deeper than 20 cm, aerates the soil by loosening it. It incorporates crop residues, solid manures, limestone and commercial fertilizers along with some oxygen. By doing so, it reduces nitrogen losses by volatilization, accelerates mineralization and increases short-term nitrogen availability for transformation of organic matter into humus. It erases wheel tracks and ruts caused by harvesting equipment. It controls many perennial weeds and pushes back the growth of other weeds until the following spring. It accelerates soil warming and water evaporation in spring because of the lesser quantity of residues on the soil surface. It facilitates seeding with a lighter seeder. It controls many enemies of crops (slugs, crane flies, seedcorn maggots-bean seed flies, borers). It increases the number of "soil-eating" earthworms (endogea) but is detrimental to vertical-dwelling earthworms (anecic).

Disadvantages of the mouldboard plough

Over-ploughing can lead to the formation of hardpan. Typically farmers break up hardpan up with a subsoiler, which acts as a long, sharp knife to slice through the hardened layer of soil deep below the surface. Soil erosion due to improper land and plough utilization is possible. Contour ploughing mitigates soil erosion by ploughing across a slope, along elevation lines. Alternatives to ploughing, such as the no till method, have the potential to actually build soil levels and humus, and may be suitable to smaller, more intensively cultivated plots, and to farming on poor, shallow or degraded soils which will only be further damaged by ploughing.

Plough parts

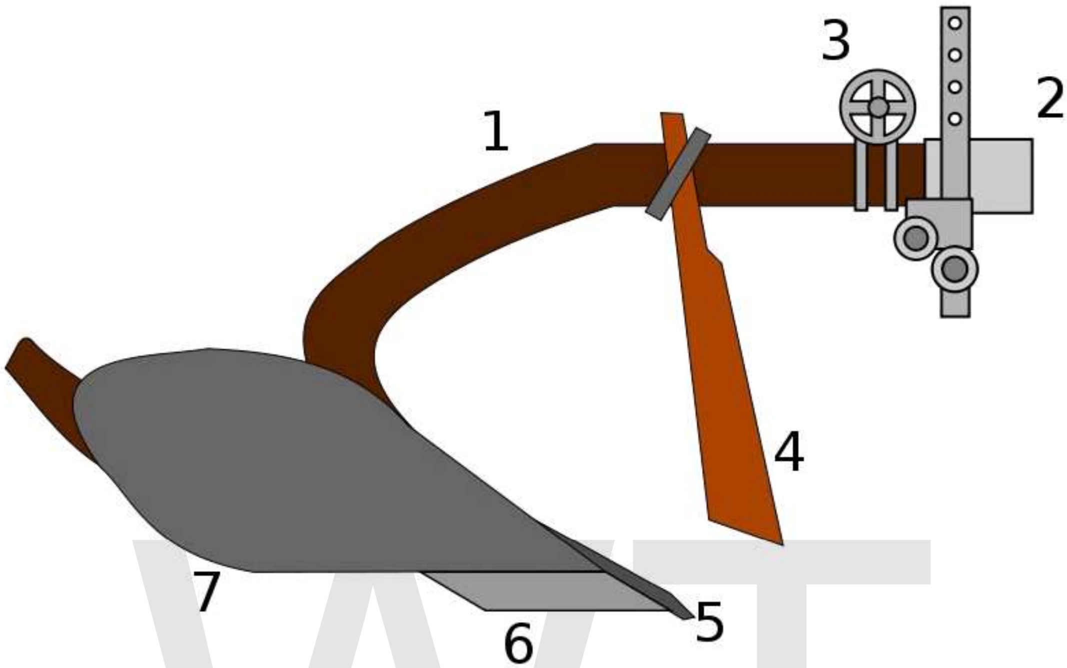


Image of a contemporary plough

The picture to the right illustrates the following parts of a plough (numbering matches parts on the image):

1. Frame
2. Three point attach
3. Height regulator
4. Knife or coulter
5. Chisel
6. Share, also called the ploughshare
7. Mouldboard

Other portions include the frog, runner, landside, shin, trashboard and handles.

On modern ploughs and some older ploughs, the mouldboard is separate from the share and runner, allowing these parts to be replaced without replacing the mouldboard. Abrasion eventually destroys all parts of a plough that contact the soil.

Chapter- 10

Rotary Tiller

F210 Honda tiller

A **rotary tiller**, also known as a **rototiller**, **rotavator**, **rotary hoe**, **power tiller**, or **rotary plough** (in US: plow), is a motorised cultivator that works the soil by means of rotating tines or blades. Rotary tillers are either self-propelled or drawn as an attachment behind either a two-wheel tractor or four-wheel tractor. For two-wheel tractors they are rigidly fixed and powered via couplings to the tractors' transmission. For four-wheel tractors they are attached by means of a three-point hitch and driven by a power take-off (PTO).

In some parts of the world, the term "power tiller" can encompass the larger and similar appearing *two-wheeled tractor,* a machine which does, however, operate different attachments; in most English-speaking regions this difference is considered more rigid, as the term power tiller refers solely to devices with soil cultivation as their primary and often only function.

Origin

Tines close-up

The powered rotary hoe was invented by Arthur Clifford Howard who, in 1912, began experimenting with rotary tillage on his father's farm at Gilgandra, New South Wales, Australia. Initially using his father's steam tractor engine as a power source, he found that ground could be mechanically tilled without soil-packing occurring, as was the case with normal ploughing. His earliest designs threw the tilled soil sideways, until he improved his invention by designing an L-shaped blade mounted on widely spaced flanges fixed to a small-diameter rotor. With fellow apprentice Everard McCleary, he established a company to make his machine, but plans were interrupted by World War I. In 1919 Howard returned to Australia and resumed his design work, patenting a design with 5 rotary hoe cultivator blades and an internal combustion engine, in 1920.

In March 1922, Howard formed the company Austral Auto Cultivators Pty Ltd, which later became known as Howard Auto Cultivators. It was based in Northmead, a suburb of Sydney, from 1927. Finding it increasingly difficult to meet a growing worldwide demand, Howard travelled to the United Kingdom, founding the company Rotary Hoes Ltd in East Horndon, Essex, in July 1938. Branches of this new company subsequently opened in the United States of America, South Africa, Germany, France, Italy, Spain, Brazil, Malaysia, Australia and New Zealand. It later became the holding company for Howard Rotavator Co. Ltd. The Howard Group of companies was acquired by the Danish Thrige Agro Group in 1985, and in December 2000 the Howard Group became a member of Kongskilde Industries of Soroe, Denmark.

Self-propelled small rotary tillers

A small rotary hoe for domestic gardens was known by the trademark **Rototiller** and another, made by the Howard Group, who produced a range of rotary tillers, was known as the **Rotavator**.

The Rototiller

Rotary tillers are popular with home gardeners who want large vegetable gardens. The garden may be tilled a few times before planting each crop. Rotary tillers may be rented from tool rental centers for single-use applications, such as when planting grass.

The small **rototiller** is typically propelled forward via a (1 - 5 horsepower or 0.8 - 3.5 kilowatts) petrol engine rotating the tines, and do not have powered wheels, though they may have small transport/level control wheel(s). To keep the machine from moving forward too fast, an adjustable tine is usually fixed just behind the blades so that through friction with deeper un-tilled soil, it acts as a brake, slowing the machine and allowing it to pulverize the soils. The slower a rototiller moves forward, the more soil tilth can be obtained. The operator can control the amount of friction/braking action by raising and lowering the handlebars of the tiller. Rototillers do not have a reverse as such backwards movement towards the operator could cause serious injury. While operating, the rototiller can be pulled backwards to go over areas that were not pulverized enough, but care must be taken to ensure that the operator does not stumble and pull the rototiller on top of himself. Rototilling is much faster than manual tilling, but notoriously difficult to handle and exhausting work, especially in the heavier and higher horsepower models. If the rototiller's blades catch on unseen subsurface objects, such as tree roots and buried garbage, it can cause the rototiller to abruptly and violently move in any direction.

The Rotavator

Unlike the Rototiller, the self propelled **Howard Rotavator** is equipped with a gearbox and driven forward, or held back, by its wheels. The gearbox enables the forward speed to be adjusted while the rotational speed of the tines remains constant which enables the operator to easily regulate the extent to which soil is engaged. For a two-wheel tractor rotavator this greatly reduces the workload of the operator as compared to a rototiller. These rotavators are generally more heavy duty, come in higher power (4-18 horsepower or 3-13 kilowatts) with either petrol or diesel engines and can cover much more area per hour.

The trademarked word "Rotavator" is one of the longest single-word palindromes in the English language.

Agricultural rotary tillers

Diesel Mini Tiller Mini tillers are a new type of small agricultural tillers or cultivators used by farmers or homeowners. These are also known as *power tillers* or *Garden Tillers* . They are powered by diesel fuel, not gasoline. They have multiple function with related tools for dryland or paddy field, pumping, transportation, threshing, ditching, spraying pesticide. They can be used on hills, mountains, in greenhouses and orchards. They are more popular in developing countries than gasoline Mini Tillers.

A Japanese two-wheel tractor.

Two-wheel tractor The higher power "riding" rotavators cross out of the home garden category into farming category, especially in Asia, Africa and South America, capable of preparing 1 hectare of land in 8 – 10 hours. These are also known as *power tillers*, *walking tractors* or *two-wheel tractors*. Years ago they were considered only useful for rice growing areas, where they were fitted with steel cage-wheels for traction, but now the same are being used in both wetland and dryland farming all over the world. Compact, powerful and, most importantly, inexpensive, these agricultural rotary tillers are providing alternatives to four-wheel tractors and in the small farmers' fields in developing countries are more economical than four-wheel tractors.

Four-wheel tractor Four-wheel tractor-drawn rotary tillers are attached to the three-point linkage, and are driven by a power take-off shaft. Generally considered a secondary tillage implement, they are commonly used for primary tillage in lighter soils instead of plowing. They are commonly termed power harrow or a rotavator in some markets. They also can also be used for cultivation between rows of vines, etc. The largest versions are now available in a 6m width, and require a tractor with a 150+ hp PTO to drive them.

Other uses

- Rotary tillers can also be used for road-making.
- Beginning in the 1970s or 1980s, hand operated rototillers were modified to clean the exterior of oilfield pipes. These pipes, either new or used, and in sizes that are just over 2 inches (51 mm) in diameter to 30 inches (760 mm) or larger, were used in the exploration, drilling and production of oil wells. These modified tools replaced cleaning using hand tools, and were ultimately supplanted within a few years by machinery that cleaned entire pipe lengths. The modification replaced the tines with wire brushes. The tool was used by a man walking the length of a pipe (typically 30 or 40 feet), which was rotated.

Chapter- 11

Cultivator & Harrow (Tool)

Cultivator

1949 Farmall C with C-254-A two-row cultivator.

A **cultivator** is a farm implement for secondary tillage, that is, stirring and pulverizing the soil, either before planting (to aerate the soil and prepare a smooth, loose seedbed) or after the crop has begun growing (to kill weeds). **Cultivation** in the general sense of the word is agriculture itself, but within agriculture the word has a narrower technical sense referring to tillage, and most especially to controlled disturbance of the topsoil close to the crop plants to kill the surrounding weeds (by uprooting them, burying their leaves to disrupt their photosynthesis, or a combination of both). Unlike a harrow, which disturbs the entire surface of the soil, **cultivator teeth** or **shanks** disturb the soil in careful patterns, disturbing the weeds and leaving the crop intact. (This pattern is also useful at the very start of the growing season, for forming the rows that the seeds will be planted in).

Cultivators are often similar in form to chisel plows, but their goals are different. Cultivator teeth work near the surface, usually for weed control, whereas chisel plow shanks work deep beneath the surface, breaking up hardpan. Consequently, cultivating also takes much less power per shank than does chisel plowing.

The basic idea of soil scratching for weed control is ancient and was done with hoes or mattocks for millennia before cultivators were developed. Cultivators were originally drawn by draft animals (such as horses, mules, or oxen) or were pushed or drawn by people. In modern commercial agriculture, the amount of cultivating done for weed control has been greatly reduced via use of herbicides instead. However, herbicides are not always desirable—for example, in organic farming. When herbicidal weed control was first widely commercialized in the 1950s and 1960s, it played into that era's optimistic worldview in which sciences such as chemistry would usher in a new age of modernity that would leave old-fashioned practices (such as weed control via cultivators) in the dustbin of history. Thus herbicidal weed control was adopted very widely. In subsequent decades, people overcame this initial irrational exuberance and came to realize that herbicidal weed control has limitations and externalities, and it must be managed intelligently. It is still widely used, and probably will continue to be indispensable to affordable food production worldwide for the foreseeable future; but its wise management includes seeking alternate methods, such as the traditional standby of mechanical cultivation, where practical.

To the extent that cultivating *is* done commercially today (such as in truck farming), it is usually powered by tractors, especially row-crop tractors. The cultivator may be an implement trailed after the tractor via a drawbar; mounted on the three-point hitch; or mounted on a frame beneath the tractor.

Small cultivators pushed or pulled by a single person are used for small-scale gardening, such as for the household's own use or for small market gardens.

Garden cultivators

A small tiller

Small tilling equipment, used in small gardens such as household gardens and small commercial gardens, can provide both primary and secondary tillage. For example, a rotary tiller does both the "plowing" and the "harrowing", preparing a smooth, loose seedbed. It does not provide the row-wise weed control that cultivator teeth would. For that task, there are single-person-pushable toothed cultivators.

Farm cultivators

A tractor-mounted tiller

Cultivators are pulled by tractors and can vary greatly in size and shape, from 10 feet (3 m) to 80 feet (24 m) wide. Many are equipped with hydraulic wings that fold up to make road travel easier and safer. Different types are used for preparation of fields before planting, and for the control of weeds between row crops.

Field cultivator

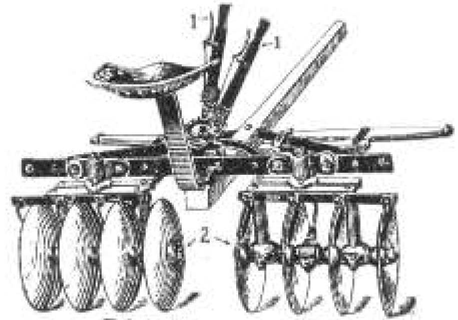
Field cultivators are used to complete tillage operations in many types of arable crop fields. The main function of the field cultivator is to prepare a proper seedbed for the crop to be planted into, to bury crop residue in the soil (helping to warm the soil before planting), to control weeds, and to mix and incorporate the soil to ensure the growing crop has enough water and nutrients to grow well during the growing season. The implement has many shanks mounted on the underside of a metal frame, and small narrow rods at the rear of the machine that smooth out the soil surface for easier travel later when planting. In most field cultivators, one-to-many hydraulic cylinders raise and lower the implement and control its depth.

Row crop cultivator

The main function of the row crop cultivator is weed control between the rows of an established crop. Row crop cultivators are usually raised and lowered by a three-point hitch and the depth is controlled by gauge wheels.

Harrow (Tool)

A spring-tooth drag harrow



Disk Harrow, p. 641.

Disc harrows

In agriculture, a **harrow** (often called a set of **harrows** in a plurale tantum sense) is an implement for breaking up and smoothing out the surface of the soil. In this way it is distinct in its effect from the plough, which is used for deeper tillage. Harrowing is often carried out on fields to follow the rough finish left by ploughing operations. The purpose of this harrowing is generally to break up clods (lumps of soil) and to provide a finer finish, a good tilth or soil structure that is suitable for seedbed use. Such coarser harrowing may also be used to remove weeds and to cover seed after sowing. Harrows differ from cultivators in that they disturb the whole surface of the soil, such as to prepare a seedbed, instead of disturbing only narrow trails that skirt crop rows (to kill weeds).

There are four general types of harrows: disc harrow, tine harrow, chain harrow and chain disk harrows. Harrows were originally drawn by draft animals, such as horses, mules, or oxen. In modern practice they are almost always tractor-mounted implements, either trailed after the tractor via a drawbar or mounted on the three-point hitch.

Types

In cooler climates the most common types are the *disc harrow*, the *chain harrow*, the *tine harrow* or *spike harrow* and the *spring tine harrow*. Chain harrows are often used for lighter work such as levelling the tilth or covering seed, while disc harrows are typically used for heavy work, such as following ploughing to break up the sod. In addition, there are various types of *power harrow*, in which the cultivators are power-driven from the tractor rather than depending on its forward motion.

Tine harrows are used to refine seed-bed condition before planting, to remove small weeds in growing crops and to loosen the inter-row soils to allow for water to soak into the subsoil. The fourth is a chain disk harrow. Disk attached to chains are pulled at an angle over the ground. These harrows move rapidly across the surface. The chain and disk rotate to stay clean while breaking up the top surface to about 1 inch (3 cm) deep. A smooth seedbed is prepared for planting with one pass.

Chain harrowing may be used on pasture land to spread out dung, and to break up dead material (*thatch*) in the sward, and similarly in sports-ground maintenance a light chain harrowing is often used to level off the ground after heavy use, to remove and smooth out boot marks and indentations. When used on tilled land in combination with the other two types, chain harrowing rolls the remaining larger clumps of soil to the surface where the weather will break them down and prevent interference with seed germination.

Crumbler roller, commonly used to compact soil after it has been loosened by a harrow

All four harrow types can be used in one pass to prepare the soil for seeding. It is also common to use any combination of two harrows for a variety of tilling processes. Where harrowing provides a very fine tilth, or the soil is very light so that it might easily be wind-blown, a roller is often added as the last of the set.

Harrows may be of several types and weights, depending on the intended purpose. They almost always consist of a rigid frame to which are attached discs, teeth, linked chains or other means of cultivation, but tine and chain harrows are often only supported by a rigid towing-bar at the front of the set.

In the southern hemisphere the so-called *giant discs* are a specialised kind of disc harrows that can stand in for a plough in very rough country where a mouldboard plough will not handle the tree-stumps and rocks, and a disc-plough is too slow (because of its limited number of discs). Giant scalloped-edged discs operate in a set, or frame, that is often weighted with concrete or steel blocks to improve penetration of the cutting edges. This sort of cultivation is normally immediately followed by broadcast fertilisation and seeding, rather than drilled or row seeding.

A drag is a heavy harrow.

Historical reference

Clydesdale horses pulling spike harrows, Murrurundi, NSW, Australia

In Europe, harrows were first used in the early Middle Ages.

The following text is taken from the *Household Cyclopedia* of 1881:

"When employed to reduce a strong obdurate soil, not more than two harrows should be yoked together, because they are apt to ride and tumble upon each other, and thus impede the work, and execute it imperfectly. On rough soils, harrows ought to be driven as fast as the horses can walk; because their effect is in the direct proportion to the degree of velocity with which they are driven. In ordinary cases, and in every case where harrowing is meant for covering the seed, three harrows are the best yoke, because they fill up the ground more effectually and leave fewer vacancies, than when a smaller number is employed. The harrowman's attention, at the seed process, should be constantly directed to prevent these implements from riding upon each other, and to keep them clear of every impediment from stones, lumps of earth, or clods, and quickens or grass roots; for any of these prevents the implement from working with perfection, and causes a mark or trail upon the surface, always unpleasing to the eye, and generally detrimental to the vegetation of the seed. Harrowing is usually given in different directions, first in length, then across, and finally in length as at first. Careful husbandmen study, in the finishing part of the process, to have the harrows drawn in a straight line, without suffering the horses to go in a zigzag manner, and are also attentive that the horses enter fairly upon the ridge, without making a curve at the outset. In some instances, an excess of harrowing has been found very prejudicial to the succeeding crop; but it is always necessary to give so much as to break the furrow, and level the surface, otherwise the operation is imperfectly performed."

George Orwell, as a soldier in 1937 in a Spanish Civil War anti-fascist unit three miles east of Huesca, Aragon, found inside “a derelict hut in no man’s land” a *harrow* of primitive design:

"There was a kind of harrow that took one straight back to the later Stone Age. It was made of boards joined together, to about the size of a kitchen table; in the boards hundreds of holes were morticed, and into each hole was jammed a piece of flint which had been chipped into shape exactly as men used to chip them ten thousand years ago."

Chapter- 12

Planting Machinery

Broadcast seeder

Modern Amazone broadcast spreader in action

Side view of a small broadcast seeder showing three-point hitch and PTO shaft

A **broadcast seeder**, alternately called a **broadcast spreader**, is a tractor implement commonly used for spreading seed, lime, fertilizer.

Broadcast seeders/spreaders can be roughly divided into three groups. The smallest of the broadcast seeders/spreaders can be carried or pushed while spreading seed or fertilizer. The next size up is designed to be towed behind a garden tractor or ATV. Very similar in size to the tow behind units are broadcast seeders that mount to the three-point hitch of a compact utility tractor, these are ideal for landscape and small property maintenance. The largest size units are commercial broadcast seeders/spreaders designed and sized appropriately for agricultural tractors and mount to the tractor's 3pt hitch. The broadcast seeders that are mounted to a 3pt hitch are powered by a power take-off (P.T.O.) shaft from the tractor.

The basic operating concept of broadcast spreads is simple. A large material hopper is positioned over a horizontal spinning disk, the disk has a series of 3 or 4 fins attached to it which throw the dropped materials from the hopper out and away from the seeder/spreader. Alternately a pendulum spreading mechanism may be employed, this method is more common in large commercial spreaders. The photos clearly show the material hopper, these hoppers are commonly made of plastic, painted steel or galvanized steel.

Some seeders/spreaders have directional fins to control the direction of the material that is thrown from the spreader. All broadcast spreaders require some form of power to spin the disk. On hand carried units, a hand crank spins gears to turn the disk. On tow behind units, the wheels spin a shaft that turns gears which, in turn, spin the disk. As is partially visible in one of the photos, with tractor mounted units, a mechanical P.T.O. shaft connected to the tractor and controlled by the tractor operator, spins the disk. There are some seeder/spreaders made for garden size tractors that use a 12 volt motor to spin the dispersing disk.

Seed Drill

A sowing machine which uses the seed drill concept

A **seed drill** is a sowing device that precisely positions seeds in the soil and then covers them. Before the introduction of the seed drill, the common practice was to *broadcast* seeds by hand. Besides being wasteful, broadcasting was very imprecise and led to a poor distribution of seeds, leading to low productivity. The use of a seed drill can improve the ratio of crop yield by as much as eight times.

Description

In older methods of planting, a field is initially prepared with a plough to expose and break up the topsoil. This produces a series of linear cuts known as *furrows*. The field is then seeded by throwing the seeds over the field, a method known as *manual* *broadcasting*. Seeds that landed in the furrows had better protection from the elements, and natural erosion or manual raking would preferentially cover them while leaving some exposed. The result was a field planted roughly in rows, but having a large number of plants outside the furrow lanes.

There are several downsides to this approach. The most obvious is that seeds that land outside the furrows will not have the growth shown by the plants sown in the furrow, since they are too shallow on the soil. Because of this, they are lost to the elements. Since the furrows represent only a portion of the field's area, and broadcasting distributes seeds fairly evenly, this results in considerable wastage of seeds. Less obvious are the effects of overseeding; all crops grow best at a certain density, which varies depending on the soil and weather conditions. Additional seeding above this limit will actually reduce crop yields, in spite of more plants being sown, as there will be competition among the plants for the minerals, water and the soil available. Another reason is that the mineral resources of the soil will also deplete at a much faster rate, thereby directly affecting the growth of the plants.

Uses

Drilling is the term used for the mechanized sowing of an agricultural crop. A typical seed drill consists of a hopper of seeds arranged above a series of tubes that can be set at selected distances from each other to allow optimum growth of the resulting plants. Arranged in front of the tubes are a series of knife blades known as *coulters*. In operation, the seed drill is dragged forward to allow the coulters to cut open the soil, with a metering mechanism on the hopper periodically allowing a number of seeds to fall into the tubes, and through them into the freshly cut soil. The result is a set of spaced seeding locations, which can then be covered by a built-in rake.

The seed drill allows farmers to sow seeds in well-spaced rows at specific depths at a specific seed rate; each tube creates a hole of a specific depth, drops in one or more seeds, and covers it over. This invention gave farmers much greater control over the depth that the seed was planted and the ability to cover the seeds without back-tracking. This greater control meant that seeds germinated consistently and in good soil. The result was an increased rate of germination, and a much-improved crop yield (up to eight times).

A further important consideration was weed control. Broadcast seeding results in a random array of growing crops, making it difficult to control weeds using any method other than hand weeding. A field planted using a seed drill is much more uniform, typically in rows, allowing weeding with the hoe during the course of the growing season. Weeding by hand is laborious and poor weeding limits yield.

History

Chinese double-tube seed drill, published by Song Yingxing in the *Tiangong Kaiwu* encyclopedia of 1637.

While the Sumerians used primitive single-tube seed drills around 1500 BC, the invention never reached Europe. Multi-tube iron seed drills were invented by the Chinese in the 2nd century BC. This multi-tube seed drill has been credited with giving China an efficient food production system that allowed it to support its large population for millennia. It has been conjectured that the seed drill was introduced in Europe following contacts with China.

The first known European seed drill was attributed to Camillo Torello and patented by the Venetian Senate in 1566. A seed drill was described in detail by Tadeo Cavalina of Bologna in 1602. In England, the seed drill was further refined by Jethro Tull in 1701 in the Agricultural Revolution. However, seed drills of this and successive types were both expensive and unreliable, as well as fragile. Seed drills would not come into widespread use in Europe until the mid-19th century.

Over the years seed drills have become more advanced and sophisticated but the technology has remained substantially the same. The first seed drills were small enough to be drawn by a single horse but the availability of steam and, later, gasoline tractors saw the development of larger and more efficient drills that allowed farmers to seed even larger tracts in a single day. Recent improvements to drills allow seed-drilling without prior tilling. This means that soils subject to erosion or moisture loss are protected until the seed germinates and grows enough to keep the soil in place. This also helps prevent soil loss by avoiding erosion after tilling.

Planter (Farm Implement)

A two row planter featuring John Deere "71 Flexi" row units

The John Deere DB120 48 row planter

John Deere MaxEmerge XP Planter with Case IH AFS precision farming system which auto-steers using GPS

Like a grain drill a **planter** is an agricultural farm implement towed behind a tractor, used for sowing crops through a field. It is connected to the tractor with a draw-bar, or a three-point hitch. Planters lay the seed down in precise manner along rows. Seeds are distributed through devices called row units. The row units are spaced evenly along the planter. Planters vary greatly in size, from 2 rows to 48, with the biggest in the world being the 48-row John Deere DB120. The space between the row units also vary greatly. The most commons row spacing today is 30 inches.

On smaller and older planters, a marker sticks out half the width of the planter and draws a line in the field where the tractor should be centered for the next pass. The marker is usually a single disc harrow disc on a rod on each side of the planter. On larger and more modern planters, GPS navigation systems and things like auto-steer for the tractor are used. Some precision farming equipment such as Case IH AFS uses GPS/RKS and computer controlled planter to sow seeds to precise position accurate within 2 cm. In irregular shaped field, the precision farming equipment will automatically hold the seed release over area already sewn when the tractor has to run overlapping pattern to avoid obstacles such as trees.

Older planters commonly have a seed bin for each row and a fertilizer bin for two or more rows. In each seed bin plates are installed with a certain number of teeth and tooth spacing according to the type of seed to be sown and the rate at which the seeds are to be sown. The tooth size (actually the size of the space between the teeth) is just big enough to allow one seed in at a time but not big enough for two. Modern planters often have a large bin for seeds that are distributed to each row.

Chapter- 13

Irrigation

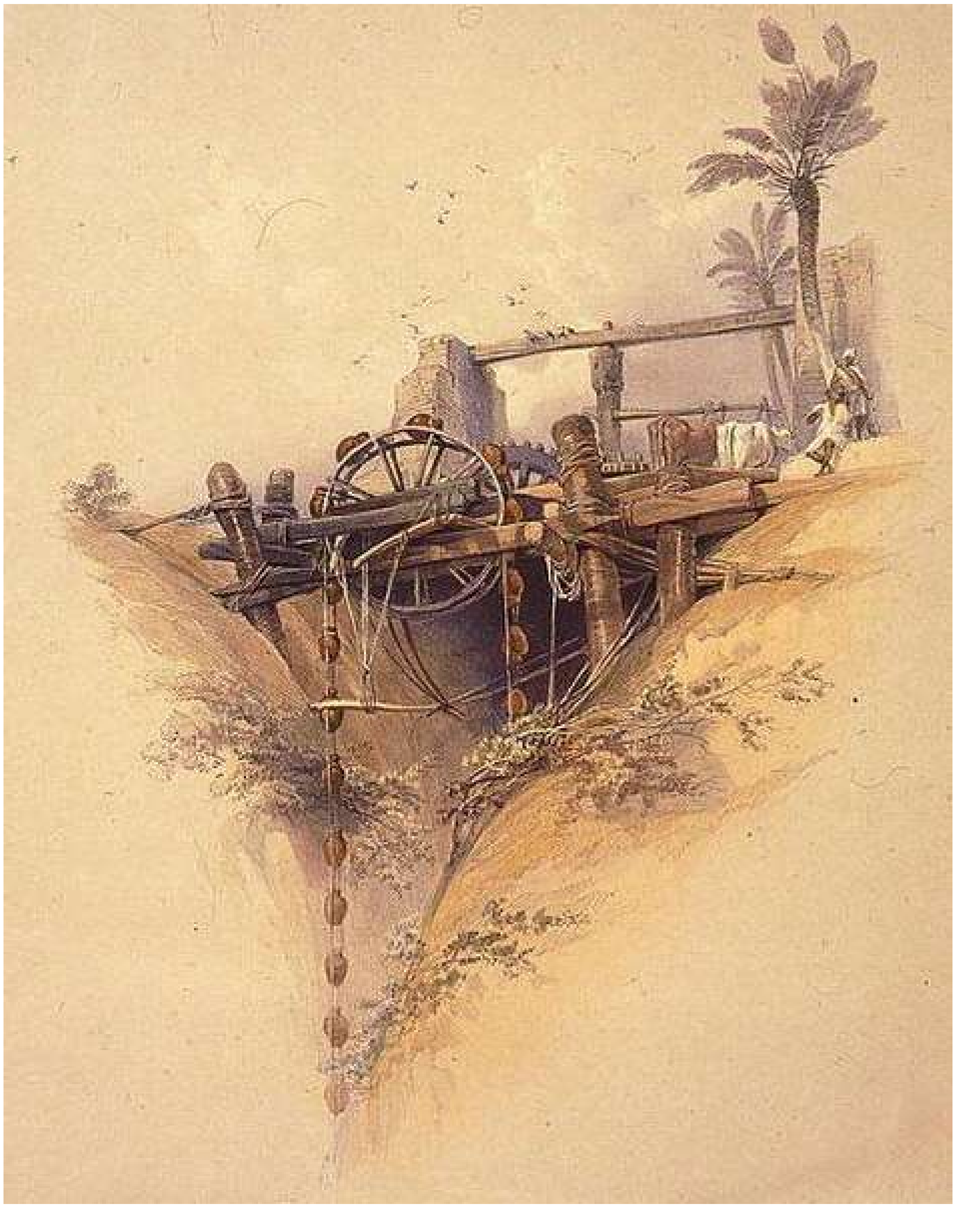
Irrigation is an artificial application of water to the soil. It is used to assist in the growing of agricultural crops, maintenance of landscapes, and revegetation of disturbed soils in dry areas and during periods of inadequate rainfall. Additionally, irrigation also has a few other uses in crop production, which include protecting plants against frost, suppressing weed growing in grain fields and helping in preventing soil consolidation. In contrast, agriculture that relies only on direct rainfall is referred to as rain-fed or dryland farming. Irrigation systems are also used for dust suppression, disposal of sewage, and in mining. Irrigation is often studied together with drainage, which is the natural or artificial removal of surface and sub-surface water from a given area.

Irrigation is also a term used in medical/dental fields to refer to flushing and washing out anything with water or another liquid.

Irrigation in a field in New Jersey, United States.

An Irrigation sprinkler watering a lawn

History



Animal-powered irrigation, Upper Egypt, ca. 1840

An example of irrigation system common in Indian subcontinent. Artistic impression on the banks of Dal Lake, Kashmir, India.

Inside a karez tunnel at Turpan, China.

Archaeological investigation has identified evidence of irrigation in Mesopotamia, Ancient Egypt and Ancient Persia (modern day Iran) as far back as the 6th millennium

BCE, where barley was grown in areas where the natural rainfall was insufficient to support such a crop.

In the Zana Valley of the Andes Mountains in Peru, archaeologists found remains of three irrigation canals radiocarbon dated from the 4th millennium BCE, the 3rd millennium BCE and the 9th century CE. These canals are the earliest record of irrigation in the New World. Traces of a canal possibly dating from the 5th millennium BCE were found under the 4th millennium canal. Sophisticated irrigation and storage systems were developed by the Indus Valley Civilization in North India, including the reservoirs at Girnar in 3000 BCE and an early canal irrigation system from circa 2600 BCE. Large scale agriculture was practiced and an extensive network of canals was used for the purpose of irrigation.

There is evidence of the ancient Egyptian pharaoh Amenemhet III in the twelfth dynasty (about 1800 BCE) using the natural lake of the Faiyum Oasis as a reservoir to store surpluses of water for use during the dry seasons, the lake swelled annually from flooding of the Nile.

The Qanats, developed in ancient Persia in about 800 BCE, are among the oldest known irrigation methods still in use today. They are now found in Asia, the Middle East and North Africa. The system comprises a network of vertical wells and gently sloping tunnels driven into the sides of cliffs and steep hills to tap groundwater. The noria, a water wheel with clay pots around the rim powered by the flow of the stream (or by animals where the water source was still), was first brought into use at about this time, by Roman settlers in North Africa. By 150 BCE the pots were fitted with valves to allow smoother filling as they were forced into the water.

The irrigation works of ancient Sri Lanka, the earliest dating from about 300 BCE, in the reign of King Pandukabhaya and under continuous development for the next thousand years, were one of the most complex irrigation systems of the ancient world. In addition to underground canals, the Sinhalese were the first to build completely artificial reservoirs to store water. Due to their engineering superiority in this sector, they were often called 'masters of irrigation'. Most of these irrigation systems still exist undamaged up to now, in Anuradhapura and Polonnaruwa, because of the advanced and precise engineering. The system was extensively restored and further extended during the reign of King Parakrama Bahu (1153–1186 CE).

The oldest known hydraulic engineers of China were Sunshu Ao (6th century BCE) of the Spring and Autumn Period and Ximen Bao (5th century BCE) of the Warring States period, both of whom worked on large irrigation projects. In the Szechwan region belonging to the State of Qin of ancient China, the Dujiangyan Irrigation System was built in 256 BCE to irrigate an enormous area of farmland that today still supplies water. By the 2nd century AD, during the Han Dynasty, the Chinese also used chain pumps that lifted water from lower elevation to higher elevation. These were powered by manual foot pedal, hydraulic waterwheels, or rotating mechanical wheels pulled by oxen. The water was used for public works of providing water for urban residential quarters and palace gardens, but mostly for irrigation of farmland canals and channels in the fields.

In 15th century Korea, the world's first water gauge, *uryanggye* (Korean:우량계), was discovered in 1441. The inventor was Jang Yeong-sil, a Korean engineer of the Joseon Dynasty, under the active direction of the king, Sejong the Great. It was installed in irrigation tanks as part of a nationwide system to measure and collect rainfall for agricultural applications. With this instrument, planners and farmers could make better use of the information gathered in the survey.

In the Americas, extensive irrigation systems were created by numerous groups in prehistoric times. One example is seen in the recent archaeological excavations near the Santa Cruz River in Tucson, Arizona. They have located a village site dating from 4,000 years ago. The floodplain of the Santa Cruz River was extensively farmed during the Early Agricultural period, circa 1200 BC to AD 150. These people constructed irrigation canals and grew corn, beans, and other crops while gathering wild plants and hunting animals.

Present extent

In the middle of the 20th century, the advent of diesel and electric motors led for the first time to systems that could pump groundwater out of major aquifers faster than it was recharged. This can lead to permanent loss of aquifer capacity, decreased water quality, ground subsidence, and other problems. The future of food production in such areas as the North China Plain, the Punjab, and the Great Plains of the US is threatened.

At the global scale 2,788,000 km² (689 million acres) of agricultural land was equipped with irrigation infrastructure around the year 2000. About 68% of the area equipped for irrigation is located in Asia, 17% in America, 9% in Europe, 5% in Africa and 1% in Oceania. The largest contiguous areas of high irrigation density are found in North India and Pakistan along the rivers Ganges and Indus, in the Hai He, Huang He and Yangtze basins in China, along the Nile river in Egypt and Sudan, in the Mississippi-Missouri river basin and in parts of California. Smaller irrigation areas are spread across almost all populated parts of the world.

Types

Basin flood irrigation of wheat.

Irrigation of the land in Punjab, Pakistan.

Various types of irrigation techniques differ in how the water obtained from the source is distributed within the field. In general, the goal is to supply the entire field uniformly with water, so that each plant has the amount of water it needs, neither too much nor too little.The modern methods are efficient enough to achieve this goal.

Surface

In surface irrigation systems, water moves over and across the land by simple gravity flow in order to wet it and to infiltrate into the soil. Surface irrigation can be subdivided into furrow, borderstrip or basin irrigation. It is often called **flood irrigation** when the irrigation results in flooding or near flooding of the cultivated land. Historically, this has been the most common method of irrigating agricultural land.

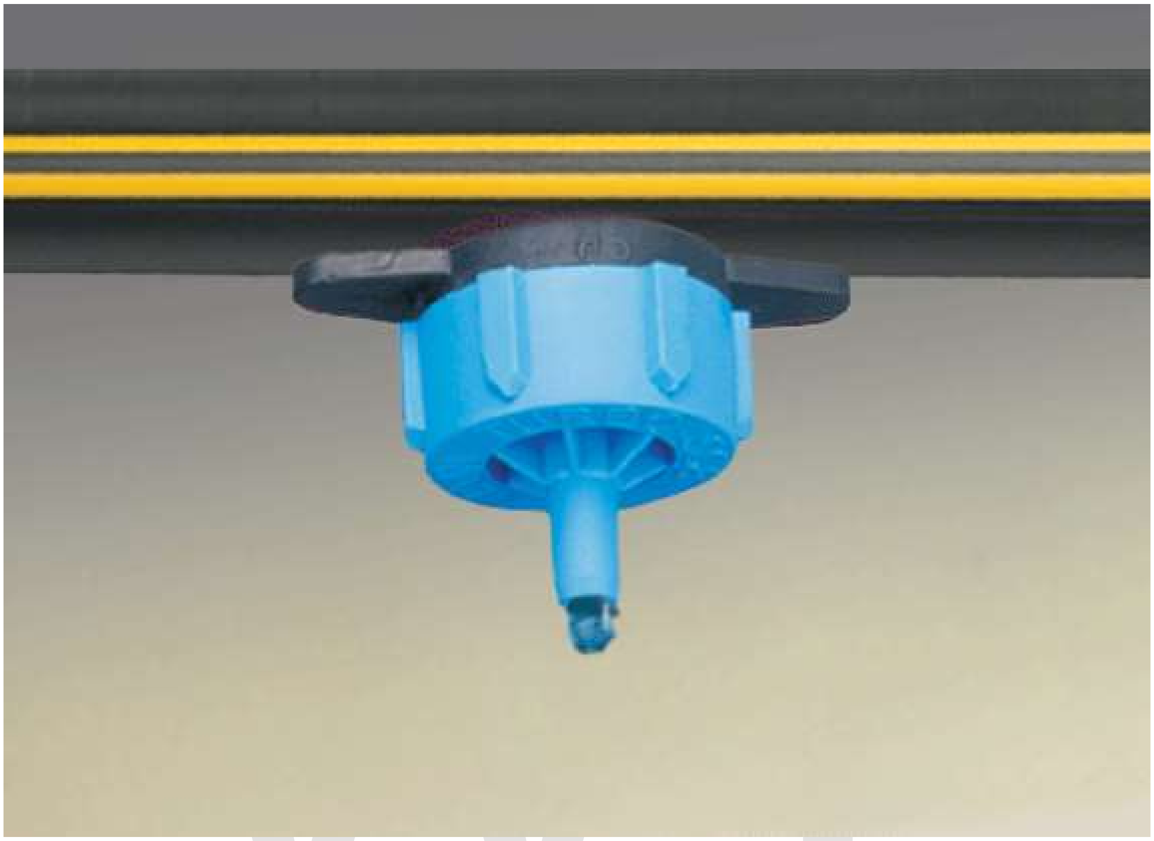
Where water levels from the irrigation source permit, the levels are controlled by dikes, usually plugged by soil. This is often seen in terraced rice fields (rice paddies), where the method is used to flood or control the level of water in each distinct field. In some cases, the water is pumped, or lifted by human or animal power to the level of the land.

Localized

Brass Impact type sprinkler head

Localized irrigation is a system where water is distributed under low pressure through a piped network, in a pre-determined pattern, and applied as a small discharge to each plant or adjacent to it. Drip irrigation, spray or micro-sprinkler irrigation and bubbler irrigation belong to this category of irrigation methods.

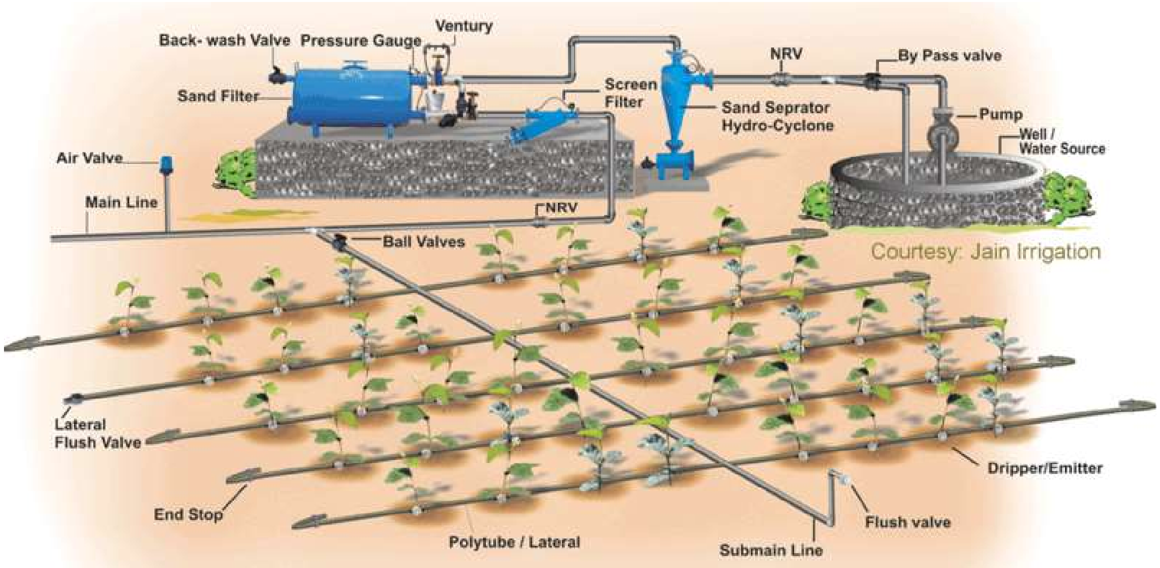
Drip



Drip Irrigation - A dripper in action

Grapes in Petrolina, just possible in this semi arid area due to drip irrigation.

Drip irrigation, also known as trickle irrigation, functions as its name suggests. Water is delivered at or near the root zone of plants, drop by drop. This method can be the most water-efficient method of irrigation, if managed properly, since evaporation and runoff are minimized. In modern agriculture, drip irrigation is often combined with plastic mulch, further reducing evaporation, and is also the means of delivery of fertilizer. The process is known as *fertigation*.



Drip Irrigation Layout and its parts

Deep percolation, where water moves below the root zone, can occur if a drip system is operated for too long of a duration or if the delivery rate is too high. Drip irrigation methods range from very high-tech and computerized to low-tech and labor-intensive. Lower water pressures are usually needed than for most other types of systems, with the exception of low energy center pivot systems and surface irrigation systems, and the system can be designed for uniformity throughout a field or for precise water delivery to individual plants in a landscape containing a mix of plant species. Although it is difficult to regulate pressure on steep slopes, pressure compensating emitters are available, so the field does not have to be level. High-tech solutions involve precisely calibrated emitters located along lines of tubing that extend from a computerized set of valves. Both pressure regulation and filtration to remove particles are important. The tubes are usually black (or buried under soil or mulch) to prevent the growth of algae and to protect the polyethylene from degradation due to ultraviolet light. But drip irrigation can also be as low-tech as a porous clay vessel sunk into the soil and occasionally filled from a hose or bucket. Subsurface drip irrigation has been used successfully on lawns, but it is more expensive than a more traditional sprinkler system. Surface drip systems are not cost-effective (or aesthetically pleasing) for lawns and golf courses. In the past one of the main disadvantages of the subsurface drip irrigation (SDI) systems, when used for turf, was the fact of having to install the plastic lines very close to each other in the ground, therefore disrupting the turf grass area. Recent technology developments on drip installers like the drip installer at New Mexico State University Arrow Head Center, places the line underground and covers the slit leaving no soil exposed.

Sprinkler

Sprinkler irrigation of blueberries in Plainville, New York, United States.

In sprinkler or overhead irrigation, water is piped to one or more central locations within the field and distributed by overhead high-pressure sprinklers or guns. A system utilizing sprinklers, sprays, or guns mounted overhead on permanently installed risers is often referred to as a *solid-set* irrigation system. Higher pressure sprinklers that rotate are called *rotors* and are driven by a ball drive, gear drive, or impact mechanism. Rotors can be designed to rotate in a full or partial circle. Guns are similar to rotors, except that they generally operate at very high pressures of 40 to 130 lbf/in² (275 to 900 kPa) and flows of 50 to 1200 US gal/min (3 to 76 L/s), usually with nozzle diameters in the range of 0.5 to 1.9 inches (10 to 50 mm). Guns are used not only for irrigation, but also for industrial applications such as dust suppression and logging.

A traveling sprinkler at Millets Farm Centre, Oxfordshire, United Kingdom.

Sprinklers can also be mounted on moving platforms connected to the water source by a hose. Automatically moving wheeled systems known as *traveling sprinklers* may irrigate areas such as small farms, sports fields, parks, pastures, and cemeteries unattended. Most of these utilize a length of polyethylene tubing wound on a steel drum. As the tubing is wound on the drum powered by the irrigation water or a small gas engine, the sprinkler is pulled across the field. When the sprinkler arrives back at the reel the system shuts off. This type of system is known to most people as a "waterreel" traveling irrigation sprinkler and they are used extensively for dust suppression, irrigation, and land application of waste water. Other travelers use a flat rubber hose that is dragged along behind while the sprinkler platform is pulled by a cable. These cable-type travelers are definitely old technology and their use is limited in today's modern irrigation projects.

Center pivot

A small center pivot system from beginning to end

The hub of a center-pivot irrigation system.

Rotator style pivot applicator sprinkler.

Center pivot irrigation is a form of sprinkler irrigation consisting of several segments of pipe (usually galvanized steel or aluminum) joined together and supported by trusses, mounted on wheeled towers with sprinklers positioned along its length. The system moves in a circular pattern and is fed with water from the pivot point at the center of the arc. These systems are found and used in all parts of the nation and allow irrigation of all types of terrain. Newer irrigations have drops as shown in the image that follows.

Center pivot with drop sprinklers. Photo by Gene Alexander, USDA Natural Resources Conservation Service.

Most center pivot systems now have drops hanging from a u-shaped pipe attached at the top of the pipe with sprinkler heads that are positioned a few feet (at most) above the crop, thus limiting evaporative losses. Drops can also be used with drag hoses or bubblers that deposit the water directly on the ground between crops. Crops are often planted in a circle to conform to the center pivot. This type of system is known as LEPA (Low Energy Precision Application). Originally, most center pivots were water powered. These were replaced by hydraulic systems (*T-L Irrigation*) and electric motor driven systems (Reinke, Valley, Zimmatic*). Many modern sprinklers features GPS devices.*

Wheel line irrigation system in Idaho. 2001. Photo by Joel McNee, USDA Natural Resources Conservation Service.

Lateral move (side roll, wheel line)

A series of pipes, each with a wheel of about 1.5 m diameter permanently affixed to its midpoint and sprinklers along its length, are coupled together at one edge of a field. Water is supplied at one end using a large hose. After sufficient water has been applied, the hose is removed and the remaining assembly rotated either by hand or with a purpose-built mechanism, so that the sprinklers move 10 m across the field. The hose is reconnected. The process is repeated until the opposite edge of the field is reached. This system is less expensive to install than a center pivot, but much more labor intensive to operate, and it is limited in the amount of water it can carry. Most systems utilize 4 or 5-inch (130 mm) diameter aluminum pipe. One feature of a lateral move system is that it consists of sections that can be easily disconnected. They are most often used for small or oddly shaped fields, such as those found in hilly or mountainous regions, or in regions where labor is inexpensive.

Sub-irrigation

Subirrigation also sometimes called *seepage irrigation* has been used for many years in field crops in areas with high water tables. It is a method of artificially raising the water table to allow the soil to be moistened from below the plants' root zone. Often those systems are located on permanent grasslands in lowlands or river valleys and combined with drainage infrastructure. A system of pumping stations, canals, weirs and gates allows it to increase or decrease the water level in a network of ditches and thereby control the water table.

Sub-irrigation is also used in commercial greenhouse production, usually for potted plants. Water is delivered from below, absorbed upwards, and the excess collected for recycling. Typically, a solution of water and nutrients floods a container or flows through a trough for a short period of time, 10–20 minutes, and is then pumped back into a holding tank for reuse. Sub-irrigation in greenhouses requires fairly sophisticated, expensive equipment and management. Advantages are water and nutrient conservation, and labor-saving through lowered system maintenance and automation. It is similar in principle and action to subsurface drip irrigation.

Manual using buckets or watering cans

These systems have low requirements for infrastructure and technical equipment but need high labor inputs. Irrigation using watering cans is to be found for example in peri-urban agriculture around large cities in some African countries.

Automatic, non-electric using buckets and ropes

Besides the common manual watering by bucket, an automated, natural version of this also exist. Using plain polyester ropes combined with a prepared ground mixture can be used to water plants from a vessel filled with water.

The ground mixture would need to be made depending on the plant itself, yet would mostly consist of black potting soil, vermiculite and perlite. This system would (with certain crops) allow to save expenses as it does not consume any electricity and only little water (unlike sprinklers, water timers, ...). However, it may only be used with certain crops (probably mostly larger crops that do not need a humid environment; perhaps e.g. paprikas).

Using water condensed from humid air

In countries where at night, humid air sweeps the countryside, water can be obtained from the humid air by condensation onto cold surfaces. This is for example practiced in the vineyards at Lanzarote using stones to condense water or with various fog collectors based on canvas or foil sheets.

Sources of irrigation water

Sources of irrigation water can be groundwater extracted from springs or by using wells, surface water withdrawn from rivers, lakes or reservoirs or non-conventional sources like treated wastewater, desalinated water or drainage water. A special form of irrigation using surface water is spate irrigation, also called floodwater harvesting. In case of a flood (spate) water is diverted to normally dry river beds (wadis) using a network of dams, gates and channels and spread over large areas. The moisture stored in the soil will be used thereafter to grow crops. Spate irrigation areas are in particular located in semi-arid or arid, mountainous regions. While floodwater harvesting belongs to the accepted irrigation methods, rainwater harvesting is usually not considered as a form of irrigation. Rainwater harvesting is the collection of runoff water from roofs or unused land and the concentration of this. Some of Ancient India's water systems were pulled by oxen.

Water scarcity

Fifty years ago, the common perception was that water was an infinite resource. At this time, there were fewer than half the current number of people on the planet. People were not as wealthy as today, consumed fewer calories and ate less meat, so less water was needed to produce their food. They required a third of the volume of water we presently take from rivers. Today, the competition for water resources is much more intense. This is because there are now nearly seven billion people on the planet, their consumption of water-thirsty meat and vegetables is rising, and there is increasing competition for water from industry, urbanisation and biofuel crops. To avoid a global water crisis, farmers will have to strive to increase productivity to meet growing demands for food, while industry and cities find ways to use water more efficiently.

Successful agriculture is dependent upon farmers having sufficient access to water. However, water scarcity is already a critical constraint to farming in many parts of the world. Physical water scarcity is where there is not enough water to meet all demands, including that needed for ecosystems to function effectively. Arid regions frequently suffer from physical water scarcity. It also occurs where water seems abundant but where resources are over-committed. This can happen where there is overdevelopment of hydraulic infrastructure, usually for irrigation. Symptoms of physical water scarcity include environmental degradation and declining groundwater. Economic scarcity, meanwhile, is caused by a lack of investment in water or insufficient human capacity to satisfy the demand for water. Symptoms of economic water scarcity include a lack of infrastructure, with people often having to fetch water from rivers for domestic and agricultural uses. Some 2.8 billion people currently live in water-scarce areas.

How an in-ground irrigation system works

Most commercial and residential irrigation systems are "in ground" systems, which means that everything is buried in the ground. With the pipes, sprinklers, emitters (drippers), and irrigation valves being hidden, it makes for a cleaner, more presentable landscape without garden hoses or other items having to be moved around manually. This does, however, create some drawbacks in the maintenance of a completely buried system.

Water source and piping

The beginning of a sprinkler system is the water source. This is usually a tap into an existing (city) water line or a pump that pulls water out of a well or a pond. The water travels through pipes from the water source through the valves to the sprinklers and emitters. The pipes from the water source up to the irrigation valves are called "mainlines", and the lines from the valves to the emitters or sprinklers are called "lateral lines". Most piping used in irrigation systems today are HDPE and MDPE or PVC or PEX plastic pressure pipes due to their ease of installation and resistance to corrosion. After the water source, the water usually travels through a check valve. This prevents water in the irrigation lines from being pulled back into and contaminating the clean water supply. Ideally a pressure control valve is also installed to regulate water pressure and help prevent excessive pressure from harming the system.

Controllers, zones, and valves

Most irrigation systems are divided into zones. A zone is a single irrigation valve and one or a group of drippers or sprinklers that are connected by pipes or tubes. Irrigation systems are divided into zones because there is usually not enough pressure and available flow to run sprinklers for an entire yard or sports field at once. Each zone has a solenoid valve on it that is controlled via wire by an irrigation controller. The irrigation controller is either a mechanical (now the "dinosaur" type) or electrical device that signals a zone to turn on at a specific time and keeps it on for a specified amount of time. "Smart Controller" is a recent term used to describe a controller that is capable of adjusting the watering time by itself in response to current environmental conditions. The smart controller determines current conditions by means of historic weather data for the local area, a soil moisture sensors (water potential or water content), rain sensor, or in more sophisticated systems satellite feed weather station, or a combination of these.

Emitters & Sprinklers

When a zone comes on, the water flows through the lateral lines and ultimately ends up at the irrigation emitter (drip) or sprinkler heads. Many sprinklers have pipe thread inlets on the bottom of them which allows a fitting and the pipe to be attached to them. The sprinklers are usually installed with the top of the head flush with the ground surface. When the water is pressurized, the head will pop up out of the ground and water the desired area until the valve closes and shuts off that zone. Once there is no more water pressure in the lateral line, the sprinkler head will retract back into the ground. Emitters are generally laid on the soil surface or buried a few inches to reduce evaporation losses.

Problems in irrigation

Irrigation can lead to a number of problems:

- Competition for surface water rights.

- Depletion of underground aquifers.
- Ground subsidence (e.g. New Orleans, Louisiana)
- Underirrigation or irrigation giving only just enough water for the plant (e.g. in drip line irrigation) gives poor soil salinity control which leads to increased soil salinity with consequent build up of toxic salts on soil surface in areas with high evaporation. This requires either leaching to remove these salts and a method of drainage to carry the salts away. When using drip lines, the leaching is best done regularly at certain intervals (with only a slight excess of water), so that the salt is flushed back under the plant's roots.
- Overirrigation because of poor distribution uniformity or management wastes water, chemicals, and may lead to water pollution.
- Deep drainage (from over-irrigation) may result in rising water tables which in some instances will lead to problems of irrigation salinity requiring watertable control by some form of subsurface land drainage.
- Irrigation with saline or high-sodium water may damage soil structure owing to the formation of alkaline soil

Chapter- 14

Tillage

Cultivating after early rain.

Tillage is the agricultural preparation of the soil by mechanical agitation of various types, such as digging, stirring, and overturning. Examples of human-powered **tilling** methods using hand tools include shovelling, picking, mattock work, hoeing, and raking. Examples of draft-animal-powered or mechanized work include ploughing (overturning with moldboards or chiseling with chisel shanks), rototilling, rolling with cultipackers or other rollers, harrowing, and cultivating with cultivator shanks (teeth). Small-scale gardening and farming, for household food production or small business production, tends to use the smaller-scale methods above, whereas medium- to large-scale farming tends to use the larger-scale methods. There is a fluid continuum, however. Any type of gardening or farming, but especially larger-scale commercial types, may also use low-till or no-till methods as well.

Tillage is often classified into two types, primary and secondary. There is no strict boundary between them so much as a loose distinction between tillage that is deeper and thorougher (primary) and tillage that is shallower and sometimes more selective of location (secondary). Primary tillage such as ploughing tends to produce a rough surface finish, whereas secondary tillage tends to produce a smoother surface finish, such as that required to make a good seedbed for many crops. Harrowing and rototilling often combine primary and secondary tillage into one operation.

"Tillage" can also mean the land that is **tilled**. The word "**cultivation**" has several senses that overlap substantially with those of "tillage". In a general context, both can refer to agriculture generally. Within agriculture, both can refer to any of the kinds of soil agitation described above. Additionally, "cultivation" or "cultivating" may refer to an even narrower sense of shallow, selective secondary tillage of row crop fields that kills weeds while sparing the crop plants.

Tillage systems

Intensive tillage

Intensive tillage systems leave less than 15% crop residue cover less than 500 pounds per acre (560 kg/ha) of small grain residue. These types of tillage systems are often referred to as **conventional tillage systems** but as reduced and conservation tillage systems have been more widely adopted, it is often not appropriate to refer to this type of system as conventional. These systems involve often multiple operations with implements such as a mold board, disk, and/or chisel plow. Then a finisher with a harrow, rolling basket, and cutter can be used to prepare the seed bed. There are many variations.

Reduced tillage

Reduced tillage systems leave between 15 and 30% residue cover on the soil or 500 to 1000 pounds per acre (560 to 1100 kg/ha) of small grain residue during the critical erosion period. This may involve the use of a chisel plow, field cultivators, or other implements.

Conservation tillage

Conservation tillage systems are methods of soil tillage which leave a minimum of 30% of crop residue on the soil surface or at least 1,000 lb/ac (1,100 kg/ha) of small grain residue on the surface during the critical soil erosion period. This slows water movement, which reduces the amount of soil erosion. Conservation tillage systems also benefit farmers by reducing fuel consumption and soil compaction. By reducing the number of times the farmer travels over the field, farmers realize significant savings in fuel and labor. Conservation tillage was used on about 38%, 109,000,000 acres (440,000 km^2), of all US cropland, 293,000,000 acres (1,190,000 km^2) planted as of 2004 according to the USDA.

However, conservation tillage systems delay warming of the soil due to the reduction of dark earth exposure to the warmth of the spring sun, thus delaying the planting of the next year's spring crop.

- No-till
- Strip-Till
- Mulch-till
- Ridge-Till

Purposes Of Tillage

Positive effects

- Ploughing loosens and aerates the soil which can facilitate some deeper penetration of roots.
- Tillage is believed to help in the growth of microorganisms present in the soil and thus, though fertility decline as microorganisms' boom period after tilling is followed by a bust period. It is debatable whether worms benefit or suffer from tillage.
- It helps in the mixing of residue from the harvest, organic matter (humus) and nutrients evenly throughout the soil.
- It is used for destroying weeds.

Negative effects of ploughing

- The soil loses a lot of its nutrients like carbon, nitrogen and its ability to store humidity.
- Some compaction of the lower layers of soil
- Eutrophication
- Can attract some harmful insects to the field.

General comments

- The type of implement makes the most difference, although other factors can have an effect.
- Tilling in absolute darkness (night tillage) might reduce the number of weeds that sprout following the tilling operation by half. Light is necessary to break the dormancy of some weed species' seed, so if fewer seeds are exposed to light during the tilling process, fewer will sprout. This may help reduce the amount of herbicides needed for weed control.

- Greater speeds, when using certain tillage implements (disks and chisel plows), lead to more intensive tillage (i.e., less residue is on the soil surface).
- Increasing the angle of disks causes residues to be buried more deeply. Increasing their concavity makes them more aggressive.
- Chisel plows can have spikes or sweeps. Spikes are more aggressive.
- Percentage residue is used to compare tillage systems because the amount of crop residue affects the soil loss due to erosion.

Definitions

Primary tillage loosens the soil and mixes in fertilizer and/or plant material, resulting in soil with a rough texture.

Secondary tillage produces finer soil and sometimes shapes the rows, preparing the seed bed. It also provides weed control throughout the growing season during the maturation of the crop plants, unless such weed control is instead achieved with low-till or no-till methods involving herbicides.

- The seed bed preparation can be done with harrows (of which there are many types and subtypes), dibbles, hoes, shovels, rotary tillers, subsoilers, ridge- or bed-forming tillers, rollers, or cultivators.
- The weed control, to the extent that it is done via tillage, is usually achieved with cultivators or hoes, which disturb the top few centimeters of soil around the crop plants but with minimal disturbance of the crop plants themselves. The tillage kills the weeds via 2 mechanisms: uprooting them, burying their leaves (cutting off their photosynthesis), or a combination of both. Weed control both prevents the crop plants from being outcompeted by the weeds (for water and sunlight) and prevents the weeds from reaching their seed stage, thus reducing future weed population aggressiveness.

History of tilling

Tilling was first performed via human labor, sometimes involving slaves. Hoofed animals could also be used to till soil via trampling. The wooden plow was then invented. It could be pulled by mule, ox, elephant, water buffalo, or similar sturdy animal. Horses are generally unsuitable, though breeds such as the scyne could work. The steel plow allowed farming in the American Midwest, where tough prairie grasses and rocks caused trouble. Soon after 1900, the farm tractor was introduced, which eventually made modern large-scale agriculture possible.

Alternatives to tilling

Modern agricultural science has greatly reduced the use of tillage. Crops can be grown for several years without any tillage through the use of herbicides to control weeds, crop varieties that tolerate packed soil, and equipment that can plant seeds or fumigate the soil without really digging it up. This practice, called no-till farming, reduces costs and environmental change by reducing soil erosion and diesel fuel usage (although it does require the use of herbicides). Most organic farming tends to require extensive tilling, as did most farming throughout history, although researchers are investigating farming in polyculture that would eliminate the need for both tillage and pesticides, such as no-dig gardening.