Agricultural Engineering

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Introduction

A modern farm tractor

Agricultural engineering is the engineering discipline that applies engineering science and technology to agricultural production and processing. Agricultural engineering combines the disciplines of animal biology, plant biology, and mechanical, civil, electrical and chemical engineering principles with a knowledge of agricultural principles. It utilizes the knowledge of engineering for making agricultural machinery.

Subfields

Wheat harvest with a combine in Denmark

Some of the specialties of agricultural engineers include:

- the design of agricultural machinery, equipment, and agricultural structures
- crop production, including seeding, tillage, irrigation and the conservation of soil and water
- animal production, including the care and processing of poultry and fish and dairy management
- the processing of food and other agricultural and biorenewable products,and food engineering.
- Bioresource engineering, which uses machines on the molecular level to help the environment.

Vodka bottling machine in Russia

History

The first curriculum in Agricultural Engineering was established at Iowa State University by J. B. Davidson in 1905. The American Society of Agricultural Engineers, now known as the American Society of Agricultural and Biological Engineers, was founded in 1907.

Pivot irrigation of cotton

Agricultural engineers

Agricultural Engineers may perform tasks as planning, supervising and managing the building of dairy effluent schemes, irrigation, drainage, flood and water control systems, perform environmental impact assessments, agricultural product processing and interpret research results and implement relevant practices. A large percentage of agricultural engineers work in academia or for government agencies such as the United States Department of Agriculture or state agricultural extension services. Some are consultants, employed by private engineering firms, while others work in industry, for manufacturers of agricultural machinery, equipment, processing technology, and structures for housing livestock and storing crops. Agricultural engineers work in production, sales, management, research and development, or applied science.

Chapter 1

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 2

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.

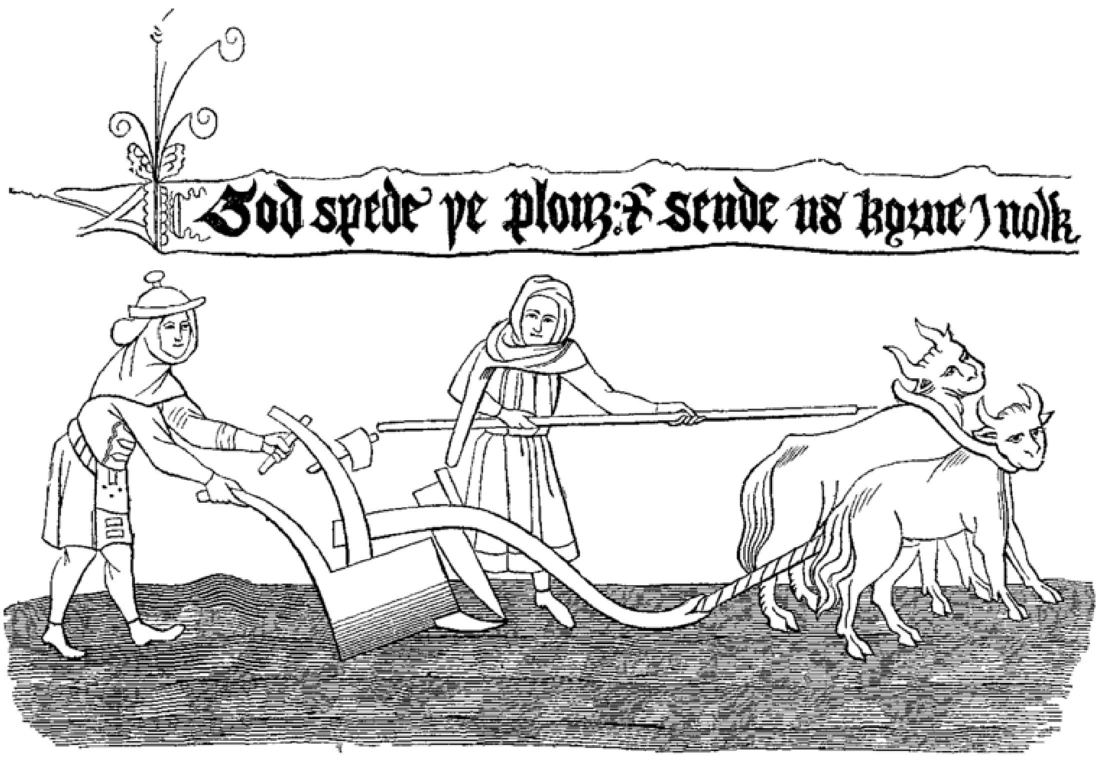


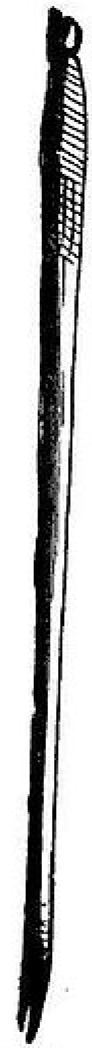
Fig. 18.—Ploughmen.—Fac-simile of a Miniature in a very ancient Anglo-Saxon Manuscript published by Shaw, with legend "God Spede ye Plough, and send us Korne enow."

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.

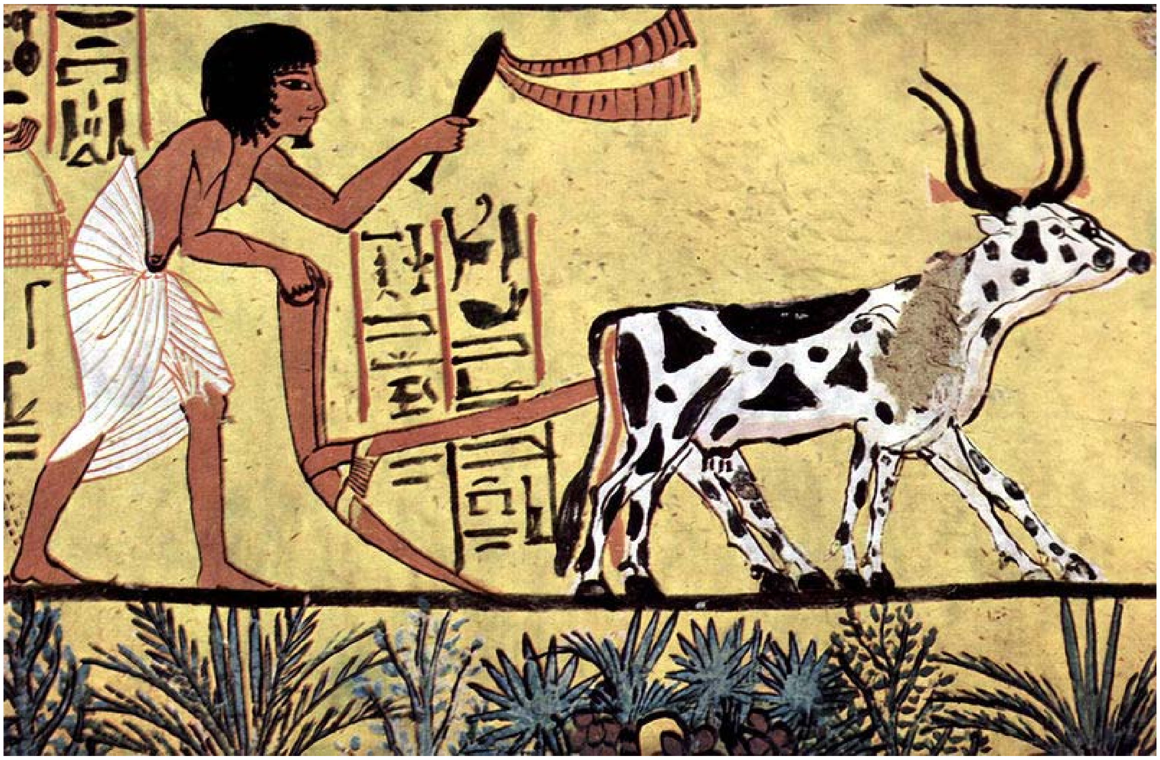
The current word *plough* also comes from English, but it appears relatively late (it is absent from Gothic), and is thought to be a loanword from one of the north Italic languages. In these it had different meanings: in Raetic *plaumorati* (Pliny), and in Latin *plaustrum* "wagon, cart", *plōstrum,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

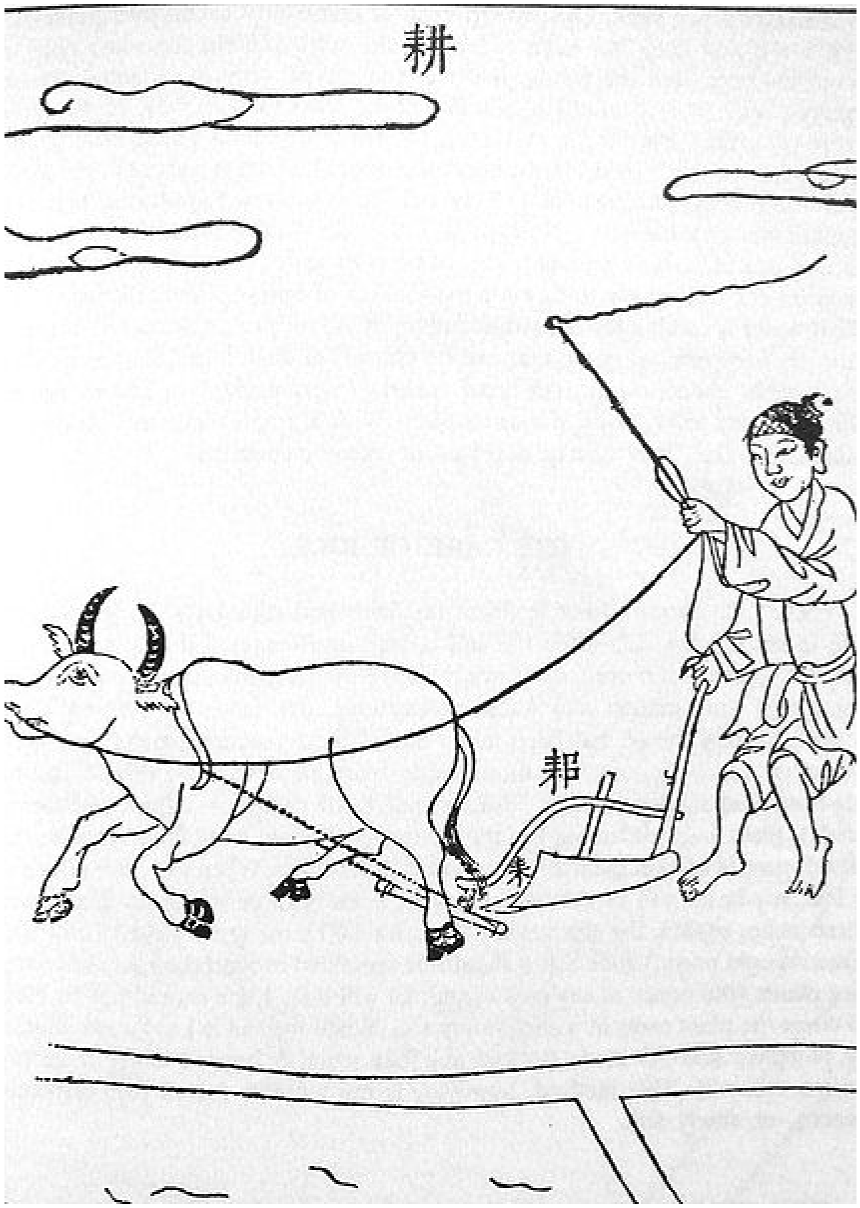
Parts of a mouldboard plough: There are 5 major parts of a mouldboard plough

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.

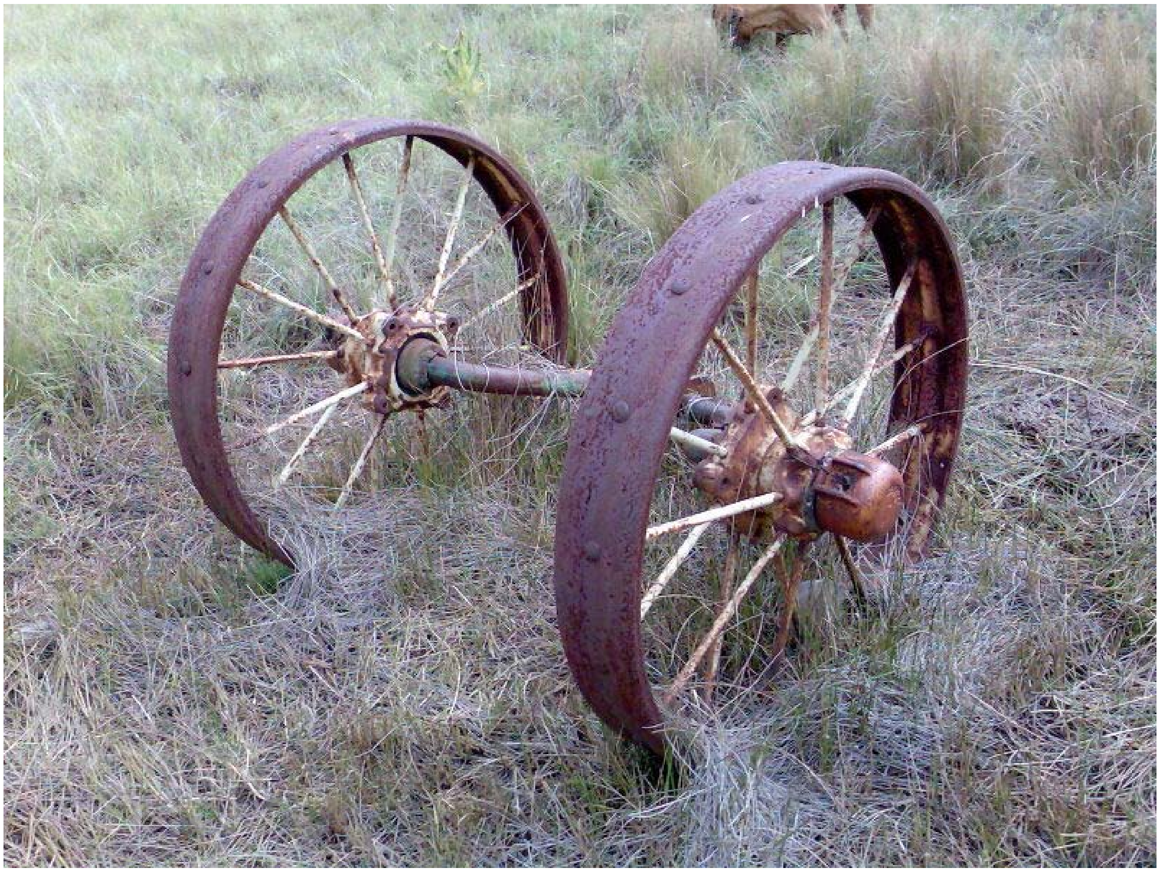
Before the Han Dynasty (202 BC–220 AD), Chinese ploughs were made almost entirely of wood, spare the iron blade of the ploughshare. By the Han period, the entire ploughshare was made of cast iron; these are the first known heavy moldboard iron ploughs.

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.

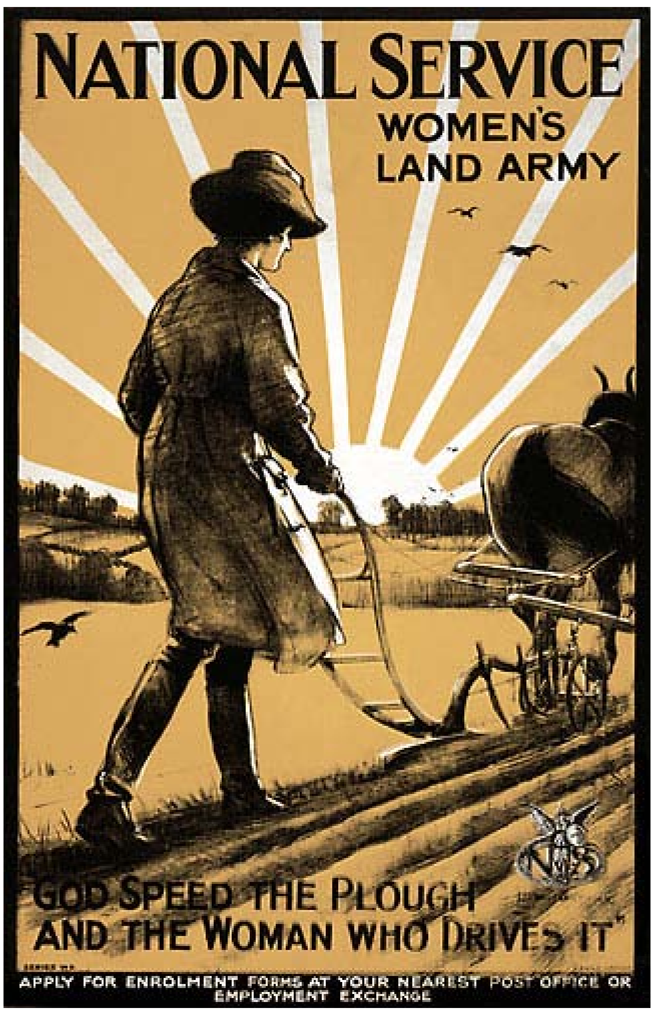
Stump-jump plough

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

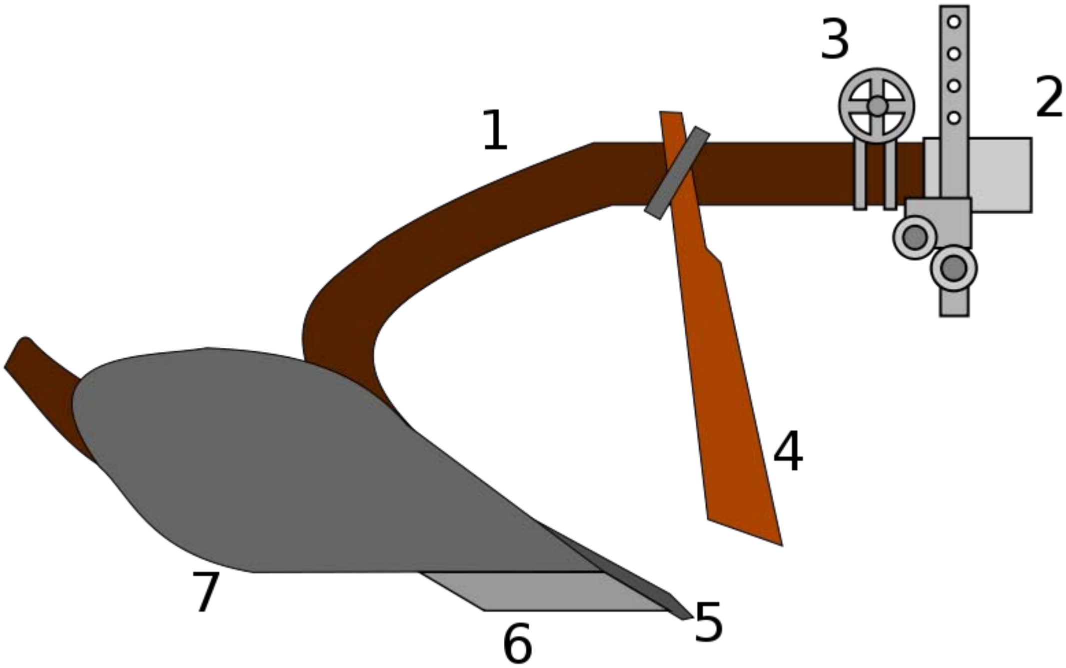


Image of a contemporary plough

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 3

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 4

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

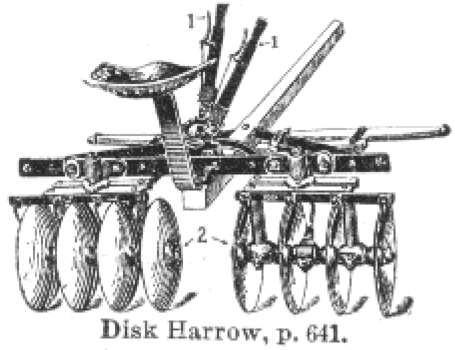
Field cultivators are used to complete tillage operations in many types of arable crop fields. The main function of the field cultivator is to prepare a proper seedbed for the crop to be planted into, to bury crop residue in the soil (helping to warm the soil before planting), to control weeds, and to 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



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 5

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 6

Irrigation

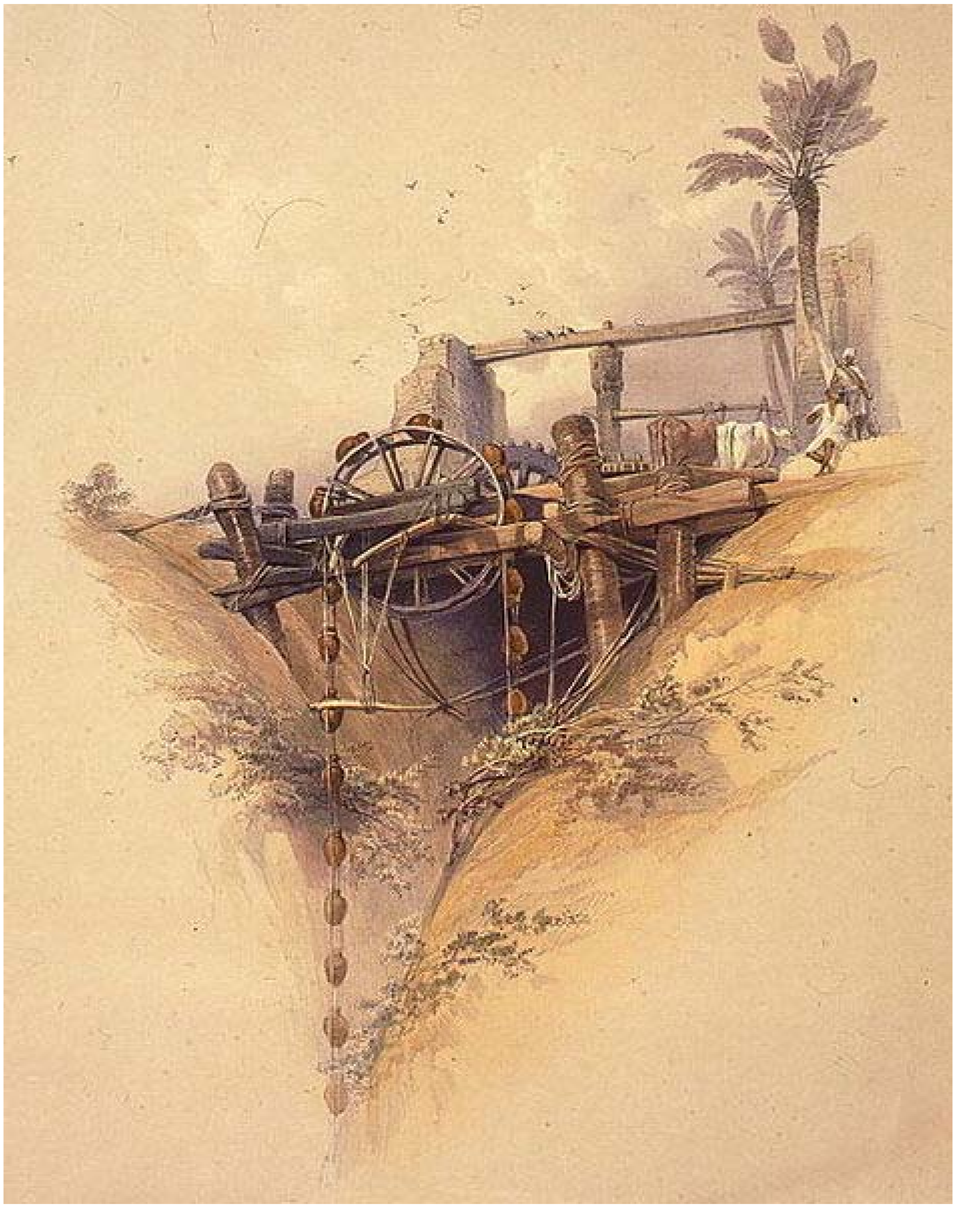
Irrigation is an artificial application of water to the soil. It is used to assist in the growing of agricultural crops, maintenance of landscapes, and revegetation of disturbed soils in dry areas and during periods of inadequate rainfall. Additionally, irrigation also has a few other uses in crop production, 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.

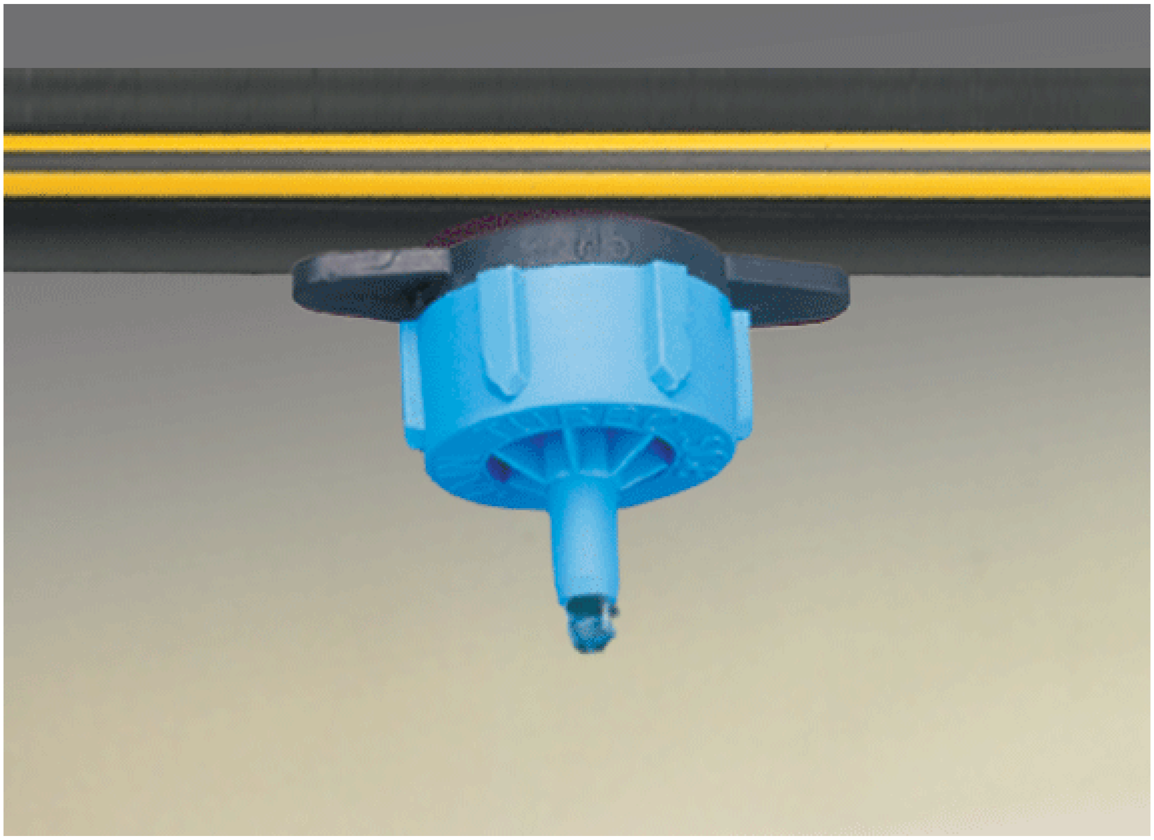
Where water levels from the irrigation source permit, the levels are controlled by dikes, usually plugged by soil. This is often seen in terraced rice fields (rice paddies), where the method is used to flood or control the level of water in each distinct field. In some cases, the water is pumped, or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

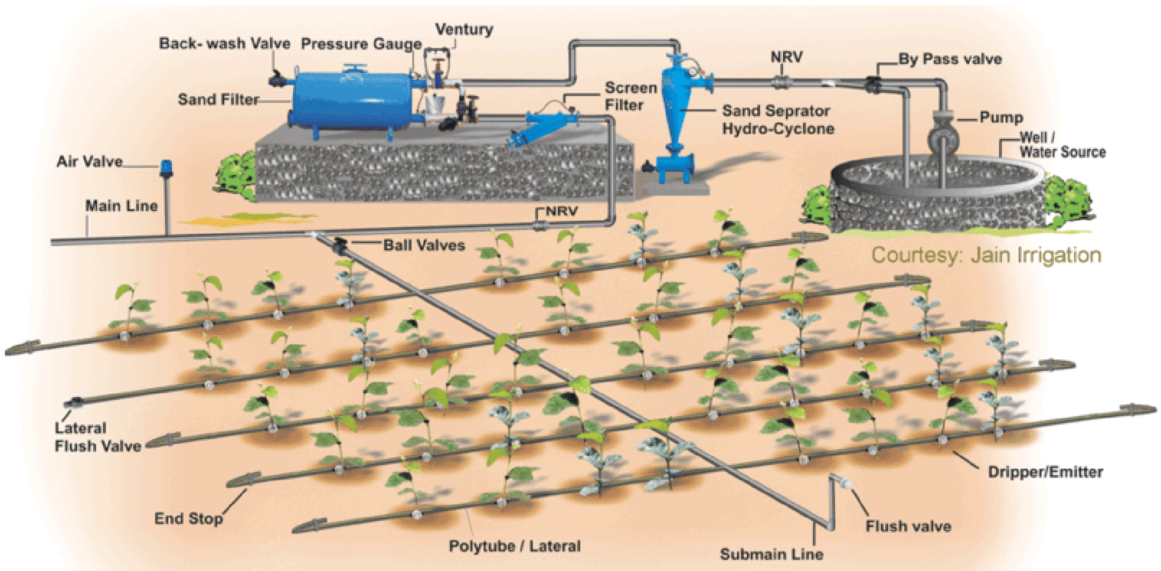
Drip



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 7

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.

Chapter 8

Industrial Agriculture

Industrial agriculture is a form of modern farming that refers to the industrialized production of livestock, poultry, fish, and crops. The methods of industrial agriculture are technoscientific, economic, and political. They include innovation in agricultural machinery and farming methods, genetic technology, techniques for achieving economies of scale in production, the creation of new markets for consumption, the application of patent protection to genetic information, and global trade. These methods are widespread in developed nations and increasingly prevalent worldwide. Most of the meat, dairy, eggs, fruits, and vegetables available in supermarkets are produced using these methods of industrial agriculture.

Historical development and future prospects

The birth of industrial agriculture more or less coincides with that of the Industrial Revolution in general. The identification of nitrogen, potassium, and phosphorus (referred to by the acronym NPK) as critical factors in plant growth led to the manufacture of synthetic fertilizers, making possible more intensive types of agriculture. The discovery of vitamins and their role in animal nutrition, in the first two decades of the 20th century, led to vitamin supplements, which in the 1920s allowed certain livestock to be raised indoors, reducing their exposure to adverse natural elements. The discovery of antibiotics and vaccines facilitated raising livestock in concentrated, controlled animal feed operations by reducing diseases caused by crowding. Chemicals developed for use in World War II gave rise to synthetic pesticides. Developments in shipping networks and technology have made long-distance distribution of agricultural produce feasible.

Agricultural production across the world doubled four times between 1820 and 1975 to feed a global population of one billion human beings in 1800 and 6.5 billion in 2002. During the same period, the number of people involved in farming dropped as the process became more automated. In the 1930s, 24 percent of the American population worked in agriculture compared to 1.5 percent in 2002; in 1940, each farm worker supplied 11 consumers, whereas in 2002, each worker supplied 90 consumers. The number of farms has also decreased, and their ownership is more concentrated. In the U.S., four companies kill 81 percent of cows, 73 percent of sheep, 57 percent of pigs, and produce 50 percent of chickens, cited as an example of "vertical integration" by the president of the U.S. National Farmers' Union. In 1967, there were one million pig farms in America; as of 2002, there were 114,000, with 80 million pigs (out of 95 million) killed each year on factory farms, according to the U.S. National Pork Producers Council. According to the Worldwatch Institute, 74 percent of the world's poultry, 43 percent of beef, and 68 percent of eggs are produced this way.

According to Denis Avery of the agribusiness funded Hudson Institute, Asia increased its consumption of pork by 18 million tons in the 1990s. As of 1997, the world had a stock of 900 million pigs, which Avery predicts will rise to 2.5 billion pigs by 2050. He told the College of Natural Resources at the University of California, Berkeley that three billion pigs will thereafter be needed annually to meet demand. He writes: "For the sake of the environment, we had better hope those hogs are raised in big, efficient confinement systems."

British agricultural revolution

The British agricultural revolution describes a period of agricultural development in Britain between the 16th century and the mid-19th century, which saw a massive increase in agricultural productivity and net output. This in turn supported unprecedented population growth, freeing up a significant percentage of the workforce, and thereby helped drive the Industrial Revolution. How this came about is not entirely clear. In recent decades, historians cited four key changes in agricultural practices, enclosure, mechanization, four-field crop rotation, and selective breeding, and gave credit to a relatively few individuals.

Challenges and issues

The challenges and issues of industrial agriculture for global and local society, for the industrial agriculture sector, for the individual industrial agriculture farm, and for animal rights include the costs and benefits of both current practices and proposed changes to those practices. This is a continuation of thousands of years of the invention and use of technologies in feeding ever growing populations.

[W]hen hunter-gatherers with growing populations depleted the stocks of game and wild foods across the Near East, they were forced to introduce agriculture. But agriculture brought much longer hours of work and a less rich diet than hunter-gatherers enjoyed. Further population growth among shifting slash-and-burn farmers led to shorter fallow periods, falling yields and soil erosion. Plowing and fertilizers were introduced to deal with these problems - but once again involved longer hours of work and degradation of soil resources(Boserup, The Conditions of Agricultural Growth, Allen and Unwin, 1965, expanded and updated in Population and Technology, Blackwell, 1980.).

While the point of industrial agriculture is lower cost products to create greater productivity thus a higher standard of living as measured by available goods and services, industrial methods have side effects both good and bad. Further, industrial agriculture is not some single indivisible thing, but instead is composed of numerous separate elements, each of which can be modified, and in fact is modified in response to market conditions, government regulation, and scientific advances. So the question then becomes for each specific element that goes into an industrial agriculture method or technique or process: What bad side effects are bad enough that the financial gain and good side effects are outweighed? Different interest groups not only reach different conclusions on this, but also recommend differing solutions, which then become factors in changing both market conditions and government regulations.

Society

The major challenges and issues faced by society concerning industrial agriculture include:

Maximizing the benefits:

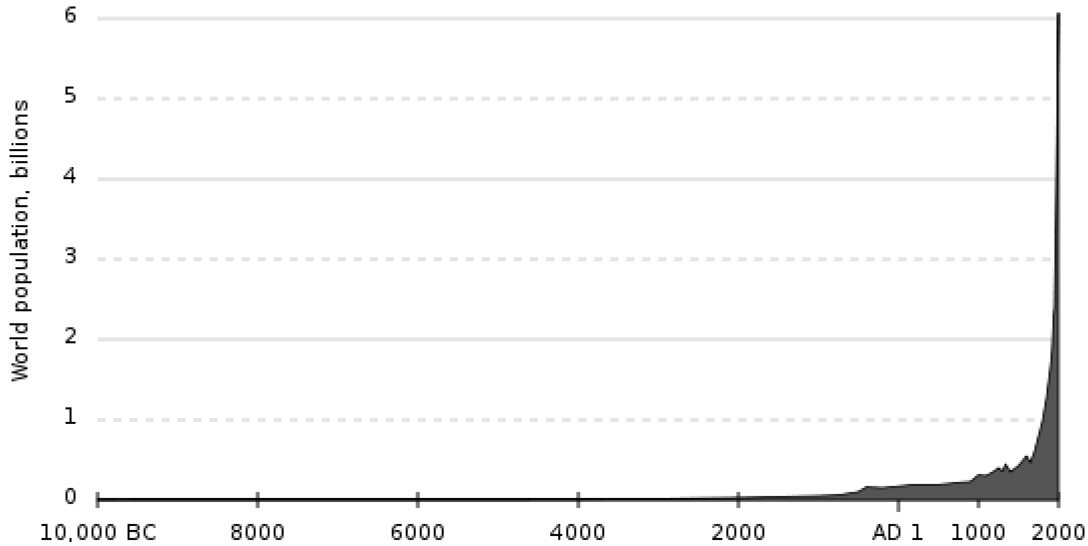
- Cheap and plentiful food
- Convenience for the consumer
- The contribution to our economy on many levels, from growers to harvesters to processors to sellers

while minimizing the downsides:

- Environmental and social costs
- Damage to fisheries
- Cleanup of surface and groundwater polluted with animal waste
- Increased health risks from pesticides
- Increased ozone pollution and global warming from heavy use of fossil fuels

Benefits

Unknown



Population (est.) 10,000 BCE – 2000 CE.

Very roughly:

- 30,000 years ago hunter-gatherer behavior fed 6 million people
- 3,000 years ago primitive agriculture fed 60 million people
- 300 years ago intensive agriculture fed 600 million people
- Today **industrial agriculture** attempts to feed 6 billion people

Estimated world population at various dates, in **thousands**

Year	World	Africa	Asia	Europe	Central & South America	North America*	Oceania
8000 BCE	8 000						
1000 BCE	50 000						
500 BCE	100 000						
1 CE	200,000 plus						
1000	310 000						
1750	791 000	106 000	502 000	163 000	16 000	2 000	2 000
1800	978 000	107 000	635 000	203 000	24 000	7 000	2 000
1850	1 262 000	111 000	809 000	276 000	38 000	26 000	2 000
1900	1 650 000	133 000	947 000	408 000	74 000	82 000	6 000

1950	2 518 629 221 214 1 398 488 547 403	167 097	171 616	12 812
1955	2 755 823 246 746 1 541 947 575 184	190 797	186 884	14 265
1960	2 981 659 277 398 1 674 336 601 401	209 303	204 152	15 888
1965	3 334 874 313 744 1 899 424 634 026	250 452	219 570	17 657
1970	3 692 492 357 283 2 143 118 655 855	284 856	231 937	19 443
1975	4 068 109 408 160 2 397 512 675 542	321 906	243 425	21 564
1980	4 434 682 469 618 2 632 335 692 431	361 401	256 068	22 828
1985	4 830 979 541 814 2 887 552 706 009	401 469	269 456	24 678
1990	5 263 593 622 443 3 167 807 721 582	441 525	283 549	26 687
1995	5 674 380 707 462 3 430 052 727 405	481 099	299 438	28 924
2000	6 070 581 795 671 3 679 737 727 986	520 229	315 915	31 043
2005	6 453 628 887 964 3 917 508 724 722	558 281	332 156	32 998**

An example of industrial agriculture providing cheap and plentiful food is the U.S.'s "most successful program of agricultural development of any country in the world". Between 1930 and 2000 U.S. agricultural productivity (output divided by all inputs) rose by an average of about 2 percent annually causing food prices paid by consumers to decrease. "The percentage of U.S. disposable income spent on food prepared at home decreased, from 22 percent as late as 1950 to 7 percent by the end of the century."

Convenience and choice

Industrial agriculture treats farmed products in terms of minimizing inputs and maximizing outputs at every stage from the natural resources of sun, land and water to the consumer which results in a vertically integrated economic sector that genetically manipulates crops and livestock; and processes, packages, and markets in whatever way generates maximum return on investment creating convenience foods many customers will pay a premium for. A consumer backlash against food sold for taste, convenience, and profit rather than nutrition and other values (e.g. reduce waste, be natural, be ethical) has led agriculture to also provide organic food, minimally processed foods, and minimally packaged foods to maximally satisfy all segments of society thus generating maximum return on investment.

Liabilities

Environment

Industrial agriculture uses huge amounts of water, energy, and industrial chemicals; increasing pollution in the arable land, usable water and atmosphere. Herbicides, insecticides, fertilizers, and animal waste products are accumulating in ground and surface waters. "Many of the negative effects of industrial agriculture are remote from fields and farms. Nitrogen compounds from the Midwest, for example, travel down the Mississippi to degrade coastal fisheries in the Gulf of Mexico. But other adverse effects are showing up within agricultural production systems -- for example, the rapidly developing resistance among pests is rendering our arsenal of herbicides and insecticides increasingly ineffective."

Social

A study done for the US. Office of Technology Assessment conducted by the UC Davis Macrosocial Accounting Project concluded that industrial agriculture is associated with substantial deterioration of human living conditions in nearby rural communities.

Animals

"Confined animal feeding operations" or "intensive livestock operations", can hold large numbers (some up to hundreds of thousands) of animals, often indoors. These animals are typically cows, hogs, turkeys, or chickens. The distinctive characteristics of such farms is the concentration of livestock in a given space. The aim of the operation is to produce as much meat, eggs, or milk at the lowest possible cost and with the greatest level of food safety.

Food and water is supplied in place, and artificial methods are often employed to maintain animal health and improve production, such as therapeutic use of antimicrobial agents, vitamin supplements and growth hormones. Growth hormones are not used in chicken meat production nor are they used in the European Union for any animal. In meat production, methods are also sometimes employed to control undesirable behaviours often related to stresses of being confined in restricted areas with other animals. More docile breeds are sought (with natural dominant behaviours bred out for example), physical restraints to stop interaction, such as individual cages for chickens, or animals physically modified, such as the de-beaking of chickens to reduce the harm of fighting. Weight gain is encouraged by the provision of plentiful supplies of food to animals breed for weight gain.

The designation "confined animal feeding operation" in the U.S. resulted from that country's 1972 Federal Clean Water Act, which was enacted to protect and restore lakes and rivers to a "fishable, swimmable" quality. The United States Environmental Protection Agency (EPA) identified certain animal feeding operations, along with many other types of industry, as point source polluters of groundwater. These operations were designated as CAFOs and subject to special anti-pollution regulation.

In 24 states in the U.S., isolated cases of groundwater contamination has been linked to CAFOs. For example, the ten million hogs in North Carolina generate 19 million tons of waste per year. The U.S. federal government acknowledges the waste disposal issue and requires that animal waste be stored in lagoons. These lagoons can be as large as 7.5 acres (30,000 m^2). Lagoons not protected with an impermeable liner can leak waste into groundwater under some conditions, as can runoff from manure spread back onto fields as fertilizer in the case of an unforeseen heavy rainfall. A lagoon that burst in 1995 released 25 million gallons of nitrous sludge in North Carolina's New River. The spill allegedly killed eight to ten million fish.

The large concentration of animals, animal waste, and dead animals in a small space poses ethical issues to some consumers. Animal rights and animal welfare activists have charged that intensive animal rearing is cruel to animals. As they become more common, so do concerns about air pollution and ground water contamination, and the effects on human health of the pollution and the use of antibiotics and growth hormones.

Some of the major benefits that are often overlooked by consumers and animal activists alike, are the overall benefits to the animals, such as controlled, comfortable climate, unlimited amounts of fresh food and clean water, and safety from predators. Animals raised in a modern setting also benefit from greater veterinary care, decreased levels of stress, and a more sanitary environment.

According to the U.S. Centers for Disease Control and Prevention (CDC), farms on which animals are intensively reared can cause adverse health reactions in farm workers. Workers may develop acute and chronic lung disease, musculoskeletal injuries, and may catch infections that transmit from animals to human beings. These type of transmissions, however, and extremely rare, as zoonotic diseases are uncommon.

Crops

The projects within the Green Revolution spread technologies that had already existed, but had not been widely used outside of industrialized nations. These technologies included pesticides, irrigation projects, and synthetic nitrogen fertilizer.

The novel technological development of the Green Revolution was the production of what some referred to as “miracle seeds.” Scientists created strains of maize, wheat, and rice that are generally referred to as HYVs or “high-yielding varieties.” HYVs have an increased nitrogen-absorbing potential compared to other varieties. Since cereals that absorbed extra nitrogen would typically lodge, or fall over before harvest, semi-dwarfing genes were bred into their genomes. Norin 10 wheat, a variety developed by Orville Vogel from Japanese dwarf wheat varieties, was instrumental in developing Green Revolution wheat cultivars. IR8, the first widely implemented HYV rice to be developed by the International Rice Research Institute, was created through a cross between an Indonesian variety named “Peta” and a Chinese variety named “Dee Geo Woo Gen.”

With the availability of molecular genetics in Arabidopsis and rice the mutant genes responsible (*reduced height(rht)*, *gibberellin insensitive (gai1)* and *slender rice (slr1)*) have been cloned and identified as cellular signalling components of gibberellic acid, a phytohormone involved in regulating stem growth via its effect on cell division. Stem growth in the mutant background is significantly reduced leading to the dwarf phenotype. Photosynthetic investment in the stem is reduced dramatically as the shorter plants are inherently more stable mechanically. Assimilates become redirected to grain production, amplifying in particular the effect of chemical fertilisers on commercial yield.

HYVs significantly outperform traditional varieties in the presence of adequate irrigation, pesticides, and fertilizers. In the absence of these inputs, traditional varieties may outperform HYVs. One criticism of HYVs is that they were developed as F1 hybrids, meaning they need to be purchased by a farmer every season rather than saved from previous seasons, thus increasing a farmer's cost of production.

Sustainable agriculture

The idea and practice of sustainable agriculture has arisen in response to the problems of industrial agriculture. Sustainable agriculture integrates three main goals: environmental stewardship, farm profitability, and prosperous farming communities. These goals have been defined by a variety of disciplines and may be looked at from the vantage point of the farmer or the consumer.

Organic farming methods

Organic farming methods combine some aspects of scientific knowledge and highly limited modern technology with traditional farming practices; accepting some of the methods of industrial agriculture while rejecting others. Organic methods rely on naturally occurring biological processes, which often take place over extended periods of time, and a holistic approach; while chemical-based farming focuses on immediate, isolated effects and reductionist strategies.

Integrated Multi-Trophic Aquaculture is an example of this holistic approach. Integrated Multi-Trophic Aquaculture (IMTA) is a practice in which the by-products (wastes) from one species are recycled to become inputs (fertilizers, food) for another. Fed aquaculture (e.g. fish, shrimp) is combined with inorganic extractive (e.g. seaweed) and organic extractive (e.g. shellfish) aquaculture to create balanced systems for environmental sustainability (biomitigation), economic stability (product diversification and risk reduction) and social acceptability (better management practices).

Chapter 9

Hydrology (Agriculture)

Agricultural hydrology is the study of water balance components intervening in agricultural water management, notably in irrigation and drainage.

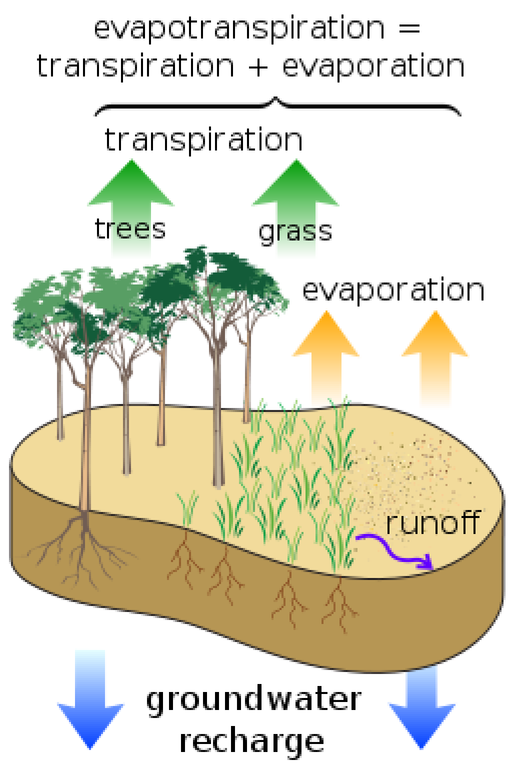
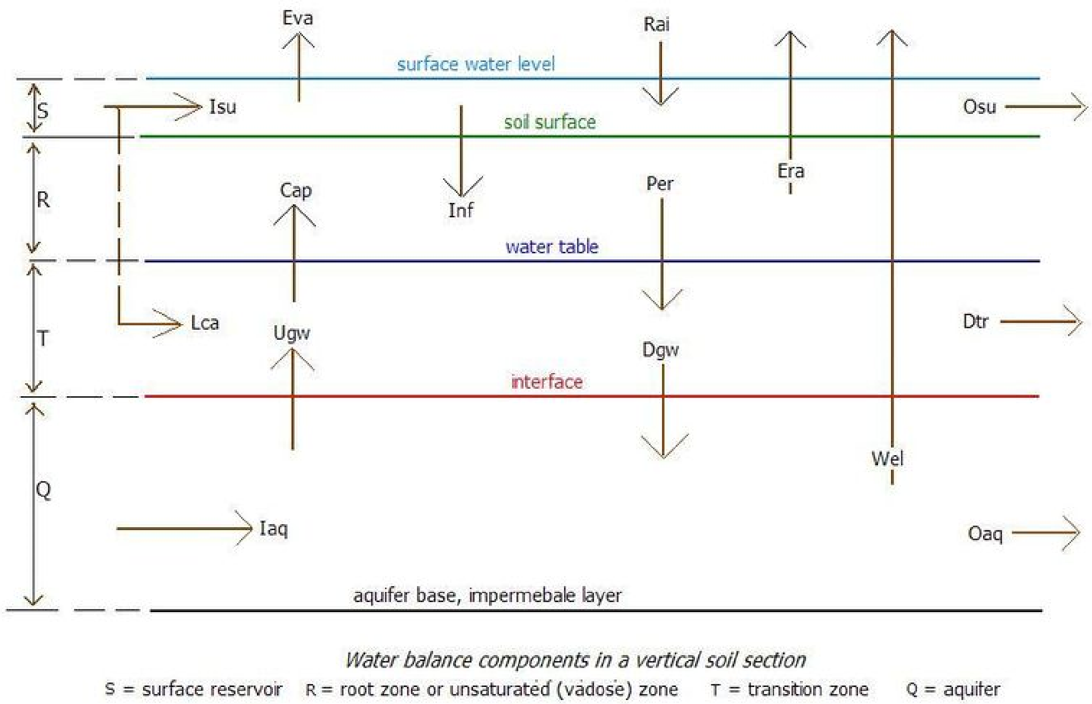


Illustration of some water balance components

Water balance components



Water balance components in agricultural land

The water balance components can be grouped into components corresponding to zones in a vertical cross-section in the soil forming reservoirs with inflow, outflow and storage of water :

1. the surface reservoir (*S*)
2. the root zone or unsaturated (vadose zone) (*R*) with mainly vertical flows
3. the aquifer (*Q*) with mainly horizontal flows
4. a transition zone (*T*) in which vertical and horizontal flows are converted

The general water balance reads:

- inflow = outflow + change of storage

and it is applicable to each of the reservoirs or a combination thereof.

In the following balances it is assumed that the water table is inside the transition zone.

Surface water balance

The incoming water balance components into the surface reservoir (*S*) are:

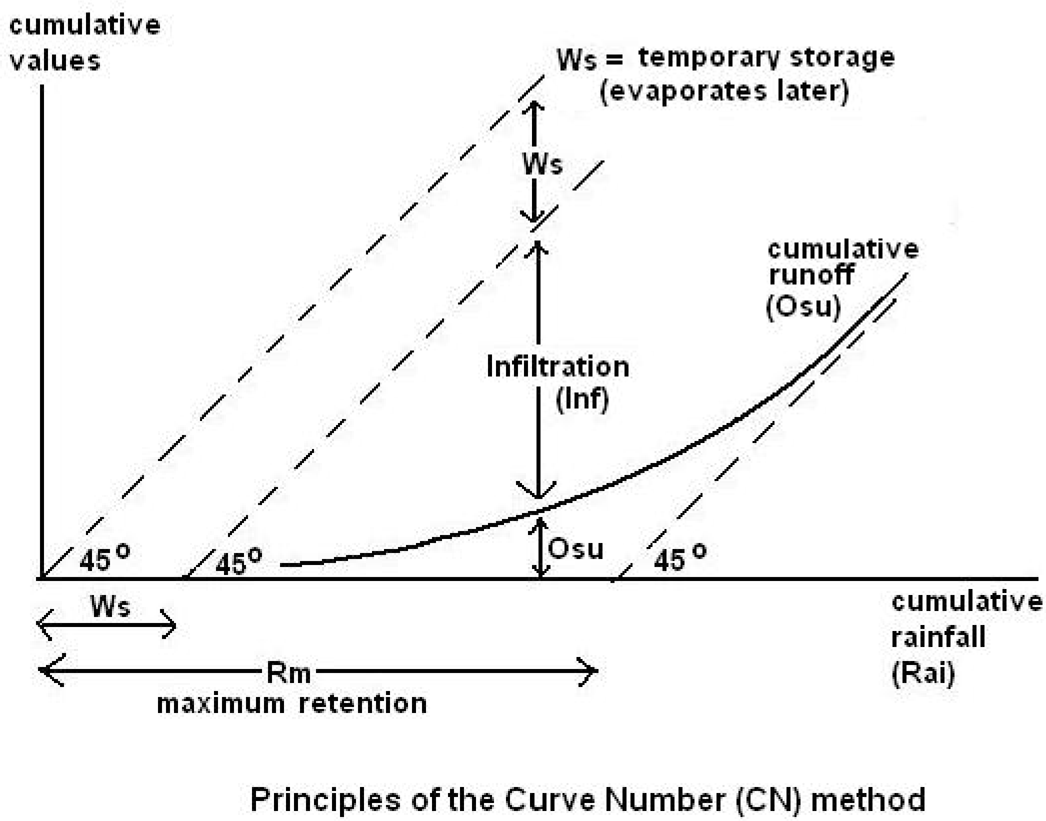
1. Rai - Vertically incoming water to the surface e.g.: precipitation (including snow), rainfall, sprinkler irrigation
2. Isu - Horizontally incoming surface water. This can consist of natural inundation and/or surface irrigation

The outgoing water balance components from the surface reservoir (*S*) are:

1. Eva - Evaporation from open water on the soil surface
2. Osu - Surface runoff (natural) or surface drainage (artificial)
3. Inf - Infiltration of water through the soil surface into the root zone

The surface water balance reads:

- Rai + Isu = Eva + Inf + Osu + Ws , where Ws is the change of water storage on top of the soil surface



Surface runoff in the Curve Number method

Example of a surface water balance

An example is given of surface runoff according to the Curve number method. The applicable equation is:

- Osu = $(Rai – Ws)^2$ / (Pp – Ws + Rm)

where Rm is the *maximum retention* of the area for which the method is used

Normally one finds that Ws = 0.2 Rm and the value of Rm depends on the soil characteristics. The Curve Number method provides tables for these relations.

The method yields cumulative runoff values. To obtain runoff intensity values or runoff velocity (volume per unit of time) the cumulative duration is to be divided into sequential time steps (for example in hours).

Root zone water balance

The incoming water balance components into the root zone (*R*) are:

1. Inf - Infiltration of water through the soil surface into the root zone
2. Cap - Capillary rise of water from the transition zone

The outgoing water balance components from the surface reservoir (*R*) are:

1. Era - Actual evaporation or evapotranspiration from the root zone
2. Per - Percolation of water from the unsaturated root zone into the transition zone

The root zone water balance reads:

- Inf + Cap = Era + Per + Wr , where Wr is the change of water storage in the root zone

Transition zone water balance

The incoming water balance components into the transition zone (*T*) are:

1. Per - Percolation of water from the unsaturated root zone into the transition zone
2. Lca - Infiltration of water from river, canal or drainage systems into the transition zone, often referred to as deep seepage losses
3. Ugw - Vertically upward seepage of water from the aquifer into the saturated transition zone

The outgoing water balance components from the transition zone (*T*) are:

1. Cap - Capillary rise of water into the root zone
2. Dtr - Artificial horizontal subsurface drainage,
3. Dgw - Vertically downward drainage of water from the saturated transition zone into the aquifer

The water balance of the transition zone reads:

- Per + Lca + Ugw = Cap + Dtr + Dgw + Wt , where Wt is the change of water storage in the transition zone noticeable as a change of the level of the water table.

Aquifer water balance

The incoming water balance components into the aquifer (*Q*) are:

1. Dgw - Vertically downward drainage of water from the saturated transition zone into the aquifer
2. Iaq - Horizontally incoming groundwater into the aquifer

The outgoing water balance components from the aquifer (*Q*) are:

1. Ugw - Vertically upward seepage of water from the aquifer into the saturated transition zone
2. Oaq - Horizontally outgoing groundwater from the aquifer
3. Wel - Discharge from (tube)wells placed in the aquifer

The water balance of the aquifer reads:

- Dgw + Iaq = Ugw + Wel + Oaq + Wq

where Wq is the change of water storage in the aquifer noticeable as a change of the artesian pressure.

Specific water balances

Combined balances

Water balances can be made for a combination of two bordering vertical soil zones discerned, whereby the components constituting the inflow and outflow from one zone to the other will disappear.
In long term water balances (month, season, year), the storage terms are often negligible small. Omitting these leads to *steady state* or *equilibrium* water balances.

Combination of surface reservoir (*S*)and root zone (*R*) in steady state yields the **topsoil water balance** :

- Rai + Isu + Cap = Eva + Era + Osu + Per , where the linkage factor *Inf* has disappeared.

Combination of root zone (*R*) and transition zone (*T*) in steady state yields the **subsoil water balance** :

- Inf + Lca + Ugw = Era + Dtr + Dgw , where Wr the linkage factors *Per* and *Cap* have disappeared.

Combination of transition zone (*T*) and aquifer (*Q*) in steady state yields the **geohydrologic water balance** :

- Per + Lca + Iaq = Cap + Dtr + Wel + Oaq , where Wr the linkage factors *Ugw* and *Dgw* have disappeared.

Combining the uppermost three water balances in steady state gives the **agronomic water balance** :

- Rai + Isu + Lca + Ugw = Eva + Era + Osu + Dtr + Dgw , where the linkage factors *Inf*, *Per* and *Cap* have disappeared.

Combining all four water balances in steady state gives the **overall water balance** :

- Rai + Isu + Lca + Iaq = Eva + Era + Osu + Dtr + Wel + Oaq , where the linkage factors *Inf*, *Per*, *Cap*, *Ugw* and *Dgw* have disappeared.

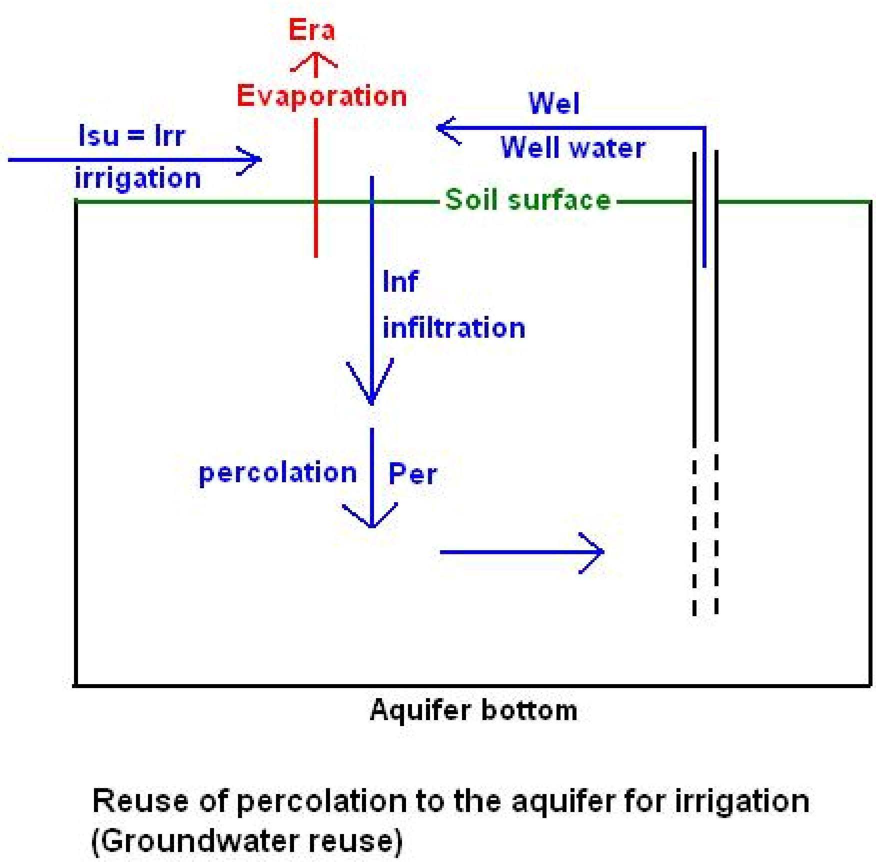


Diagram for reuse of groundwater for irrigation by wells

Example of an overall water balance

An example is given of the reuse of groundwater for irrigation by pumped wells.

The total irrigation and the infiltration are:

- Inf = Irr + Wel , where *Irr* = surface irrigation from the canal system , and *Wel* = the irrigation from wells

The field irrigation efficiency (*Ff* < 1) is:

- Ff = Era / Inf , where *Era* = the evapotranspiration of the crop (consumptive use)

The value of *Era* is less than *Inf* , there is an excess of irrigation that percolates down to the subsoil (*Per*):

- Per = Irr + Wel – Era , or:
- Per = (1 - Ff) (Irr + Wel)

The percolation *Per* is pumped up again by wells for irrigation (*Wel*), hence:

- Wel = Per , or:
- Wel = (1 - Ff) (Irr + Wel) , and therefore:
- Wel / Irr = (1 - Ff) / Ff

With this equation the following table can be prepared:

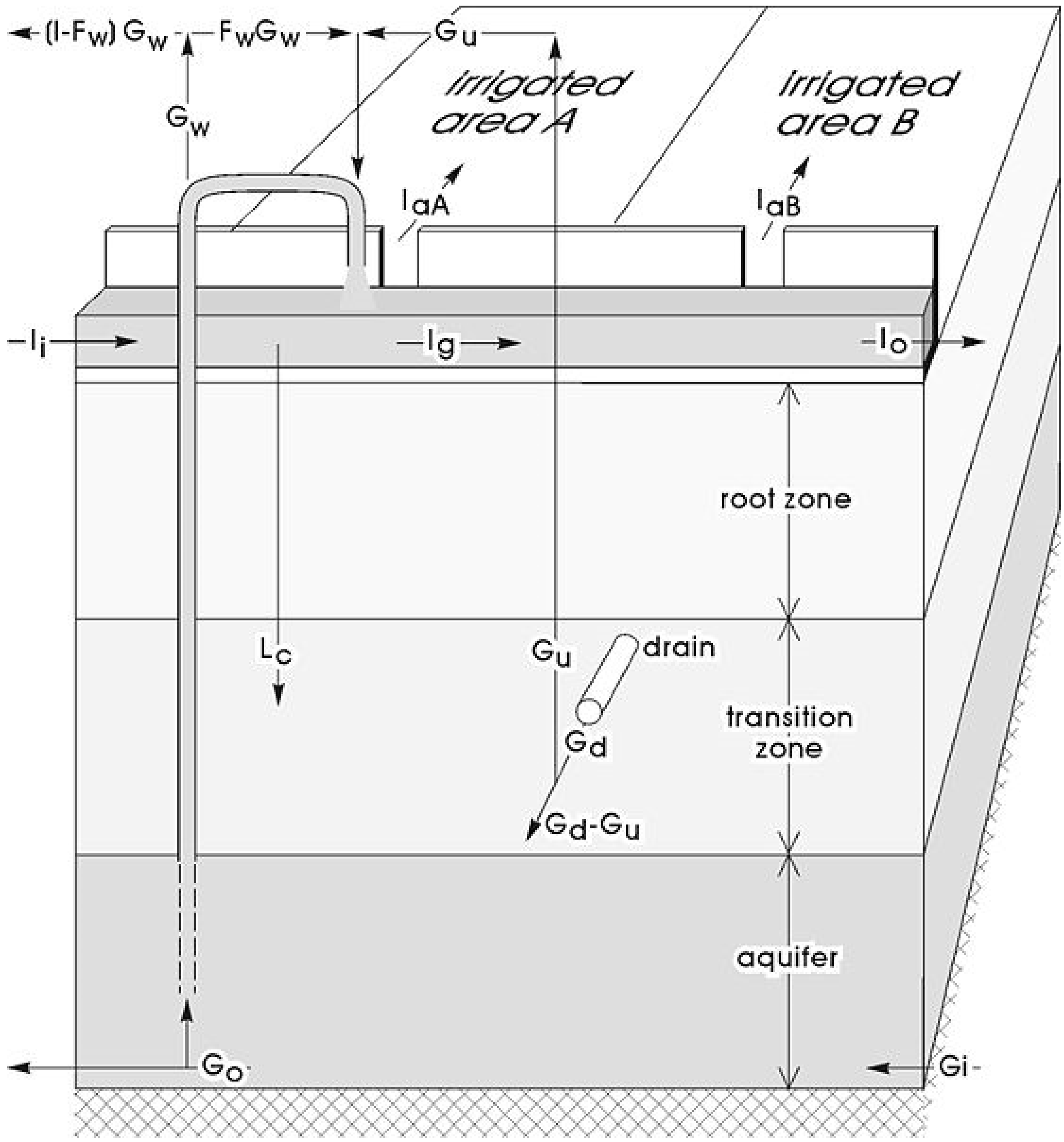
Ff	0.20	0.25	0.33	0.50	0.75
Well / Irr	4	3	2	1	0.33

It can be seen that with low irrigation efficiency the amount of water pumped by the wells (*Wel*) is several time greater than the amount of irrigation water brought in by the canal system (*Irr*). This is due to the fact that a drop of water must be recirculated on the average several times before is used by the plants.

Water table outside transition zone

When the water table is above the soil surface, the balances containing the components *Inf*, *Per*, *Cap* are not appropriate as they do not exist. When the water table is inside the root zone, the balances containing the components *Per*, *Cap* are not appropriate as they do not exist. When the water table is below the transition zone, only the *aquifer balance* is appropriate.

Reduced number of zones



Saltmod water balance components

Under specific conditions it may be that no aquifer, transition zone and/or root zone is present. Water balances can be made omitting the absent zones.

Net and excess values

Vertical hydrological components along the boundary between two zones with arrows in the same direction can be combined into *net values* .
For example : Npc = Per − Cap (net percolation) , Ncp = Cap − Per (net capillary rise).
Horizontal hydrological components in the same zone with arrows in same direction can

be combined into *excess values* .
For example : Egio = Iaq − Oaq (excess groundwater inflow over outflow) , Egoi = Oaq − Iaq (excess groundwater outflow over inflow).

Salt balances

Agricultural water balances are also used in the salt balances of irrigated lands.
Further, the salt and water balances are used in agro-hydro-salinity-drainage models like Saltmod.
Equally, they are used in groundwater salinity models like SahysMod which is a spatial variation of SaltMod using a polygonal network.

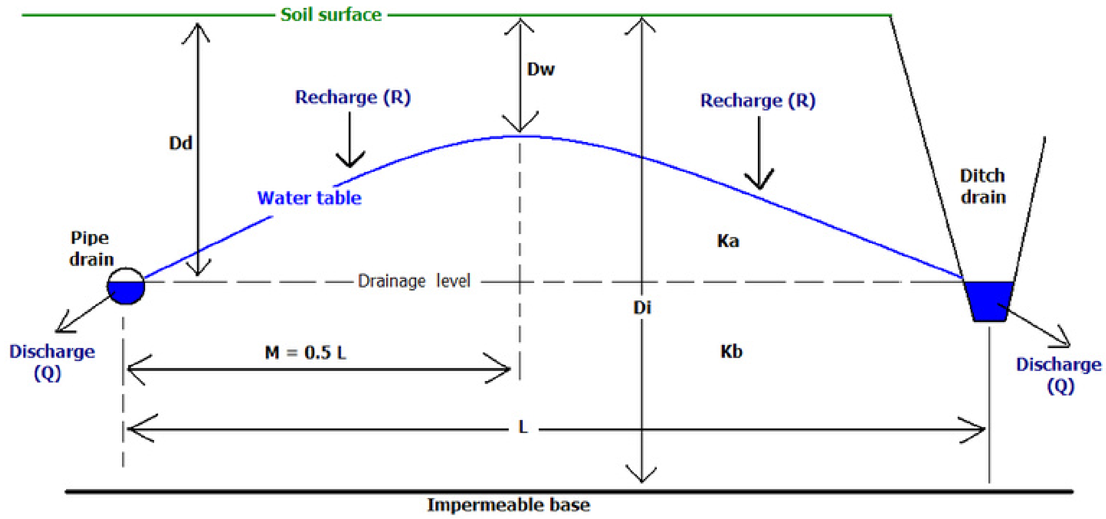
Irrigation and drainage requirements

The *irrigation requirement* (Irr) can be calculated from the *topsoil water balance*, the *agronomic water balance* and/or the *overall water balance*, as defined in the section "Combined balances", depending on the availability of data on the water balance components.
Considering surface irrigation, assuming the evaporation of surface water is negligibly small (Eva = 0), setting the actual evapotranspiration Era equal to the potential evapotranspiration (Epo) so that Era = Epo and setting the surface inflow Isu equal to Irr so that Isu = Irr, the balances give respectively:

- Irr = Epo + Osu + Per − Rai − Cap
- Irr = Epo + Osu + Dtr + Dgw − Rai − Lca − Ugw
- Irr = Epo + Osu + Dtr + Oaq − Rai − Lca − Iaq

Defining the *irrigation efficiency* as IEFF = Epo/Irr, i.e. the fraction of the irrigation water that is consumed by the crop, it is found respectively that :

- IEFF = 1 − (Osu + Per − Rai − Cap) / Irr
- IEFF = 1 − (Osu + Dtr + Dgw − Rai − Lca − Ugw) / Irr



Geometry subsurface drainage system by pipes or ditches

D = depth K = hydraulic conductivity L = Drain spacing

The drain discharge determines the drain spacing

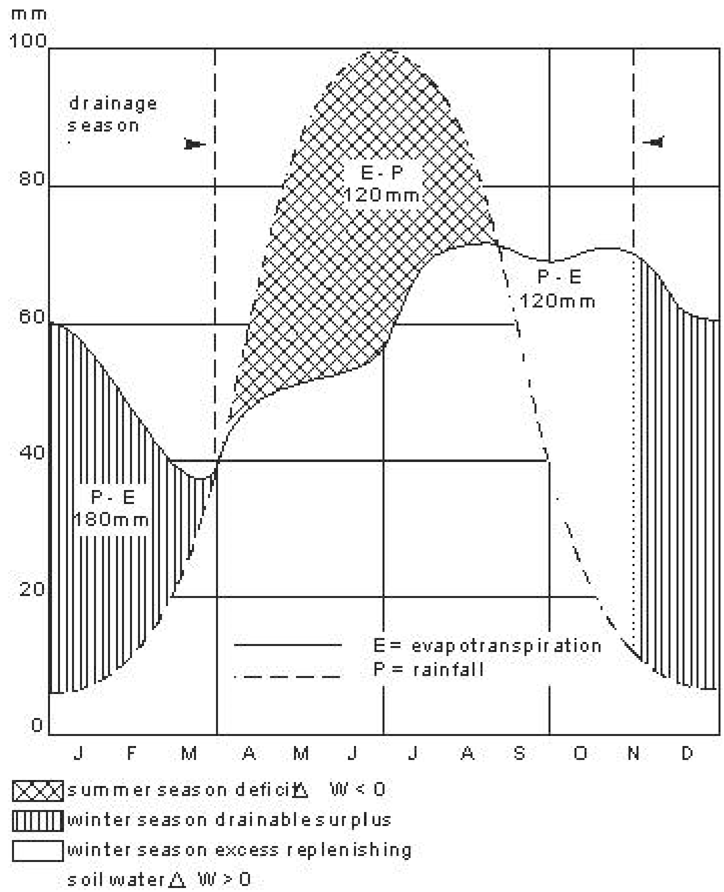
- IEFF = 1 − (Osu + Dtr + Oaq − Rai − Lca − Iaq) / Irr

Likewise the *safe yield* of wells, extracting water from the aquifer without overexploitation, can be determined using the *geohydrologic water balance* and/or the *overall water balance*, as defined in the section "Combined balances", depending on the availability of data on the water balance components.

Similarly, the subsurface drainage requirement can be found from the drain discharge (Dtr) in the *subsoil water balance*, the *agronomic water balance*, the *geohydrologic water balance* and/or the *overall water balance*.

In the same fashion, the well drainage requirement can be found from well discharge (Wel) in the *geohydrologic water balance* and/or the *overall water balance*.

The *subsurface drainage requirement* and *well drainage requirement* play an important role in the design of agricultural drainage systems.



Average climatic data and drainage in the Netherlands

Example of drainage and irrigation requirements

The drainage and irrigation requirements in The Netherlands are derived from the climatic characteristics (see figure).

Climatic data in the figure (mm)	Summer Apr-Aug	Winter Sep-Mar	Annual
Precipitation P	360	360	720
Evaporation E	480	60	540
Change of storage ΔW	–120	+120	0
Drainage requirement D	0	180	180
Irrigation requirement	variable	0	variable

The quantity of water to be drained in a normal winter is:

- $D = P - E - \Delta W$

According to the figure, the drainage period is from November to March (120 days) and the discharge of the drainage system is
D = 180 / 120 = 1.5 mm/day corresponding to 15 m^3/day per ha.

During winters with more precipitation than normal, the drainage requirement increase accordingly.

The irrigation requirement depends on the rooting depth of the crops, which determines their capacity to make use of the water stored in the soil after winter. Having a shallow rooting system, pastures need irrigation to an amount of about half of the storage depletion in summer. Practically, wheat does not require irrigation because it develops deeper roots while during the maturing period a dry soil is favorable.

The analysis of cumulative frequency of climatic data plays an important role in the determination of the irrigation and drainage needs in the long run.

Chapter 10

Shifting Cultivation

Shifting cultivation is an agricultural system in which plots of land are cultivated temporarily, then abandoned. This system often involves clearing of a piece of land followed by several years of wood harvesting or farming, until the soil loses fertility. Once the land becomes inadequate for crop production, it is left to be reclaimed by natural vegetation, or sometimes converted to a different long-term cyclical farming practice. The ecological consequences are often deleterious, but can be partially mitigated if new forests are not invaded. Of these cultivators, many use a practice of slash-and-burn as one element of their farming cycle. Others employ land clearing without any burning, and some cultivators are purely migratory and do not use any cyclical method on a given plot. Sometimes no slashing at all is needed where regrowth is purely of grasses, an outcome not uncommon when soils are near exhaustion and need to lie fallow.

The political ecology of shifting cultivation

Shifting cultivation is a form of agriculture in which the cultivated or cropped area is shifted regularly to allow soil properties to recover under conditions of natural successive stages of re-growth. In a shifting cultivation system, at any particular point in time a minority of 'fields' are in cultivation and a majority are in various stages of natural re-growth. Over time, fields are cultivated for a relatively short time, and allowed to recover, or are fallowed, for a relatively long time. Eventually a previously cultivated field will be cleared of the natural vegetation and planted in crops again. Fields in established and stable shifting cultivation systems are cultivated and fallowed cyclically.This type of farming is called jhumming in India.

Fallow fields are not unproductive. During the fallow period, shifting cultivators use the successive vegetation species widely for timber for fencing and construction, firewood, thatching, ropes, clothing, tools, carrying devices and medicines. It is common for fruit and nut trees in fallows to be planted in fallow fields to the extent that parts of some fallows are in fact orchards. Soil-enhancing shrub or tree species may be planted or protected from slashing or burning in fallows. Many of these species have been shown to fix nitrogen. Fallows commonly contain plants that attract birds and animals and are important for hunting. But perhaps most importantly, tree fallows protect soil against physical erosion and draw nutrients to the surface from deep in the soil profile.

The relationship between the time the land is cultivated and the time it is fallowed are critical to the stability of shifting cultivation systems. These parameters determine whether or not the shifting cultivation system as a whole suffers a net loss of nutrients over time. A system in which there is a net loss of nutrients with each cycle will eventually lead to a degradation of resources unless actions are taken to arrest the losses. In some cases soil can be irreversibly exhausted (including erosion as well as nutrient loss) in less than a decade.

The longer a field is cropped, the greater the loss of soil organic matter, the reduction in the cation-exchange-capacity and in nitrogen and phosphorus, the greater the increase in acidity, the more likely soil porosity and infiltration capacity is reduced and the greater the loss of seeds of naturally occurring plant species from soil seed banks. In a stable shifting cultivation system, the fallow is long enough for the natural vegetation to recover to the state that it was in before it was cleared, and for the soil to recover to the condition it was in before cropping began. During fallow periods soil temperatures are lower, wind and water erosion is much reduced, nutrient cycling becomes closed again, nutrients are extracted from the subsoil, soil fauna increases, acidity is reduced, soil structure, texture and moisture characteristics improve and seed banks are replenished.

No universal optimum relationship exists between the length of the cropping period and the length of the fallow period. In favourable agricultural environments, cropping periods can be longer and fallow periods shorter, than in less favourable agricultural environments. In favourable environments soil conditions at the beginning of a cropping cycle will be better and fallow successional stages will proceed faster. Nevertheless, even in the most favourable environments, it is likely that if the cropping period is extended beyond a certain point, the fallow conditions required for an adequate recovery of soils and vegetation will be jeopardized.

If the fallow period is shortened there will be less time in which the soil recovery processes and vegetation successions can take place. The length of fallow period required to prevent net loss of nutrients will again depend on the quality of the environment, which will in turn, determine the rate at which recovery occurs. But sooner or later, if the fallow period continues to be reduced, an observable change will occur in the fallow vegetation. Secondary forest may be reduced to shorter, thinner stemmed, fewer, woody bush or jungle species, bush may be reduced to scrub and tall grasses and scrub and tall grasses may be reduced to short grasses. Less directly observable, but nevertheless critical changes will also be occurring in the soil. Changes in environmental conditions that happen subsequent to either a lengthening of the cropping period or a shortening of the fallow period often result in a fall in crop yields. It is not difficult to perceive how a shifting cultivation system, once destabilized, can proceed into a vicious circle of declining yields and shortening fallows or lengthening cropping periods, which in turn lead to further degradation of environmental conditions. This process, its causes and possible solutions are discussed further below.

The secondary forests created by shifting cultivation are commonly richer in plant and animal resources useful to humans than primary forests, even though they are much less bio-diverse. Shifting cultivators view the forest as an agricultural landscape of fields at various stages in a regular cycle. People unused to living in forests cannot see the fields for the trees. Rather they perceive an apparently chaotic landscape in which trees are cut and burned randomly and so they characterise shifting cultivation as ephemeral or 'pre-agricultural', as 'primitive' and as a stage to be progressed beyond. Shifting agriculture is none of these things. Stable shifting cultivation systems are highly variable, closely adapted to micro-environments and are carefully managed by farmers during both the cropping and fallow stages. Shifting cultivators may possess a highly developed knowledge and understanding of their local environments and of the crops and native plant species they exploit. Complex and highly adaptive land tenure systems sometimes exist under shifting cultivation. Introduced crops for food and as cash have been skillfully integrated into some shifting cultivation systems.

Stereotypes: primitive, backward, wasteful, unproductive

Shifting cultivation systems are perceived both by numerous scientists as well as the general public, as primitive, backward, wasteful, unproductive, exploitative and the cause of widespread environmental degradation. Shifting cultivators are blamed for the destruction of much of the world's tropical forests, land degradation, atmospheric pollution and global climatic change. While contemporary manifestations of these attitudes towards shifting cultivators are often political and reflect competition between land occupying farmers, migrant settlers, loggers and international capital seeking access to tropical forests, they can sometimes be traced to the late 19th and early 20th centuries, to European colonial administrations in tropical and sub-tropical South Asia, Southeast Asia and South America. Indigenous occupants were then characterized by the colonizers as primitive and hence their agriculture systems, which were commonly a form of shifting cultivation were also viewed as primitive. In addition, there was a fundamental misunderstanding that shifting cultivators selected sites for cropping at random, thus destroying forests.

These attitudes may have prevented observers of tropical environments from understanding the social and economic conditions underlying shifting cultivation. It is ironic that in a major pioneering work in the recognition of the extent of human impacts upon the Earth published in the 1950s (Thomas 1956) a chapter on agriculture in the tropics states "No matter where we go we find primitive agriculture was carried on at the expense of forest" and makes a distinction between "primitive tropical horticulture" and "agriculture" as practiced by "higher cultures" (Bartlett 1956). This chapter implies all shifting cultivation systems are destructive of resources. In the same book another chapter describes massive loss of the forests in Europe prior to the beginning of the 20th century and details the social and economic conditions, other than shifting cultivation, that brought about their destruction (Darby 1956). Some of the conditions responsible for the deforestation of Europe are similar to those causing deforestation today.

Shifting cultivation in Europe

Shifting cultivation was still being practiced as a viable and stable form of agriculture in many parts of Europe and west into Siberia at the end of the 19th century and in some places well into the 20th century. In the Ruhr in the late 1860s a forest-field rotation system known as Reutbergwirtschaft was using a 16 year cycle of clearing, cropping and fallowing with trees to produce bark for tanneries, wood for charcoal and rye for flour (Darby 1956, 200). Swidden farming was practiced in Siberia at least until the 1930s, using specially selected varieties of “swidden-rye” (Steensberg 1993, 98). In Eastern Europe and Northern Russia the main swidden crops were turnips, barley, flax, rye, wheat, oats, radishes and millet. Cropping periods were usually one year, but were extended to two or three years on very favourable soils. Fallow periods were between 20 and 40 years (Linnard 1970, 195). In Finland in 1949, Steensberg (1993, 111) observed the clearing and burning of a 60,000 square metre swidden 440 km north of Helsinki. Birch and pine trees had been cleared over a period of a year and the logs sold for cash. A fallow of alder (Alnus) was encouraged to improve soil conditions. After the burn, turnip was sown for sale and for cattle feed. Shifting cultivation was disappearing in this part of Finland because of a loss of agricultural labour to the industries of the towns. Steensberg (1993, 110-152) provides eye-witness descriptions of shifting cultivation being practiced in Sweden in the 20th century, and in Estonia, Poland, the Caucasus, Serbia, Bosnia, Hungary, Switzerland, Austria and Germany in the 1930s to the 1950s.

That these agricultural practices survived from the Neolithic into the middle of the 20th century amidst the sweeping changes that occurred in Europe over that period, suggests they were adaptive and in themselves, were not massively destructive of the environments in which they were practiced. This raises the question: if shifting cultivation did not lead to the disappearance of European forests, what did?

The earliest written accounts of forest destruction in Southern Europe begin around 1000 BC in the histories of Homer, Thucydides and Plato and in Strabo’s Geography. Forests were exploited for ship building, and urban development, the manufacture of casks, pitch and charcoal, as well as being cleared for agriculture. The intensification of trade and as a result of warfare, increased the demand for ships which were manufactured completely from forest products. Although goat herding is singled out as an important cause of environmental degradation, a more important cause of forest destruction was the practice in some places of granting ownership rights to those who clear felled forests and brought the land into permanent cultivation. Evidence that circumstances other than agriculture were the major causes for forest destruction was the recovery of tree cover in many parts of the Roman empire from 400 BC to around 500 AD following the collapse of Roman economy and industry. Darby observes that by 400 AD “land that had once been tilled became derelict and overgrown” and quotes Lactantius who wrote that in many places “cultivated land became forest”.(Darby 1956, 186). The other major cause of forest destruction in the Mediterranean environment with its hot dry summers were wild fires that became more common following human interference in the forests.

In Central and Northern Europe the use of stone tools and fire in agriculture is well established in the palynological and archaeological record from the Neolithic. Here, just as in Southern Europe, the demands of more intensive agriculture and the invention of the plough, trading, mining and smelting, tanning, building and construction in the growing towns and constant warfare, including the demands of naval shipbuilding, were more important forces behind the destruction of the forests than was shifting cultivation.

By the Middle Ages in Europe, large areas of forest were being cleared and converted into arable land in association with the development of feudal tenurial practices. From the 16th to the 18th centuries, the demands of iron smelters for charcoal, increasing industrial developments and the discovery and expansion of colonial empires as well as incessant warfare that increased the demand for shipping to levels never previously reached, all combined to deforest Europe. With the loss of the forest, so shifting cultivation became restricted to the peripheral places of Europe, where permanent agriculture was uneconomic, transport costs constrained logging or terrain prevented the use of draught animals or tractors. It has disappeared from even these refuges since 1945, as agriculture has become increasingly capital intensive, rural areas have become depopulated and the remanent European forests themselves have been revalued economically and socially.

Simple societies, shifting cultivation and environmental change

The forests of Europe were destroyed by the seemingly inexorable ‘advances’ of civilisation, industrialisation and warfare, the sort of ‘advances’ that many of those who criticised shifting cultivators in the 19th century thought were desirable and indicative of “higher cultures”. The same sort of processes are leading to the destruction of tropical forests in the last decade of the 20th century. So ‘advances’ in civilization, now known as ‘development’, have not resolved these problems. The problems are located not in the practice of a particular form of agriculture, but within the fundamental relationships that human societies have with their environments. In complex developed economies these relationships become very elaborate and are difficult to comprehend. However in simple economies, where agriculture is the major source of wealth creation, they can be easier to understand.

A growing body of archaeological and palynological evidence finds that simple human societies brought about extensive changes to their environments before the establishment of any sort of state, feudal or capitalist, and before the development of large scale mining, smelting or shipbuilding industries. In these societies agriculture was the driving force in the economy and shifting cultivation was the most common type of agriculture practiced. By examining the relationships between social and economic change and agricultural change in these societies, insights can be gained on contemporary social and economic change and global environment change, and the place of shifting cultivation in those relationships.

As early as 1930 questions about relationships between the rise and fall of the Mayan civilization of the Yucatán Peninsula and shifting cultivation were raised and continue to be debated today. Archaeological evidence suggests the development of Mayan society and economy began around 250 AD. A mere 700 years later it reached its apogee, by which time the population may have reached 2,000,000 people. There followed a precipitous decline that left the great cities and ceremonial centres vacant and overgrown with jungle vegetation. The causes of this decline are uncertain; but warfare and the exhaustion of agricultural land are commonly cited (Meggers 1954; Dumond 1961; Turner 1974). More recent work suggests the Maya may have, in suitable places, developed irrigation systems and more intensive agricultural practices (Humphries 1993).

Similar paths appear to have been followed by Polynesian settlers in New Zealand and the Pacific Islands, who within 500 years of their arrival around 1100 AD turned substantial areas from forest into scrub and fern and in the process caused the elimination of numerous species of birds and animals (Kirch and Hunt 1997). In the restricted environments of the Pacific islands, including Fiji and Hawaii, early extensive erosion and change of vegetation is presumed to have been caused by shifting cultivation on slopes. Soils washed from slopes were deposited in valley bottoms as a rich, swampy alluvium. These new environments were then exploited to develop intensive, irrigated fields. The change from shifting cultivation to intensive irrigated fields, occurred in association with a rapid growth in population and the development of elaborate and high stratified chiefdoms (Kirch 1984). In the larger, temperate latitude, islands of New Zealand the presumed course of events took a different path. There the stimulus for population growth was the hunting of large birds to extinction, during which time forests in drier areas were destroyed by burning, followed the development of intensive agriculture in favorable environments, based mainly on sweet potato (Ipomoea batatas) and a reliance on the gathering of two main wild plant species in less favorable environments. These changes, as in the smaller islands, were accompanied by population growth, the competition for the occupation of the best environments, complexity in social organization, and endemic warfare (Anderson 1997).

The record of human induced changes in environments is longer in New Guinea than in most places. Agricultural activities probably beginning 5,000 to 9,000 years ago. However the most spectacular changes, in both societies and environments, are believed to have occurred in the central highlands of the island within the last 1,000 years, in association with the introduction of a crop new to New Guinea, the sweet potato (Golson 1982a; 1982b). One of the most striking signals of the relatively recent intensification of agriculture is the sudden increase in sedimentation rates in small lakes. The root question posed by these and the numerous other examples that could be cited of simple societies that have intensified their agricultural systems in association with increases in population and social complexity is not whether or how shifting cultivation was responsible for the extensive changes to landscapes and environments. Rather it is why simple societies of shifting cultivators in the tropical forest of Yucatán, or the highlands of New Guinea, begin to grow in numbers and to develop stratified and sometimes complex social hierarchies?

At first sight, the greatest stimulus to the intensification of a shifting cultivation system is a growth in population. If no other changes occur within the system, for each extra person to be fed from the system, a small extra amount of land must be cultivated. The total amount of land available is the land being presently cropped and all of the land in fallow. If the area occupied by the system is not expanded into previously unused land, then either the cropping period must be extended or the fallow period shortened.

At least two problems exist with the population growth hypothesis. First, population growth in most pre-industrial shifting cultivator societies has been shown to be very low over the long term. Second, no human societies are known where people work only to eat. People engage in social relations with each other and agricultural produce is used in the conduct of these relationships. These relationships are the focus of two attempts to understand the nexus between human societies and their environments, one an explanation of a particular situation and the other a general exploration of the problem.

In a study of the Duna in the Southern Highlands, a group in the process of moving from shifting cultivation into permanent field agriculture post sweet potato, Modjeska (1982) argued for the development of two “self amplifying feed back loops” of ecological and social causation. The trigger to the changes was very slow population growth and the slow expansion of agriculture to meet the demands of this growth. This set in motion the first feedback loop, the “use-value” loop. As more forest was cleared there was a decline in wild food resources and protein produced from hunting, which was substituted for by an increase in domestic pig raising. An increase in domestic pigs required a further expansion in agriculture. The greater protein available from the larger number of pigs increased human fertility and survival rates and resulted in faster population growth.

Increasing numbers of people also set in motion the second or “exchange-value” loop of social causalities. More people meant greater numbers of human interactions, including increased opportunities for conflict. There arose the need for a means to mediate these relationships. The Duna (and other highlanders in New Guinea) says Modjeska, substituted pigs for humans and began to exchange pigs to compensate for losses of humans in warfare, or in marriage and deaths from natural causes (disease). Demand for pigs increased and the production of pigs increased to meet the demand, with all of the consequences observed in the use-value loop. This is what Brookfield (1972) called “social production”. Increased pig production and the exchange of pigs to mediate relations between individuals and groups created opportunities for leadership and management of resources and some men gained authority over other men and all women. As groups became more complex, competition between men and between groups increased, increasing the opportunities for conflict.

The outcome of the operation of the two loops, one bringing about ecological change and the other social and economic change, is an expanding and intensifying agricultural system, the conversion of forest to grassland, a population growing at an increasing rate and expanding geographically and a society that is increasing in complexity and stratification. The second attempt to explain the relationships between simple agricultural societies and their environments is that of Ellen (1982, 252-270). Ellen does not attempt to separate use-values from social production. He argues that almost all of the materials required by humans to live (with perhaps the exception of air) are obtained through social relations of production and that these relations proliferate and are modified in numerous ways. The values that humans attribute to items produced from the environment arise out of cultural arrangements and not from the objects themselves, a restatement of Karl Sauer's dictum that "resources are cultural appraisals". Humans frequently translate actual objects into culturally conceived forms, an example being the translation by the Duna of the pig into an item of compensation and redemption. As a result, two fundamental processes underlie the ecology of human social systems: First, the obtaining of materials from the environment and their alteration and circulation through social relations, and second, the giving of the material a value which will affect how important it is to obtain it, circulate it or alter it. Environmental pressures are thus mediated through social relations.

Transitions in ecological systems and in social systems do not proceed at the same rate. The rate of phylogenetic change is determined mainly by natural selection and partly by human interference and adaptation, such as for example, the domestication of a wild species. Humans however have the ability to learn and to communicate their knowledge to each other and across generations. If most social systems have the tendency to increase in complexity they will, sooner or later, come into conflict with, or into "contradiction" (Friedman 1979, 1982) with their environments. What happens around the point of "contradiction" will determine the extent of the environmental degradation that will occur. Of particular importance is the ability of the society to change, to invent or to innovate technologically and sociologically, in order to overcome the "contradiction" without incurring continuing environmental degradation, or social disintegration.

An economic study of what occurs at the points of conflict with specific reference to shifting cultivation is that of Esther Boserup (1965). Boserup argues that low intensity farming, extensive shifting cultivation for example, has lower labor costs than more intensive farming systems. This assertion remains controversial. She also argues that given a choice, a human group will always choose the technique which has the lowest absolute labor cost rather than the highest yield. But at the point of conflict, yields will have become unsatisfactory. Boserup argues, contra Malthus, that rather than population always overwhelming resources, that humans will invent a new agricultural technique or adopt an existing innovation that will boost yields and that is adapted to the new environmental conditions created by the degradation which has occurred already, even though they will pay for the increases in higher labor costs. Examples of such changes are the adoption of new higher yielding crop, the exchanging of a digging stick for a hoe, or a hoe for a plough, or the development of irrigation systems. The controversy over Boserup's proposal is in part over whether intensive systems are more costly in labor terms, and whether humans will bring about change in their agricultural systems before environmental degradation forces them to. A number of very important things happen in the passage from simple to more complex societies and agricultural systems (Ellen 1982, 272-273). Demands for production on a local system by an external one may destabilize the local ability to regulate human environment relations. Parts of the agricultural system may become more specialized, species diversity may be reduced or lost, wild plant and animal resources reduced or lost and ecosystems become more fragile. Improved communications result in a higher rate of innovation and hence a greater rate of change. Higher rates of change and increased differentiation in the society give rises to increased conflict. Increased differentiation also leads to larger numbers of individuals not producing anything, and more being produced by fewer, such that the system as a whole becomes less efficient. Greater organization and specialization results in greater complexity, technical division of labor and a greater codification of cultural responses with more extensive social control.

Shifting cultivation in the contemporary world and global environmental change

The estimated rate of deforestation in Southeast Asia in 1990 was 34,000 km^2 per year (FAO 1990, quoted in Potter 1993). In Indonesia alone it was estimated 13,100 km^2 per year were being lost, 3,680 km^2 per year from Sumatra and 3,770 km^2 from Kalimantan, of which 1,440 km^2 were due to the fires of 1982 to 1983. Since those estimates were made huge fires have ravaged Indonesian forests during the 1997 to 1998 El Niño associated drought. Efforts are being made in Indonesia to encourage shifting cultivators to alter the mix of activities and examine alternative cropping patterns, so that the slash and burn portion of their shifting cultivation is a smaller fraction of the time interval of the farming cycle . For example by introducing jungle rubber farming instead of coffee, the farming cycle for growing rubber trees can extend up to 28 years versus about seven for coffee. The outcomes not only reflect less time spent in the slash and burn phase, but also allows a cover crop (rubber) that provides a forest habitatquality much higher than the coffee farm environment. Furthermore the coffee use often is abandoned entirely, yielding litte of residual habitat and inviting a much earlier slash and burn element to recur.

Shifting cultivation was assessed by the FAO to be one a causes of deforestation while logging was not. The apparent discrimination against shifting cultivators caused a confrontation between FAO and environmental groups, who saw the FAO supporting commercial logging interests against the rights of indigenous people (Potter 1993, 108). Other independent studies of the problem note that despite lack of government control over forests and the dominance of a political elite in the logging industry, the causes of deforestation are more complex. The loggers have provided paid employment to former subsistence farmers. One of the outcomes of cash incomes has been rapid population growth among indigenous groups of former shifting cultivators that has placed pressure on their traditional long fallow farming systems. Many farmers have taken advantage of the improved road access to urban areas by planting cash crops, such as rubber or pepper as noted above. Increased cash incomes often are spent on chain saws, which have enabled larger areas to be cleared for cultivation. Fallow periods have been reduced and cropping periods extended. Serious poverty elsewhere in the country has brought thousands of land hungry settlers into the cut over forests along the logging roads. The settlers practice what appears to be shifting cultivation but which is in fact a one-cycle slash and burn followed by continuous cropping, with no intention to long fallow. Clearing of trees and the permanent cultivation of fragile soils in a tropical environment with little attempt to replace lost nutrients may cause rapid degradation of the fragile soils.

The loss of forest in Indonesia, Thailand and the Philippines during the 1990s was preceded by major ecosystem disruptions in Vietnam, Laos and Cambodia in the 1970s and 1980s caused by warfare. Forests were sprayed with defoliants, thousands of rural forest dwelling people uproots from their homes and moved and roads driven into previously isolated areas. The loss of the tropical forests of Southeast Asia is the particular outcome of the general possible outcomes described by Ellen (see above) when small local ecological and social systems become part of larger system. When the previous relatively stable ecological relationships are destabilized, degradation can occur rapidly. Similar descriptions of the loss of forest and destruction of fragile ecosystems could be provided from the Amazon Basin, by large scale state sponsored colonization forest land (Becker 1995, 61) or from the Central Africa where what endemic armed conflict is destabilizing rural settlement and farming communities on a massive scale.

Comparison with other ecological phenomena

In the tropical developing world, shifting cultivation in its many diverse forms, remains a pervasive practice. Shifting cultivation was one of the very first forms of agriculture practiced by humans and its survival into the modern world suggests that it is a flexible and highly adaptive means of production. However, it is also a grossly misunderstood practice. Many casual observers cannot see past the clearing and burning of standing forest and do not perceive often ecologically stable cycles of cropping and fallowing. Nevertheless, shifting cultivation systems are particularly susceptible to rapid increases in population and to economic and social change in the larger world around them. The blame for the destruction of forest resources is often laid on shifting cultivators. But the forces bringing about the rapid loss of tropical forests at the end of the 20th century are the same forces that led to the destruction of the forests of Europe, urbanization, industrialization and the application the latest technology to extract ever more resources from the environment in pursuit of political power by competing groups.

Studies of small, isolated and pre-capitalist groups and their relationships with their environments suggests that the roots of the contemporary problem lie deep in human behavioral patterns, for even in these simple societies, competition and conflict can be identified as the main force driving them into contradiction with their environments.

Alternative practice in the Pre-Columbian Amazon basin

Slash-and-char, as opposed to slash-and-burn, may create self-perpetuating soil fertility that supports sedentary agriculture, but the society so sustained may still be overturned, as above.