17

Managing Too Little or Too Much Water: Irrigation and Drainage

Deficits and excesses of water are the most significant yield-limiting factors to crop production world-wide. It is estimated that more than half of the global food supply depends on some type of water management. In fact, the first major civilizations and population centers emerged when farmers started to control water, resulting in more consistent yields and stable food supplies. Examples include Mesopotamia — literally the "land between the rivers" (the Tigris and Euphrates), the lower Nile Valley, and China. High yields in drained and irrigated areas allowed for the development of trade specialization, because no longer did everyone need to provide for their own food supply. This led to important innovations like markets, writing, the wheel, etc. Moreover, new water management schemes forced societies to get organized, work together on irrigation and drainage schemes and develop laws on water allocations. But water management failures were also responsible for the collapse of societies. Notably, the salinization of irrigated lands in Mesopotamia and filling up of ditches with sediments — cleaned out by enslaved Israelites among others — resulted in lost land fertility and an inability to sustain large centrally governed civilizations.

Today, many of the most productive agricultural areas depend on some type of water management. The best fields in the U.S. Corn Belt have had drainage systems installed, which made those soils even more productive than they were naturally. Drainage of wet fields allows for a longer growing season because farmers can get onto those fields earlier in the spring and harvest later in the fall without causing extreme compaction. In the United States, average crop yields of irrigated farms is greater than the corresponding yields of dryland farms by 118% for wheat and 30% for corn. At a global scale, irrigation is used on 18% of the cultivated lands, but they account for 40% of the world's food production. The great majority of agricultural lands in the Western U.S. and other dry climates around the world would not be productive without irrigation water, and the majority of the U.S. horticultural crop acreage — especially in California — is entirely dependent on elaborate irrigation infrastructures. Even in humid regions most high-value crops are grown with irrigation during dry spells to insure crop quality and steady supplies for market outlets, in part due to the fact that the soils have become less drought resistant from intensive use.

The benefits of irrigation and drainage are thus obvious. They are critical to food security as well the agricultural intensification needed to protect natural areas. Concerns with climate change, which is resulting in greater occurrences of deficits and excesses of precipitation, will increase pressure for more irrigation and drainage. But they also exact a price on the environment. Drainage systems provide hydrological shortcuts and are responsible for increased chemical losses to water resources. Some irrigation systems have resulted in drastic changes in river and estuarine ecosystems, resulted in land degradation through salinization and sodium build up, and have been sources of international conflict. In the case of the Aral Sea — formerly the fourth largest inland freshwater body in the world — the diversion of rivers to use for irrigated cotton farming in the former USSR, resulted in a 50% decrease in the area of the Sea. It also became severely contaminated with drainage water from agricultural fields.

Irrigation

First consider soil improvement

Healthy soils with good and stable aggregation, enhanced organic matter levels, and limited to no compaction go a long way toward “drought proofing” your farm. In addition, reduced tillage with residues on the surface also helps to enhance water infiltration and reduce evaporation losses from the soil. Cover crops, while using water for their growth, once suppressed and acting as a surface mulch can have a positive effect on water availability in many regions. But, of course, water *is* needed to grow crops — from 19 to 100s or more gallons of water for each pound of plant or animal product (table 17.1). And if it doesn’t rain for a few weeks, crops on even the best soils will start to show drought stress. Even in humid regions there can be stretches of dry weather that can cause stress and reduced crop yield and/or quality. Irrigation, therefore, is an essential part of growing crops in many regions of the world. But the healthier soil you have, the less irrigation water that will be needed because natural rainfall will be used more efficiently.

Table 17.1 Approximate amounts of water needed for food production (source: FAO).

Product	**Gallons of water per pound**
Wheat	150
Rice	300
Maize	50
Potatoes	19
Soybean	275
Beef	1800
Pork	700
Poultry	300
Eggs	550
Milk	100
Cheese	600

There are several different types of irrigation systems, depending of water source, size of the system, and water application method. Three main water sources exist, surface water, groundwater, and recycled waste water. Irrigation systems run from small on-farm arrangements using a local water supply to vast schemes that involve thousands of farms and controlled by governmental authorities. Water application methods include conventional flood / furrow irrigation — which depends on gravity flow, pumped water for sprinkler systems, and pumped water for super-efficient drip irrigation.

Surface water sources

Streams, rivers and lakes have traditionally been the main source of irrigation supplies. Historical efforts involved the diversion of river waters and then the development of storage ponds. Small scale systems — like those used by the Anazasi in the southwestern US and the Nabateans in what is now Jordan — involved cisterns that were filled by small stream diversions.

Small scale irrigation systems nowadays tend to pump water directly out of streams or farm ponds (figure 17.1). These water sources are generally sufficient for cases where *supplemental* irrigation is used — in humid regions where rainfall and snowmelt supplies most of the crop water needs, but limited amounts of additional water may be needed for good yields or high-quality crops. Such systems generally managed by a single farm have limited environmental impacts. Most states require permits for such water diversions to insure against excessive impacts on local water resources.

Figure 17.1 A farm pond (left) is used as a water source for a traveling overhead sprinkler system on a vegetable farm.

Large-scale irrigation schemes have been developed around the world with strong involvement of state and federal governments. The US government invested $3 billion to create the intricate Central Valley project in California that has provided a 100 fold return on investment. The Imperial Irrigation District, located in the dry desert of Southern California was developed in the 1940s with the diversion of water from the Colorado River. Even today, large-scale irrigation systems are being initiated, like the GAP project in southeastern Turkey which involves a large dam to impound water (figure 17.2). Such projects often drive major economic development efforts in the region and function as a major source for national or international food or fiber production. On the other hand, large dams have also frequently had the detrimental effects of displacing people and flooding productive cropland or important wetlands. The building of the Three Gorges Dam on China's Yangtze River has displaced well over a million people.

Figure 17.2. The Ataturk dam in Turkey diverts water from the Euphrates River (left). Main canal (middle) conveys water to the Harran Plain for furrow irrigation (right).

Groundwater

When good aquifers are present, groundwater is a relatively inexpensive source of irrigation water. A significant advantage is the fact that it can be pumped locally and does not require large government-sponsored investments in dams and canals. It also has less impact on regional hydrology and ecosystems, although pumping water from deep aquifers requires energy and regional climates may be affected. Center-pivot overhead sprinklers (figure 17.3) are often used, and individual systems, irrigating from 120 to 500 acres, typically draw from their own well. A good source of groundwater is critical for the success of such systems, and low salt levels are especially critical to prevent the build up of soil salinity. Most of the western region of the U.S. Great Plains has been developed into productive agricultural land supported by the large (174,000 square miles) Ogallala aquifer that is relatively shallow and accessible (figure 17.3). It is, however, being utilized faster than it is recharging from rainfall — clearly an unsustainable practice. Deeper wells requiring more energy to pump water, plus more expensive energy, will make this mining of water an increasingly questionable practice.

Figure 17.3 Left: Satellite image of Southwest Kansas showing crop circles from center-pivot irrigation systems (Photo by NASA). Right, groundwater-fed center-pivot system on pasture.

Recycled Wastewater

In recent years, water scarcity has forced governments and farmers to look for alternative sources of irrigation water. Since agricultural water does not require the same quality as drinking water, recycled wastewater is a good alternative. It is being used in regions where (1) densely populated areas generate significant quantities of wastewater and are close to irrigation districts, and (2) surface or groundwater sources are very limited or need to be transported over long distances. Several irrigation districts in the U.S. are working with municipalities to provide safe recycled wastewater, although some concerns still exist about long-term effects. Other nations with advanced agriculture and critical water shortages — notably Israel and Australia — have also implemented wastewater recycling systems for irrigation purposes (Figure 17.4).

Figure 17.4. Recycled wastewater from the City of Adelaide, Australia is pumped into an irrigation pond for a vegetable farm. Wastewater-conveying pipes are painted purple to distinguish them from fresh water conduits.

Irrigation Methods

Main types of irrigation

- Flood / furrow irrigation
- Sprinkler irrigation
- Drip / trickle irrigation
- Manual irrigation

Flood or furrow irrigation is the historical approach and remains widely used around the world. It basically involves the simple flooding of a field for a limited amount of time, allowing it to infiltrate. If the field has been shapes into ridges and furrows, the water is applied through the furrows and infiltrates down and laterally into the ridges (figure 17.5). Such systems mainly use gravity flow and require nearly flat fields. These systems are by far the cheapest to install and use, but water application rates are very inexact and typically uneven. Also, these systems are most associated with salinization concerns. Flood irrigation is also used in rice production systems where dikes are used to keep the water ponded.

Figure 17.5. Furrow irrigation is generally inexpensive but also inefficient with respect to water use. Photo by USDA-ERS.

Sprinkler irrigation systems apply water through pressurized sprinkler heads and require conduits (pipes) and pumps. Common systems include stationary sprinklers on risers (figure 17.6) and traveling overhead sprinklers (center pivot and lateral; figures 17.3 and 17.1). These systems allow for more precise water application rates than flooding and more efficient water use. But they require larger up-front investments and the pumps use energy. Large traveling gun sprayers can efficiently apply water to large areas and are also used to apply liquid manure.

Localized irrigation — especially useful for tree crops — can often be accomplished using small sprinklers (figure 17.7) that are connected using small diameter “spaghetti tubing” and relatively small pumps, making the system relatively inexpensive.

Figure 17.6. Portable sprinkler irrigation system commonly used with horticultural crops.

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Figure 17.7. Small (micro) sprinklers allow for localized water application at low cost (photo: North Dakota State University).

Drip or trickle irrigation systems also use flexible or spaghetti tubing combined with small emitters. They are mostly used in bedded or tree crops using a line source with many regularly spaced emitters or applied directly near the plant through a point-source emitter (figure 17.8). The main advantage of drip irrigation is the parsimonious use of water and the high level of control. Drip irrigation systems are relatively inexpensive, can easily be installed, use low pressure, and have low energy consumption. In small-scale systems like market gardens, pressure may be applied through a gravity hydraulic head from a water container on the small platform. Subsurface drip irrigation systems are now also coming into use where the lines and emitters are semi-permanently buried to allow field operations. Such systems require attention to the placement of the tubing and emitters. They need to be close to the plant roots as lateral flow from the trickle line is limited.

Figure 17.8 Drip irrigation of bean plants. Lateral movement of water to reach plant roots may be limited with drip systems (left), unless each crop row has its own drip line or the spacing between rows is decreased by using narrow twin rows (right). Note: the apparent leaf discoloration on the left is due to a low sun angle.

Manual Irrigation involves watering cans, buckets, inverted soda bottles, etc. Although they don’t fit with large-scale agriculture, they are still widely used in gardens and small-scale agriculture in underdeveloped countries.

Fertigation is an efficient method to apply fertilizer to plants through pumped systems like sprinkler and drip irrigation. The fertilizer source is mixed with the irrigation water to provide low doses of liquid fertilizer that are readily absorbed by the crop. This also allows for “spoon feeding” of fertilizer to the crop through multiple small applications, which would otherwise be a logistical challenge.

Concerns with Irrigation

- accumulation of salts and/or sodium in the soil
- energy use
- increased nutrient and pesticide loss potential
- water use away from natural systems
- large dams displace people and may flood productive cropland, wetlands, or archeological sites.
- competing users: urban areas and downstream communities

Environmental Concerns and Management Practices

Irrigation has numerous advantages, but significant concerns exits as well. The main threat to soil health in dry regions is the **accumulation of salts and in some cases also sodium**. As salt accumulation increases in the soil, crops have more difficulty getting the water that’s there. When sodium accumulates, aggregates break down and soils become dense and impossible to work (chapter 6). Over the centuries, many irrigated areas have been abandoned due to salt accumulation, and it still a major threat in several areas in the U.S. and elsewhere (figure 17.9). Salinization is the result of the evaporation of irrigation water, which leaves salts behind. It is especially prevalent with flood irrigation systems, which tend to over-apply water and can raise saline groundwater tables. Once the water table gets close to the surface, capillary water movement transports soil water to the surface where it evaporates and leaves salts behind. When improperly managed, this can render soils unproductive within a matter of years. Salt accumulation can also occur with other irrigation practices - even with drip systems, especially when the climate is so dry that leaching of salts does not occur through natural precipitation.

The removal of salts is difficult, especially when lower soil horizons are also saline. Irrigation systems in arid regions should be designed to *supply* water, and also to *remove* water – implying that irrigation should be combined with drainage. This may seem paradoxical, but salts need to be removed by application of additional water to dissolve the salts, leach them out of the soil, and subsequently remove the leachate through drains or ditches – where they may still create concerns from downstream areas due to its high salt contents. One of the long-term success stories of irrigated agriculture - the lower Nile Valley - provided irrigation during the river’s flood stage in the fall and natural drainage after it subsided to lower levels in the winter and spring. In some cases, deep rooted trees are used to lower regional water tables, which is the approach used in the highly salinized plains of the Murray Darling Basin in southeastern Australia. Several large-scale irrigation projects around the world were designed only for the water supply component, and funds were not allocated for drainage systems, ultimately causing salinization.

The removal of sodium can be accomplished by exchange with calcium on the soil exchange complex, which is typically done through the application of gypsum. In general, salinity and sodicity are best prevented through good water management. (See chapter 21 for discussion of reclaiming saline and sodic soils.)

Figure 17.9. Over-irrigation can raise groundwater tables (visible at bottom of pit, left). Surface evaporation of water traveling upward through soil capillaries (very small channels) from the shallow groundwater causes salt accumulation (right).

Salt accumulation is generally not an issue in humid regions, but over-irrigation causes concerns with nutrient and pesticide leaching losses in these areas. High application rates and amounts can push nitrate and pesticides past the root zone and increase groundwater contamination. Soil saturation from high application rates can also generate denitrification losses.

A bigger issue with irrigation, especially at regional and global scales, is the high water consumption levels and competing interests. Agriculture consumes approximately 70% of the global water withdrawals. Humans use less than a gallon of water for direct consumption, but about 150 gallons are needed to produce a pound of wheat and 1800 gallons are needed for a pound of beef (table 17.1, above). According to the U.S. Geological Survey, 68% of high quality groundwater withdrawals in the U.S. is used for irrigation. Is this sustainable? The famous Ogallala aquifer mostly holds “ancient” water that accumulated during previous wetter climates. As mentioned above, withdrawals are currently larger than the recharge rates and this limited resource is therefore slowly being mined.

Several large irrigation systems affect international relations. The high withdrawal rates from the Colorado River diminish it to a trickle when it reaches the US-Mexico border and the estuary in the Gulf of California. Similarly, Turkey’s decision to promote agricultural development through the diversion of Euphrates waters has created tension with the downstream countries, Syria and Iraq.

Good Irrigation Management

- Build soil to be more resistant to crusting and drought by increasing organic matter contents, aggregation and rooting volume
- Use water conservatively: consider deficit irrigation scheduling
- Monitor soil, plant and weather for precise estimation of irrigation needs
- Use precise water application rates; do not over-irrigate
- Use water storage systems to accumulate rainfall when feasible
- Use good quality recycled wastewater when available
- Reduce tillage and leave surface residues
- Use mulches to reduce surface evaporation
- Integrate water and fertilizer management to reduce losses
- Prevent salt or sodium accumulation; Leach salt through drainage and reduce sodium contents through gypsum application.

Irrigation Management at the Farm Level

Sustainable irrigation management and prevention of salt and sodium accumulation requires solid planning, appropriate equipment, and monitoring. A first step is to build the soil so it optimizes water use by the crop. As we discussed in chapters 5 and 6, soils that are low in organic matter and high in sodium have low infiltration capacities due to surface sealing and crusting from low aggregate stability. Overhead irrigation systems often apply water as “hard rain”, creating further problems with surface sealing and crusting.

Healthy soils have more water supply capacity than ones that are compacted and depleted of organic matter. It is estimated that for every 1% loss in organic matter content in the surface foot, the soil can hold 16,500 gallons less plant-available water per acre. Additionally, surface compaction creates lower root health and density, and hard subsoils limit rooting volume. These processes are captured by the concept of the *optimum water range* — which we discussed in chapter 6 — where the combination of compaction and lower plant-available water retention capacity limits the soil water range for healthy plant growth. Such soils therefore have less efficient crop water use and require additional applications of irrigation water. In fact, it is believed that many farmers in humid climates have started to use supplemental irrigation because the soils became compacted and depleted of organic matter. As we discussed before, poor soil management is often compensated for by increased inputs.

Reducing tillage, adding organic amendments, preventing compaction, and using perennial crops in rotations can increase water storage. A long-term tillage and rotation experiment showed that plant-available water capacity in the surface horizon increased by up to 34% by reducing tillage and rotations (table 17.2). When adding organic matter, consider stable sources that are mostly composed of “very dead” materials such as composts. They are more persistent in soil and are a primary contributor to soil water retention. But don’t forget fresh residues (the “dead”) that help form new and stable aggregates. Increasing rooting depth greatly increases plant water availability by extending the volume of soil available for roots to explore. When distinct plow pans are present, ripping through them makes subsoil water accessible to roots. Practices like zone-tillage increase rooting depth and also result in long-term increases in organic matter and water storage capacity.

Table 17.2 Increase in plant-available water capacity for surface soils in long-term tillage and rotation experiments in New York (from: Moebius et al., 2008).

Tillage Experiments	**Plant-Available Water Capacity (%)**		
	Plow Till	**No Till**	**increase**
Silt loam – 33 years	24.4	28.5	17%
Silt loam – 13 years	14.9	19.9	34%
Clay loam – 13 years	16.0	20.2	26%
Rotation Experiment	**Continuous corn**	**Corn after grass**	**% increase**
Loamy sand – 12 years	14.5	15.4	6%
Sandy clay – 12 years	17.5	21.3	22%

These practices have the most significant impact in humid regions where supplemental irrigation is used to reduce drought stress during dry periods between rainfall events. Building a healthier soil will reduce irrigation needs and conserves water, because increased plant water availability extends the time period until the onset of drought stress and greatly reduces the probability of stress occurrence. For example, let’s assume that a degraded soil with a plow (A) pan can provide adequate water to a crop for 7 days without irrigation, and a healthy soil with deep rooting (B) allows for 12 days. A 12-day continuous drought, however, is a much less likely occurrence. Based on climate data for the Northeast USA, the probability of such an event at any time in the month of July is 1 in 100 (1%), while the probability for an 8-day dry period is 1 in 20 (5%). The crops growing on soil A would run out of water and suffer stress in July 5% of the years, while the crops on soil B would be stress-free. A healthy soil would reduce or eliminate the need for irrigation in many cases.

Increasing surface cover – especially with heavy mulch – significantly reduces evaporation from the soil surface. Cover crops can increase soil organic matter and provide surface mulch, but caution should be used with cover crops because when growing they can consume considerable amounts of water that may be needed to leach salts or supply the cash crop.

Conservative water use prevents many of the problems that we discussed above. This can be accomplished by monitoring the soil, the plant, or weather indicators and applying water only when needed. Soil sensors — like tensiometers (figure 17.10), moisture blocks, or new TDR or capacitance probes — can evaluate of soil moisture conditions. When the soil moisture levels reach critical levels, irrigation systems can be turned on and water applications can be made to meet the crop's needs without excess. The crop itself can also be monitored as water stress results in increased leaf temperatures that can be detected with thermal or near infrared imaging. Another approach involves the use of weather information — either from government weather services or small on-farm weather stations — to estimate the balance between natural rainfall and evapotranspiration. Electronic equipment is available for continuous measuring of soil, plant and weather and monitoring from a distance using wireless or phone communication. Also, computer technology and site-specific water and fertilizer application equipment — now available with large modern sprinkler systems — allow farmers to tailor irrigation to acre-scale localized water and fertilizer needs. Researchers have also demonstrated that *deficit irrigation* – water applications that are less than 100% of evapotranspiration and greater reliance on stored water - can provide equal yields with reduced water consumption. Deficit irrigation is also used purposely with grapevines that need limited water stress to enrich quality-enhancing constituents like anthocyanins.

Many of these practices can be effectively combined. For example, a vegetable grower in Australia uses beds with controlled traffic (figure 17.11). A sorghum-sudan cover crop is planted during the wet season and mulched down after maturing, leaving a dense mulch. Subsurface trickle irrigation is installed in the beds and stays in place for five or more years (annual removal and re-installation is necessary with tilled systems). No tillage is performed and vegetable crops are planted using highly accurate GPS technology to insure that they are within a couple of inches from the drip emitters.

Figure 17.10. Tensiometers used for soil moisture sensing in irrigation management (photo by Irrometer Company).

Figure 17.11 No-till irrigated vegetables grown on beds with cover crop mulch. Drip irrigation lines are placed at 1-2 inches depth in the beds (not visible).

Drainage

Soils that are naturally poorly drained and have inadequate aeration are generally high in organic matter content. But poor drainage makes them unsuitable for growing most crops other than a few water-loving plants like rice and cranberries. When such soils are artificially drained, they become very productive as the high organic matter content provides all the good qualities we discussed in earlier chapters. Over the centuries, humans have converted swamps into productive agricultural land by digging ditches and canals, subsequently also combined with pumping systems to remove the water from low-lying areas. Aztec cities were mostly supported by food from Chinampas, which were canals dug in shallow lakes with the rich mud used to build raised beds. Large areas of Holland were drained with ditches to create pasture and hay land to support dairy-based agriculture. Excess water was removed by windmill power, and later by steam and oil powered pumping stations (figure 17.12). Today, new drainage efforts are primarily accomplished with subsurface corrugated PVC tubes that are installed with laser-guided systems (figure 17.13). In the USA land drainage efforts have been significantly reduced as a result of wetland protection legislation, and large-scale government sponsored projects are no longer initiated. But at the farm level, recent adoption of yield monitors on crop combines has quantified the economic benefits of drainage on existing cropland, and additional drainage lines are being installed at an accelerated pace in many of the very productive lands in the U.S. corn belt and elsewhere.

Figure 17.12 The Wouda pumping station was built to drain large areas in Friesland, Netherlands and is the largest steam pumping station ever built. It is now on the World Heritage List.

Figure 17.13 Drainage ditch removes excess water and lowers water table (left). Installation of perforated corrugated PVC drain lines using a laser-guided trencher (right).

Benefits of drainage

Drainage results in the lowering of water tables by removal of water through ditches or tubes (figure 17.14). The main benefit is the creation of a deeper soil volume that is adequately aerated for growth of common crop plants. If crops are grown that can tolerate shallow rooting conditions — like grasses for pastures or hay — the water table can still be maintained relatively close to the surface or drainage lines can be spaced far apart, thereby reducing installation and maintenance costs - especially in low-lying areas that require pumping. Most commercial crops like corn, alfalfa and soybeans require a deeper aerated zone and subsurface drain lines need to be installed at 3 to 4 feet depth and spaced from 20 to 80 feet apart, depending on soil characteristics.

Drainage increases the timeliness of field operations and reduces the potential for compaction damage. Farmers in humid regions have limited numbers of dry days for spring and fall field work and inadequate drainage then prevents field operations prior to the next rainfall. With drainage, field operations can commence within several days after rain. As we discussed in chapters 6 and 15, most compaction occurs when soils are wet and in the plastic state, and drainage helps soils transition into the friable state more quickly during drying periods — except for soils with high plasticity like most clays. Runoff potential is also reduced by subsurface drainage because compaction is reduced and soil water contents are decreased by removal of excess water. This allows the soil to absorb more water through infiltration.

Installing drains in poorly drained soils therefore has agronomic and environmental benefits because it reduces compaction and loss of soil structure. This also addresses other concerns with inadequate drainage, like high nitrogen losses through denitrification. A large fraction of the denitrification losses can occur as nitrous oxide, which is a potent greenhouse gas. As a general principle, croplands that are regularly saturated during the growing season should either be drained, or revert to pasture or natural vegetation.

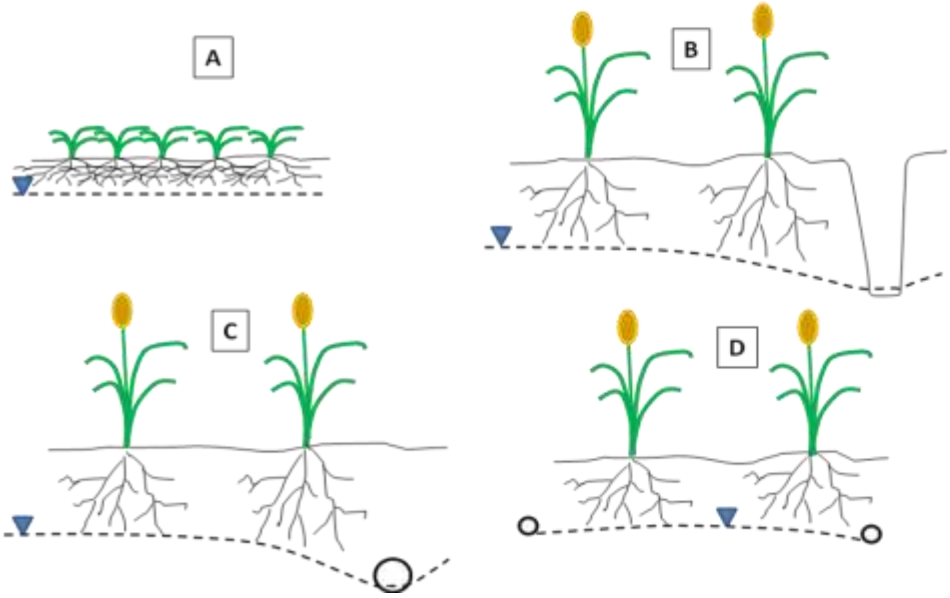

Figure 17.14 Drainage systems lower water tables and increase rooting volume. A: Undrained with pasture, B: drainage ditch, C: subsurface tube drain (tile), and D: mole drain. Water table is indicated by dashed line with inverted triangle.

Is Drainage Really Needed?

Croplands with shallow or perched water tables benefit from drainage. But prolonged water ponding on the soil surface is not necessarily an indication of a shallow water table. Inadequate drainage can also result from poor soil structure. Intensive use, loss of organic matter, and compaction makes a soil drain poorly in wet climates. It may be concluded that the installation of drainage lines will solve this problem. Although this may help reduce further compaction, the correct management strategy is to build soil health and increase its permeability.

Figure 17.15 A soil with apparent drainage problems that are the result of poor soil structure.

Common Types of Drainage Practices Used in Agriculture

- Ditches
- Subsurface drain lines (tile)
- Mole drains
- Surface drains
- Raised beds and ridges

Types of Drainage Systems

Ditching was used to drain lands for many centuries, but most agricultural fields are now drained through perforated corrugated PVC tubing that is installed in trenches and backfilled (figure 17.13). They are still often referred to as drain “tile”, which dates back to the practice of installing clay pipes during the 1800s and early 1900s. Subsurface drain pipes are preferred in a modern agricultural setting as ditches interfere with field operations and take land out of production. A drainage system still needs ditches at the field edges to convey the water away from the field, to wetlands, streams, or rivers.

If the entire field requires drainage, the subsurface pipes may be installed in *grids* with mostly parallel lines (figure 17.16). This is common for flat terrains. On undulating lands, drain lines are generally installed in swales and other low-lying areas where water accumulates. This is generally referred to as *random* drainage (although a better term is *targeted* drainage). *Interceptor* drains may be installed at the bottom of slopes to remove excess water from upslope areas.

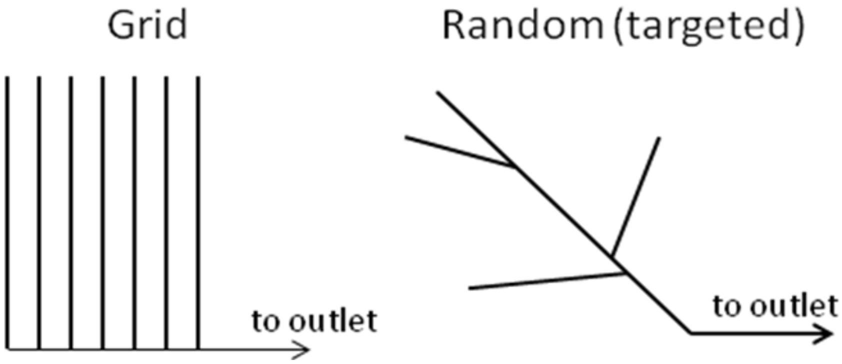

Figure 17.16 Grid and random (targeted) patterns for subsurface drain lines.

Fine-textured soils are less permeable than coarse-textured ones and require closer drain spacing to be effective. A common drain spacing for a fine loam is 50 feet, while in a sand drains pipes may be installed at 100 feet spacing, which is considerably less expensive. Installing conventional drains in heavy clay soils is often too expensive due to the need for close drain spacing. But alternatives can be used. *Mole* drains are developed by pulling a tillage-type implement with a large bullet through soil in the plastic state at approximately 2 feet depth (figure 17.17). The implement cracks the drier surface soil to create water pathways. The bullet creates a drain hole and an expander smears the sides to give it more stability. Such drains are typically effective for several years, after which the process needs to be repeated. Like PVC drains, mole drains discharge into ditches at the edge of fields.

Clay soils may also require *surface drainage* that involves the shaping of the land surface to allow water to run over the soil surface to the edge of fields where it can be discharged by a grass waterway (figure 17.18). Soil shaping is also used to smooth out localized depressions where water would otherwise accumulate and remain ponded for extended periods of time.

Figure 17.17 A mole drain in a clay soil (left) is created with the use of a mole plow (right).

A very modest system of drainage involves the use of *ridges* and *raised beds*, especially on fine-textured soils. This involves modest surface shaping where the crop rows are slightly raised relative to the inter-rows. This may provide a young seedling with enough aeration to survive through a period of excessive rainfall. These systems may also include reduced tillage - ridge tillage involves minimal soil disturbance – as well as controlled traffic to reduce compaction (chapters 16 and 17).

Figure 17.18 Surface drainage on clay soils in Ontario, Canada. Excess water travels over the surface to a grass waterway.

Concerns with Drainage

- Loss of wetland habitat
- Loss of landscape buffering of water flow and chemical movement
- Water loss from soil profile and diversion to surface waters
- Enhanced movement of chemicals from soils into surface

Concerns with Drainage

The extensive drainage of lands has created sufficient concern that many countries are now strictly controlling drainage efforts. In the U.S., the 1985 Food Security Act contains the so-called Swampbuster Provision that strongly discourages conversion of wetlands to cropland, and has since been strengthened. The primary justification for these laws was the loss of wetland habitats and landscape hydrological buffers.

Wetlands are among the richest natural habitats due to the ample supplies of organic sources of food, and they are additionally critical to migrating waterfowl that require food and habitat away from land predators. In addition, these wetlands play important roles in buffering the hydrology of watersheds. During wet periods and snow melt they fill with runoff water from surrounding areas and during dry periods they receive groundwater that re-surfaces in lower landscape position. The retention of this water in swamps reduces the potential for flooding in downstream areas and also allows nutrients to be cycled into aquatic plants and stored as organic material. When they are drained, these nutrients are in turn released by the oxidation of the organic materials and are mostly lost through the drainage system into watersheds. The extensive drainage of glacially-derived pothole swamps in the North Central and Northeast USA and Canada has contributed to significant increases in flooding and losses of nutrients into their watersheds.

Drainage systems also increase the potential for losses of nutrients, pesticides and other contaminants by providing a hydrologic shortcut for percolating waters. While water under natural conditions would be retained in the soil and slowly seep to groundwater, it is now captured by the drainage systems and diverted into ditches, canals, streams, lakes, and estuaries (figure 17.19). This is especially a problem because medium and fine-textured soils generally allow for very rapid movement of surface applied chemicals to subsurface drain lines (figure 17.20). Unlike sands, which can effectively filter percolating water, fine-textured soils contains structural cracks and large (macro) pores down to the depth of a drain line. In general, we would consider these to be favorable, because they facilitate water percolation and aeration. However, when application of fertilizer, pesticides or liquid manure is followed by significant precipitation — especially intense rainfall that causes short-term surface ponding — these contaminants can enter these large pores and rapidly (sometime within one hour!) move to the drain lines. These contaminants, by-passing the soil matrix not filtered or adsorbed by soil particles, can enter drains and surface waters at high concentrations (figure 17.21). Management practices can be implemented to reduce the potential for such losses (see textbox).

Reducing Rapid Chemical Leaching to Drain Lines

- Build soils with crumb structure that readily absorb rainfall and reduce the potential for surface ponding.
- Avoid applications on wet soils (with or without artificial drainage) or prior to heavy rainfall.
- Inject or incorporate applied materials. Even modest incorporation reduces flow that bypasses the mass of the soil.

Artificial drainage of the soil profile also reduces the amount of water stored in the soil and the amount of water available for a crop. Farmers in effect play a game with the weather where they want to drain water out of the soil in case of excess rain, but would like to retain it in case of drought. *Controlled drainage* allows for some flexibility and involves the retention of water in the soil system through the use of weirs in the ditches at the sides of fields. In effect, this keeps the water table at a higher level than the depth of the drains, but the weir can be lowered in case the soil profile needs to be drained. Controlled drainage is also recommended during winter fallows to slow down oxidations of organic matter in muck (organic) soils and reduce nitrate leaching in sandy soils.

Figure 17.19 Subsurface drain line discharges into an edge-of-field ditch, diverting groundwater to surface waters.

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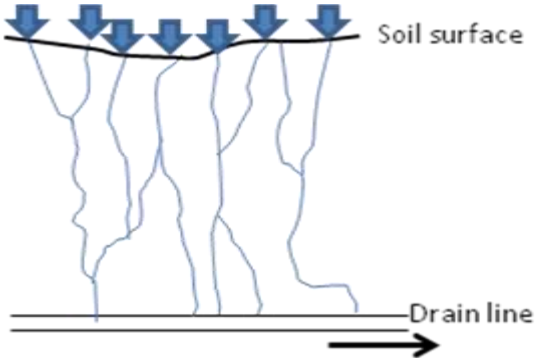

Figure 17.20 Continuous large (macro) pores may cause rapid movement of contaminants from the soil surface to drain lines, bypassing the soil matrix.

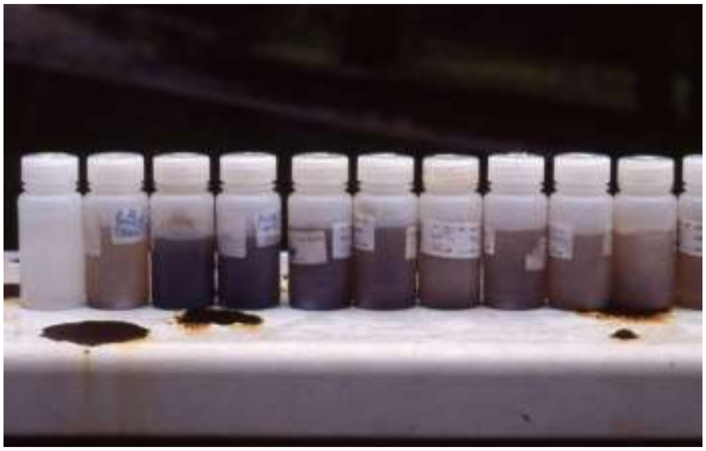

Figure 17.21 Water samples taken from a subsurface drain line when heavy rainfall followed liquid manure application. From left, water samples represent fifteen-minute sampling intervals from the onset of drain discharge. (photo by Larry Geohring).

Summary

Irrigation and drainage allow for high yields in areas that otherwise have shortages or excesses of water. There is no doubt that we need such water management practices to secure a food supply for a growing population and provide the high yields needed to arrest the conversion of natural lands into agriculture. Some of the most productive lands use drainage and/or irrigation and the ability to control water regimes provide great advantages. Yet, there is a larger context, and these practices exact a price on the environment by diverting water from its natural course and increasing the potential for soil and water contamination. Good management practices can be used to reduce the impacts of altered water regimes. Building healthy soils is an important component of making soil and water management more sustainable by reducing the need for irrigation and drainage. In addition, other practices that promote more judicious use of water and chemical inputs also help reduce environmental impacts.

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