7

CHAPTER 7. WATER AND SOIL MANAGEMENT

Water and soil are the raw materials from which all farm products are grown. Sunshine supplies the energy for the synthesis of atmospheric carbon dioxide and water by the process of photosynthesis. The resulting crop growth, called primary production, supports the vast majority of the human population on this planet.

An understanding of watershed functions is fundamental to planning for water and soil conservation. Watershed functions may be evaluated as a water budget, with measured quantities of precipitation considered as the input, and run-off, evaporation and transpiration, and storage functions as the outputs. The basic relationship may be expressed with the formula:

$$PREC = RNOF + EVTP + STGE$$

where PREC = precipitation,
RNOF = run-off,
EVTP = evapotranspiration, and
STGE = storage.

The amounts of water involved in each of these three functions are dependent on both the physical and biological characteristics of the watershed and atmosphere, including such things as size of the watershed, steepness of the slopes, permeability and water-holding capacity of the soil, the density and life-form of the vegetation, and atmospheric conditions.

This CHAPTER includes brief introductions to watershed characteristics and the management of water and soil resources. Wild as well as domestic animals are dependent on them; differences in the two groups lie in the amount of control exercised over their lives by man.

TOPIC 1. WATER MANAGEMENT

A discussion of water management should begin with the identification of the three sources of water for use in agriculture: precipitation, surface water, and subsurface water. The first of these--precipitation--replenishes the surface and subsurface water. Developed water supplies use only four percent of the total annual precipitation in the 48 continuous States, and only 13 percent of the precipitation available after evaporation and transpiration have been considered (Schwab et al. 1981). Thus, only a relatively small part of the total rainfall is actually used; problems in water management focus on the availability of water in space and time. Too much water and shortages occur in certain areas at different times, causing problems in agricultural production and in a very water-dependent society.

A watershed is an area that stores and supplies water from natural sources (Chapman and Carter 1976). It may be large, such as a mountainside and large river, or small, such as the hills surrounding a small creek on a farm. Whatever it's size, it is a natural unit for the evaluation of water and soil relationships. The watershed approach to water and soil conservation is a logical one, for there is little point in installing contours and terraces in the lower part of a watershed if the upper part of the watershed is subject to rapid run-off and erosion.

Several watershed factors affect run-off, including size, shape, orientation, topography, geology, and vegetation (Schwab et al. 1981). In general, the absolute rates and volumes of run-off increase with larger watershed areas, but the rates and volumes of run-off per unit area decrease.

Surface water and subsurface or ground water are of considerable long-term importance in water management. Surface water is found in natural basins and stream channels, and in developed catchment basin and reservoirs. Developed reservoirs store water when natural storage is not adequate to meet the needs for water in that area. There are two extreme approaches to water management: one, do everything technically possible to manipulate water resources for man's immediate benefit, and two, do nothing beyond the natural, using only naturally-developed water characteristics and resources. As more is learned about the long-term consequences of water management, more desirable management practices between these two extremes may be implemented.

UNIT 1.1. WATER CONSERVATION

Water conservation involves both liquid water and water vapor. The former is visible and obvious, the latter invisible and subtle. Plants respond to both, and good conservation practices consider the effects of both.

Farming practices which reduce run-off and enhance surface storage are, from an ecological point of view, desirable on a large scale. Individuals do not and cannot always farm in accordance with long-term ecological ideals, and the result is a patchwork approach to conservation measures, used by those who have adequate financial resources and not by those who are in need of short-term financial gains in order to remain solvent.

What farming practices may be used to reduce run-off and enhance surface storage? Terraces and contour cultivation reduce run-off, and natural and artificial basins enhance surface storage.

TERRACES

Land that is too steep and the slopes too long may be "terraced" to shorten the distances that water will flow before reaching a barrier. Terraces are ridges, or combinations of ridges and channels, which are built on the contour of sloping land. The spacing of terraces varies with the steepness of the slope; as steepness increases, distance between terraces decreases. In some mountainous countries, terraces are step-like on the slopes.

Small terraces may be built quite inexpensively with discs. Large terraces are expensive as they require large equipment. Terrace-building of any size requires careful engineering as they must be designed properly to not only hold water, but also to direct the retarded water into properly-designed waterways.

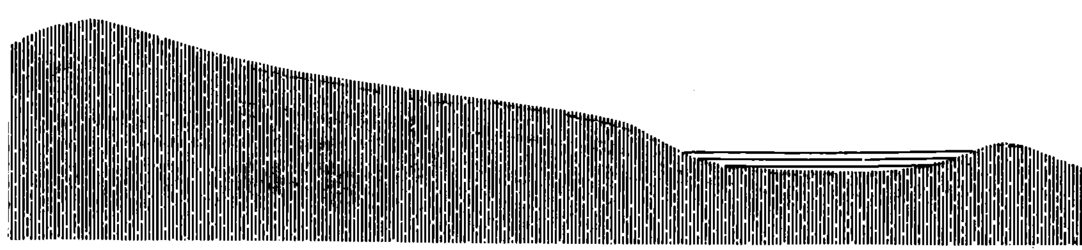


Figure 7-1. Cross-section of a terrace on gently-sloping land.

Contour cultivation, with tillage practices following level lines around the hills as contour lines do on a topographic map, results in each furrow functioning as a miniature terrace or dam, retarding the flow of water and increasing infiltration (Figure 7-2).

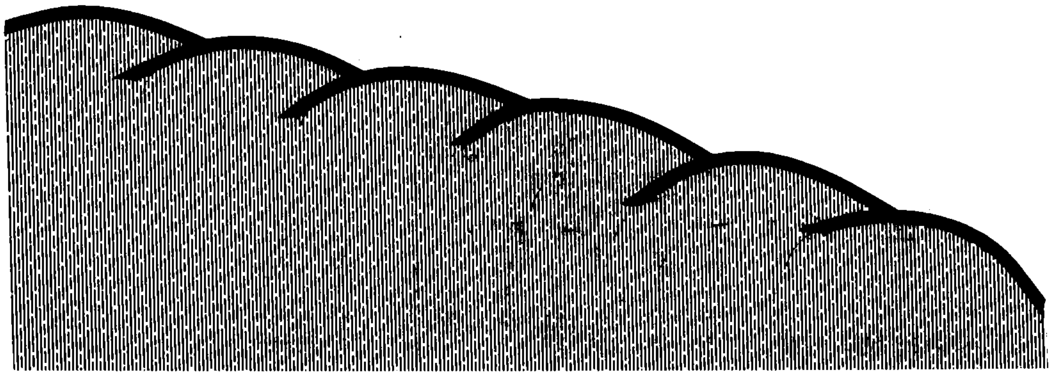


Figure 7-2. Cross-section of contour plowing; each furrow slice acts as a tiny dam, retarding the flow of water and increasing filtration.

TRANSPIRATION

Transpiration is an important but rather subtle form of water loss that has been given considerable attention by agronomists in recent years. It is an invisible form of loss, until plants begin to wilt. Then there is little the farmer can do except wait for cooler temperatures and rain, unless prepared to irrigate. Transpiration may be reduced by careful planning of the layout of the fields and distribution of crops. The alternation of several rows of corn with several rows of soybean, for example, is a good way to reduce transpiration from the soybean crop. The corn acts as a windbreak, reducing wind speed, thereby reducing the mass transport of water as vapor.

Crop residues and litter on the soil surface help reduce evaporation from the soil surface. Moist soil is less subject to movement by wind than dry soil is, so crop residues such as stubble not only reduce wind velocities as discussed earlier but also reduce transpiration, both of which reduce erosion and make the soil a better medium for plant growth, as well as providing better cover for wildlife.

UNIT 1.2. SURFACE WATER

Surface water, such as marshes, potholes, and ponds, provide an aesthetic appearance to the landscape, provide water for livestock when managed properly, and are reservoirs of water that retard run-off and contribute to the maintenance of the water table, depending on the subsurface drainage characteristics. Such areas of surface water also occupy potentially valuable farmland, and have been drained by the thousands, especially in the pothole region of the midwestern states and the provinces of Canada. This has resulted in the destruction of thousands of breeding marshes and potholes for ducks, and the loss of the dryer edges of the marsh habitats that are used by pheasants and other species of wildlife. Elimination of such marshes has also meant the destruction of breeding areas for red-winged blackbirds, which can cause considerable damage to corn crops. Thus, there are economic considerations in the establishment of agricultural priorities in relation to wildlife values. As technology and machinery have made it possible to drain more land, wildlife habitats have become more vulnerable.

EPHEMERAL PONDS

Ephemeral ponds, containing water only in the spring and then only for varying but usually brief lengths of time, serve as temporary wildlife habitat only. Such ponds are usually not suitable as breeding areas, because they change rapidly when the water is gone. Drainage of such areas, either by surface drainage or perforated tile, results in less potential loss of wildlife habitat than the drainage of permanent marshes, and an economic gain to the farmer. Thus, the kind of surface water to be drained is an important consideration when evaluating the advantages and disadvantages of drainage practices. It is conceivable that such temporary basins of water can become breeding death-traps as their suitability for brood rearing is so low that mortality of the young is almost a certainty.

FARM PONDS

Farm ponds have been built--almost 2 million of them (Yearbook of Agriculture, 1970)--in many areas of the United States where natural ponds do not occur. Three types in common use are listed by Schwab et al. (1981): (1) dug-out ponds, (2) on-stream ponds, and (3) off-stream ponds. Dug-out ponds are constructed on slopes less than four per cent where there is a reliable water table within one meter of the ground surface. On-stream ponds are constructed across streams and are fed by the surface run-off, and off-stream ponds are constructed adjacent to streams and the stream-water diverted into the ponds.

Pond site selection and construction are dependent on the purposes of the pond and on the topography and soil characteristics. Farm ponds are used for agricultural purposes, providing water for livestock, irrigation, and fire protection, and for recreational purposes, providing habitat for fish and wildlife to be both observed and harvested.

Ponds must be managed properly if they are to retain their usefulness. Grazing should not be allowed on the dikes, and deciduous trees should not be allowed to encroach too heavily. Water levels should be maintained, a variety of shrubs should be nearby, protective cover should be provided on the banks and dikes, and neat oxes and resting platforms will make the pond more attractive to wildlife (Figure 7-3).

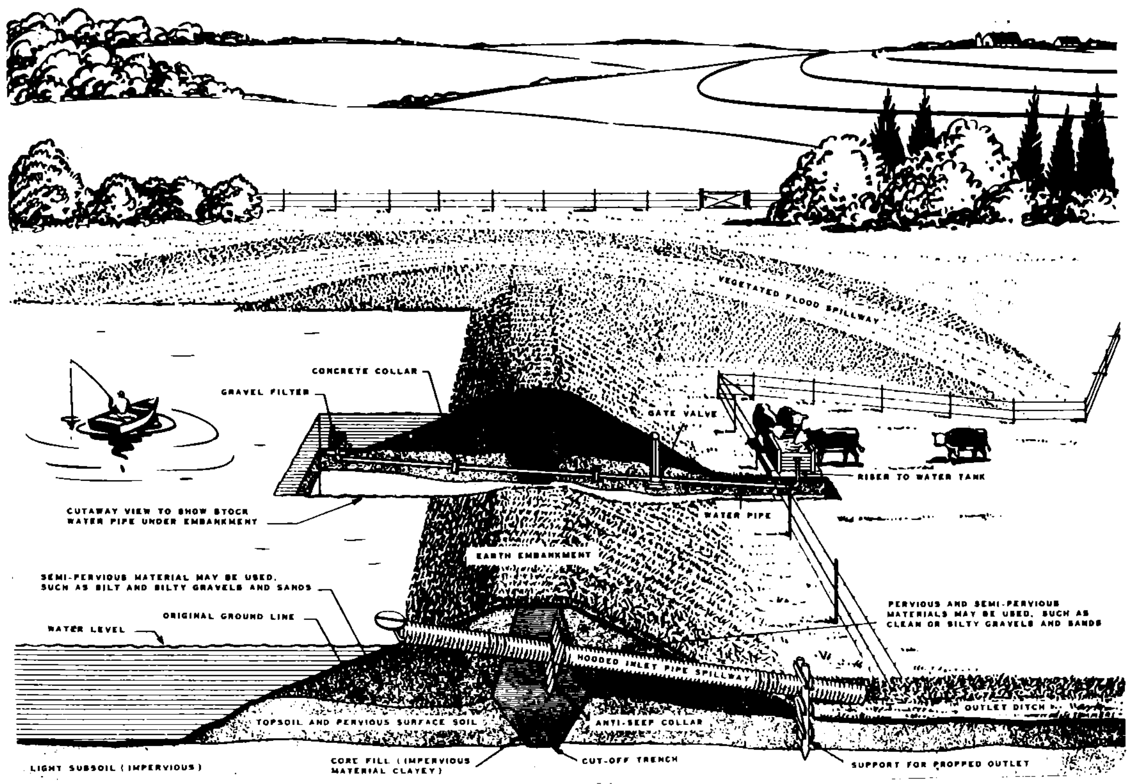


Figure 7-3. A well-designed farm pond with a separate outlet for watering cattle. (Source: Farmers Bulletin No.2256, USDA).

UNIT 1.3. IRRIGATION SYSTEMS

Irrigation is an old practice in those areas where farming depends on it, but a rapidly-spreading one in marginal areas where irrigation systems are a type of crop insurance. The amount of water available to growing crops is a very important determinant of production, and the ability to control water provides for much more stable production from year to year.

Surface irrigation is practiced by diverting water from natural lakes, rivers, and streams directly or through irrigation canals to fields. Water is pumped from the canal or regulated by gravitational flow and allowed to run over the field to soak into the soil and be absorbed by the plants. Some irrigation systems have control valves on the canal gates which close the gates when the appropriate amount of water has covered the field (Figure 7-4).

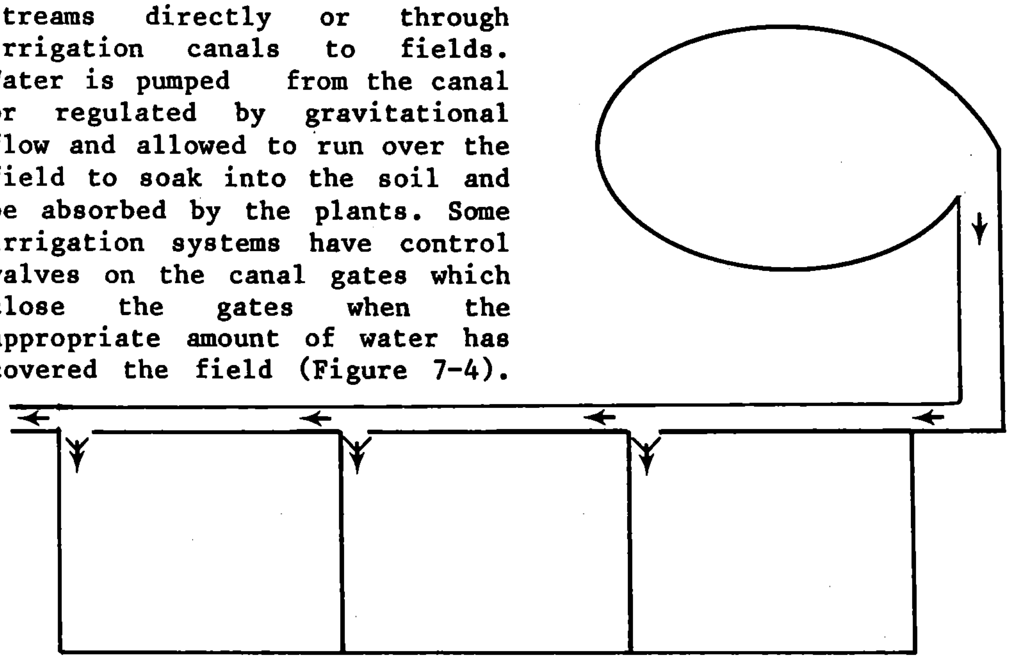


Figure 7-4. Schematic of a gravity-fed, automatically closing irrigation system.

Underground water for irrigation systems is made available by pumping water from wells to be sprayed on the crops with large traveling booms. The booms are on wheels, are moved by gear-driven water pressure. They may be linear, moving in one direction, or circular, rotating about a fixed point. There is a potential for reducing the water table; cone-like depressions of depleted underground water form when removal occurs at a greater rate than replenishment (Figure 7-5).

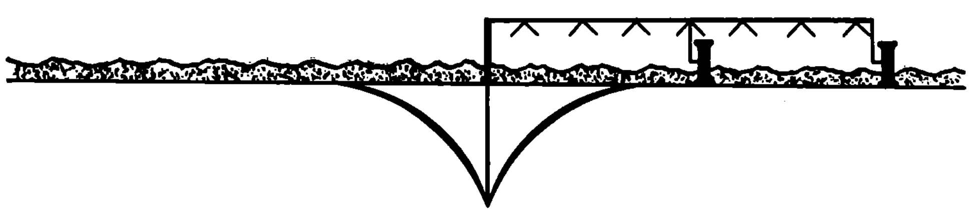


Figure 7-5. An irrigation boom over an underground water source.

TOPIC 2. SOIL MANAGEMENT

Tillage operations disturb the upper part of the soil profile, making it vulnerable to wind and water erosion. Some crop residues should be left to form a layer of litter on the soil surface when tillage operations occur in the upper part of the topsoil. Chisel plows open up the soil, hastening the decomposition and incorporation of litter. The moldboard plow turns the soil over, burying much of the litter; it should be adjusted to leave parts of the stubble exposed between the furrows (Figure 7-6).

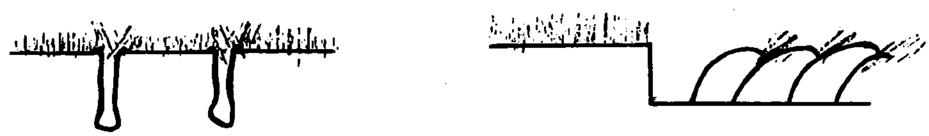


Figure 7-6. Cross-sections of furrows from chisel plows and moldboard plows. Note the stubble that should be exposed between the furrows.

Water and soil management are very closely allied, and both are considered together when making decisions about tillage practices and crops to be grown. Soil management practices designed to reduce erosion--contour cultivation and terracing--have already been discussed. Additional information on their roles as soil conservation measures will be given.

Soil management has become a highly technical operation. In years past, a 4-year rotation of a small grain for one year, alfalfa or clover for two years, and corn for one year was standard practice. There are some virtues in simple crop rotations, but current technology and economics seem to dictate more specialized management practices.

Soil consists of particles which vary in size from the largest, coarse to medium to fine sand (0.05 to 2.0 mm diameter), silt (0.002 to 0.05 mm), and the smallest particles, clay (< 0.002 mm diameter). These particles supply the mineral elements necessary for plant growth, and good soil contains the proper proportions of particle sizes that results in the water-holding capacity necessary for minerals to be dissolved and free water absorbed by the plant roots.

The soil texture triangle (Figure 7-7) shows schematically the relative amounts of sand, silt, and clay in different textural classes of soil. Pure sand is too coarse to hold much water; silt and clay are too fine for water and air transport. The best soils have a mixture of sand, silt, and clay, and they are classified as loams. Note in the texture triangle that loams with more sand is called sandy loam, and with more clay and silt, clay loam and silt loam. Soils with appropriate mixtures of particle sizes have the necessary air spaces and water-holding capacities for healthy plant growth.

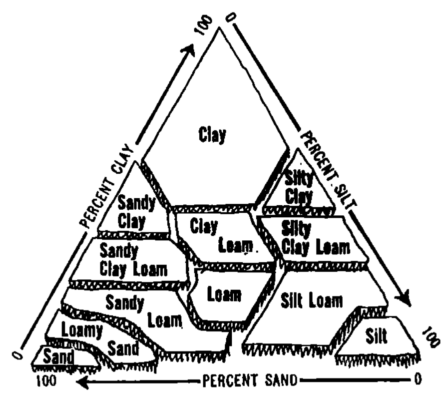


Figure 7-7. The soil texture triangle showing the relative amounts of sand, silt, and clay in different textural classes of soil. (Source: Yearbook of Agriculture, 1957).

Soil contains much more than physical particles, however. Soil is a living medium called a soil system, and it includes not only the physical particles, but also living plant and animal material and their decomposing residues and remains. Biological activities in soil result in the absorption and release of gases, liquids, and solids. These activities, along with the mechanical actions of both biological and physical factors, results in the development of soil profiles.

Soil profiles contain one to several layers of different kinds of soil materials, not quite as distinctly separated as shown in Figure 7-8, but nevertheless recognizable by the soils student. Particular soil profiles have different numbers and depths of layers. Good farming soils have depths of many inches, and active upper layers with both humus and mineral soil.

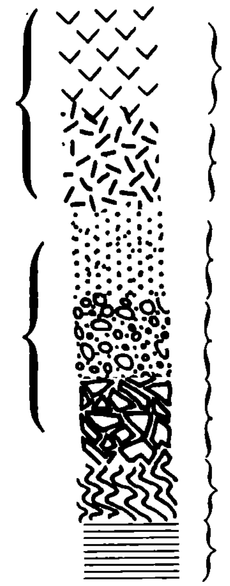


Figure 7-8. Major layers in soil profiles.

Litter contains plant material that has not yet decomposed. It may be quite dry or moist, depending on recent rainfall. Underneath the litter there is more moisture, and decomposition occurs as a result of the action of molds and other organisms. The decomposed litter becomes humus, and is incorporated into a layer of humus and mineral soil. Percolating water removes some of the humus and mineral soil layer, including dissolved minerals, and transports it to an accumulation zone. There, water transport is reduced or stopped. Weathered parent material and bedrock underly these active layers.

The rate at which soil formation occurs is dependent on conditions in the soil system. Adequate moisture and optimum temperatures for a large part of the year result in soil profiles with active layers up to a meter or more deep. Such profiles may be found in the rich farming country of the United States. Colder temperatures, short growing seasons, and parent material that is not rich in minerals may result in very slow rates of soil formation--less than an inch of soil formed in a thousand years.

One interesting and sobering characteristic of the soil resource is that it is foil-thin; inches separate the human race from sterile subsoil and bedrock. The deepest soils are often found in glacial river valleys where sediment has been deposited as water levels dropped. These areas are also the easiest places to build roads and houses, so the short-sighted human being, purported to be the most intelligent creature on the planet, "develops" these areas, removing many acres of land from permanent production. We humans readily sacrifice, for short-term economic benefits, resources that have taken thousands of years to develop.

Soil classification systems are necessary in order to arrange soil characteristics into logical sequences for identification and recall. Since more than 10,000 soil series (the most specific kind of soil) have been identified in the United States, a usable classification system can only be developed with great care and deliberation.

A new system of soil classification was adopted by the United States Department of Agriculture in 1967 after a 20-year period of development and review. This system is similar in structure to the taxonomic hierarchy of plants and animals. Rather than the Kingdom, Phylum, Class, Order, Family, Genus, and Species familiar to biologists, soils are classified at six levels as follows:

Order,
Sub-order,
Great group,
Subgroup,
Family, and
Series.

The 10 soil Orders are listed in Table 7-1 with their characteristics and land areas in the United States. Much additional information may be found in recent books on soil science and crop management.

The best soils for agricultural purposes are fertile and have good water-holding capacity. Such soils are found in the Order Mollisol. Note that they are the most abundant in the United States, but comprise only 25% of the land area. They need to be managed wisely; the next two UNITS emphasize soil conservation and enrichment.

Table 7-1. Soil Orders, their characteristics, and extent in the United States. (Compiled from data in Chapman and Carter 1976, and Follett et al. 1981.)

Order	Characteristics	Sq. miles in U.S.	Percent of land area
Alfisol	Gray to brown soils with an accumulation of clay in the sub-surface soil.	478,645	14
Ardisol	Soils in dry areas; low in organic matter	411,860	12
Entisol	Young soils with indistinct profile	282,140	8
Histisol	Soils rich in organic matter	18,600	1
Inceptisol	Young soils with poorly developed profiles	642,050	18
Mollisol	Soils rich in organic matter and in exchangeable bases.	890,200	25
Oxisol	Soils that contain quartz and/or hydrated oxides.	500	T
Spodisol	Soils with an accumulation of amorphous material in the subhorizons.	171,620	5
Ultisol	Soils, with a clay horizon, that are low in exchangeable bases.	451,620	13
Vertisol	Cracking clay soils	35,125	1
Miscellaneous		158,600	4

UNIT 2.1 SOIL CONSERVATION

Erosion is a continuous source of soil loss. Erosion is not a new phenomenon; wind erosion since the last glaciation resulted in the deposition of loess, which makes up some of the best farmland in the world in the "corn belt." Water erosion that transports fine soil particles into streams and rivers eventually is deposited as deltas, and deltas are also rich farming areas. Once the rich topsoil is gone from an area, however, it takes years to build up the subsoil into a productive condition. In fact, it is not possible on a large scale.

Erosion due to modern tillage practices is usually more accelerated than natural erosion, and any loss of the foil-thin topsoil over the earth's surface should be of concern to everyone. A government agency, the Soil Conservation Service, is active in soil management practices, promoting soil conservation by providing both information and funds to the nation's farmers.

No-till farming, with crops planted directly into soil below the crop residues and litter that has accumulated, is a relatively new practice, brought on more by the fuel shortage of the '70s than the concern for soil surface profiles. Such direct planting in residues is successful as long as selective herbicides are used to kill competing weeds. Without such herbicides, competition between the crop planted and the residual weeds is so great that the crop will produce just a fraction of its genetic potential. The use of chemicals, which is of concern to many, for weed control makes no-till farming possible. No-till farming has reduced erosion in the Palouse areas of Washington and Idaho by as much as 90% (Russnogle, 1983). Thus, trade-offs exist, and once again we find there are no simple answers to complex questions. It is important that studdents of ecology and those having special concerns for the environment become well-informed before embarking on crusades.

WIND EROSION

Exposed topsoil will dry out and the small particles of humus and mineral soil become very subject to wind erosion. The light and small particles are picked up by the wind and carried for long distances. The decisive factor in dust storms is the depletion of vegetative cover which is associated with the way we use the land, and with rainfall. The decade of the 1930's, known as the dust bowl, was a time of severe wind erosion due to tillage practices which exposed the topsoil, and to dry weather conditions. At times, the sky was filled with clouds of dust that effectively blocked out the sun, and drifts of transported soil were found burying even machinery, as snow does in the winter.

The size of soil particles transported by wind is dependent on wind speed. As wind speed is increased, larger particles are carried. Reductions in wind velocities cause wind-borne particles to be deposited. Vegetative cover and litter over soil causes wind speeds to be low enough so soil transport does not occur. Wind profiles over bare soil and a stubble field are distinctly different, with the steeper gradients over the bare soil due to differences in the amounts of friction between the moving air and the substrata: bare soil or stubble (Figure 7-8).

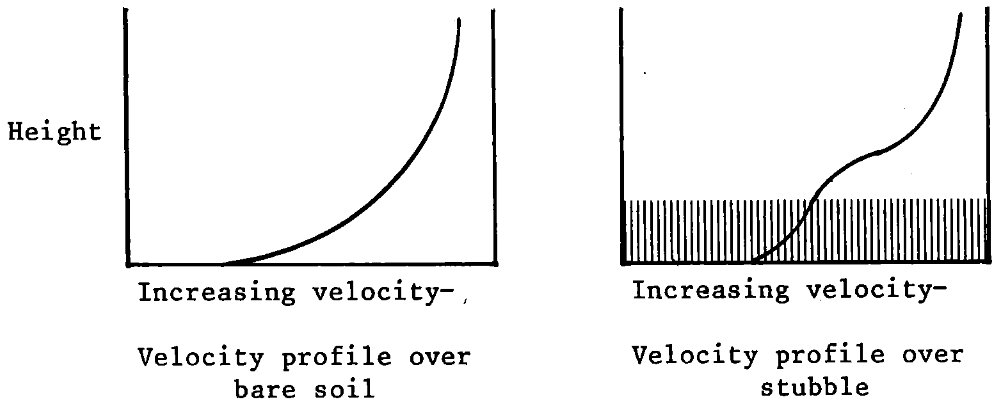


Figure 7-9. Wind velocity profiles over bare soil and stubble.

Equations have been derived by meteorologists for average velocities at different heights in such vertical profiles. There is a logarithmic increase in velocity with height, with a general formula being (from Moen 1973):

$$U_z = (U_*/k)\ \ln(z/z_o)$$

where U_z = wind velocity at height z,
U_* = friction velocity,
h = von Karmon constant = 0.4,
z = height in cm, and
z_o = roughness length of the surface.

The formula is converted to an equation by first determining the roughness length of the surface being considered, which is the height at which the mean in-line velocity goes to zero. It is dependent on both the height of the vegetation and the wind speed. Representative values for agricultural crops are listed in Table 7-2 (data from Sellers 1965).

Table 7-2. Surface types, heights of vegetation, and their z values for calculating wind profiles. (Data summarized from Sellers 1965).

Type of Surface	Height(cm)	z_0(cm)
Corn	220-300	71.5 - 127.0
Wheat	60	22.0 - 23.3
Grass	60-70	8.0 - 15.4
Alfalfa-brome	15	2.5 - 2.7
Grass	2-6	0.14 - 0.75
Smooth sand, mud flats		0.001 - 0.03

U_* is determined by substituting the measured velocity at height z when z_0 was determined for U_* and rearranging the equation to determine U_*. The U_* and Z_0 values are then used when determining U_* at any height, z.

Why emphasize the mathematics of this relationship? Because wildlife biologists should use such predictive relationships to estimate the conditions to which wild animals are exposed. Upland game birds, for example, live in the lower centimeters of vertical wind profiles, and calculations of wind velocities at their heights in different cover types are more useful than general weather data. The profile on the right in Figure 7-8, for example, is much more suitable for wildlife than the one on the left; small mammals and birds find the stubble to be effective protection from wind.

The profile on the left in Figure 7-9 results in wind erosion when the soil is dry. Some kind of protective cover not only reduces wind velocities near the soil surface, but also the rate of drying, both important factors affecting the extent of wind erosion.

Wind erosion may also be reduced by alternating small grain crops with fallow land. This is common practice on the large farms in the wheat belt with low annual rainfall. There, half of the land is plowed and left fallow each year, with alternating strips of wheat and fallow land (Figure 7-10). This is called wind strip cropping. The strips are laid out perpendicular to the direction of the prevailing winds.

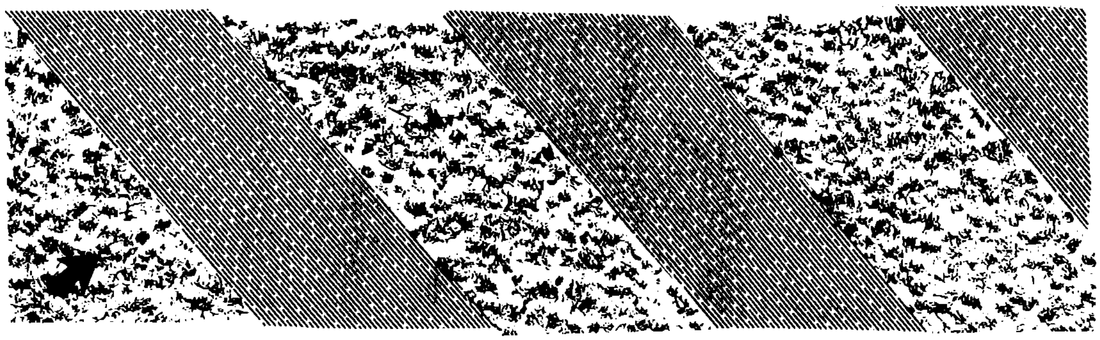
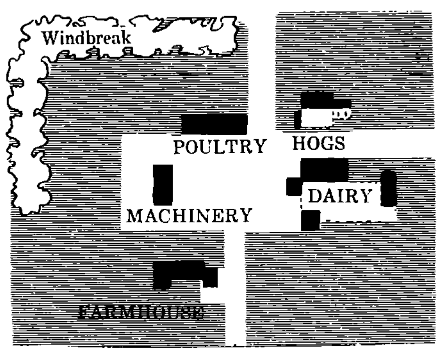


Figure 7-10. Field design for strip cropping. Note the arrow indicating the direction of prevailing winds.

Wind erosion is not so severe in the farming areas where precipitation is more plentiful, except in unusually dry years. In drought years there, wind erosion is more severe in the winter when the fields may be either plowed or have a minimum of crop residue. If there is little or no snow cover, the exposed soil is more subject to wind erosion.

Shelterbelts and windbreaks are plantings of trees and shrubs that are high enough and dense enough to reduce wind velocity and prevent the drifting of snow. They shelter farm buildings, livestock, fields and orchards, they hold snow, protect highways from drifting snow, provide habitat for wildlife, and may provide some posts and fuel wood.



WATER EROSION

Water erosion is a potential problem on farms almost everywhere. The extent of water erosion is dependent on the steepness of the land, tillage practices, soil compaction, soil moisture, and the intensity of rainfall. The first and last of these are beyond the control of the farmer. The middle three can be controlled to a significant extent by tillage practices. Of the rainfall that reaches the ground, the amount that enters the soil is important because nearly all of the rest of the water becomes run-off, with it's physical capacity for causing erosions.

There are three kinds of soil erosion by water: sheet erosion, rill erosion and gully erosion. Sheet erosion occurs over large areas with a more or less uniform layer of topsoil removed. Rill erosion begins in very small channels, such as the tillage marks from a harrow. As the rills become deeper and wider and erosion continues, they combine to form small gullies. Then gullies widen, deepen, and move upslope (Figure 7-11).

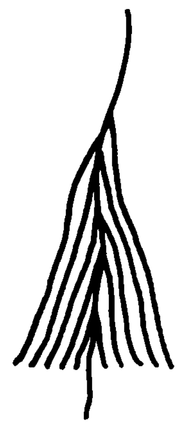


Figure 7-11. Gullies move upslope as they become deeper and wider.

The amount of run-off is a function of many characteristics of the watershed. These are summarized (from Foster 1973;62) in Table 7-3, providing an overall view of the effects of four watershed characteristics on the potential for runoff.

The potential for runoff is partially related to interactions between these watershed characteristics; steep terrain can hardly be accompanied by a large number of lakes, ponds, or marshes. Any given watershed can be managed for the lowest possible runoff potential by providing the growth of the best vegetative cover possible. That is the one characteristic which the farmer has most to do with as decisions are made in relation to farming operations. Steeper slopes should be left in permanent cover, and grazed only lightly.

Soil compaction results when machinery is driven over the soil. If the soil is wet, compaction may be severe, especially in soils that are high in clay content. Tractors with wide flotation-type tires and dual wheels reduce compaction, but such equipment encourages the use of machinery when the soil is wetter, too. Thus wide-tires increase the number of possible working days in the field while they decrease soil compaction. Compact wheel tracks become channels for water to flow, and gullies will start in such tracks on hillsides that are steep enough. The best practice is to farm on the contour.

Table 7-3. Four watershed characteristics and their effects on the potential for runoff. (Source: Engineering Handbook for Farm Planners, Upper Mississippi Valley Region III, Soil Conservation Service, 1953).

Characteristic	Potential for run-off			
	Extremely high	High	Normal	Low
Relief	Steep terrain, slopes 30%	Hilly, slopes 10-30%	Rolling, slopes 5-10%	Flat, slopes 0-5%
Soil infiltration	Thin or no soil mantle, negligible infiltration	Clay, gumbo low infiltration	Deep loam, normal infiltration	Deep sand high infiltration
Surface storage	Negligible, no ponds or marshes	Low, with small drainageways, no ponds or marshes	Normal, with considerable surface-depression storage, 2% in ponds & marshes	High, with large flood-plain storage or large number of lakes, ponds or marshes
Vegetative cover	Sparse plant cover, mostly bare	Poor to fair natural cover as cultivated crops, 10% under good	Fair to good cover 50% in good permanent cover, 50% cultivated	Good to excellent cover, 90% in good permanent cover

CONTOUR CULTIVATION

Contour cultivation, with tillage practices following level lines around the hills rather than up and down the slope, reduces erosion by reducing the velocity of runoff water as each contour furrow acts as a tiny dam with a basin on the upslope side for water retention and infiltration. Strip cropping, which consists of alternating strips of small grain, row crops, and hayfields, helps retard water movement. Small depressions down slope should be planted into permanent vegetation that will function as waterways (Figure 7-12).

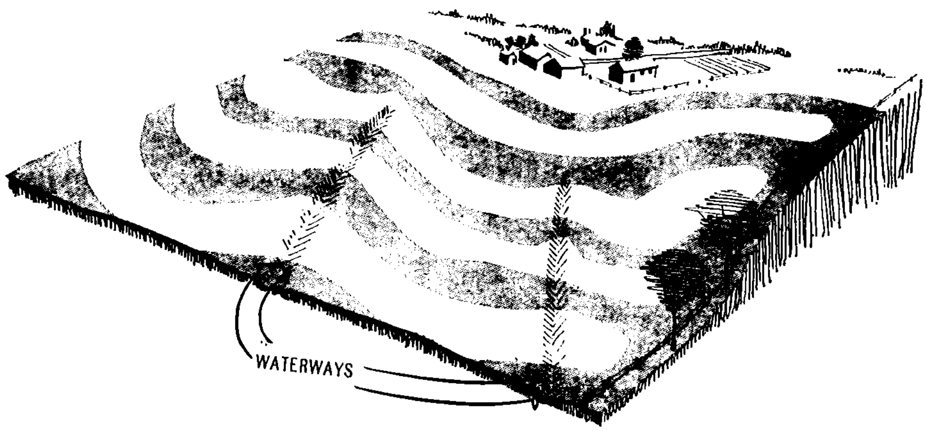


Figure 7-12. Strip cropping on the contour with permanent vegetation in waterways to prevent gully erosion. (Source: Yearbook of Agriculture, 1957.)

UNIT 2.2. FERTILIZERS

It might be nice to dream about living in an ecologically ideal world where all resource use is perfectly balanced and all resources needed are locally available, but such is reality for primitive societies only. Technological solutions to agricultural problems are often thought of as detrimental to wildlife species and their habitats, but the wise use of air, water, and soil resources by agricultural enterprises also benefit wildlife. Follett et al. (1981) state that appropriate use of fertilizers and soil amendments increase production by 40%. If food production were to remain at the present level (and we have a very small surplus considering the number of people on the earth and the longevity of the human race) and fertilizers were not used, then 40% more land would have to come under cultivation. That would result in significant encroachment on areas designated as wildlife management areas, refuges, parks, and other areas designated primarily for wildlife, as well as on hedgerows, woodlots, and other non-cultivated areas on farms.

Wildlife biologists need to understand agricultural science in order to play significant roles in decision-making about both natural and agricultural systems. It is important to realize that all soils are not naturally fertile. Natural plant communities have developed over time as a result of species responses to the availability of the resources they require. Before intensive harvests by man, the nutrients assimilated by plants were returned to the soil as plant remains decomposed. After intensive harvests by man, using machines to cut and remove parts of plants, nutrients are displaced and depletion of the soil's nutrient resources is inevitable.

Evaluation of the use of fertilizers should be made in the ecological contaxt of primary productivity and optimum biological efficiency. Thus, for maximum productivity, plants need the following resources in appropriate balanced amounts (summarized from Follett et al. 1981):

1. Water and air,
2. Favorable water and air temperature,
3. Light, and
4. Essential elements for adequate plant nutrition.

The fourth-listed resource deals with fertilizers and soil amendments, both natural and artificial, organic and inorganic. It is interesting that, out of 88 natural elements, only 16 are presently considered essential for plant growth by most plant physiologists. The 16 elements and their sources are listed in Table 7-4.

The nitrogen content of cultivated soil after 50 years or more of cropping is usually much lower than when first plowed. Cultivation accelerates microbiological activities and the rate of release of ammonia from soil organic matter. A considerable part of the nitrogen may be lost through leaching and erosion, and a large proportion is removed by the crops grown. Further, less vegetation material is returned to the soil when cropped than when growing naturally. Unless nitrogen and other essential elements are added as manure, legumes, or commercial fertilizers, soil productivity gradually declines.

Table 7-4. The sources and classification of 16 elements essential for plant growth (summarized from Follett et al. 1981).

Source	Classification and Elements
Air and water	Carbon
	Hydrogen
	Oxygen
Soil and Fertilizers	Primary nutrients
	Nitrogen
	Phosphorus
	Potassium
	Secondary nutrients
	Magnesium
	Calcium
	Sulphur
	Micronutrients
	Chlorine
	Copper
	Boron
	Iron
	Manganese
	Molybdenum
	Zinc

Nutrient availability is stressed very much with modern farming practices because the crops grown have genetic potentials for production far greater than the original natural varieties. Plant populations are also high, and most of the plant, including not only the grain but the vegetative parts as well, is harvested and used as food or fiber. Thus the natural cycle of growth, death, and decay is interrupted by mechanical harvesting. Since nutrients from the soil are synthesized into plant tissue, any removal of plant material is a direct loss to the soil.

Balanced plant nutrition is a worthy goal, just as balanced animal nutrition and balanced human nutrition. In an agricultural and industrial society, these goals can be reached only by providing the nutrients required in a rational manner. Thus soil is fertilized for plants, feeds are enriched with supplements for animals, and humans supplement their diets by importing food from other areas at different times of the year, and by taking vitamins and other supplements to augment their diets.

The primary nutrients--nitrogen, phosphorus, and potassium--in the plow layer (the first 7 inches of soil), are of real interest to farmers. How many tons of soil and of these three elements are there in an acre of the plow layer? The bulk density of the plow layer is given by Brady (1974) as 1.43 gms per cubic centimeter. An area 12 x 12 inches and 7 inches deep equals 12 x 12 x 7 = 1008 cubic inches. One cubic inch contains 16.39 cubic centimeters of soil, and weighs 23.43 gms. An area one foot square and seven inches deep weighs 23,621 gms, or about 52 pounds. One acre of such soil seven inches deep weighs 52 x 43,560 = about 1,133 tons.

Soil with good fertility contains nitrogen, phosphorous, and potassium, the primary mineral elements in the soil. A crop of corn yielding 100 bushels to the acre contains 5600 pounds of dry-weight grain (not including the cob). The grain contains about 10% protein and about 1.6% N, so a yield of 100 bushels results in the removal of 90 pounds of N per acre. An additional 50 pounds would be removed if the plant was used as stover. Where does the nitrogen come from to replenish the soil? There are two main sources of nitrogen: the atmosphere, nitrogen-fixing bacteria, and fertilizers.

ATMOSPHERIC NITROGEN

Physical fixation. The atmosphere is a source of fixed inorganic nitrogen as a result of the conversion of nitrogen (N_2) to oxides such as NO and NO_2 by lightning. The total amount of nitrogen added to the soil is about nine pounds per acre per year, except in industrial areas where emissions of nitrogen oxides and ammonia gas may result in 54 to 62 pounds per acre added from industrial contamination (Follett et al. 1981).

Biological fixation. Nitrogen-fixing bacteria which live in the nodules on the roots of legumes fix large amounts of nitrogen. Nitrogen-fixing by nodule organisms in alfalfa ranged from 188 to 260 pounds per acre in New York (Brady 1974). Not all of this is available to crops, however since the plants themselves use some. The net requirement for soil nitrogen by legumes is less than that of nonlegumes, and that high-protein legume crops can be harvested with little depletion of soil nitrogen. Brady refers to legumes as nitrogen-savers.

ORGANIC FERTILIZERS

Nutrients may be returned to the soil by spreading livestock wastes, or manure, back on the land. Since some of the crop nutrients have been synthesized into animal tissue and removed from the farm, the manure contains only part of the crop nutrients removed. Further, some of this is lost as liquids, so the solid wastes returned by manure are only part of the amounts processed by animals. The amounts of nitrogen, sometimes phosphoric acid, and potash in manure is given in Table 7-5.

Table 7-5 . Composition (%) of solid and liquid excrement of mature animals. (Source: Yearbook of Agriculture, 1957, p.232). See Page 145, Table 6-5 for amounts produced each day.

	Nitrogen		Phosphoric oxide(P_2O_5)		Potash (K_2O)		Lime (CaO)	
	Solid	Liquid	Solid	Liquid	Solid	Liquid	Solid	Liquid
Horses	0.52	1.20	0.30	Trace	0.24	1.50	0.15	0.45
Cattle	0.32	0.95	0.21	0.03	0.16	0.95	0.34	0.01
Sheep	0.65	1.68	0.46	0.03	0.23	2.10	0.46	0.16
Hogs	0.60	0.30	0.46	0.12	0.44	1.00	0.09	0.00
Hens	1.00		0.80		0.40			

Since manure is absorbed by the litter used in most barns, the litter itself becomes a source of nutrients. The amounts of litter of different types required to absorb 100 pounds of liquid and the content per ton of air-dry litter are given in Table 7-6.

Green manure crops are sometimes planted for rapid and lush vegetative growth, and then plowed under. Such crops do not increase the total amounts of elements in the soil, but they do alter the chemical arrangement of these elements as they are synthesized into the organic matter that is plowed under for slow release as it becomes humus. The humus also improves soil tilth, which in turn improves water-holding characteristics of the soil.

Table 7-6. Amounts of litter required and nutrient contents (all in pounds) of different litters. (Source: Yearbook of Agriculture, 1957, p. 233).

	Litter required to absorb 100 lbs of liquid	Nitrogen held per ton of litter	Nitrogen	Phosphoric oxide	Potash
Wheat straw	45	4.5	11	4	20
Oat straw	35	7.1	12	4	26
Rye straw	45	3.4	12	6	16
Chopped straw	20-30	3.4	12	6	16
Cornstalks (shredded)	25-35	5.3	15	8	18
Sawdust	25	0	4	2	4
Wood shavings	25-45	0	4	2	4

INORGANIC FERTILIZERS

Inorganic fertilizers are commonly used in agriculture today. Stores of nutrients are mined or synthesized to produce an inorganic fertilizer that is spread in pelleted or liquid form. Pelleted fertilizers are processed with different ratios of N, P, and K, and the suitable ratio is selected on the basis of soil fertility tests for application to the land for the crop to be planted. Different crops require different amounts of N, P, and K, and there is little logic in applying more fertilizer than is needed by the particular crop to be planted.

Soil fertility tests are essential if inorganic fertilizers are to be applied in correct amounts. Two decisions are required when determining correct amounts: The amount of money allocated to fertilizer purchases, and crop production expected. If too little is applied, then crop production will not meet expectations. Too much is a waste of money. Determining the right amount requires some technical knowledge; recommendations are usually made when the results of the soil tests are returned to the farmer.

How dependent are we on fertilizers? Follett et al. (1981) make a frightening statement (p.515):

"The production of satisfactory quantities of food to feed the world population is bound to the production and distribution of adequate quantities of chemical fertilizers."

Before you begin to crusade for alternative agriculture, let me suggest that the whole area of water and soil conservation be evaluated, that the use of less than 1% of our energy resources go into fertilizer production be considered, and that we use our minds to develop rational alternatives before letting our emotions gain control.

Solutions are more difficult to find than problems. Water and soil conservation, agricultural production, and economics all go together. The wisest use of our natural resources is the wisest course of action to follow in the long run. Let us work together to find conservation-type solutions, and we will all benefit, as will wildlife.

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