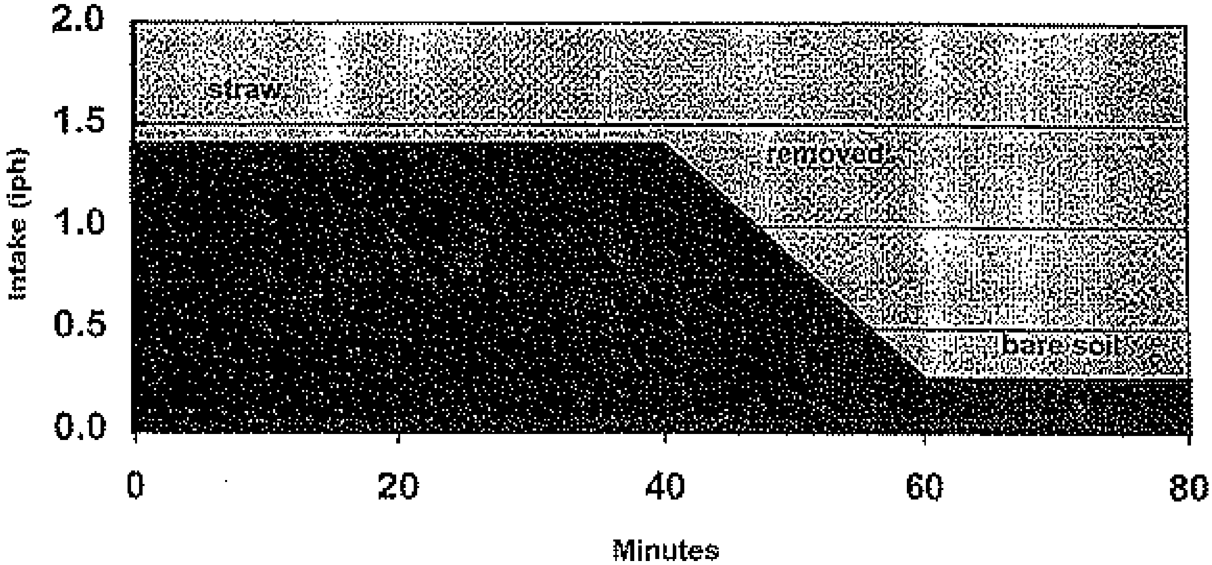
is a result of severe breakdown of soil structure due in part to an assorting action

Figure 4. Effect of Protective Cover on Infiltration



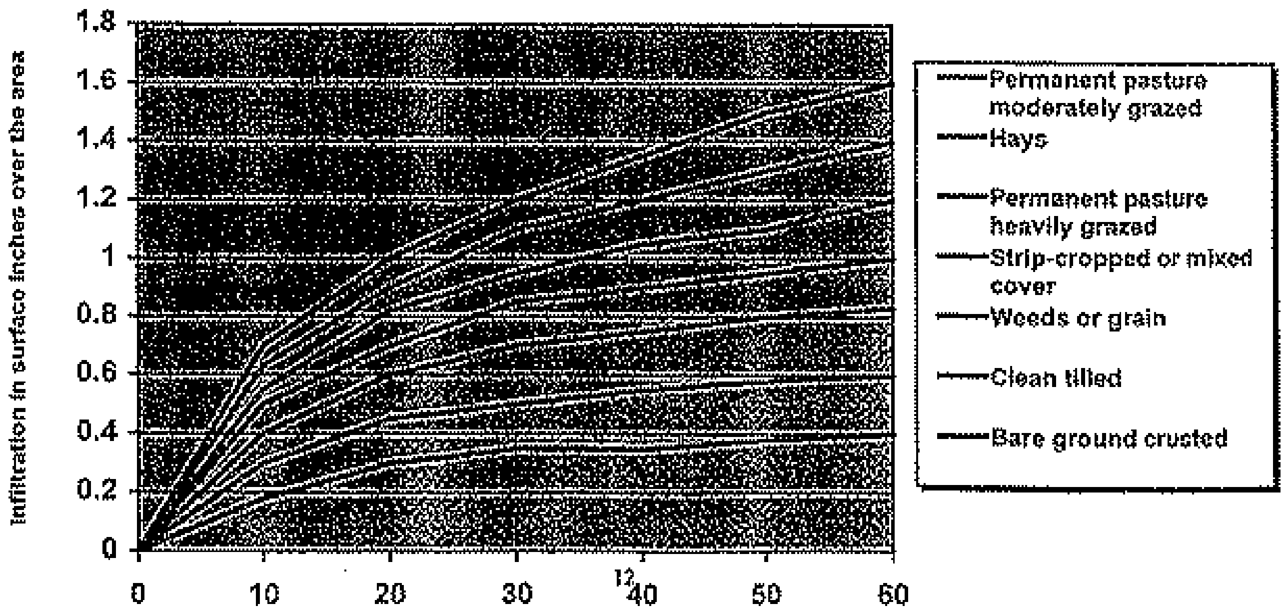
of splash action and of the water flowing over the surface. This action fits the fine particles around and between the larger ones to form a relatively impervious seal giving the surface of the soil a slick appearance.

This surface-sealing effect can largely be eliminated when the soil surface is protected by mulch or by some other permeable physical protection. The effectiveness of such protection is illustrated by figure 4, which shows the constant infiltration rate of soil covered by straw. After 40 minutes of infiltration at a constant rate, the straw was removed and the infiltration rate dropped to about one-sixth of its original value (12).

Borst and Woodburn (13), showed that a 4,000 lbs/acre straw mulch, applied to a loose, porous surface, increased infiltration 75 percent as compared with infiltration from an unprotected, loose, porous soil surface. The same amount of straw applied to a crusted soil surface increased infiltration only 13 percent as compared with infiltration on an unprotected, crusted soil surface.

The importance of vegetative surface cover for increased infiltration cannot be over emphasized. Figure 5 illustrates the effectiveness of several different surface cover conditions in South Carolina (14).

Figure 5. Typical Mass Infiltration Curves



Cultivation has the effect of temporarily loosening surface soil and increasing infiltration. However, if the surface is not protected by vegetation or mulches, rain and wind will soon consolidate the surface and reduce the infiltration rate. Special methods of cultivation may be used under certain conditions to increase infiltration and prevent surface sealing. So called "subsurface plowing" stirs the soil beneath the surface. This usually results in a higher infiltration rate. One must remember, however, that intensive tillage, which breaks up the aggregated soil particles and exhausts organic matter, is one of the most common besetting hazards to favorable soil structure. Cultivation on the contour and terraces can delay runoff and give more time for the infiltration process.

Simulated rainfall studies in Indiana and Illinois determined the relative effectiveness of several tillage methods or systems. In table 4, chisel and no-tillage systems are shown to reduce runoff and increase infiltration 51 and 35 percent, respectively, compared with conventional tillage after a high intensity storm. Row direction was perpendicular to a 9 percent slope. Under these extreme conditions, chisel plowing was most effective in increasing infiltration (15). However, this increase was not sustained.

TABLE 4

Infiltration on a 9 Percent Bedford Silt Loam From One-Hour Artificial Rainstorms, 1972

(a)

Tillage System	Infiltration 1st Hour	Infiltration 2nd Hour
Spring plow, disk, plant	0.72	0.31
Spring chisel, plant	2.05	0.99
No-Till	1.46	0.96

(a) Storms of 2.5 inches per hour were applied within 4 weeks after planting. Data are averages of two replications

The moisture content of the soil at the beginning of the rain also affects the infiltration rate. Collodial material in the soil tends to swell when wetted, thereby reducing both the size of pore space and rate of water movement. Soil with a high content of colloidal material tends to crack when dry, resulting in a high infiltration rate until the cracks are filled. The effects of soil moisture on infiltration is greatest on those soils with a large percentage of colloidal material. Soil moisture is usually higher in the spring than in the summer.

The effect of slope on rate of infiltration has generally been shown to be small, and to be more important on slopes less than 2 percent than on steeper gradients (16). Some investigators feel that the effects of slopes steeper than 2 percent on infiltration are not significant.

C. PERCOLATION AND DRAINAGE

The ultimate goal in water management is maintenance of optimum available moisture for plant use. What happens when rainfall and irrigation water is absorbed by the surface soil is of upmost importance when examining available soil water and the extent to which water deflections and losses may occur. Landusers and conservationists are concerned with two general types of water losses; namely,
(1) percolation to ground water and drainage, and (2) evaporation and transpiration.

Water entering the soil wets successively deeper layers to field capacity, which is the moisture content each layer must reach before water naturally drains through the soil profile. When field capacity is reached throughout the soil mass, additional water entering the soil drains into the underground, later emerging in springs, and seeping into streams, or adding to the ground water table.

Water held within the soil after drainage has ceased can be transpired by plants or lost by evaporation. Plants cannot utilize all water stored in the soil; they can dry the soil only to the wilting point, a moisture content at which the force holding water to the soil particles equals the maximum water-absorbing force of plant roots. Just as clay soils can hold more water at field capacity than sands, so also is the wilting point of a clay higher than that of a sand. Both the upper and lower limits of the available moisture range, between wilting point and field capacity, are determined primarily by porosity and soil texture. Conservation and management practices have limited influence on this range (17).

Clays and other fine-textured soils tend to have higher porosity than coarse soils, hence, when all of the small pores are filled with water, a fine soil will contain more water than a coarse soil. Clay soils, which contain many fine particles, tend mainly to have small pores. During and following the entry of rain and irrigation water, sandy soils with a preponderance of large pores usually conduct water more rapidly than fine-textured soils. For that reason, and because they contain less water to begin with, sandy soils retain less water for plant use. Some sands four feet deep can retain only two inches of water, while some clays of the same depth can hold twelve inches (18).

Storage capacity of soils and consequently available water for plant utilization can be increased by additions of organic matter in the soil profile. This will influence porosity. Increasing soil depth can also extend the effective rooting depth to utilize available soil water at lower depths.

D. EVAPORATION AND TRANSPIRATION

While the relationship between evaporation and transpiration is very complex and frequently open to question, the removal of water at the surface by evaporation and from the soil through the tissues of living plants or transpiration is very large and of great concern. Evaporation normally predominates early in the growing season while transpiration predominates when plant cover becomes more complete.

In spite of the fact that evaporation is subject to several variable influences, and that only the upper or surface layer of soil is seriously subject to large losses, the amount of moisture removed is surprisingly large. According to Wendt (19), from 40 to 75 percent of the annual rainfall in humid regions is lost by evaporation. The deduction is clear—evaporation from the surface of the soil is a vitally important factor in crop production and any substantial reduction in these tremendous losses would greatly enhance crop yields.

Several factors account for this large loss of water by evaporation. Principal factors are: (1) The relative humidity of the atmosphere , (2) The temperature difference at the surface and the atmosphere, (3) Wind action, and (4) The amount of water at the soil surface and its rate of replacement by capillarity. Let's take a brief look at each of these.

Temperature differences, especially as influenced by sunlight, play a particularly important part in establishing vapor pressure gradient at the surface of soils. In direct sunlight, the soil and its water often have temperatures several degrees above that of the atmospheric air. This increases the vapor pressure and so markedly steepens the gradient that evaporation is greatly encouraged.

Any changes in the vapor-pressure gradient and hence in the rate of evaporation will be determined by fluctuations in the relative humidity of the atmosphere immediately above. The lower the relative humidity, the more pronounced will be the evaporation tendency. Sometimes the relative humidity of the atmosphere approaches 100 percent. Under this condition, evaporation might not only cease, but condensation could be induced. Since relative humidity fluctuates rather widely from time to time, it cannot but exert a variable yet important influence upon the loss of water from soil by evaporation.

Air movement or wind disperses the moist layer found directly over the evaporating water surface and increases evaporation as compared to stagnant conditions. The drying effect of a gentle wind is noticeable even though the air in motion may be at a high relative humidity.

Generalizing on the amount of evaporation from soil surfaces is difficult due to soil texture and the expected capillary action. However, it is known that most evaporation of water from soils takes place almost entirely at the immediate soil surface. Therefore, unless the soil is kept moist at its surface, a vapor pressure gradient adequate for rapid evaporation cannot be maintained any length of time. Were it not for capillarity, or the upward pumping action of water movement, the loss of water by vaporization would be of little practical significance.

Lennon, as quoted by Unger and Phillips (20), divided evaporation into three stages. In the first stage, the loss is relatively fast and depends on the evaporative demands of the above-ground environment. The first phase continues as long as the water flow rate to the surface equals the loss rate by evaporation. For any given soil, this stage may last from a few hours to several days, depending on the evaporative potential at the surface.

The second stage is characterized by a rapid decline of water loss and is controlled more by capillarity than by the evaporative potential at the soil surface. During this stage, most of the water loss is in vapor form and results in appreciable surface drying. In the third stage, the rate of water loss is relatively low. Evaporation in this stage must diffuse as vapor through a dry soil layer which increases in thickness as evaporation continues. Evaporation potential at the surface has little influence during this stage.

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The potential for decreasing evaporation lies in a decreasing of turbulent transfer of water vapor to the atmosphere by allowing plant stubble to stand, adding or maintaining mulch, and increasing soil surface roughness. Conservation tillage reduces evaporation primarily by reducing the turbulent transfer of water vapor to the atmosphere and by shielding the surface against the effects of solar radiation. By reducing evaporation rates and lengthening the first stage drying, plants can utilize some of the water in the surface layers. Also, the internal drainage of water can be enhanced, thus permitting storage at greater depths where the water is less susceptible to evaporation.

Although surface mulches reduce initial evaporation as compared with evaporation from bare soil, cumulative evaporation over extended periods may be similar (21), but will have little influence on cumulative evaporation. This is schematically shown in Figure 6. This figure also shows how no-till is slower to allow drying out of the soil, but eventually also dries out. In application, substantial increases in potentially available soil water can be obtained when a mulched soil surface receives small additions of water from rainfall or irrigation at frequent intervals. The same additions of water to a bare soil may cause no increase in soil water. By the same evaluation, if additions of water are not made at frequent intervals, then mulch on the soil surface would have little effect in increasing soil water. Here the advantage would be greatest if the plants were able to utilize some of the soil surface water before evaporation. Figure 7 shows step-wise increases in soil water for mulched and bare-soil conditions.

Figure 6. Schematic diagram showing cumulative evaporation from a bare and mulched soil as influenced by time

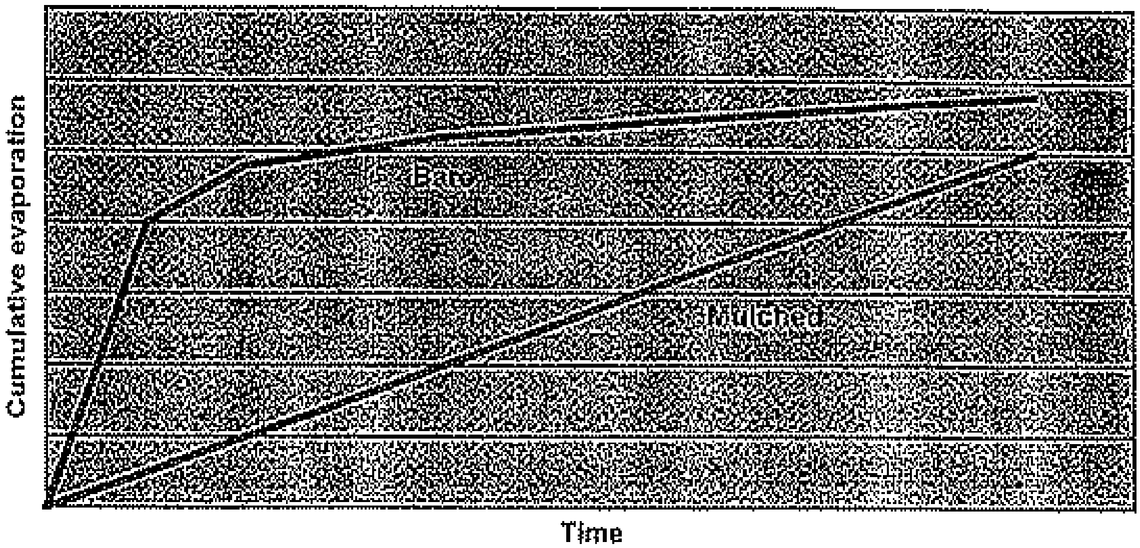
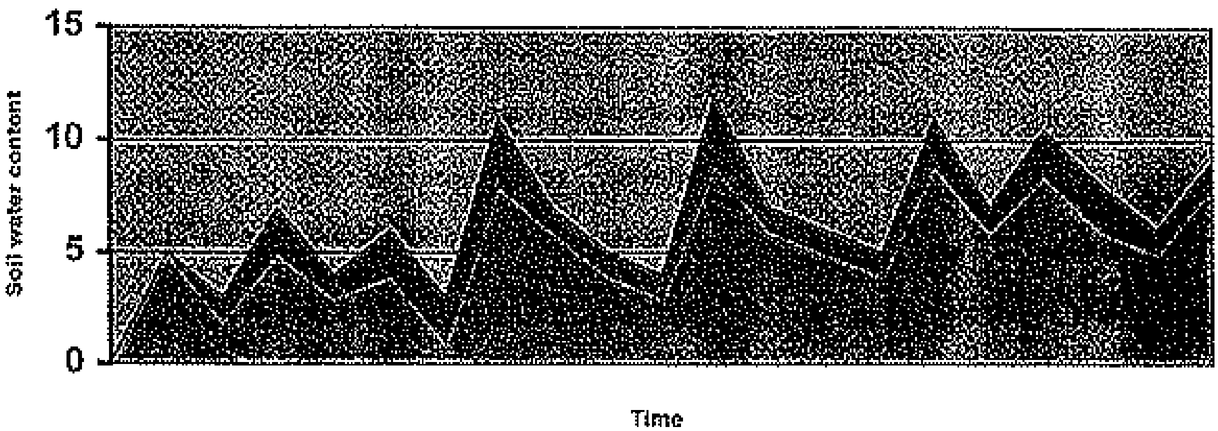


Figure 7. Schematic diagram showing soil water contents of a bare and mulched soil as influenced by time



Transpiration also accounts for a substantial portion of the total moisture available during the growing season. Transpiration amounts vary depending largely upon the moisture available, the kind of plant, density of plant growth, the amount of sunshine, and the soil fertility. Less than 1 percent of the water absorbed by plants is actually retained by plants (22).

As a rule, the less the rainfall, the lower is the humidity, and the greater is the relative transpiration. The more intense the sunshine, the higher the temperature, the lower is the humidity, and the greater is likely to be the wind velocity. All of this would tend to raise the transpiration rate. In general, an increase in the moisture content of a soil above optimum levels results in increased transpiration, provided the water supply is held at optimum levels. However, when raising the productivity of the soil, the potential for greater amounts of plant production for each unit of water utilized is enhanced and the total quantity of water taken from the soil will probably be larger.

In spite of the magnitude of water loss through crop transpiration, it must be more or less satisfied if adequate harvests are to be attained. Therefore, when moisture is critical, competing losses should be curtailed as much as possible. For example, the control of weeds is considered a measure which reduces water losses through transpiration.

A monthly summary of water depletion during 1944-45 at the Coshocton, Ohio Soil Conservation Service experiment station appears in Table 5 (23). Although loam soil, a study of the distribution and losses can further define the expected available water for plant use and the need for water control and management to insure most efficient use of rainfall for crop production. As can be seen in this data, the factors discussed earlier surely influence runoff and infiltration.

TABLE 5

A Monthly Summary of Precipitation and Disposal of Water, (Inches) by Evapo-Transpiration and Percolation

	Precipitation		Evapo-Transpiration		Percolation Drainage		Totals	
	1944	1945	1944	1945	1944	1945	1944	1945
January	2.23	3.06	1.52	1.50	0.	0.26	1.52	1.84
February	2.63	4.41	1.28	1.50	.01	2.22	1.31	3.74
March	7.37	9.83	2.01	2.80	3.45	7.74	5.49	10.73
April	4.62	4.88	2.28	3.48	3.22	1.82	5.51	5.35
May	2.60	5.98	4.53	4.58	.50	1.83	5.03	6.88
June	3.92	4.91	4.52	3.97	.10	.34	4.67	5.40
July	2.92	3.05	4.25	4.73	.02	.13	4.33	4.94
August	4.91	1.42	4.58	4.16	0	.04	4.54	4.25
September	2.50	11.93	3.16	3.40	0	.01	3.20	7.15
October	2.66	3.65	2.26	3.20	0	.25	2.27	3.84
November	2.29	4.84	1.69	2.32	0	.68	1.69	3.05
December	4.99	3.56	1.00	1.00	.02	.93	1.08	2.53
TOTALS:	43.64	61.52	32.88	36.91	7.33	16.25	40.64	59.50

III. EFFECTIVE WATER MANAGEMENT

Water management begins on the land. Conservation and management measures such as the reinforcement of vegetation, strip cropping, terraces, contour rows, and tillage can and will influence water/plant relationships. Conservationist designing water management systems on cropland should incorporate as many practices as is feasible to reduce runoff, increase infiltration, reduce evaporation, and increase soil water storage.

Cropland water management involves the entire soil mass. This is the volume of earth material which is occupied by the roots. It is in this zone that changes in water behavior can be best induced. A brief review of conservation practices which collectively and in various combinations form resource management systems, should enable one to evaluate the primary effects on the availability and use of precipitation and irrigation water. Table 6 summarizes water management benefits expected from use of several current conservation practices.

(Refer to page 24 for Table 6)

TABLE 6

Effects of Conservation Practices on Water Management

Conservation Practices	Reduce Runoff	Increase Infiltration	Reduce Evaporation	Increase Soil Storage
Contour Cultivation	+	+	-	-
Terraces	+	+	-	-
Strip Cropping	+	+	+	+
Tillage	+	+	-	-
Crop Residue Mgt.	+	+	+	+
Crop Rotations	+	+	-	+
Sod-Cover Crops	+	+	+	++
No-Till	+	+	+	+
Conservation Tillage	+	+	+	+
Land Leveling	+	-	-	-
Long Term No-Till	++	++	++	++
Cover Crops	+	+	+	+

+ Benefit

- Little to no benefit

A detailed discussion of there practices follows. It must be remembered that irregular landscapes throughout North Carolina do not lend themselves to maximum effectiveness of contour cultivation, terraces, and stripcropping.

A. CONTOUR CULTIVATION

Contouring effectively conserves water when used with other good management practices. Ridges and trenches resulting from planting and cultivation of crops form a series of small basins that will reduce runoff velocities below those coming from up and down hill cultivation on the same slope. The temporary retention of the water allows the soil to absorb additional water that otherwise would be lost as runoff. Contouring provides the greatest benefits in storms of moderate to low intensity. It offers little benefit in the occasionally severe storm that causes extensive row or ridge breakovers. Because of breakovers and the reduction in effectiveness, contouring appears to be most effective on slopes of less than 12 percent (24).

The overall effectiveness of contour cultivation in the conservation of water is influenced by such factors as soil type, rainfall intensity, rainfall distribution and amount, land slope, and length of slope. Research at several locations supports a reduction in runoff of 15 to 60 percent. For example, at Urbana, Illinois, on a Flanagan silt loam with 2 percent slope and 180 foot slope length, corn cultivated on the contour resulted in a 44 percent reduction in runoff when compared to up and down hill cultivation. Soybeans cultivated on the contour had 0.67 inches average annual runoff compared to up and down hill planted soybeans having 1.95 average annual runoff (25). This study was the result of averaging 13 years of data.

Comparisons of a 2 year rotation with and without contour cultivation made on Ida silt loam at Castana, Iowa, on 14 percent slope and plots 72.6 feet long, gave some useful information on the value of contour tillage. A study of Table 7 shows that contouring reduced runoff losses in the corn crop 31 percent and that the additional 1.1 inch of water resulted in 7.8 bushel yield increase (26).

TABLE 7

Average Annual Runoff and Yields Comparing Row Directions

CROP	PRACTICE	RUNOFF (Inches)	YIELD/PER ACRE
Corn	Up-Down Hill	3.42	65.2 bushels
Oats-Sweet clover	Up-Down Hill	1.92	
AVERAGE		2.67	

CROP	PRACTICE	RUNOFF (Inches)	YIELD/PER ACRE
Corn	Contoured	2.36	73.0 bushels
Oats-Sweet Clover	Contoured	1.99	
AVERAGE		2.18	