Potential for reducing evaporation during summer fallow

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INITIAL attempts by farmers to settle the dryland areas of the United States failed when they tried farming methods used in more humid areas. A stable agriculture developed only after summer fallowing was introduced.

Even with modern tillage methods, no more than 30 percent of all precipitation is stored in most dryland soils during an entire fallow period—from fall, at harvest, through the summer fallow year, to the spring of the crop year. Evaporation accounts for most of the precipitation lost. Methods to suppress evaporation are thus needed.

The principles of controlling evaporation are known for a hypothetical soil system. They can involve the use of vapor barriers, controlling thermal gradients in the soil profile, disrupting capillary flow by creating large pores, or decreasing hydraulic conductivity by reducing surface soil moisture to the point where only very thin films remain. Other control methods might involve reducing the vapor gradient over the evaporating surface by reducing the wind speed or its turbulence, and chemicals can be applied to the soil to reduce capillary attraction of water to soil (and, thus, water's upward movement) by increasing the contact angle of the soil and water interface. However, factors affecting evaporation are so interrelated under field conditions that changing one facet results in a complex and continually changing system. Therefore, applied field experiments have been used to interpret overall results.

History of Summer Fallow Use

Successful homesteading in the Great Plains, then called the Great American Desert, necessarily followed four main events: (1) the completion by 1870 of two railroads crossing the area, one from Omaha to the West Coast, another from Kansas City to Denver; (2) the ability to drill deep domestic water wells, a skill acquired by the developing oil industry; (3) the invention of barbed wire, patented in 1874; and (4) the introduction of drought-tolerant wheat and dryland know-how by Ukranian and other immigrants.

Gleaming railroad company advertisements offering productive farmland and even free passage lured some earlier, but unsuccessful, settlers to the Plains. These unsuspecting takers experienced a bitter lesson about the fickleness of summer rains. Their wheat, adapted to more humid climates, produced poorly.

Longhorn cattle proved to be another tribulation for the settlers. It seems the cattle's meanderings were not restricted by the homesteader's smooth wire or sod fences. Before barbed wire was invented, up to half the space in local newspapers was devoted to fencing methods, reflecting the seriousness of this problem.

Russian, Ukranian, and other immigrants from dryland regions of Europe knew about summer fallowing. Fallowing, in fact, can be traced to the eighth century B.C. in Greece, when Homer wrote about a frolicking event on "thrice-plowed ground."

Although summer fallowing seemed almost unnecessary during years with above normal rainfall, it was hardly adequate during drought periods. For example, after several productive years, Samuel Aughey *(2)* in 1880 was deluded into writing the following about Nebraska's weather: "It is the great increase in absorptive power of the soil, wrought by cultivation that has caused and continues to cause an increasing rainfall in the state." But severe drought in the 1890s caused two-thirds of the farm population in some western Kansas counties to abandon their lands and retreat from this once again desert.

Summer fallowing and other dryland farming methods, although some-

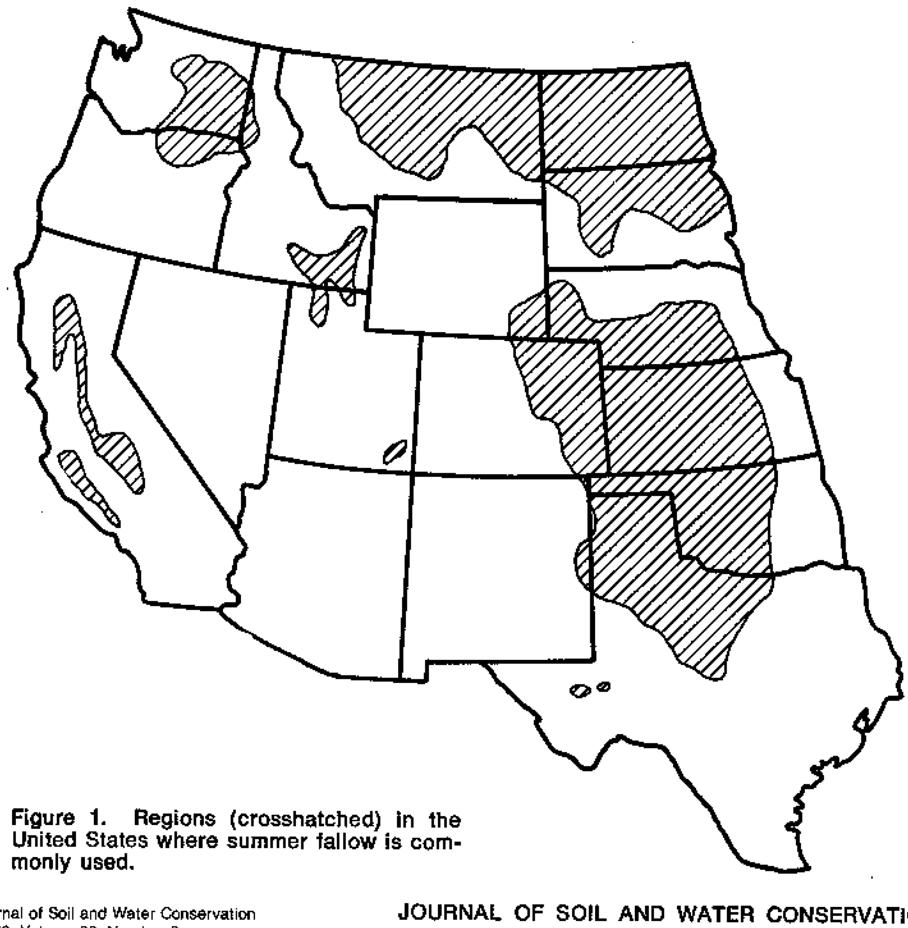

Figure 1. Regions (crosshatched) in the United States where summer fallow is commonly used.

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what unsophisticated then, became mainstays during resettlement of the Plains at the turn of the century. Favorable public sentiment toward these farmers led to the establishment of experiment stations on drylands. Even railroad companies contributed to the stations in the hope that a permanent agriculture would result and their customers would not ebb and flow with the tides of the weather.

Fallow acreage in the United States increased steadily until recently (Figure 1). In 1973 there were 12.5 million hectares (30.9 million acres) of summer fallow (*21*). Between 1930 and 1973, summer fallow acreage increased 2.6 times, even though the acreage of all crops declined from 170 million to 156 million hectares (420 million to 385 million acres).

Although fallow is needed to stabilize agriculture on dryland, it is far from 100 percent efficient in storing water from precipitation. Soils fallowed for a 21-month period (from harvest to spring of crop year) can be expected to lose three-fourths of the precipitation received—about 45 centimeters (18 in.) of surface water (*9*). Wheat yields could be increased 0.66 quintals per hectare for each additional centimeter (2.5 bu/a for each additional inch) of water stored by fallow. If only one-tenth of the water lost (4.5 centimeters) could be stored in addition to that normally saved, production in marginal areas would increase about 25 percent.

Table 1. Moist soil temperatures required to prevent evaporation into the air at various relative humidities and temperatures.

Soil Temperature		*Air Temperatures* 15°C (59°F)	25°C (77°F)	35°C (95°F)
		% relative humidity		
0°C	(32°F)	36	19	11
5°C	(41°F)	51	28	16
10°C	(50°F)	72	39	22
20°C	(68°F)	—[a]	74	42

[a]Not attainable.

Soil Water Losses from Fallow

Soil Water Evaporation

Evaporating water consumes large amounts of heat. Nearly six times more heat is needed to change water from a liquid into a vapor than to heat an equal amount of water from its freezing point to its boiling point. In the absense of thermal energy, water does not evaporate. Consequently, reducing evaporation of water from soil is a problem of keeping the water separated from sources of heat.

Water vapor moves spontaneously from air with high concentrations of water vapor into air with lower concentrations of water vapor. Importantly, the concentration of water vapor in air is not the air's relative humidity. The concentration must be expressed as a vapor pressure or an analogous unit. The relative humidity of air in moist soil is always essentially 100 percent, yet the concentration of water vapor in soil air decreases rapidly as the soil temperature falls. Evaporation will thus cease if the soil temperature is lowered enough to reduce the concentration of water vapor in the soil air to some point below the concentration of water vapor in the air above the soil surface.

Table 1 shows the moist soil temperature that is low enough to prevent soil drying when the air just above the surface has a specific temperature and relative humidity. Again, reducing soil water evaporation is principally a problem of keeping the damp layers of soil cool by protecting them from sources of heat. The system functions somewhat like a refrigerator. When its coils are cold, water from the air condenses on the walls of the freezing compartment; but when the defrost cycle starts, the walls are warmed and the water evaporates back into the air.

Stages of Drying

Soil drying occurs at three somewhat arbitrary stages (Figure 2). During the first stage, the soil surface is visibly wet or at least moist. The rate of evaporation depends directly on the amount of energy received at the soil surface from the sun and warm winds. During stage one, evaporating water often consumes 70 percent of daily solar radiation (*12*).

Stage-two drying develops when the upward flow of soil water is less than the evaporation rate at the soil surface. This causes the surface to lose its damp appearance. The evaporation rate drops rapidly during this stage because the drying soil begins to insulate the underlying moist soil from heat available at the surface. Also, the lighter colored surface reflects more sunlight, and dry soil restricts the upward flow of liquid water, but not vapor.

A very dry surface soil layer and low rates of evaporation characterize stage-three drying. Researchers once thought stage-three drying did not depend on the energy available at the surface. This was a misunderstanding. The difference is that relatively large increments of heat arriving at the soil surface cause only small changes in drying. Evaporation during stage three consumes less than 5 percent of the incoming energy.

Still, leakage of heat down through the dry surface soil ultimately causes evaporation to continue. The more energy available to a dry soil surface, the warmer it will become and the more heat will be conducted to the moist soil. When insufficient heat is available at the surface, drying continues for only a short time. Evaporation eventually cools the moist soil to a temperature low enough to halt further evaporation (Table 1).

Conserving Soil Water

There are three general ways to reduce water evaporation from fallow soil: (1) reduce the solar energy available at the soil surface, (2) reduce wind over the soil surface, that is, turbulent transfer management, and (3) improve the separation of moist soil from energy sources by using mulches or by increasing the size of soil pores near the soil surface.

Solar Energy Reduction

Light-colored soil surfaces reflect more solar energy than darker ones. In a study comparing the reflectance of a brown (10YR 5/2, dry) surface soil with its grey-white (10YR 8/2, dry) subsoil the lighter subsoil reflected about twice as much light energy (*4*). Where the darker surface soil was scraped away in a 5-year field experiment, average fallow water storage in the soil profile increased from 12.2 to 18.5 centimeters (4.8-7.3 in.) at winter wheat planting time.

In another experiment, the results

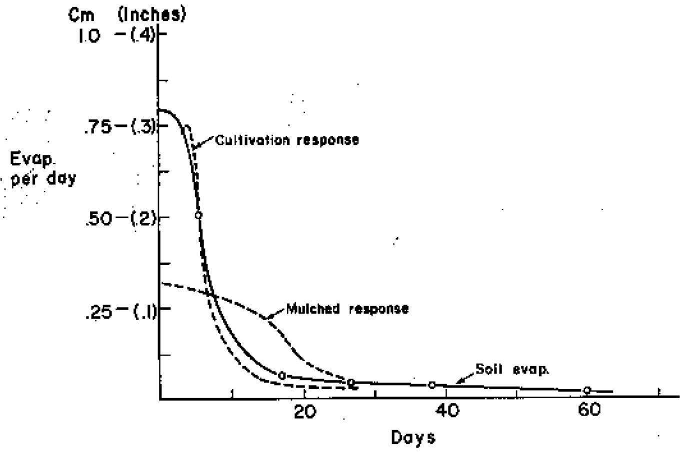

Figure 2. Observed evaporation from a bare silt loam soil and Weather Bureau pan evaporation during July and August when no significant rainfall occurred after irrigation at the start of the period (8). Vertical lines indicate the approximate boundaries of the stree stages of soil drying.

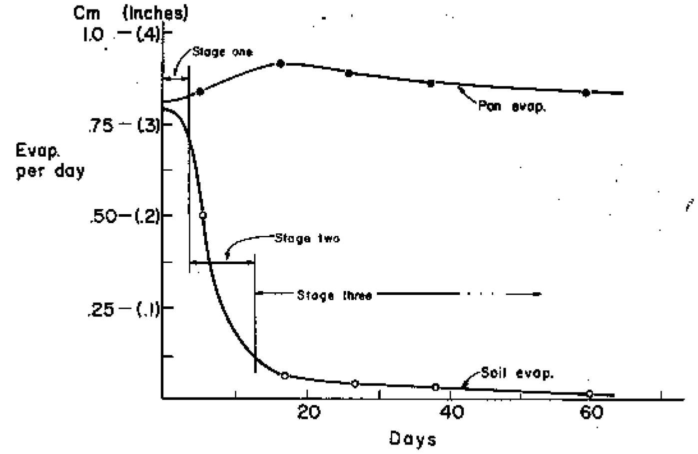

Figure 3. The solid line represents the same experimental measurements of soil evaporation given in figure 2. The two dashed curves illustrate possible responses one might expect (1) from a shallow cultivation at the start of stage-two drying or (2) from using an effective surface mulch.

of which have not been published, a natural brown soil surface (10YR 5/2, dry) color was altered by applying lampblack or whitewash. Net radiation (solar incoming minus reflected) and soil water were measured during summer fallow. Herbicides controlled weeds, so that cultivation did not destroy the surface treatment. The whitewash treatment reduced daytime net radiation 32 percent, and summer fallow water loss dropped 16 percent (Table 2). In comparison, the black treatment increased net radiation and evaporation only slightly (6 and 7 percent, respectively). This indicates that the natural brown soil has an energy adsorption regime similar to those soils that appear much darker.

Net radiation reportedly can be reduced 2 to 3 percent with a smooth, dense, single-grained surface, compared with a loose, granular surface *(8)*. Results such as these indicate some potential for saving moisture by reflecting extra light energy, particularly if one considers the use of artificial mulches *(7)*.

Little opportunity exists for increasing the dissipation of solar energy by increasing the heat emission characteristics of soil surfaces. The emission coefficient of most soils is generally above 0.95, compared with 1.0 for a perfect black body *(12)*.

Turbulent Transfer

Wind has offsetting effects on soil water losses. One action of wind removes moist air. This reduces the vapor concentration above the soil surface, which increases the rate of drying. However, there may be some beneficial advective soil cooling from wind. Advective cooling results from a heat exchange between a warm soil and cooler air. It is not associated with the cooling from evaporation. Advective warming of the soil can occur under some conditions also. On dry fallow surfaces in a windbreak test the soils leeward to the windbreaks were warmer *(15)*. There were no differences in soil moisture, so the cooler, unprotected soils had not lost extra heat through the evaporation process, but through advection.

A Montana study *(1)* used wheatgrass strips as windbreaks on fallow land. After sprinkling the fallow with 3.8 centimeters (1.5 in) of water, the researchers found that wheatgrass strips effectively retained more soil water for about a week. The researchers concluded that even this brief delay could in many cases enhance crop germination and reduce wind erosion.

This same conclusion could also apply to older experiments in Russia *(13)*, England *(19)*, and the United States where a wind reduction initially reduced evaporation. After a time though, the soil water content reached the same level as that where there was no wind reduction. The converse can also be concluded: there are no advantages to hastening the drying by wind because the "self-mulched" soil will not, over the long term, retain water at a higher level than soils that initially lost water more slowly.

Table 2. Effect of surface soil color on net radiation (average of July-August sunny days) and 180-centimeter (6-ft.) soil profile water loss during summer fallow.

Soil Surface Treatment	*Net Radiation (langleys/min)*	*Profile Loss (cm)*	*(in)*
Untreated	0.59	6.4	2.5
Whitewashed	.40	5.3	2.1
Blackened	.63	6.9	2.7

Mulches

Stubble mulch slows evaporation by acting as a heat barrier, by reflecting light, and by reducing wind. Under average-to-dry climatic conditions, mulches showed little or no benefit in older experiments *(16)*. But these experiments necessarily relied on improvised mulching machinery, and weed control was difficult. Plows with moldboards removed were often used to obtain the mulch fallow. In the classic tests at Lincoln, Nebraska, mulching was done initially with a hand shovel.

More recently, good results with mulching were reported following a comparison of 16-year experimental results at three Great Plains locations *(10)*. A treatment using modern mulching techniques and 6.7 metric tons per hectare (3 t/a) more straw than on control (low straw) plots retained 50 percent more fallow-period precipitation by fall seeding time. Any delay in ending stage-one drying caused by the additional straw was, therefore, of overall benefit.

This same aspect was noted in another study *(5)* in which stage-one drying was delayed an extra 57 days with 17.9 metric tons per hectare (8 t/a) of straw (compared with stage one ending in 3 days with no straw). The extra water saved by the straw declined as the drying time was extended even further, but the amount saved always remained above the control (no straw) level.

Gravel and stone mulches have been used in China, probably for over 3,000 years *(20)*. Their effects, depending on drying conditions, resemble those of straw *(11)*.

Dry surface soil itself is an effective barrier and is sometimes termed a "self-mulched" soil. Adding dry soil over moist soil in one study *(11)* proved to be a better mulch than straw or gravel.

Loose, dry soil is a thermal insulator *(18)*. It also inhibits upward flow of water because of its many large pores. When soil water content is below saturation, water will not flow from smaller pores into larger ones. Thus, like straw and gravel mulches, loose, dry soil on top of damp soil prevents water from flowing upward to the warmer soil surface and heat from flowing downward to the water. Use of a "dust mulch" produces an erosion hazard, however.

Generally, it is advantageous to use a mulch instead of bare soil even though stage-one drying time is prolonged. The longer the delay, the longer the time before mulched soils dry to water contents similar to those of unmulched soils *(3)*. Even though an unmulched soil surface dries quickly and the dry surface retards further evaporation, the higher initial water loss is never regained (Figure 3).

A previously wetted but unmulched soil has similar (less than 10 percent difference) evaporation rates, whether it is crusted or left quite fluffy *(8)*. Therefore, except for extreme conditions with deep cracking or dust mulches at least 10 centimeters (4 in.) thick, the visible surface condition of soils without mulch hardly depicts their evaporation rate.

Restricting Upward Water Flow

Shallow tillage near the beginning of stage-two drying destroys the continuity of small capillary pores so that deeper soil water does not rise to the surface *(23)*. Figure 3 shows the curve resulting from this break in continuity. This tillage is most applicable on mulched soils. Mulching brings about an extended period of intermediate moistness at this stage, but less profile water has been lost than on unmulched soils having the same water condition in the upper surface.

Under these conditions, provided physical compaction will not result, there is an opportunity to take advantage of the reduced evaporation during stage one by the stubble mulch and also slow further drying with a light cultivation. This tillage practice differs from schemes that encouraged the surface to dry rapidly. It also differs from schemes based on reducing water loss during stage two at the expense of intensifying stage one.

These latter ideas can be traced to early research *(6)*. They are somewhat analogous to the driver of a car saving gasoline by accelerating enough to shift the transmission into high gear.

Another method of shortening stage-one drying involves the use of long-chain alcohols *(14, 17)*. Theoretically, these alcohols reduce the attraction between soil and water so that water does not rise in capillary pores quickly enough to replace water lost at the soil surface. A reduced stage-two evaporation rate is acquired without the usual expenditure of soil water. Results with these chemicals are inconsistent, however. Sometimes, at low application rates, initial evaporation is slow but prolonged, finally exceeding that of untreated soils.

There may be many chemicals that can reduce capillary action by changing the wetting angle between water and soil *(15)*. Some natural materials in organic matter may do this, as indicated by the hydrophobic characteristics of some soil surfaces after a range or forest fire.

It does little good, of course, to reduce evaporation using any soil treatment that also reduces infiltration and increases runoff. Also, growing plants cannot be tolerated in a fallow field. A plant shading an area of soil surface will remove as much or more soil water than an equal area of wet surface soil undergoing stage-one drying. Plants provide one of the best capillary links between soil water and the energy available to evaporate it by transpiration.

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