ASSESSING SOIL MOISTURE REMOTELY[1]

by

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INTRODUCTION

Space-age technology has produced tools, which, when turned to earthly pursuits, can provide information on food and fiber production. Soil moisture, that ingredient essential to the survival of many forms of life, has the potential for being remotely assessed. The rapid assessment of this parameter from aircraft or satellites could be used by many people for many purposes.

Some crop pests depend on the soil-water status in the upper few centimeters of soil to complete their life cycle (Chauvin, 1967). The desert locust (Schistocerca gregaria, Forsk.), for example, lays its eggs in the upper 5 cm of soil in many uninhabited areas of Africa and Asia (Rainey, 1967). As the soil becomes wet from rain, the eggs hatch. The insect can develop from laying to fledging in as few as 6 weeks. The locust will remain in a nonflying stage about 5 days before becoming airborne and devastating all vegetation in its path. If, however, soil moisture could be monitored routinely, emergence of the insect could be predicted, and poisoned bait could be dropped in the area before the locust entered the winged stage. The possibility of drastically reducing locust plagues exists.

The persistence of pesticides in soils depends partly on soil moisture. Adequate water may either stimulate or retard microbial decomposition of many of these compounds (Messersmith et al., 1971), and certain optimum soil-water contents promote volatilization of pesticides (Spencer and Cliath, 1973). Knowledge of the status of soil water could be used to assess the persistence and effectiveness of pesticides at various times after application or to determine their optimum application time to minimize losses.

A successful reseeding program on watersheds or rangelands is dependent on soil moisture and soil temperature (Slatyer, 1969). Proper combinations of these parameters are necessary for adequate germination, and knowledge of their magnitude could aid in scheduling reseeding programs.

Models used to predict crop yields require a knowledge of soil moisture before and during the growing season, although current methods actually use precipitation data to obtain soil moisture. Techniques that would provide actual soil-water content data routinely over large areas would be much more valuable than techniques used to merely estimate the soil-water status (Bauer, 1972). Similarly, the effectiveness of various cultural practices used to conserve moisture could be evaluated. This would be particularly significant in the Great Plains, where the wheat yields are dependent on soil moisture.

One parameter used by hydrologists to predict runoff from watersheds is antecedent moisture, or the amount of water in the soil at the time of a rain. Routine remote sensing should provide more accurate knowledge of this parameter than will estimates based on a water budget analysis.

These are but a few examples of the many areas where a knowledge of the status of soil water is important. It appears reasonable that a routine, direct measure of this parameter would be superior to any technique used to estimate it. This is, of course, if the information is rather easily obtained, is not too costly, and is quantitative rather than qualitative.

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MEASUREMENT TECHNIQUES

A plethora of photographs (imagery) have been taken remotely in various regions of the spectrum to assess specific features on the earth's surface. Analysis of this information has been mostly qualitative, and understandably so: Groundtruth is difficult and costly to acquire. However, the time has come to quantify this information into a form usable by people with diverse backgrounds and interests.

Generally, three regions of the spectrum have been used to assess soil moisture: the visible, the infrared, and the microwave. Sensors to measure radiation in these regions have been used at ground level, from aircraft, and from satellites.

REFLECTANCE

In the visible region, 0.3 to 3 μm, albedo (the ratio of reflected to incoming solar radiation) varies significantly for many soils over the soil-water content range from air dry to field capacity (Idso and Reginato, 1974). When normalized to remove sun zenith angle effects, the curves for all depth intervals converge at the maximum albedo value at a very low water content approaching zero for Avondale loam (Figure 1). The curves also converge at a low value of albedo at volumetric water contents greater than 0.2. An extrapolation procedure (Idso et al., 1975a) indicates that albedo is a linear function of water content at the soil surface. In the top 2 cm of soil, the albedo-water content relationship is dependent on soil type but independent of season. Additionally, albedo has been used to differentiate between the potential rate (energy limiting phase) of evaporation following an application of water and the succeeding falling rate (energy non-limiting phase) of evaporation. Although a multitude of parameters apparently may be evaluated from albedo, the technique has drawbacks.

Albedo is sensitive to surface soil conditions. Correlations between this parameter and water content with soil depth are tenuous due to factors such as soil type, surface roughness, and amount of water applied to the soil. Albedo remotely sensed from aircraft or satellites also requires a knowledge of the incoming solar radiation at ground level and the attenuation of the reflected radiation through the atmosphere. With current technology albedo may best be obtained from ground-based sensors.

THERMAL

The second portion of the spectrum that has the potential for assessing soil moisture is the infrared region, 8 to 14 μm (Blanchard et al., 1974). Thermal images or actual surface temperatures can be obtained from infrared radiometers. Temperature is a parameter that could be easily understood and used by people with diverse interests.

Research has shown that surface soil temperature may provide a practical means of estimating the water content in the upper few centimeters of the soil (Idso et al., 1975b). Both the amplitude of the diurnal surface soil temperature wave and the maximum value of the surface soil-air temperature differential can be used to estimate soil-water content in the top few centimeters. Each soil has its own specific temperature-water content relationship. In Figure 2 the amplitude of the diurnal surface soil temperature waves for clear day-night periods that prevailed during the experiment is shown as a function of the mean volumetric soil-water content. These data indicate that every soil would have to be calibrated if this temperature parameter was to be used to remotely assess soil moisture -- an impractical approach to any large scale project. A second study, however, has shown that there is a unique relationship between the temperature parameter and soil-water pressure potential, independent of soil type (Figure 3). The relations for the four different soils are considerably more similar than those shown in Figure 2. In this context, an "average" line has been added to Figure 3 to graphically represent a general thermal parameter-soil water pressure potential relation for the four soils tested. Pressure potential, commonly referred to as tension or suction, is often used to describe the availability of water to plants. In some cases this parameter may be potentially more useful than the actual quantity of water in the soil (Meats, 1974). Therefore, soil temperatures derived from infrared measurements may allow large scale assessment of the status of soil moisture which, in turn, can be used to predict when conditions are optimum for biological activity in the upper few centimeters of bare soil. It should be emphasized that there will be situations where both water content and pressure potential are desired, so that the quantity of available water can be determined.

Surface soil temperature can be measured with an infrared radiometer from aircraft or satellites if there are no obstructions (vegetation, clouds, etc.) in the line-of-sight. The temperature parameter-water content relationship is a soil-type dependent, but the temperature-pressure potential relationship appears to be independent of soil type. The major drawback for the accurate measurement of soil temperature by infrared radiometry is that the emittance of the soil must be known. Studies are in progress to define the magnitude of the effects of soil type and water content on soil emittance. Actual values of emittance are relatively unimportant if the amplitude of the diurnal surface soil temperature wave is used to assess soil-water pressure potential rather than the surface soil-air temperature differential. This latter statement implies that ground-truth may not be necessary, and global surveillance of the status of surface soil moisture is in the realm of possibility. However, the fact that the condition of only the soil surface is being sensed should caution the user in inferring too much about the water status of deeper depths.

MICROWAVE

The third portion of the electromagnetic spectrum that has been considered for sensing soil moisture is the microwave region. Here the intensity of observed radiation is essentially proportional to the product of the temperature and emissivity of the soil-water system, this product generally being referred to as brightness temperature (Schmugge et al., 1974). Data from aircraft flying over bare land have demonstrated that brightness temperature is a linear function of soil-water content from air-dry to near-saturation at a wavelength of 21 cm (Figure 4) with no apparent difference between soil types. At wavelengths of about 1 cm surface roughness has a pronounced effect on a brightness temperature, whereas at longer wavelengths the effect appears to be minimal.

Microwave radiometry can assess soil moisture to greater soil depths than can either the reflectance or the thermal methods, and possibly even through a plant canopy. The microwave region ranges from a wavelength of about 0.1 to 80 cm, so it appears possible to sense soil moisture within the upper portion of active root zone of most agricultural crops. As with the other methods, this one also has its limitations. The longer the wavelength, the bigger and bulkier is the hardware, which can cause problems when one proposes satellite-based sensors. Experiments have shown that surface roughness and soil salinity influence the results from microwave radiometers. Also, the water content in the uppermost portion of the soil profile (0.2 wavelength) seems to influence the response of this radiometer more than does the average soil-water content to the depth of the wavelength. For example, from a 50-cm wavelength microwave radiometer, with present technology, the water content in essentially the top 10-cm layer of soil would be sensed.

SUMMARY

Three techniques capable of remotely assessing soil moisture are under study. Two of the methods, reflectance and thermal, are sensitive to the conditions of the bare soil surface, and empirically derived relations between those parameters and water content to any soil depth more than a couple of centimeters are quite tenuous. The third technique, microwave emission, appears to have good potential for assessing soil moisture with depth, because of its greater wavelength. Several technological problems must be investigated and solved before this method can be classified as useful.

Many of the limitations of all three methods should be overcome through improved technology and additional experimentation. Being able to assess soil moisture rapidly over large areas and having the information easily accessible to a variety of users would greatly benefit mankind. From this knowledge it should be possible to predict crop yields with greater accuracy than is currently being done; to predict the potentiality of crop pest infestations, such as locusts; to evaluate various cultural practices for conserving moisture under dryland farming conditions; to assess the persistence of pesticides in the soil; and to assess myriad other soil-moisture-dependent phenomena.

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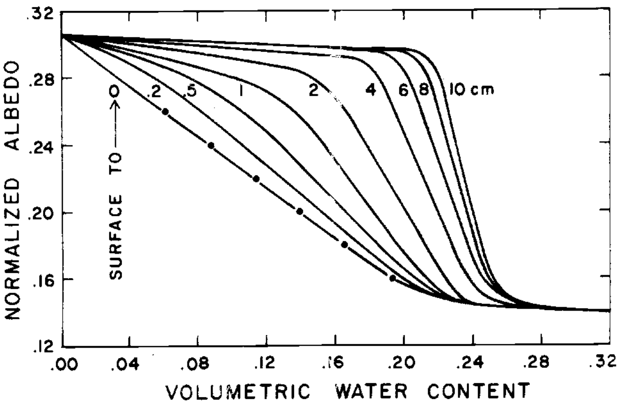

Fig. 1. Normalized albedo vs. average volumetric water content of Avondale loam for nine different soil layers having the surface as their upper boundary.

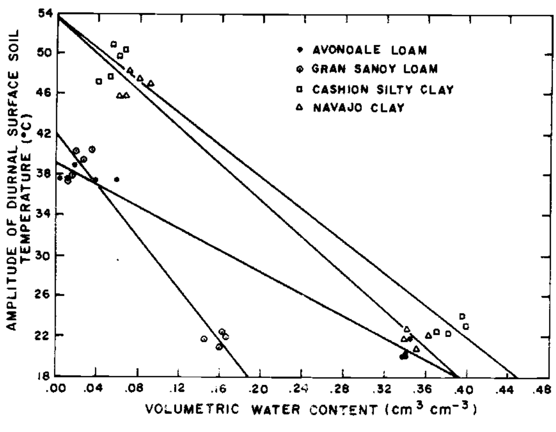

Fig. 2. The amplitude of the diurnal surface soil temperature wave vs. the mean daylight volumetric soil-water content of the 0- to 2-cm depth increment for four different soils.

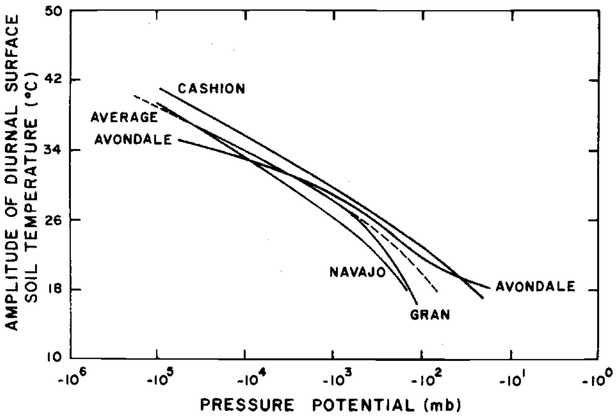

Fig. 3. The amplitude of the diurnal surface soil temperature wave vs. the mean daylight soil-water pressure potential of the 0- to 2-cm depth increment for four different soils.

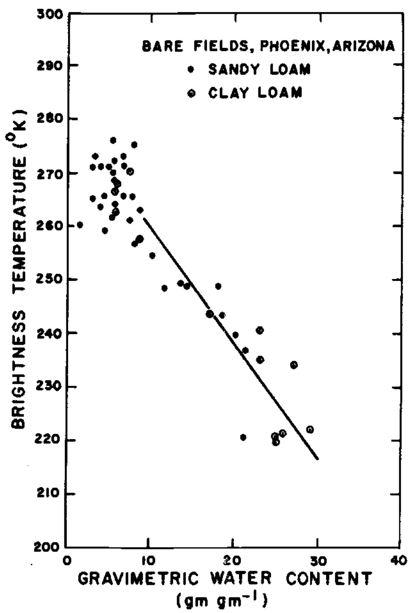

Fig. 4. Brightness temperature versus gravimetric soil-water content for bare fields. Soil textures range from sandy loam to clay loam (Schmugge et al., 1974).