Surface Temperature on a Soil Consisting of Two Layers

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APPLICATION of a layer of sand, clay, or organic material is practiced as a means to influence soil temperature. Such a layer on top of a soil is called "mulch." The temperature at the surface of a mulch may be either higher or lower than at the surface of the uncovered soil. Which case actually applies depends on the thermal properties of the mulch and of the underlying soil.

In some parts of Europe nightfrost danger is reduced by a protective sand or clay layer on top of a peat soil. The nocturnal minimum temperature is increased by this procedure. An example of a mulch which lowers minimum nocturnal temperature is a cultivated layer on top of the uncultivated subsoil. A straw mulch is often applied in warm climates to prevent the occurrence of excessive soil temperatures during the day.

Though many temperature data on mulched soils have been published, few articles deal with the physical background of temperature in a mulched soil.

The efficacy of a sand layer on a peat soil was calculated by de Vries and de Wit (1954) who as a first approximation assumed that the total amount of heat which penetrates into the soil remains unchanged by the mulch. This is, however, not the case. The heat flux densities in the mulched and unmulched soil will be different. They follow from the heat balance at the soil surface as is shown below.

Van Duin (1956) used the heat balance in calculating the temperature of a cultivated soil in respect to the original soil. This was a first approach in which several unknown factors had to be assumed.

Sinusoidal Variation

The influence of the different surface temperatures on a soil before and after mulching will now be investigated. Sinusoidal variation of the radiant energy flux densities is assumed. The full period is 24 hours. The layered and homogeneous soils, short wave radiation (sun, clouds, sky) and for similar meteorological conditions so that the turbulent thermal conductivity of the air is also equal over both soils. Equal evaporation must also be assumed to obtain a reasonable basis of comparison as surface temperature is strongly influenced by evaporation.

The heat balance at the surface of the homogeneous soil is then written as

\[(1 - r_h) R_s + R_i - R_i = B_h + L_h + E_h \]  \[1\]

Here \( r_h \) is the reflection coefficient for short wave radiation of the homogeneous soil. Zero reflection coefficient for long wave radiation is assumed.

With the above assumptions each of the quantities in eq. \[1\] is a sinusoidal function of the time, for example:

\[ B = S \sin (\omega t + \phi_b) \]

\[ L = A \sin (\omega t + \phi_L) \]

and the net radiant flux density for long wave is assumed to be equal at both soils. With these assumptions the left hand sides of the two equations for the homogeneous and for the layered soil become equal. Further the factor \( \sin (\omega t + \phi) \) can be equating the right hand sides and assuming the same solution for both soils. This results in

\[ S_h + A_h = S + A \]

as the comparison is made at equal evaporation.

This equation takes the place of the previous (de Vries and de Wit, 1954) of equal soil heat flux density in both cases. The ratio of the surface temperatures found for equal \( S \) has to be multiplied by \( \sin (\omega t + \phi) \).

Equal Heat Flux Density to Soil

The theory of heat conduction in a homogeneous and in a medium consisting of two layers gives an expression for the ratio of the temperature at the surface in case of equal \( S \) for homogeneous and layered soils,

\[ \frac{\theta_h}{\theta_l} = \left( \frac{\lambda_h C_h (\exp (4 d/D_1) + 2 f \exp (2 d/D_1) (2 d/D_1) + \cdots)}{\lambda_l C_l (\exp (4 d/D_1) - 2 f \exp (2 d/D_1) \cos (2 d/D_1) + \cdots)} \right)^{1/2} \]

in which \( d \) is the depth in that layer, \( \lambda_h \) and \( \lambda_l \), the thermal conductivities of the homogeneous and of the upper layer of the layered soil, respectively, and \( C_h \) and \( C_l \) the corresponding heat capacities. \( \theta_l \) is the temperature amplitude at the soil interface of the layered soil, \( \theta_h \) at the homogeneous soil. The symbol \( f \) denotes

\[ f = \frac{\sqrt{\lambda_l C_l} - \sqrt{\lambda_h C_h}}{\sqrt{\lambda_l C_l} + \sqrt{\lambda_h C_h}} \]

Inserting the thermal constants of the soils (sand on peat) one obtains for the diurnal variation \((\omega = 7.27 \times 10^{-5} \sec^{-1})\) the results presented.

Equal Heat Flux Density to Soil

The distribution of heat between soil and air on the thermal properties of both soil and a medium consisting of turbulent heat transfer in air is at

<table>
<thead>
<tr>
<th>Table 1—Thermal properties of sand and peat</th>
<th>(de Vries and De Wit, 1954)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x_m )</td>
<td>( x_w )</td>
</tr>
<tr>
<td>Sand</td>
<td>0.573</td>
</tr>
<tr>
<td>Peat</td>
<td>0.100</td>
</tr>
</tbody>
</table>

\( x_m \) = volume fraction of soil. \( x_w \) = volume fraction of water.