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COLLOQUIUM

SMR/147- 29

COLLEGE ON SOIL PHYSICS
15 April - 3 May 1985

COLLOQUIUM ON ENERGY FLUX AT THE SOIL ATMOSPHERE INTERFACE
6 - 10 May 1985

PHYSICS OF MULCHING WITH PARTICULAR EMPHASIS ON GRASS MULCHES

C.J. STIGTER
Department of Physics & Meteorology
Agricultural University
Duivendaal 1
Wageningen 6701 AP
The Netherlands

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C.J.STIGTER

Paper presented at the International Colloquium on Energy Flux at the Soil / Atmosphere Interface, International Center for Theoretical Physics, Trieste (Italy), May 5 - 10, 1985.

Physics of mulching, with particular emphasis on grass mulches.

C.J.Stigter
Dutch Government (DGIS) sabbatical fellow, Agricultural University, Wageningen, The Netherlands *)

INTRODUCTION

The aim of soil management practices is to create an environment which promotes germination and emergence and causes no limitation to further crop growth (Goss et al.,1984).Under many conditions soil conservation and protection are the first management practices to be applied. As indicated in our earlier paper in this Colloquium (Stigter, 1985), the application of dead or living vegetation as a soil cover is the most common and often most economical and effective protection method. This is in effect an example of mulching, which is a traditional method in crop space management in third world low-input agriculture. By mulching among other things also micrometeorological conditions are modified traditionally (Allan, 1965; Wilken, 1972; Stigter, 1984).

Mulch is best defined, in line with traditional concepts, as a shallow layer established naturally or artificially at the soil/air interface, with properties differing from the original unmodified soil surface layer. Changes created within this original top soil layer are also covered by this wide definition (Stigter, 1984 b). Reviews exist which show the multi-purpose use and multi-effect functioning of mulches (Davies, 1975 a;1975 b; Stigter, 1984). From the point of view of microclimate management most is known quantitatively on soil temperature modification, although the interpretation of its effect on crop growth remains a cumbersome exercise (Van Bavel, 1972; Monteith, 1979). It is recognized that mulching techniques have potential for substantial environment modification with low energy input (Walker and Barfield, 1979). Mechanisms and principles of soil temperature control are reasonably well known and understood as energy balance management (Voorhees et al., 1981). However, operational methods which easily quantify effectiveness of mulches in the field are not generally available (Othieno et al., 1985).It appears that it is possible to derive such an operational method by studying soil temperature fluctuation modification (Stigter et al.,1984; 1984 b). An understanding of the method is increased

*) From 1975-1984 Professor of Physics, Section Agricultural Physics, Physics Department, University of Dar es Salaam.

by studying other physical effects of the mulches than temperature modification within the soil (Stigter et al.,1984 c).

THEORY

Our work on the physics of mulching started from two ends. In early (1976-1980) M.Sc.-work in Dar es Salaam on soil surface and air temperature modification by albedo manipulation (reviewed in Stigter et al., 1984; 1984 d) we developed a theory expressing temperature fluctuations in soil and air as a function of absorption coefficients of non-transmitting surfaces. At the same time but fully independently, diurnal variation of soil temperature was observed for several years under a variety of mulches under young tea in Kenya. These mulches were basically applied for soil and water conservation purposes (Othieno and Ahn,1980; Othieno, 1982), but some of them negatively influenced root development by reducing soil temperatures too much.When confronted with each others work in 1981 it was successfully attempted to use the earlier theory not only on bare surfaces with different albedo but also for mulched soils (Stigter et al.,1984; 1984 b; Othieno et al.,1985).In such cases the actual soil absorption coefficient $(1-\rho)$, with ρ, reflection coefficient, becomes an apparent one $(1-\rho_{app})$, which remains a function of the modification of absorbed radiation $(1-\rho)\,H_{sh}$ but now also includes contributions from the modification of other energy balance terms H_{nl}, H_a, H_e, and H_s when

$$(1-\rho)\,H_{sh} = H_{nl} \pm H_a \pm H_e \pm H_s \qquad \text{Eq.1}$$

The meaning of ρ_{app} in our case is that it indicates how much solar radiation energy should have been reflected from the bare soil surface to give the same change in soil temperature fluctuation as the actual modification of all energy balance terms. We explained in our earlier paper (Stigter, 1985) why this approach is allowed with grasses. Finally this simplified approach was made into an operational method.

The theory was mathematically developed along the lines of the heat continuity equation for a homogeneous medium and Eqs. 2 - 7 (see p.8). Eq. 2 is a well known solution for a homogeneous soil with damping depth $D = \sqrt{2a_s/\omega}$, where a_s is the thermal diffusivity of the soil and ω the frequency of (in our case) the diurnal variations studied. Applied to two identical soils differing only in (apparent) absorption coefficient, Eq.3 is obtained. Introducing the diurnal variations in the terms of the energy balance(Eqs. 4) and solving with the varying terms for the ratio of two different (apparent) absorption coefficients we obtain Eq. 5. For relatively low but identical evaporation (such as with most covers) or on dry soils it is possible to express the amplitudes of all energy balance terms as a function of the soil surface temperature amplitude, which ultimately leads to Eq. 6. Combination with Eq. 3 then brings forward the final Eq. 7 for Stigter's ratio R. Details can be obtained from Stigter et al. (1984). The theory is optimally valid for albedo changes and more complicated modifications at the surface as long as a symmetrical diurnal temperature pattern is established. However, also for less ideal conditions the theory can be useful, because it can be proved that an identical approach applies to temperature rises after sudden changes in solar radiation exposure (van Wijk, 1966; Stigter et al., 1984 d). In general, physical properties of the mulch, whether plastic, any other anorganic mulch, grass or other living or dead organic mulches, should be known for a proper interpretation of the results.

PRACTICE

The method we derived was tested in a demonstration experiment in Tanzania on soil surface temperatures (Stigter et al., 1984; 1984 d), soil temperatures under mulched tea in Kenya (Stigter et al., 1984 b; Othieno et al., 1985) and black plastic and two gifts of a traditionally applied East African grass in Tanzania (Stigter et al., 1984 c). An important condition in all cases is the homogeneity of the soil in time and space under the applied mulches. This could be checked by the operational method of comparing D-values obtained from diminishing amplitude with depth and from changing phase with depth. Eq. 2 implies that

$$^{A}\theta_{z} = {}^{A}\theta_{o}\, e^{-z/D} \qquad \text{Eq. 8}$$

Applying the ln of Eq. 8 to two depths, taking the amplitude $^{A}\theta_{z}$ as half of the difference between maximum and minimum temperature, gives

$$D = (z_2 - z_1) / (\ln {}^{A}\theta_{z1} / {}^{A}\theta_{z2}) \qquad \text{Eq. 9}$$

Eq. 2 implies also that taking the moment t_{av} at which average temperature is passed by the temperature wave as a reference, a choice based in our case on graph reconstruction from sampled observations, we have

$$\omega t_{av} + \varphi_o - z/D = 0 \qquad \text{Eq. 10}$$

Applying this at two depths gives

$$D = (z_2 - z_1) / \omega (t_{av2} - t_{av1}) \qquad \text{Eq. 11}$$

When D-values obtained along these two lines do not differ too much and the small difference is systematical, soils may be supposed to be homogeneous (e.g. van Wijk, 1966). Tables I(a) and I(b) show the homogeneity of the Kenyan soil in time and space. Two important operational conclusions can be drawn from these results:

1. It follows from Eqs. 9 and 11 that only the depth difference of thermometers occurs in D-calculations. This means that if erosion takes place without changing this distance nor the horizontality (or slope) of the original surface, D is not influenced and its determination remains also valid after addition of fresh identical soil to compensate for the losses. A discontinuity was only observed in November 1975 and attributed to soil compression by hail stones (Tab. I a, Stigter et al., 1984; Stigter, 1985).

2. From Febr. 1975 - April 1976 incl. the tea shade above black plastic, stone chippings and the clean weeding treatment increased from about larger than 25% to about 60% but D did not change (Tab. I a). This means that the tea up till this cover, where differences between mulches become negligible, has only a shading character and not an additional mulch property because of its relative openess. It subsequently follows from this conclusion that shade and mulch character can be fully separated in this case and a shade correction for tea is allowed if the influence of the mulches should be studied separately. The functioning of the tea as a shade in daytime and the conservativeness of D also show once more that at night the amplitude diminishment is comparable to the daytime one (comp. Stigter, 1985).

The above allowed application of our method to a comparison of four different mulches (three dry, one living) under young tea. These mulches influence average temperature (Tab. II). However, the influence on R, the ratio of temperature fluctuations of shaded bare soil (clean treatment) and the mulch concerned, is much more indicative because of the much higher sensitivity of R. The differences in effects because of differences in decay rate and in amounts and time (wet or dry season) of application, as visually observed and suggested by water conservation observations (Othieno, 1980), could now be accurately quantified (Tab. III). NG = Napier Grass (*Pennisetum purpureum*); GG = Guatemala Grass (*Tripsacum laxum*); EC = *Eragrostis curvula*; Grass = growing Kikuyu grass (*Pennisetum clades-*

tinum). In the year concerned measurements were only obtained at one depth, so we had developed in this way a very operational method of quantifying grass mulch effects (that is efficiency or effectiveness of their application) on soil temperature. Details can be obtained from Othieno et al.(1985).

To test the method further, R-values independently obtained from two different depths were compared under a traditionally applied dry grass in Tanzania. For the lowest gift of 2.5 tons/ha the R-values from 5 and 10 cm were 1.7 ± 0.15 and 1.6 ± 0.10 respectively, with a ρ_{app} of 0.51. For the highest gift of 10 tons/ha the R-values were 8.1 ± 2.1 and 7.8 ± 1.3 respectively, with a ρ_{app} of 0.90 (Stigter et al., 1984 c). This range shows once more the high sensitivity of R for grass mulch thickness. Two more interesting sets of observations were made on this grass. Grass surface temperatures taken with thoroughly field tested infra-red thermometers were compared with temperatures at 5 cm depth within the original soil for the two different gifts (Fig. 1). Separately an experiment was set up to measure solar radiation transmission through layers of the same grass (Fig.2). This physical approach, on which details can be found in Stigter et al.(1984 c), gives more insight in how the grass mulch system works. Complete modelling of the system in a way comparable to what is possible for a crop canopy (e.g. Stigter et al., 1977) will give comparable difficulties. Quantification of air movement and its consequences in the top layer of the grass mulch will be one of the largest complications in this respect. Our work shows that a modelling approach is not necessary for the derivation of a quantitative operational method. Our work shows also that along the indicated lines quantitative operational information and advise can be given to farmers. We have called such advise concerning influence of agronomic practices on environmental parameters part of weather advisories (Stigter and Weiss, 1985).

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$$\theta(z,t) = \bar{\theta}_{sz} + {}^{A}\theta_0 \exp(-z/D)\sin(\omega t + \Phi_0 - z/D)$$

Eq. 2

$$\frac{\theta_1(z,t) - \bar{\theta}_{s1z}}{\theta_2(z,t) - \bar{\theta}_{s2z}} = \frac{\theta_1(z',t) - \bar{\theta}_{a1z'}}{\theta_2(z',t) - \bar{\theta}_{a2z'}} = \frac{{}^{A}\theta_{01}}{{}^{A}\theta_{02}}$$

Eq. 3

$$H_{nl} = \bar{H}_{nl} + {}^{A}H_{nl}\sin\omega t$$

$$H_{sh} = \bar{H}_{sh} + {}^{A}H_{sh}\sin(\omega t + \Phi_{sh})$$

$$H_a = \bar{H}_a + {}^{A}H_a\sin(\omega t + \Phi_a)$$

$$H_c = \bar{H}_c + {}^{A}H_c\sin(\omega t + \Phi_a)$$

$$H_s = \bar{H}_s + {}^{A}H_s\sin(\omega t + \pi/4)$$

Eqs. 4

$$\frac{1-\varrho_1}{1-\varrho_2} = \frac{{}^{A}H_{nl1}\sin\omega t + ({}^{A}H_{a1} + {}^{A}H_{c1})\sin(\omega t + \Phi_a) + {}^{A}H_{s1}\sin(\omega t + \pi/4)}{{}^{A}H_{nl2}\sin\omega t + ({}^{A}H_{a2} + {}^{A}H_{c2})\sin(\omega t + \Phi_a) + {}^{A}H_{s2}\sin(\omega t + \pi/4)}$$

Eq. 5

$$R = \frac{1-\varrho_1}{1-\varrho_2} =$$

$$\frac{{}^{A}\theta_{01}}{{}^{A}\theta_{02}} \times \frac{4\varepsilon\sigma\bar{\theta}^3_{s10}\sin\omega t - b/2\ln(\gamma r_0/2)\sin(\omega t + \Phi_a) + (\lambda_{s1}C_{s1}\omega/2)^{1/2}\sin(\omega t + \pi/4)}{4\varepsilon\sigma\bar{\theta}^3_{s20}\sin\omega t - b/2\ln(\gamma r_0/2)\sin(\omega t + \Phi_a) + (\lambda_{s2}C_{s2}\omega/2)^{1/2}\sin(\omega t + \pi/4)} =$$

$$= K\frac{{}^{A}\theta_{01}}{{}^{A}\theta_{02}} \simeq \frac{{}^{A}\theta_{01}}{{}^{A}\theta_{02}}$$

Eq. 6

$$R = \frac{1-\varrho_1}{1-\varrho_2} = \frac{\theta_1(z,t) - \bar{\theta}_{s1z}}{\theta_2(z,t) - \bar{\theta}_{s2z}} = \frac{\theta_1(z',t) - \bar{\theta}_{a1z'}}{\theta_2(z',t) - \bar{\theta}_{a2z'}}$$

Eq. 7

TABLE I(a)

D-values (cm) obtained from diminishing amplitudes (I) and phase changes (II) with depth, comparing BS, BP, CT and SC. To CT must be added July 1976: 8.0 (I); 6.1 (II)

	Bare Soil		Black Plastic		Control Treatment		Stone Chippings	
	I	II	I	II	I	II	I	II
1975								
Feb	7.2	8.2	6.2	6.4	5.0	6.5	6.4	6.8
Mar	6.7	8.2	7.0	8.2	4.9	6.2	5.8	6.8
Apr	6.8	7.5	9.3	11.4	5.0	6.5	—	—
May	6.3	7.7	8.2	11.4	5.6	6.4	—	—
June	6.2	7.2	—	—	—	—	—	—
July	6.8	6.7	8.0	9.5	5.9	6.1	—	—
Aug	7.2	7.2	9.0	11.0	—	—	—	—
Sep	6.8	6.5	—	—	—	—	—	—
Oct	6.8	7.5	9.2	9.1	—	—	—	—
Nov	8.9	12.0	9.6	9.5	6.8	7.3	—	—
Dec	8.9	8.4	8.6	11.9	5.6	5.7	—	—
1976								
Jan	8.0	10.6	8.7	9.9	5.3	7.3	-	—
Feb	8.2	9.9	9.4	10.2	5.6	6.5	7.2	7.3
Mar	7.7	8.9	9.3	10.6	6.2	6.7	—	—
Apr	8.4	11.4	9.7	10.6	—	—	—	—

TABLE I(b)

***D*-values (cm) obtained from same methods as in Table Ia. BS only**

	Bare Soil			Bare Soil	
	I	II		I	II
1976			**1977**		
May	9.1	8.8	June	11.4	12.4
June	10.8	8.4	July	7.9	7.0
July	8.3	8.4	Aug	8.6	9.5
Aug	7.4	9.9	Sept	10.0	9.2
Sept	—	—	Oct	9.2	9.9
Oct	—	—	Nov	9.1	9.5
Nov	—	—	Dec	-	—
Dec	8.4	9.5			
1977			**1978**		
Jan	—	—	Jan	8.6	9.5
Feb	9.0	10.2	Feb	8.6	9.5
Mar	—	—	Mar	8.7	10.2
Apr	-	—	Apr	10.0	9.9
May	9.0	8.9	May	9.3	9.9
			June	9.2	11.0

TABLE II: Average tea cover (c in %) and soil temperature at 7.5 cm ($\bar{\theta}_{7.5}$ in °C) for three artificial grass mulches used. For comparison control treatment and growing grass have been added.

Mulch	NG		GG		EC		CT	Grass
	c	$\bar{\theta}_{7.5}$	c	$\bar{\theta}_{7.5}$	c	$\bar{\theta}_{7.5}$	c	$\bar{\theta}_{7.5}$	$\bar{\theta}_{7.5}$
February	-	17.3	-	17.2	-	18.2	-	22.2	-
March	1	17.1	2	17.1	1	17.4	2	17.9	-
April	2	17.7	1	17.4	2	18.0	2	19.3	-
May	3	16.8	3	16.8	4	17.3	5	17.9	17.8
June	3	17.1	2	16.7	4	18.1	5	19.6	18.9
July	5	16.0	6	16.0	5	17.0	8	16.6	16.6
August	6	16.6	5	16.4	10	17.4	11	18.4	16.5
September	6	16.1	6	15.9	10	16.4	12	16.7	15.1
October	11	16.2	8	16.6	12	16.7	13	17.3	15.6
November	12	16.3	13	17.0	15	16.8	21	17.9	15.8
December	13	14.9	15	16.1	18	16.6	23	19.9	15.5
Mean		16.6		16.6		17.3		18.5	(16.5)

TABLE III: R values and their S.D. determined relative to CT. Where (Larger) has been indicated, marginal hours point towards larger values.

1974	R(CT/NG)	R(CT/GG)	R(CT/EC)	R(CT/Grass)
February	2.2 ± 0.7	2.4 ± 0.7	2.0 ± 0.25	
March	-	-	-	
April	2.0 ± 0.5	1.8 ± 0.25	1.5 ± 0.7	
May	1.7 ± 0.4	1.5 ± 0.4	1.25 ± 0.1	1.0 ± 0.5
June	-	-	-	1.1 ± 0.45
July	(Larger)	(Larger)	1.4 ± 0.35	1.4 ± 0.25
August	(Larger)	(Larger)	1.3 ± 0.45	1.9 ± 0.4
September	1.75 ± 0.15	2.45 ± 0.15	1.05 ± 0.3	2.05 ± 0.5
October	1.65 ± 0.05	1.9 ± 0.15	1.05 ± 0.4	1.85 ± 0.6
November	1.55 ± 0.3	2.05 ± 0.6	1.15 ± 0.4	(Larger)
December	(Larger)	(Larger)	1.85 ± 0.65	-

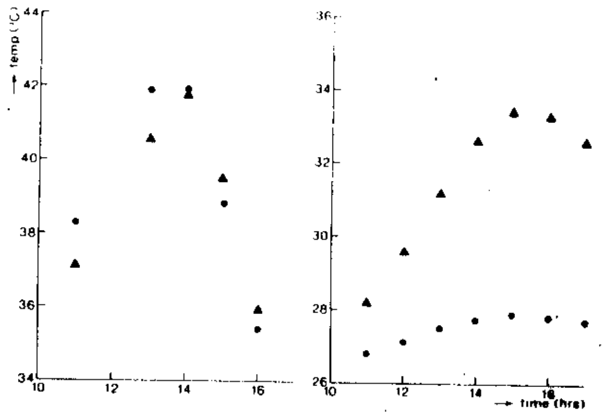

Fig.1. Grass surface temperatures (left) and temperatures at 5 cm depth in the original soil for lowest (▲) and highest (●) gifts of Panicum Trichoclacum grass traditionally applied as mulching material.

Fig.2. Logarithmic extinction of solar radiation in dry grass (Panicum Trichoclacum).T = Transmission;L = Leaf area index.