Tarım Makinaları Bilimi Dergisi (Journal of Agricultural Machinery Science)
2014, 10 (4), 311-316

Numerical Determination of Mulching Effect on Soil Temperature Distribution in Adana, Turkey

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Received (Geliş Tarihi): 25.07.2014 Accepted (Kabul Tarihi): 02.08.2014

Abstract: Time of mulching can influence the soil temperatures at various depths. In this work, different time intervals for mulching process are studied. A numerical model is developed based on Fourier differential equation with appropriate boundary conditions. In the numerical calculations, at least 20-year daily mean values of ambient temperature, relative humidity, wind velocity and solar radiation are used for the calculation of soil temperature distribution. The data are taken from the State Meteorological Affairs General Directorate (DMI) for Adana city in Turkey. Different time intervals of year are defined for mulching processes. Soil surface, end, maximum and minimum temperatures and the depths of maximum and minimum soil temperatures are determined with this model for every mulching period. Artificial change of soil surface cover has a considerable effect on soil temperatures and it can be very useful for ground source heat pumps (GSHP) and agricultural applications. From the results, we can see that surface temperatures with mulching can be higher than 13 °C compared with surface temperatures with no mulching case. The calculations demonstrate that one can obtain 4 °C higher maximum temperature and 3 °C higher minimum temperature compared with no mulching case.
Key words: Mulching, meteorological data, soil temperature

INTRODUCTION

Mulching is covering the soil with an organic or inorganic material for a certain time of year. Mulching is used to increase the soil temperature because the solar radiation is absorbed at higher rates by mulch and also the water evaporation from soil is prevented. Mulching can be used to decrease the soil temperature using a cover material with lower absorption coefficient than the soil surface. Because soil surface temperature and soil temperature at different depths can be changed by using mulching method, it provides very useful opportunities for agricultural and GSHP applications.

There are many studies about mulching process. Ramakrishna et al. (2006) used three different mulching materials to show different effects on soil temperature. Ranasinghe et al. (2003) realized two field experiments with mulches in Sri Lanka to investigate the effects of different soil moisture conservation practices. Chakraborty et al. (2008) compared two different mulching materials which eventually provided a better soil physical environment in terms of soil moisture retention. Olasantan (1999) applied different mulching periods and experimentally investigated the changes in soil temperature and moisture regime. Zhang et al. (2008) evaluated the influence of mulching on soil temperature, soil water storage and wheat yield on three different land types. Jordán et al. (2010) studied the effects of different mulch rates on soil bulk density, soil porosity, soil aggregate stability and organic matter content and consequently determined the optimum rate of mulch application under semi-arid conditions in the studied area. Mulumba and Lal (2008) determined the optimum level of mulch application beyond which additional mulch results in minimal changes in soil temperatures. Dahiya et al. (2007) presented the effect of wheat straw mulching and they also showed a model for simulating water vapor and heat flow in mulched soil under field conditions.

There is no numerical investigation about mulching in literature. In this study, mulching is treated numerically. Six different time intervals covering six-month period are determined for mulching process. Soil surface (T_s) and end temperatures (T_{end}), soil maximum (T_{max}) and minimum temperatures (T_{min}) and the depths of maximum and minimum temperatures are determined with this model for every mulching period. At least 20-year daily mean values of ambient air temperature, solar radiation, relative humidity and wind velocity are used in this model for climatic data. The meteorological data are taken from DMI for Adana city in Turkey. Adana is selected due to its importance in agricultural production of Turkey. Adana is also a good place for the mulching and GSHP applications both for heating and cooling purposes.

MATERIALS and METHOD

Mathematical Modeling

Figure 1 represents the soil which is assumed to consist of two different homogeneous layers, namely from the upper layer and lower layers. x is the coordinate vertical to soil surface and directed into the soil.

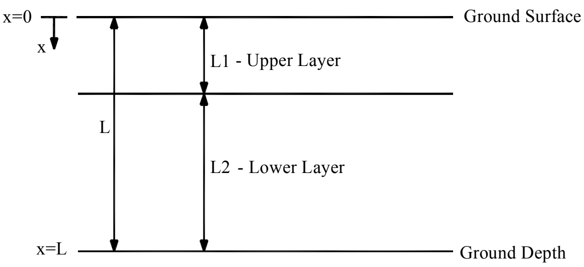

Figure 1. Two-layer soil

Fourier differential equation describing temperature distribution (T) in the soil is valid for the upper and lower layers:

$$\frac{\partial T}{\partial t} = a_i \frac{\partial^2 T}{\partial x^2} \tag{1}$$

where a_i is the thermal diffusivity of the upper and lower layers and t is the time and x is coordinate vertical to the soil surface. The boundary conditions at $x=L_1$ and x=L are:

$$x = L_1 \quad : \quad k_1\left(\frac{dT}{dx}\right)_1 = k_2\left(\frac{dT}{dx}\right)_2 \tag{2}$$

$$x = L \quad : \quad \frac{dT}{dx} = 0 \tag{3}$$

if L is taken enough deep, Eq. (3) can be considered as satisfied. In this work, total length of upper and lower layers L is taken as 12 m. L_1 and L_2 signify the lengths of upper and lower layers, k_1 and k_2 are thermal conductivities of the upper and lower layers, respectively. The following equation can be written at soil surface (El-Din, 1999; Mihalakakou et al., 1997; Mihalakakou, 2002):

$$x = 0 : -k_1\left(\frac{\partial T}{\partial x}\right) = h(T_a - T_s) + a_s\dot{q} - \dot{q}_{lw} - \dot{q}_v \tag{4}$$

Here, h is the convective heat transfer coefficient between soil surface and ambient. T_a and T_s are ambient air and soil surface temperatures, respectively. a_s is the surface absorption coefficient and $\dot{q}$ is solar radiation heat flux. $\dot{q}_{lw}$ is long wave radiation heat flux difference and $\dot{q}_v$ is the heat flux due to the water vapor evaporation from the soil surface.

Convective heat transfer coefficient between ambient air and soil surface can be determined with Duffie and Beckman (1980):

$$h = 5.7 + 3.8u \tag{5}$$

where u is wind velocity. The effects of free convection and long wave radiation are included in this equation. According to ASHRAE (2003), one can assume:

$$\dot{q}_{lw} = 63\, W/m^2 \tag{6}$$

For $\dot{q}_v$, the following equation is used by Mihalakakou et al. (1997):

$$\dot{q}_v = 0.0168\ f\ h(p_{ss} - \varphi\, p_{sa}) \tag{7}$$

where p_{ss} and p_{sa} are saturation pressures of water vapor at soil surface and ambient conditions, respectively. For the calculation of saturation pressures, Yılmaz et al. (2009) used the exact relationship between surface and ambient temperatures. φ is relative humidity of ambient air. Water evaporation factor f depends on water evaporation at soil surface and moisture content of the soil (El-Din, 1999).

Eq. (1) is solved iteratively by considering the boundary conditions in Eqs. (3) and (4) using finite difference method developed by Yılmaz et al. (2009). Details of numerical methods and temperature distribution are given in that study.

Soil and Mulching Material Types

Thermal conductivity (k) and thermal diffusivity (a) exist in boundary conditions and in differential equations (Eqs. 1, 2, 4). Thermal properties are given for used soil and mulching material types in Table 1. The analysis is carried out for one soil type (humid-heavy lower layer), which represents the average soil condition for Adana. In the first (part 1, 6 months) and second parts (part 2, 6 months) of mulching period, linoleum and polyurethane are used as mulching materials, respectively.

Starting and end time of six different mulching periods with part 1 and part 2 and physical properties of the cover used on soil surface are given in Table 2.

When there is no mulching in a year, calculations are carried out assuming that the upper and lower layers are both humid heavy soil. That is, there is no material cover over the soil surface. a_s value can be taken as 0.8 for no mulching case for bare soil according to Mihalakakou et al. (1997).

Table 1. Thermal properties of used soil and mulching materials

Material Name		Thermal Properties	
		k [W/m°C]	a [mm²/s]
Upper layer	Linoleum	0.17	0.0964
	Polyurethane foam	0.025	0.378
Lower layer	Humid-heavy soil	1.30	0.648

Table 2. Starting and finishing time of the mulching periods

	Part 1 (6 Months)	Part 2 (6 Months)
1st Mulching period	between January 1st – June 30th a_s=0.9, f=0.0	Rest of the year a_s=0.2, f=0.45
2nd Mulching period	between March 1st –August 31st a_s=0.9, f=0.0	
3rd Mulching period	between May 1st –October 31st a_s=0.9, f=0.0	
4th Mulching period	between July 1st –December 31st a_s=0.9, f=0.0	
5th Mulching period	between September 1 st – February 28th a_s=0.9, f=0.0	
6th Mulching period	between November 1 st – April 30th a_s=0.9, f=0.0	
No Mulching	For all days in a year a_s=0.8, f=0.45	

Mulching process should be applied at a certain time interval. In this study, six different month periods of mulching time intervals are considered and starting time of mulching periods is assumed as the first days of January, March, May, July, September and November. First mulching period is applied between January 1st – June 30th and the last one is applied between November 1st and April 30th. In a mulching period (Part 1), it is assumed that the soil surface is covered with a dark colored and water-vapor-impermeable material such as linoleum (a_s=0.9, f=0.0), and in the rest of the year (Part 2), soil surface is covered with a thin and light colored material which passes the water vapor such as polyurethane foam (a_s=0.2 and f=0.45) instead of linoleum.

RESULTS and DISCUSSION

In this study, the effect of mulching process on the soil temperatures for humid-heavy soil type is investigated. The mulching process is applied at different time intervals. f, a_s, k and a are changed in the numerical calculations for upper and lower layers. The thicknesses of mulching materials covering the soil surface and lower layer are assumed as 2 mm and 12 m, respectively.

When soil surface is covered artificially with a thin water-vapor-impermeable black colored linoleum material, heat transfer to the atmosphere due to water evaporation will not occur and the evaporation fraction will be zero. Because of the black color of the linoleum material, the value of absorption coefficient will be higher and linoleum material will then absorb more sunlight and consequently soil temperature will be higher.

If soil surface is covered with a white colored thin polyurethane foam material, water in the soil can be vaporized easily because of porosity of the material but considerable amount of incoming sunlight to the soil surface will be reflected to the atmosphere due to the white color of this material.

Figures 2 and 3 show the variation of soil temperatures with depth for all mulching periods on January 23 and July 23 in Adana, respectively. If there is no mulching, the variation of soil temperature with depth can also be seen from these figures.

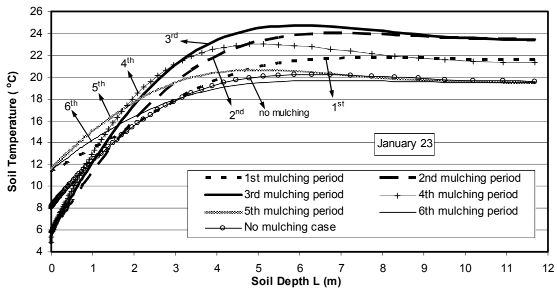

Figure 2. Variation of soil temperatures with depth for all mulching periods in Adana on January 23

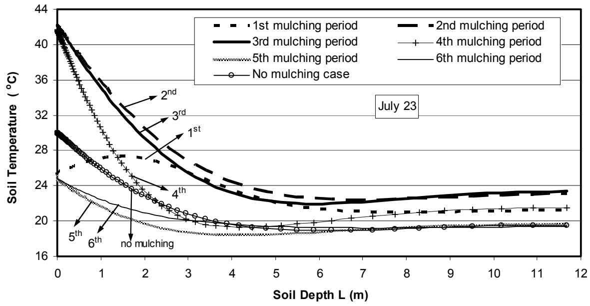

Figure 3. Variation of soil temperatures with depth for all mulching periods in Adana on July 23

Surface temperatures of the 1st, 5th and 6th mulching cases are higher than that of no mulching case (Figure 2). The surface temperatures of the cases 2nd, 3rd, 4th are lower than that of no mulching case because upper layer absorption coefficients in part 2 of 2nd, 3rd and 4th mulching periods are lower than no mulching case. In addition, soil surface temperatures of the cases 1st, 5th, 6th in summer months (Figure 3) are lower than no mulching case. The surface temperatures of the cases 2nd, 3rd, 4th are higher than no mulching case because of the higher soil surface absorption coefficient and zero water evaporation.

If mulching periods are in high solar energy months, then soil temperature increases between 2-4 °C, as can be seen in Figure 2 for the cases 2nd, 3rd and 4th. Similarly, surface temperature increases rapidly during mulching periods and decreases during no mulching periods in a year (the cases 1st, 5th, 6th) as seen in Figure 3.

Figure 4 represents yearly variation of soil end temperatures for all mulching periods and no mulching case for Adana. This figure shows that soil end temperatures occurred in the cases 2nd-3rd, 1st- and 4th, while the cases 5th and 6th are close to each other. There is about 2 °C temperature difference between these mulching period groups. There is no important temperature difference between the cases 5th-6th and no mulching case because mulching periods occur in winter months with low solar energy.

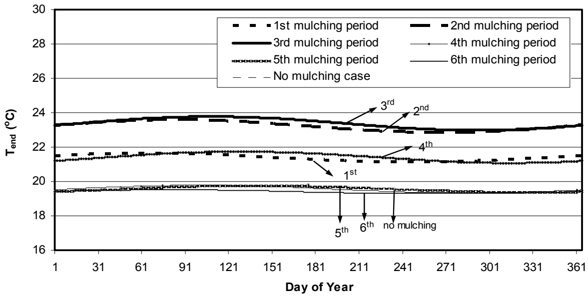

Figure 4. Yearly variation of soil end temperatures for all mulching periods in Adana

It can be concluded that mulching process applied in winter months has very little effect on the soil end temperatures.

Figure 5 presents the variation of maximum soil temperatures on January 23 and minimum soil temperatures on July 23 with different mulching periods for Adana. While the maximum soil temperature differences between the cases 5th, 6th and no mulching case in winter are close to each other; the minimum soil temperature differences between the cases 4th, 5th, 6th and no mulching case in summer are close to each other, as well. But the temperature differences between the cases 2nd and 3rd mulching period and no mulching case in winter and summer months are approximately 4 °C and 3 °C, respectively.

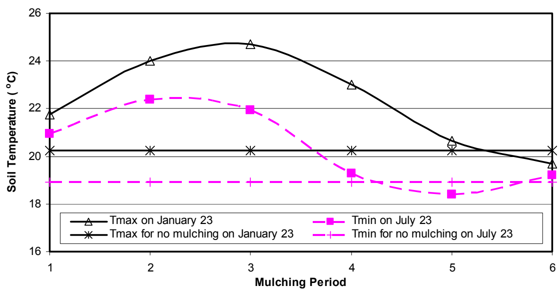

Figure 5. Variation of maximum and minimum soil temperatures with mulching periods in Adana

Figure 6 shows the variation of soil end temperatures with different mulching periods for January 23 and July 23 in Adana. This figure shows that soil end temperature differences between the cases 5th, 6th and no mulching case for both January 23 and July 23 are close to each other as expected. But the temperature differences between the cases 2nd and 3rd mulching period and no mulching case in winter and summer months are approximately 4 °C for both cases.

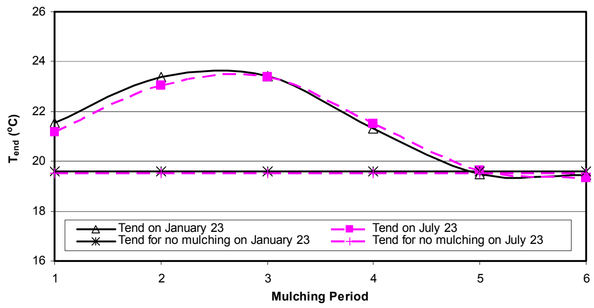

Figure 6. Variation of soil end temperatures with mulching periods in Adana

CONCLUSIONS

Soil end, maximum and minimum soil temperatures and the depth of maximum and minimum soil temperatures are calculated numerically for mulching processes which are applied at different time intervals for Adana Province in Turkey. Soil surface and soil temperatures at various depths can change considerably by applying mulching process at different mulching periods. The differences can be as high as 13 °C for surface temperatures. The minimum and maximum temperature in January and June 23 can be as high as 4 °C compared with no mulching case. The depth of the maximum and minimum temperatures in the soil can be less than 2 m compared with the mulching case. It is seen that soil temperatures and depth of maximum and minimum temperatures can be controlled by changing soil surface cover artificially which can be very useful for GSHP and agricultural applications.

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