METABOLISMO ENERGÉTICO

Teórico – Prática 18 & 25 de outubro de 2021, 8:00 – 9:30

Balanço Energético da Folha

Programa da aula de hoje: O balanço energético da folha: radiação visível, radiação de infra-vermelhos e calor latente e sensível. Princípios da medição de temperatura por termografia de infra-vermelhos.

$$\underbrace{\begin{array}{l}\text{absorbed solar}\\ \quad\text{irradiation,}\\ \text{absorbed infrared}\\ \quad\text{irradiation from}\\ \quad\text{surroundings}\end{array}}_{\text{energy into leaf}} - \underbrace{\begin{array}{l}\text{emitted infrared}\\ \quad\text{radiation,}\\ \text{heat convection,}\\ \text{heat conduction,}\\ \text{heat loss accompanying}\\ \quad\text{water evaporation}\end{array}}_{\text{energy out of leaf}} = \underbrace{\begin{array}{l}\text{photosynthesis,}\\ \text{other metabolism,}\\ \text{leaf temperature}\\ \quad\text{changes}\end{array}}_{\text{energy storage by leaf}} \qquad (7.1)$$

The law of conservation of energy (the first law of thermodynamics) states that energy cannot be created or destroyed but only changed from one form to another.

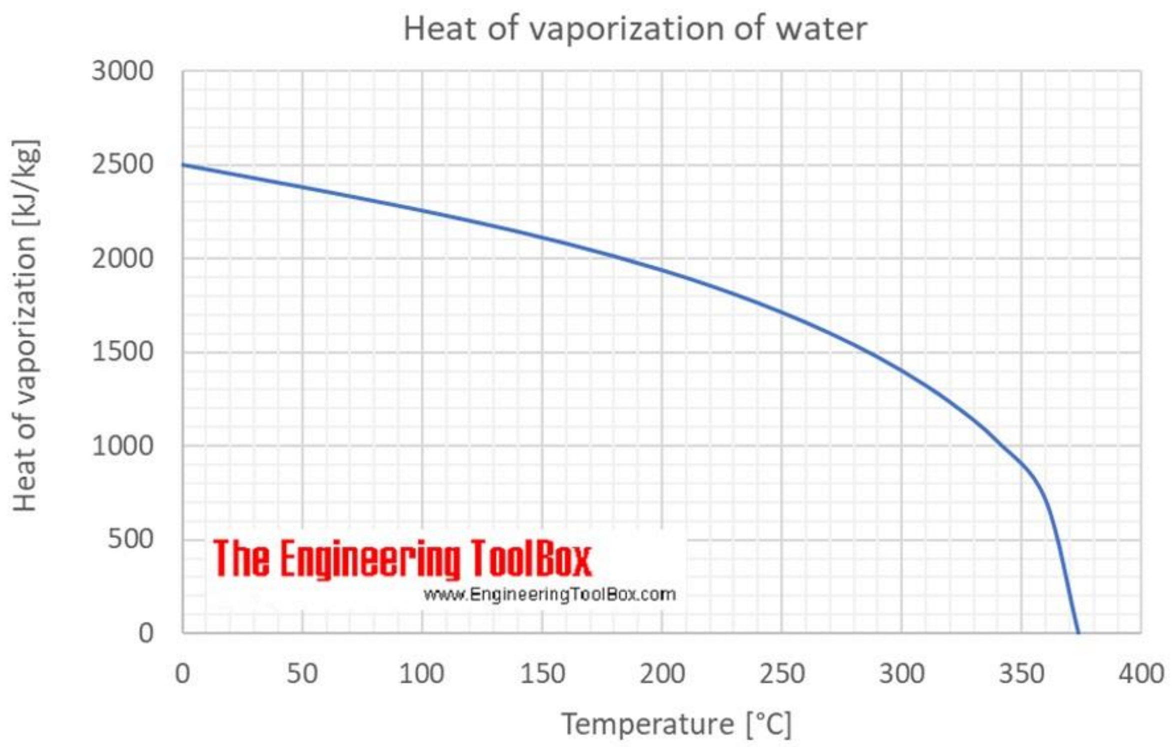
$$\underbrace{\begin{array}{l}\text{absorbed solar} \\ \quad\text{irradiation,} \\ \text{absorbed infrared} \\ \quad\text{irradiation from} \\ \quad\text{surroundings}\end{array}}_{\text{energy into leaf}} \cong \underbrace{\begin{array}{l}\text{emitted infrared} \\ \quad\text{radiation,} \\ \text{heat convection,} \\ \text{heat conduction,} \\ \text{heat loss accompanying} \\ \quad\text{water evaporation}\end{array}}_{\text{energy out of leaf}} \qquad (7.2)$$

Sensible heat

Latent heat

The **(latent) heat of vaporization** (ΔH_{vap}) also known as the enthalpy of vaporization or evaporation, is the amount of energy (enthalpy) that must be added to a liquid substance, **to transform a given quantity of the substance into a gas**.

The enthalpy of vaporization is a function of the pressure at which that transformation takes place. The heat of vaporization diminishes with increasing temperature and it vanishes completely at a certain point called the critical temperature (Critical temperature for water: 373.946 °C or 705.103 °F, Critical pressure: 220.6 bar = 22.06 MPa = 3200 psi).



https://www.engineeringtoolbox.com/water-properties-d_1573.html

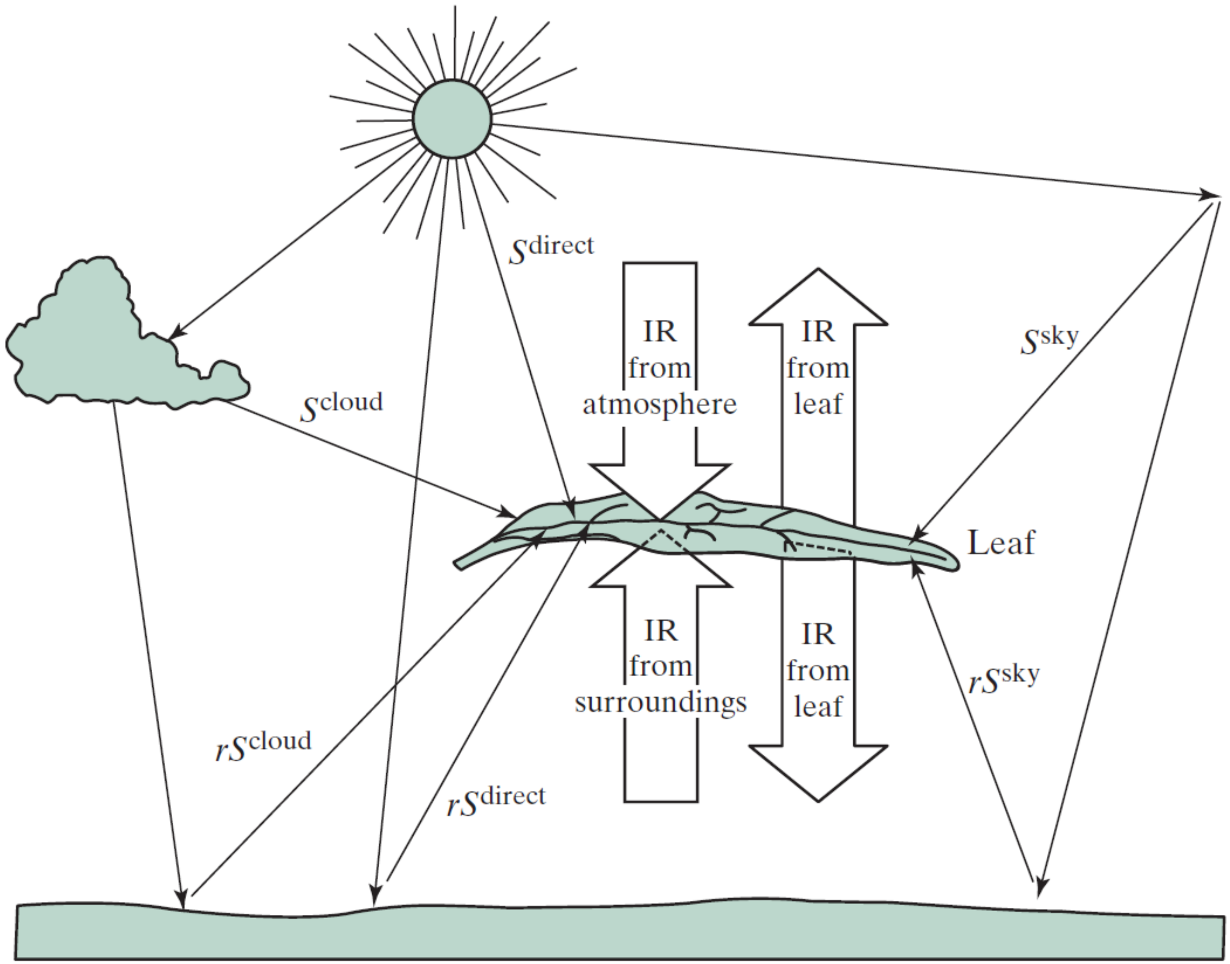


Figure 7-1. Schematic illustration of eight forms of radiant energy incident on an exposed leaf, including six that involve shortwave radiation from the sun and contain the letter *S*, and of the infrared radiation emitted from the two leaf surfaces.

$$\text{absorbed solar irradiation} \cong a(S^{\text{direct}} + S^{\text{cloud}} + S^{\text{sky}}) + ar(S^{\text{direct}} + S^{\text{cloud}} + S^{\text{sky}}) = a(1 + r)S \quad (7.5)$$

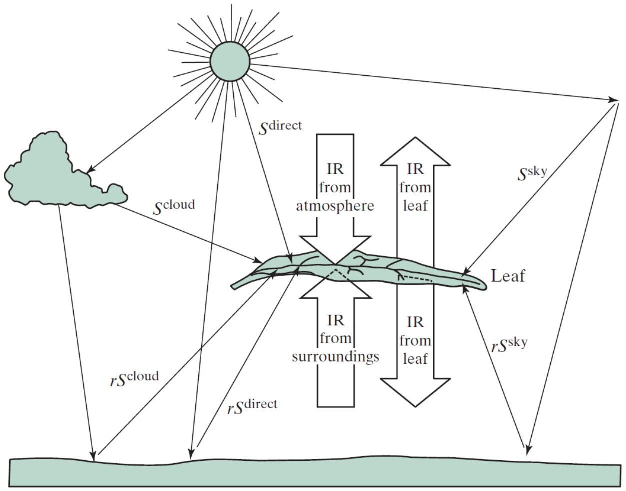
where the *absorptance* a is the fraction of the global radiant energy flux density S absorbed by the leaf, and the *reflectance* r is the fraction of S reflected from the surroundings onto the leaf. Absorptance is often called *absorptivity*, and reflectance is called *reflectivity*, especially when dealing with smooth surfaces of uniform composition.

the IR absorbed by a leaf is

$$\text{IR irradiation absorbed} = a_{\text{IR}}\sigma[(T^{\text{surr}})^4 + (T^{\text{sky}})^4] \qquad (7.6)$$

where the absorptance a_{IR} is the fraction of the energy of the incident IR irradiation absorbed by the leaf.

σ = constante de Stefan-Boltzmann



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Lei de Stefan-Boltzmann

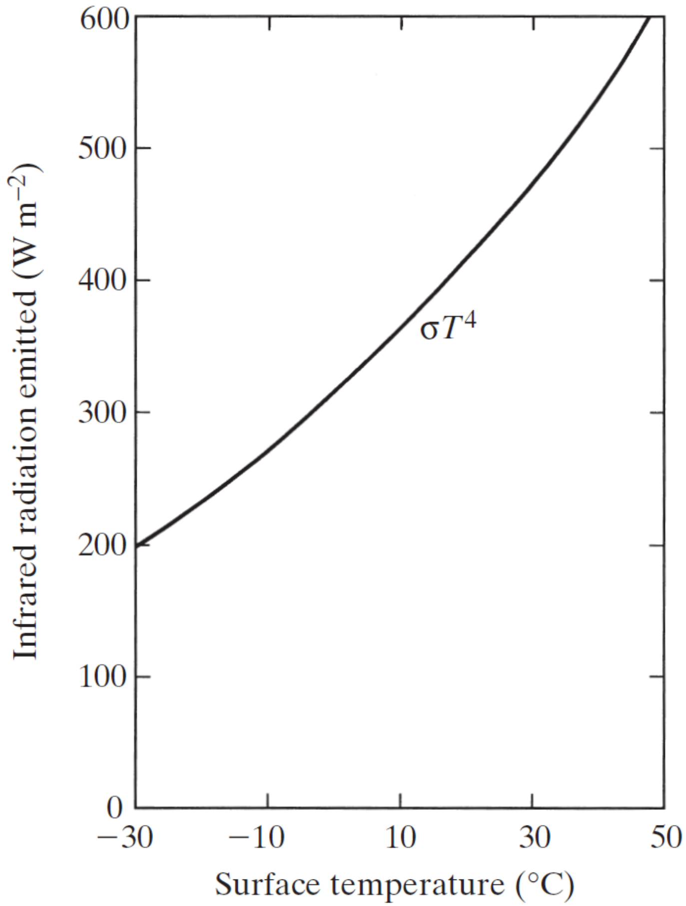

Figure 7-3. Rate of emission of infrared (longwave) radiation per unit area by a blackbody ($e_{IR} = 1.00$) as a function of its surface temperature, as predicted by the Stefan–Boltzmann law (Eq. 6.18).

$$\text{IR radiation emitted} = 2e_{IR}\sigma(T^{\text{leaf}})^4 \qquad (7.7)$$

We have now considered each of the terms that involve radiation in the energy balance of a leaf (Eq. 7.2). These quantities comprise the *net radiation* balance for the leaf:

$$\text{net radiation} = \text{absorbed solar irradiation} + \text{absorbed IR from surroundings} - \text{emitted IR radiation} \qquad (7.8a)$$

Using Equations 7.5 through 7.7, we can express the net radiation balance as

$$\text{net radiation} = a(1+r)S + a_{\text{IR}}\sigma\left[(T^{\text{surr}})^4 + (T^{\text{sky}})^4\right] - 2e_{\text{IR}}\sigma(T^{\text{leaf}})^4$$

(For the case in which the object does not radiate as a blackbody, the radiant energy flux density at the surface of the radiator equals eσT4, where e is the emissivity. Emissivity depends on the surface material of the radiating body and achieves its maximum value of 1 for a blackbody).

Sensible heat
Latent heat

energy into leaf	−	energy out of leaf	=	energy storage by leaf
absorbed solar irradiation, absorbed infrared irradiation from surroundings		emitted infrared radiation, heat convection, heat conduction, heat loss accompanying water evaporation		photosynthesis, other metabolism, leaf temperature changes

(7.1)

The law of conservation of energy (the first law of thermodynamics) states that energy cannot be created or destroyed but only changed from one form to another.

heat flow by conduction, J^{C}_{H}, equals

Sensible heat

$$J_H^{\mathrm{C}} = -K\frac{\partial T}{\partial x} \tag{7.13}$$

where K is the thermal conductivity coefficient of air (e.g., $\mathrm{W m^{-1}\ {}^{\circ}C^{-1}}$) and ∂T/∂x is the temperature gradient;

Equation 7.13 is sometimes referred to as Fourier's heat-transfer law.

Because heat can be conducted across the boundary layers on both sides of a leaf, the factor 2 is needed to describe the total rate of heat flux by conduction per unit area of one side of a leaf. For convenience we will assume that the boundary layers on the two sides are of equal thickness, δ^{bl}. The heat conducted across the boundary layers and convected away from a leaf per unit time and area therefore is

$$J_H^C = -2K^{air}\frac{\partial T}{\partial x} = 2K^{air}\frac{(T^{leaf} - T^{ta})}{\delta^{bl}} \qquad (7.14)$$

where J^C_H is the rate of heat conduction per unit area (e.g., W m^{-2}), K^{air} is the thermal conductivity coefficient of air, T^{leaf} is the leaf temperature, and T^{ta} is the temperature of the turbulent air outside an air boundary layer of thickness δ^{bl}.

Due to the difficulties in accurately estimating the boundary layer thickness, the following simplified relation is used to describe the heat flux density across the air boundary layer:

$$J_H^{\mathrm{C}} = 2 h_c (T^{\mathrm{surf}} - T^{\mathrm{ta}}) \qquad (7.17)$$

where hc is called the heat convection coefficient (or the convective heat transfer coefficient); Equation 7.17 is known as Newton’s law of cooling.

Latent heat

We will represent the flux density of water vapor diffusing out of a leaf during transpiration by J_{wv}. If we multiply the amount of water leaving per unit time and per unit leaf area, J_{wv}, by the energy necessary to evaporate a unit amount of water at the temperature of the leaf, H_{vap}, we obtain the heat flux density accompanying transpiration, J_H^{T}:

E = evaporation site

$$J_H^{\text{T}} = J_{wv} H_{\text{vap}} = H_{\text{vap}} \frac{D_{wv} \Delta c_{wv}^{\text{total}}}{\Delta x^{\text{total}}} = \frac{H_{\text{vap}} D_{wv} (c_{wv}^{\text{e}} - c_{wv}^{\text{ta}})}{\Delta x^{\text{total}}} \qquad (7.22)$$

ta = turbulent air

where Fick's first law has been used to express Jwv in terms of the diffusion coefficient for water vapor, Dwv, and the total drop in water vapor concentration, c^{total} / x^{total}. I

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Temperature sensing in the thermal infrared is based on the fact that all objects emit an amount of radiation (R; W m^{-2}) that depends on the 4^{th} power of the temperature (T; degree Kelvin) according to the Stefan-Bolzmann Law:

$$R = \varepsilon \sigma T^4$$

http://www.gotoinfrared.com/electrical-mechanical-cameras.htm

Protocol **Infrared estimations of leaf or canopy temperature**

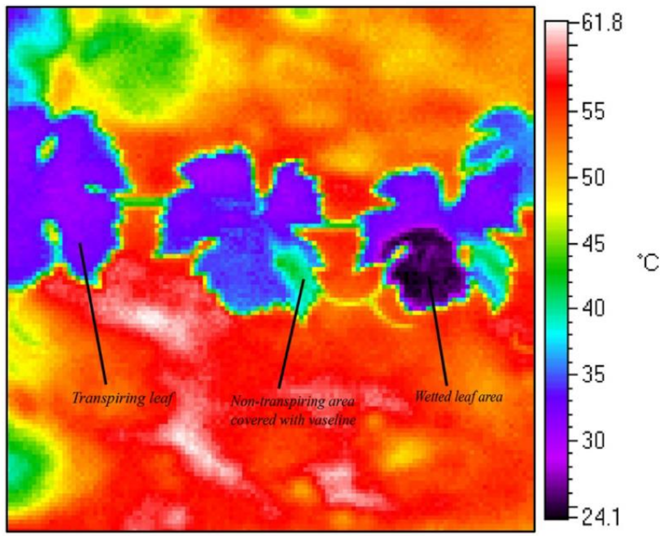
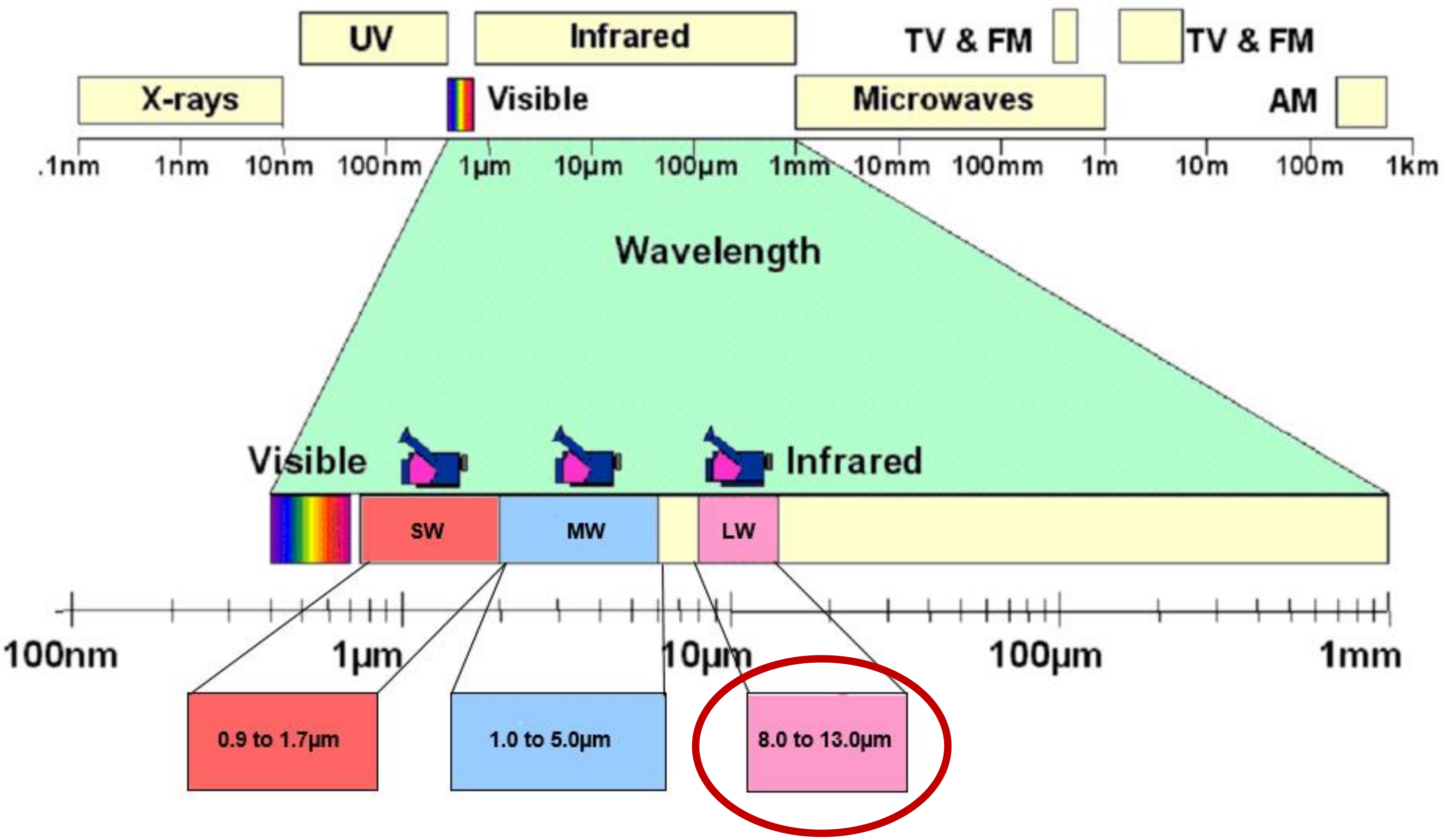


Fig. 1. Illustration of the use of non-transpiring (Petroleum-jelly-covered) and wetted areas as temperature references for thermography of grape-vine leaves.



https://movitherm.com/knowledgebase/thermal-infrared-imaging-explained/

https://pt.pinterest.com/pin/365213851009292822/

(4 grupos)

Controlo 1 | Controlo 2 | Stress 1 | Stress 2

Controlo 1: hidratado
Controlo 2: hidratado e humedecido
Stress 1: desidratado
Stress 2: cobertura com vaselina

(pesagem após excisão e após medição)

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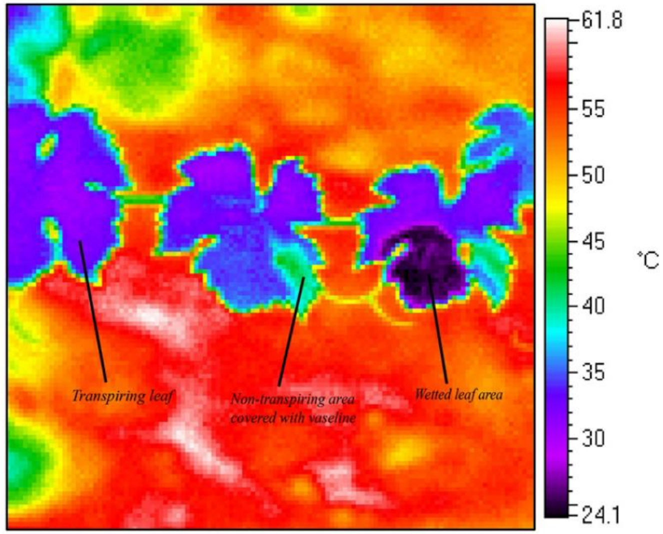

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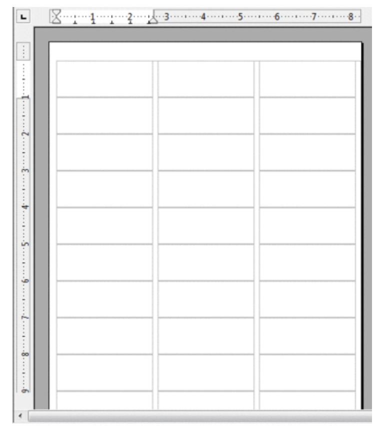

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Leitura Recomendada

- Nobel, P.S. (2005). Physicochemical and Environmental Plant Physiology (3rd ed.), Elsevier / Academic Press, San Diego **(Chapt. 7)**

- Jones, H.G. and PrometheusWiki contributors (2010). Infrared estimations of leaf or canopy temperature. PrometheusWiki. May 20, 2010, 17:08 UTC. Available at: http://www.publish.csiro.au/prometheuswiki/tiki-pagehistory.php?page=Infrared estimations of leaf or canopy temperature&preview=11. Accessed November 05, 2016, 14:02

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