Thermal imaging as a tool for studying plant responses to environmental stress

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Leaf temperature is important to plants both through its subtle effects on the rates of key physiological processes and because of the damaging effects of extreme temperatures. Because of the importance of evaporative cooling as a major component of the leaf energy balance, leaf temperature can be used as an indicator of rates of water loss or of stomatal opening. Although in principle one could also use temperature measurements to study changes in thermogenic metabolism, these differences are usually too small to detect in the field, so most applications of thermal imaging in plant ecophysiology relate to changes of transpiration in response to environmental stress. Modern thermal imagers can readily detect small differences in transpiration reflecting differences in stomatal aperture (Fig. 1); as a result thermal imaging can be a powerful tool aiding the diagnosis and monitoring of plant responses to environmental stresses.

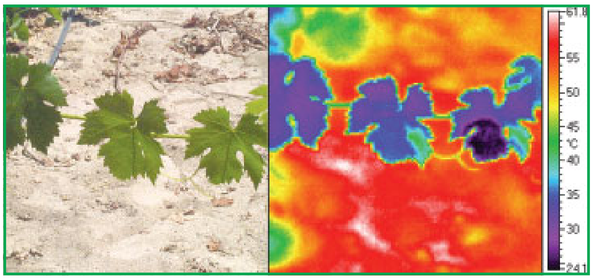

Figure 1 A visible image and a corresponding thermal image of grape vine leaves, indicating the cooling effect of evaporation. The cool area of the right hand leaf (dark purple, *c.* 25°C) has been wetted while warm areas (blue-green, *c.* 40°C) are where transpiration has been prevented.

Irrigation scheduling Monitoring of canopy temperatures has been used for some years to indicate the need for irrigation, but it has not been very sensitive in temperate climates. We have introduced thermography, which together with the use of wet and dry 'reference' surfaces, has opened up exciting new possibilities for irrigation scheduling in a much wider range of situations. When combined with modern image analysis techniques it is possible to automate the extraction of leaf temperature and potentially even to automate an irrigation control system. We are currently collaborating in a Defra LINK project aiming to devise an automated irrigation controller for the hardy nursery stock industry. The principle of the extraction of leaf temperatures from combined thermal and visible images is illustrated in Fig. 2.

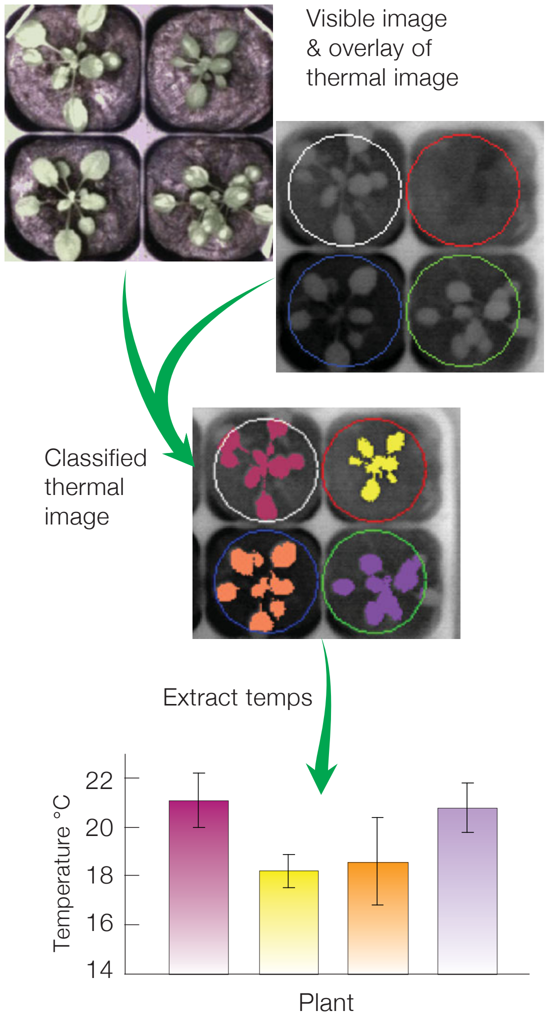

Figure 2 The automated procedure for extraction of leaf temperatures involves the combination and overlaying of thermal and visible images, image classification to identify leaf areas and extraction of temperatures.

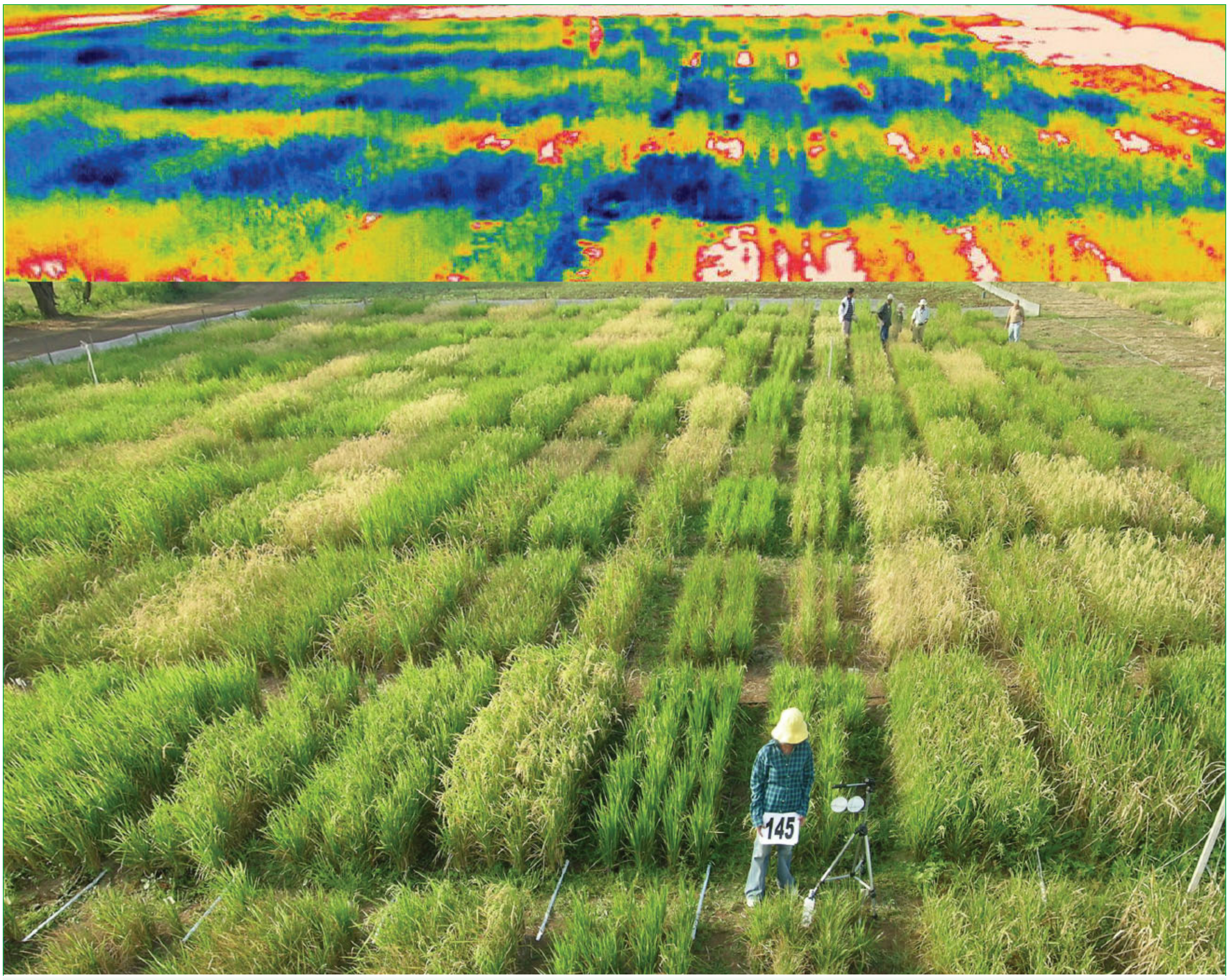

Figure 3 Field “macro-array” of rice genotypes being tested for drought response together with a corresponding thermal image showing genotypic variation in canopy temperature. (Collaboration with International Rice Research Institute).

Drought “phenotyping” Another powerful application of thermal imaging is to provide a rapid means for screening for stomatal mutants or for the identification of genotypes with particular stomatal responses to imposed drought. Thus far thermography has successfully been used to identify a number of stomatal mutants; our work has concentrated on its application in field studies where it is important to have tools available that allow large-scale phenotyping of breeding material in field arrays (Fig. 3).

Use in evaluation of canopy structure. Thermal imagery can also be combined with multiangular viewing and hyperspectral reflectance for the diagnosis and monitoring of water and nitrogen stresses in various agricultural crops. The multi-angular visible images can be analysed to extract the leaf area index and leaf angle distributions (the latter indicative of wilting in response to water deficits). The thermal data provide information on stomatal responses while the spectral reflectance data indicate pigment changes such as chlorophyll concentration that can be indicative of nutrient stresses such as nitrogen deficiency.

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