Radiative and thermal effects on fruit ripening induced by differences in soil colour

Effets thermiques et radiatifs sur la maturation des raisins induits par des différences de couleur du sol

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Abstract

One of the intrinsic parts of a vineyard "terroir" is soil type and one of the characteristics of the soil is it's colour. This can differ widely from bright white, as for some calcareous soils, to red, as in "terra rossa" soils, or black, as in slate soils. The aim of this study was to assess how soil colour can influence vineyard microclimate and fruit properties including aroma precursors. After flowering, (BBCH 79) a loess-type soil (control) was covered with a thin layer of three different materials: a) black coarse slate, b) red clay brick, and c) white pumice. The vines (*Vitis vinifera* L. cvs. Riesling and Pinot noir) were trained to a vertical shoot positioning (VSP) system. Surface colour had significant effects on the quantity and quality of reflected radiation into the fruiting zone. The pumice covered soil showed the highest amount of reflected - and the highest ratio of red-to far red light, important in phytochrome mediated enzyme activity in the fruit.

Large thermal effects on soil surface temperature and on berry skin temperature were found. By varying the distance of clusters to the ground, the temperature of berry skins declined rapidly within the first 0.3 m when fruit was exposed to the red, white or natural coloured soil. In contrast, over coarse ground slate the absolute berry surface temperature was higher and remained constant over the same distances. Berry ripening was affected by surface colour and preliminary results indicate that altered vineyard microclimate has effects on berry composition.

Keywords: light, microclimate, polyphenols, temperature, thermal imagery

Introduction

One fundamental factor to grape quality is climate and in particularly solar radiation. Due to its influence on berry development and composition, the radiation microclimate within the bunch zone is of particular interest (Smart *et al.*, 1988). Despite of the acknowledged importance of light microclimate to fruit quality, the relationship between light quality, light reflectance from the soil and neighbouring canopy walls and fruit temperature has not been well defined. Some elements of fruit quality, such as aroma precursors and polyphenols are directly under the influence of temperature (Spayd et al., 2002; Yamane et al., 2006), light intensity (Downey *et al.*, 2004) and light quality (Kliewer and Smart, 1989) but it is difficult to study the impact of individual environmental components separately. As for sunlight reflectance from the soil surface, bare soil can disperse the incoming energy in different ways: (A) conduct energy into the soil, (B) warm the air above it by convection or (C) reflect energy as long-wave radiation. Depending on the soil type, bare soils can store more energy and have higher temperatures than vegetative surfaces which convert part of the incoming energy into latent heat for transpiration (Jones, 1992). Apart of the energy aspect of solar radiation and it's dispersal within a vineyard, radiation composition of reflected light has been shown to affect fruit composition through the regulation of enzymes such as nitrate reductase, phenyl-alanin ammonia lyase (PAL) and invertase (Kliewer and Smart, 1989) and has been at the basis of experiments with respect to the artificial manipulation of soil reflectance (Robin *et al.*, 2000). Downey *et al.* (2006) have recently provided a review on the role of one class of receptive compounds, flavonoids, in wine quality and how these flovonoids respond to environmental factors and cultural practices.

The aim of the present study was to assess how soil material of different colour can influence soil radiative properties and hence vineyard soil surface temperature and how this would affect fruit composition.

Material and Methods

Field experiments were conducted with *Vitis vinifera* cvs. 'Riesling' (clone Gm 198; grafted onto rootstock '5C') and 'Pinot Noir' (clone Gm 1-1; grafted onto rootstock 'SO4') in a research vineyard located at Geisenheim, Germany (50°N, 8°E). The row orientation was north to south. Both vineyards were planted with vine densities of 2.0 x 1.0 m, row and vine spacing, respectively. Vines were trained to a VSP-type canopy system with a distance of 0.5 to 0.8 m of the fruiting zone from the ground.

For each treatment a permanently grass free area of 100 m^2 of deep loess-type soil (control), was covered with a 7 to 10 cm thin layer of three different materials: a) black coarse slate, b) red clay brick and c) white pumice. The material was deployed at the grapevine developmental stage BBCH 79 (Eichhorn and Lorenz, 1977) i.e. almost pea size berries.

Absorption spectra were measured at 0.5 m above ground with a portable spectro-radiometer (LiCor 1800, Lincoln, USA) during different stages of fruit development. The instrument operates in a waveband between 330 nm and 1100 nm. Fruit zone temperature was monitored with thermometers (Diligence EV N2013, Comark Instruments Inc., UK). An automated data collection system (Datahog 2, Eijkelkamp, NL) using three thermistors (SKTS200, Eijkelkamp, NL) for each treatment was used to measure soil temperature at a depth of 5 cm and at various positions within the row.

Thermal images were obtained using a non-cooled focal plane array infrared camera (TH7102 MX, NEC, Japan). The instrument operates in the waveband between 8-14 µm. The detector array has a geometric resolution of 1.58 m rad (320 x 240 pixels focal plane array and a 29^{o} x 22^{o} field of view lens with a minimum focus distance of 0.3 m). The thermal resolution is 0.06 ^{o}C and with an accuracy of absolute temperature measurement smaller than ±2 ^{o}C. For measurements of berry temperature the emissivity was set to 0.95 (Idso *et al.,* 1969) whilst for the different soil surfaces the emissivity was set to 0.85, 0.98, 0.9 and 0.96 for white pumice, black slate, red clay and the control respectively (NEC datasheet, Japan). The imager was mounted on a tripod and held approximately 0.3 m from the target bunches. For soil surface temperature measurements the thermal imager was used facing down onto the rows.

When fruit was more mature, that is more than 17 ^{o}Brix, three 20-berry samples per treatment were randomly collected once a week and frozen at -20^{o}C. Peeled berry skin tissue was ground to powder in liquid nitrogen. Polyphenols were extracted from 0.1 g berry skin sample by thorough mixing in 5 mL acetonitrile and 200µL 5 % SO_2. Samples were stored 30 min in an ultrasonic bath with additional vortexing every 5 min. Extracted skin tissue was then pelleted via centrifugation at 3000 g. The supernatant was reduced using a rotor evaporator, re-dissolved in ultra pure water, filtered (45 µm cartridge) and then analysed by HPLC (Tab 1).

280 nm	320 nm	360 nm
procyanidin B1	cumaroyl-glucose	que-3-rut
catechin	caftaric acid	que-3-gal
tyrosol	glutathionyl-caftaric acid	que-3-glc
procyanidin B2	p-Coumaroyl-glucosyl-tartrate (p-CGT)	que-3-xyl
epi-catechin	coutaric acid	que-3-ara
		que-3-rha

Table 1 List of polyphenols identified by HPLC analysis.

Results and discussion

Reflected radiation

The most likely effect of soil-colour or different materials covering the soil is to change the soil surface temperature and the spectral composition of reflected light which both can affect grapevine physiology. Light quality was determined from spectral data of a wavelength between 330 and 1100 nm. This covers the range of wavelengths which play a major signalling role in plant and fruit development (Briggs and Olney, 2001). Figure 1 shows the differences in the spectral signature of reflected radiation between the four materials. Dependent on the wavelength and the time when measurements were taken, the amount of reflected radiation from white pumice was up to ten times that of black slate for example. This shift in radiation properties measured at the height of the bunchzone may activate grapevine photoreceptor systems as has been demonstrated with artificial sun light reflecting films using blue, green or red colour (Robin *et al.*, 2000).

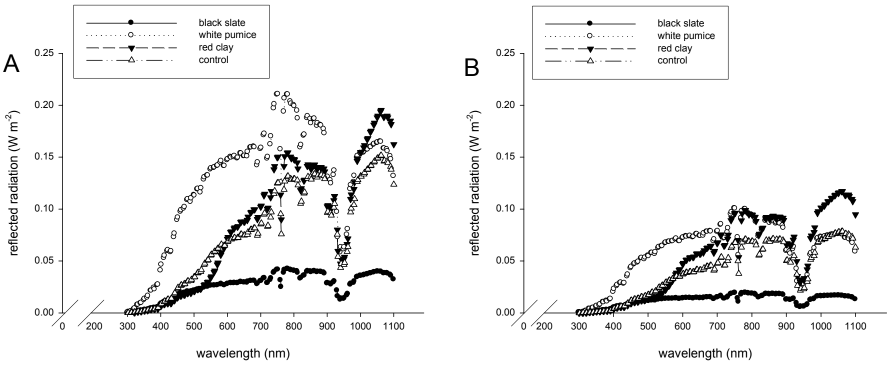

Figure 1 Effects of different soil surface material on reflected radiation. Reflection readings were recorded at (A) 17th July 2007 and (B) 22nd September 2007 between 2.00pm and 3.00pm.

Soil surface temperature

Thermal imaging interferes little with the environment and the canopy and can be automated allowing for analysis of high temporal and spatial sensitivity and covering large areas (Figure 2). It was found that surface temperature differed substantially between different positions within the rows and between each treatment (Figure 3). Compared to other treatments, black slate generally had the highest surface temperature. In contrast, the other materials which exhibited higher radiation reflection showed lower soil temperatures (data not shown) and lower soil surface temperatures as measured by infrared thermography. On a warm and sunny day with an air temperature of 31.4 °C (average 2-3pm), soil surface temperature was up to 15.5 °C and 26 °C above ambient for control and black slate, respectively. For black slate the average temperature of the soil surface was 42 °C. Furthermore, when temperature differences of minimum and maximum temperature within a row were compared, the maximum temperature difference was 36.1 °C and 21.6 °C for black slate and the control, respectively.

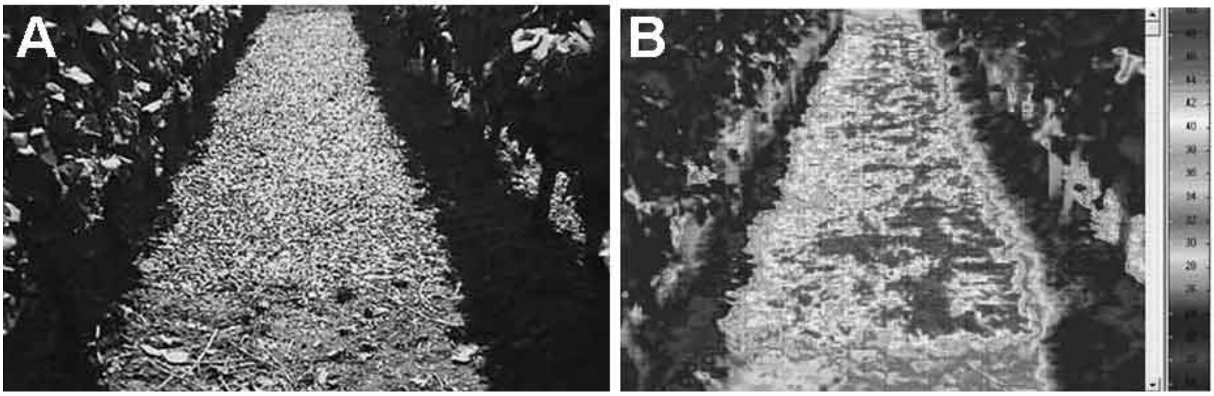

Figure 2 Corresponding image taken looking down the row. The photograph (A) and thermal image (B) include soil and canopy both from shaded or sunlit areas.

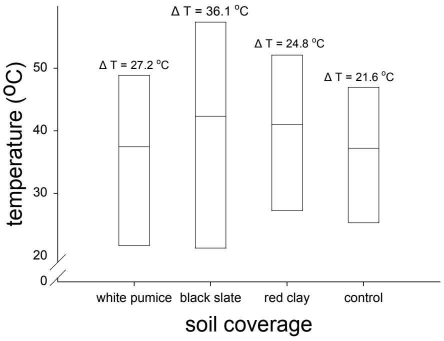

Figure 3 Effects of soil surface material on soil surface temperature at mid-day (2-3pm). Soil surface temperature measured by thermal imagery within the row (4th of Aug. 2007). Bars represent the maximum and minimum temperatures of sunlit *vs.* shaded areas of the soil with average temperature indicated by horizontal lines. Air temperature was 31.4 °C on average during this time period.

Fruit temperature variation

Under hot climatic conditions, berry temperature can be up to 15 °C higher than air temperature (Stoll and Jones, 2007). Such excessive absolute fruit temperatures can have a detrimental effect on fruit quality and for red varieties there is extensive evidence that it can reduce anthocyanin concentrations (Spayd *et al.*, 2002). Temperature measurements of small parts of bunches (app. 10 to 15 berries) mounted at 0.1, 0.3 and 0.5 m above ground showed a decline in temperature with increasing height for all treatments. When temperature distribution of single pixels along the berry skin surface was analysed, the treatments with higher reflected radiation (i.e. white pumice or red clay) showed a different frequency distribution compared to black slate (data not shown). Despite soil surface temperatures substantially exceeding air temperature, fruit temperature above 0.6 m was little affected by the different soil surface materials.

Berry composition

Grape berries can contain large amounts of polyphenols which include hydroxy-cinnamic acids and flavonoids (flavan-3-ols, anthocyanins and proanthocyanidins) (Lu and Foo, 1999). The total amount of polyphenols measured for each group and detected at different wavelengths varied substantially for all treatments. Whilst the differences for the groups of polyphenols measured at 280 nm and 320 nm were small, the group of polyphenols measured at 360 nm showed larger but not significant differences (Figure 4). It is noteworthy that the treatments with higher reflected radiation showed a higher content of polyphenols compared to treatments with less reflection.

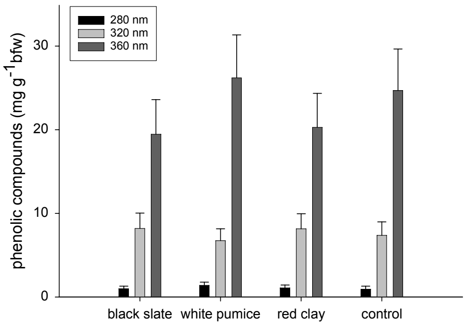

Figure 4 Effects of different soil surfaces on the content of polyphenols measured at the wavelength 280, 320 and 360 nm (*Vitis vinifera* L. cv. Riesling; n=20 ± s.dev.).

Conclusion

The different soil materials influenced the microclimate through at least two mechanisms: temperature and spectral composition of reflected radiation. Thermal imaging was used to monitor temperature distribution either of the soil or in various positions of the canopy. The technique has the capacity of effective replication and high levels of precision and hence remains best suited for comparative studies. Since the synthesis of flavour and phenolic compounds depend on complex interactions between light and temperature, some effects of different soil surface properties are expected. However, the preliminary results shown should be treated with some caution since they only present results of one season. Furthermore, the time when the different soil colours were deployed was almost at pea size of the berries when precursor formation of phenols is well advanced (Robinson, 2006). Small effects on fruit phenolic composition due to changes in micro-climate were found but it remains to be determined whether these changes will ultimately affect wine quality.

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