DIFFUSE LIGHT DUE TO WILDFIRE SMOKE ENHANCES GAS EXCHANGE OF SHADED LEAVES

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Abstract:

Context and purpose of the study – The risk of wildfires is increasing as the frequency and severity of drought and heat waves continue to rise. Wildfires are associated with the combustion of plant materials and emit smoke. In the atmosphere, smoke may spread readily across large areas. Smoke is composed of solid and liquid phase particulates and gases and has been identified as a causal agent of "smoke taint" in wine. On a smoky day, the intensity of direct light decreases because these particulates scatter sunlight. Even though this effect is frequently assumed to decrease plant photosynthesis, this assumption ignores the potential changes in diffuse light and may be based on scant evidence. This study compared leaf gas exchange on the sunny and shaded sides of a grapevine canopy during a very smoky, and thus hazy, day.

Material and methods – Five own-rooted Cabernet Sauvignon vines were used in a north-south oriented vineyard row in warm and arid eastern Washington during wildfire events in North America. Vines were drip-irrigated, spur-pruned, and trained to a loose vertical shoot-positioning system. Leaves at a height of 1.5 m were sampled on both sides of the canopy. Leaf temperature, light intensity, stomatal conductance, and gas exchange were measured with a portable infrared gas analyzer on 9 August 2018, in the afternoon about 4:00 PM. The diffuse light was estimated by blocking the direct light to the quantum sensor facing the sun.

Results – Diffuse light accounted for 40% of the incoming light. On the sun-exposed west side of the canopy, the light intensity in the afternoon was 1000 µmol m^{-2} s^{-1}, while on the east side the light intensity was slightly above 100 µmol m^{-2} s^{-1}. Leaves on the west-facing side of the canopy were 2°C warmer than leaves on the other side, and the former also had higher photosynthesis and transpiration rates, but leaves on both sides had the same stomatal conductance. Only receiving 10% sunlight, the shaded leaves maintained positive net carbon assimilation and had photosynthesis rates of 25% compared to the fully exposed leaves. While the leaves on the west side transpired at a rate of 7.6 mmol m^{-2} s^{-1}, their counterparts on the east side maintained a rate of 6.1 mmol m^{-2} s^{-1}.Therefore, the water use efficiency (WUE) was 27% lower for the east-facing canopy than for the opposite side. These results indicate leaves on the sunny side still received light at saturation level and leaves on the shaded side may provide surplus photosynthates on a smoky day. Further, in a well-watered vineyard, shaded leaves open their stomata once there is enough sunlight for photosynthesis even if the leaves are operating at lower WUE.

Keywords: photosynthesis, transpiration, stomata conductance, water use efficiency, light intensity

1. Introduction.

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Diffuse light due to wildfire smoke enhances gas exchange of shaded leaves

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Context and Purpose

- Warming and earlier spring increase wildfire risk in the Western US (Westerling *et al.*, 2006)
- Combustion of plant materials produces smoke

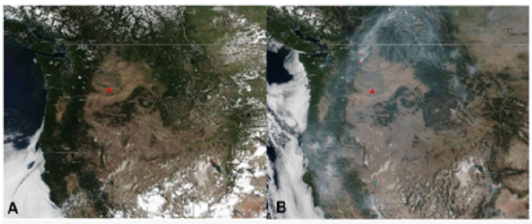
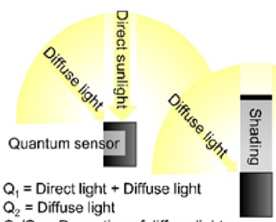


Fig. 1. Satellite image of US Pacific Northwest before (A; 7/21/2018) and during (B; 8/9/2018) California and British Columbia wildfires in 2018. The red triangles (▲) indicate the location of the experiment site in Prosser, WA, USA. The red dots (·) indicate fires and thermal anomalies.

- Smoke can spread across large areas (Fig. 1)
- Particulates in the smoke scatter sunlight
- Smoke may cause "smoke taint" in wine
- Smoke may reduce sunlight intensity
- Question:
  - **Decreased photosynthesis activity?**

Material and Methods

- Own-rooted Cabernet Sauvignon grapevines
- North-south oriented vineyard (▲ in Fig. 1)
- Loose, vertically shoot-positioned canopy
- Leaves at a height of 1.5 m were sampled on east side (shade) and west side (sunny) of canopy in the afternoon of 9 August 2018
- Light intensity (Q_{leaf}), leaf temperature (T_l), stomatal conductance (g_s), and gas exchange were measured
- Diffuse light was estimated by blocking the direct light to the quantum sensor facing the sun (Fig. 2)
- Air quality data was collected from nearest station (42 km away; both sites were in the same smoke system in Fig. 1B)



Q_1 = Direct light + Diffuse light
Q_2 = Diffuse light
Q_2/Q_1 = Proportion of diffuse light

Fig. 2. Diffuse light was estimated around 5 PM on 8/9/2018. Q_1 is the light intensity measured without any obstruction. Q_2 is the light intensity measured with direct sunlight blocked by a pole 1 m away from the sensor. The proportion of diffuse light was estimated by dividing Q_2 by Q_1.

Results

- Solar radiation was stable on a smoky day

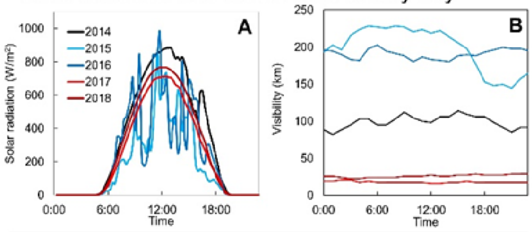


Fig. 3. Diurnal solar radiation (A) and visibility (B) on 9 August 2014-2018. In 2014, 9 August was mostly sunny. In 2015 and 2016, 9 August was cloudy. In 2017 and 2018, 9 August was smoky.

- Smoke redistributed light in the vineyard

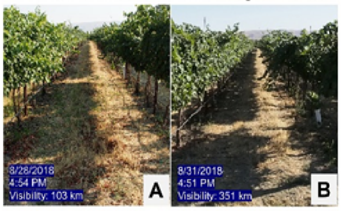


Fig. 4. Vineyard photos taken on a smoky day (A) and a clear day (B) with camera facing south. Note the better definition of background terrain and darker shadow in B. However, more details are visible on the shaded canopy side in A than B.

Leaf gas exchange on a smoky day (Table 1)

- Diffuse light accounted for almost 40% of the incoming light (visibility 29 km)
- The sunny canopy side received saturating Q_{leaf}
- Q_{leaf} was well above the light compensation point on the shaded canopy side
- Stomata were open on both the shaded and the sunny side
- Leaves on the sunny side had higher transpiration (*E*) and photosynthesis rates (*A*)
- Water use efficiency (*WUE*) was 27% lower in leaves on the shaded side

Table 1. Gas exchange in grape leaves on the shaded and sunny canopy sides.

	Q_{leaf} (µmol m² s⁻¹)	T_l (°C)	g_s (mol m² s⁻¹)	*E* (mmol m² s⁻¹)	*A* (µmol m² s⁻¹)	*WUE* (µmol/mol)
Shade	122±4	36.8±0.5	0.27±0.01	6.1±0.3	2.7±0.2	0.45±0.05
Sun	998±36	39.1±0.5	0.31±0.02	7.6±0.5	12.4±1.3	1.67±0.16
p	<0.001	0.02	0.20	0.03	0.002	0.001

Take home messages

- Wildfire smoke does not decrease *A* in leaves
- Diffuse light enhances gas exchange in leaves on the shaded side but decreases *WUE*

ACKNOWLEDGMENTS

Funding was provided by the Chateau Ste. Michelle Distinguished Professorship. We thank Lynn Mills and Alan Kawakami for technical assistance.

Reference

Westerling, A.L., Hidalgo, H.G., Cayan, D.R., and Swetnam, T.W. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science 313: 940-943.