Scaling Leaf g_s Measurements to Canopy: Choosing Appropriate Boundary-Layer Conductance for Generating the g_s -Light Curves Under Field Conditions

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Scaling leaf g_s measurements to canopy: choosing appropriate boundary-layer conductance for generating the g_s-light curves under field conditions

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According to John Norman[1], probably the easiest way to scale the leaf level gas exchange (photosynthetic rate and stomatal conductance) data to canopy level is to consider the effect of light gradient within the canopy. An example (for photosynthesis) is shown in his 1998 book[2]. The typical crops considered by J. M. Norman are broad-leaved, and may be as tall as corn. So the recommended boundary-lay conductance (g_{La}) for chamber measurement of the g_{La}-light curves, which is 0.5 to 1 $mol\ m^{-2}s^{-1}$, may be somewhat too low for use in prairie situation, where the average wind speed is high, the canopy is low and leaves (for grasses) are narrow. The purpose of this note is to estimate the appropriate values of g_{La} for grasslands near Streeter, ND, so that it will facilitate the scaling of leaf-level measurements to the canopy level, which is directly related to the quantitative evaluation of grassland water and carbon budgets.

During the period of 2001-2002, we measured leaf gas exchange rates using the LI-6200, which is a closed system. Because the temperature increase during the measurement is an issue, the average fan speed used in the chamber was high. This tends to increase g_{La} during the measurement. Considering the specific environmental situation on the prairie as mentioned earlier, we hypothesis that this high fan speed (and high g_{La}) probably corresponds to what happens averagely under the field situation.

What we have decided to do is to take a look at the past 5 years' wind data and use some accepted bio-physical relations of wind and boundary layer conductance to see if the above assumption is acceptable.

According to Campbell and Norman (1998), the wind speed at any height z can be described, as

$$\mu(z) = \frac{\mu^*}{0.4} \ln \frac{z-d}{z_m} \tag{1}$$

in which, μ^* is the friction velocity, d the zero plane displacement, and z_m the momentum roughness parameter, and the factor 0.4 is the von Karman constant. Under normal situation, $d = 0.65h$ and $z_m = 0.1h$, where h is the canopy height. Because the wind data was measured at the 3m height, if we assume the average canopy height is 12 cm, then, solving for μ^* using data observed at 3 m height, we can find the value of μ^*. The wind speed for 12 cm height is then calculated using Eq. 1 and the above obtained μ^* value, namely, $\mu(h) = \frac{\mu^*}{0.4} \ln \frac{h(1-0.65)}{0.1h} = \frac{\ln 3.5}{0.4}\mu^*$. Assume the average leaf width (d_p)is 0.005 m (for example for western wheatgrass), the g_{La} values for the 12 cm height and with the calculated wind speed at this height can be obtained, according to Baker an Norman, as

[1] John M. Baker and John M. Norman, Evaporation from natural surfaces. A section from a book.

[2] Gaylon S. Campbell and John M. Norman, An Introduction to Environmental Biophysics. 1998. Springer-Verlag New York Inc.

Table 1: Daytime (8 am to 20 pm) wind speed observed at 3m height ($z = 3m$), wind speed estimated for the 12 cm height (canopy height, $h = 0.12m$), as well as estimated boundary-layer conductance (g_{La}) for a typical 0.5 cm wide leaf. The daytime wind speed is for May to September from 2000 to 2004 observed at Streeter Station. The wind speed at 12 cm height as well as g_{La} were calculated using Eqs. 1 and 2

$Month$	$Data$	$\mu(z)(mph)$	$\mu(z)(ms^{-1})$	$z(m)$	$h(m)$	$\mu(h)(ms^{-1})$	$g_{La}(molm^{-2}s^{-1})$
May	*average*	12.3	5.5	3	0.12	1.25	3.5
May	*min*	1.6	0.7	3	0.12	0.16	1.3
May	*max*	29.6	13.5	3	0.12	3.02	5.4
Jun	*average*	10.7	4.8	3	0.12	1.09	3.2
Jun	*min*	1.4	0.6	3	0.12	0.14	1.2
Jun	*max*	28.7	12.8	3	0.12	2.92	5.3
Jul	*average*	9.1	4.1	3	0.12	0.93	3.0
Jul	*min*	1.6	0.7	3	0.12	0.16	1.3
Jul	*max*	23.0	10.3	3	0.12	2.34	4.8
Aug	*average*	10.2	4.6	3	0.12	1.04	3.2
Aug	*min*	1.2	0.5	3	0.12	0.12	1.1
Aug	*max*	29.4	11.8	3	0.12	2.69	5.1
Sep	*average*	10.8	4.8	3	0.12	1.10	3.3
Sep	*min*	1.2	0.5	3	0.12	0.12	1.1
Sep	*max*	26.6	11.9	3	0.12	2.71	5.1

$$g_{La} = 0.22\sqrt{\mu(h)/d_p} \tag{2}$$

where $\mu(h)$ is the wind speed at canopy height, h. The results are shown in Table 1. These are the predicted for leaves at the canopy top in grasslands near Streeter, ND. The wind speed at the height z within the canopy can be calculated as[3]

$$\mu = \frac{\mu(h)}{(1 + m[1 - \frac{z}{h}])^2} \tag{3}$$

where m may be about 1.5 for open canopies and 2.5 for closed canopies. Assuming an average top-canopy wind speed of 1 m/s, the wind speed at 6 cm depth within the canopy is about 0.25 m/s, and g_{La} for a typical grass leave located at this depth is about 1.6-1.8 $mol\ m^{-2}s^{-1}$, according to Eq. 3. This is one-sided conductance, corresponding to 3.2-3.6 $mol\ m^{-2}s^{-1}$ of the displayed BLC in LI-6400.

It is clear that for average wind speed of Streeter, ND, the values of g_{La} for leaves located in the middle to upper part of the grassland canopies lies in the upper bounds of the typical g_{La} values used in gas exchange chamber systems (1-4 $mol\ m^{-2}s^{-1}$ as reviewed by Baker and Norman). This is especially so if we consider other more narrower leaves, such as those of Kentucky bluegrass which are about 0.15-1.20 cm in width (See Figure

[3]Thom, A.S. 1971. Momentum absorption by vegetation. Quar. J. Roy. Meteorol. Soc. 97: 414-428.

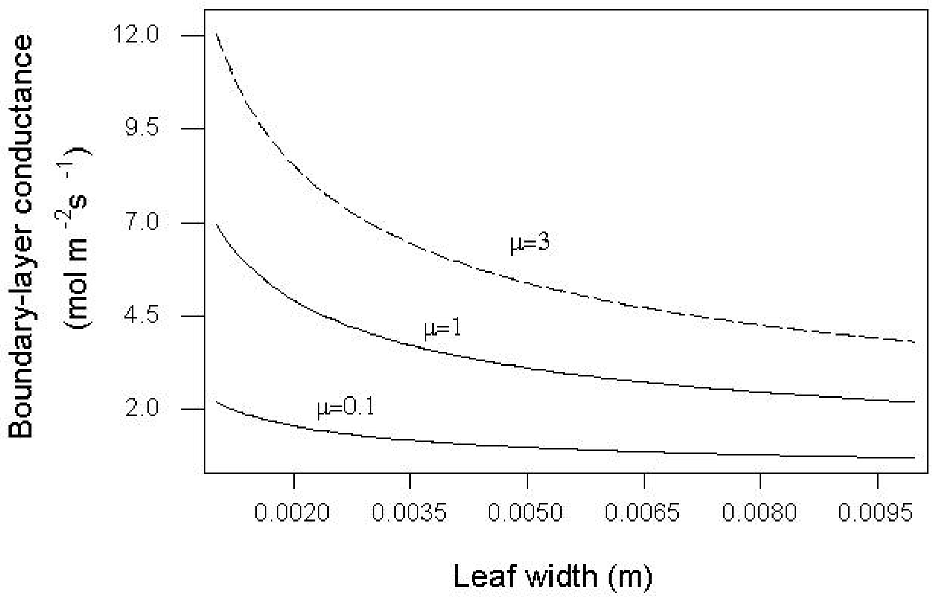

Figure 1: *Boundary-layer conductance as a function of wind speed and leaf width. The unit of wind speed, μ, is in m/s. The graph is generated using Eq. 2*

1 for approximate g_{La} values corresponding to narrower leaves). As a result, we believe the previously used larger fan speed in measuring the narrow-leaved prairie grasses are probably close to the natural values near the canopy height. Adjusting fan speed, and thus the chamber g_{La}, as suggested by John Norman for typical broad-leaved crops, may not be necessary if we measure the normally narrow leaves of the prairie grasses under a natural wind situation (which is frequently high).