Stomatal control of gas exchange

I. Stomatal Physiology
II. Stomatal conductance
III. Water Use efficiency

Water use efficiency: What is it?

A broad definition:
"Amount of carbon gain per unit water loss"

Many different variations on this definition:

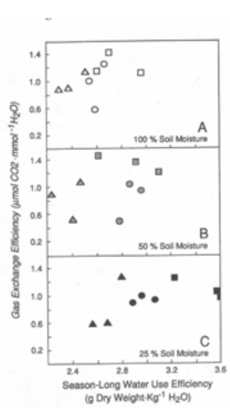
- •Leaf photosynthetic rate per transpiration rate
- •Leaf photosynthetic rate per stomatal conductance
- •(above ground) plant growth per unit transpiration
- •Crop biomass gain per unit evapotranspiration

Units of WUE can be (for example):

•kg dry matter per kg H_2O (long time scales – WUE of production)

•mol m^{-2} s^{-1} CO_2 per mol m^{-2} s^{-1} H_2O (short time scales – photosynthetic WUE)

•Long term vs. short term measurements often do not agree (Fig 12.3 Kramer/Boyer)



Things to keep in mind when considering WUE:

•**WUE is not a true "efficiency"** because it does not have a maximum value of 1

•**High WUE is not always adaptive**. Often, high efficiency is associated with low growth rate, which may not be a good 'strategy'.

•There is no point to having high WUE if water supply is non-limiting

•It is more important for a plant to maximize carbon gain in relation to the amount of water available, rather than to just have the highest ratio of carbon gain to water loss.

WUE differs substantially by plant form

Functional Type	WUE (mmol mol^{-1})
CAM plants	4-20
C4 plants	4-12
Woody C3	2-11
Herbaceous C3	2-5
Hemiparasitic C3	0.3-2.5

Early studies found higher WUE in C4 compared to C3 crops before these metabolic pathways were even known!

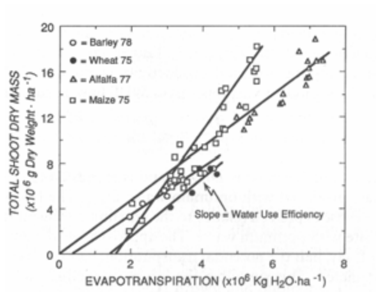
High atmospheric humidity generally promotes higher WUE, while high soil moisture may be associated with low WUE.

Thus, the same plant or species, in the same location, can show seasonal variation in WUE e.g. Wheat in Russia ranged from 1.7 to 3.3 x 10^{-3} grams/gram from 1911-1917 (Maximov 1929)

By the same token, plants of the same species can show variation in WUE from one environment to another

Nevertheless, there can be a surprising level of constancy in WUE within species at a given site

Figure 12.1 Kramer/Boyer



A puzzle: crop WUE seemed to be insensitive to *spatial* variation in soil water among plots within a year, but show *inter-annual* differences (e.g. Maximov 1929) that seem to be associated with similar, but *temporal* variation in soil moisture.

More work needed to understand soil nutrient levels, planting density, etc.

Using C isotopes to indicate WUE

•Has advantages over gas exchange, because it integrates over the entire time period in which a tissue has grown – e.g. accounts for night respiration, etc.

•99% atmospheric CO_2 is $^{12}CO_2$ 1% is $^{13}CO_2$

•More than 99% of plant tissue is made of ^{12}C

•Plants 'discriminate' against ^{13}C: Why?

Plants discriminate against ^{13}C

•$^{12}CO_2$ is lighter than $^{13}CO_2$ and diffuses across stomates faster

•Rubisco also 'prefers' $^{12}CO_2$ over $^{13}CO_2$

• The wider stomates are open, the more Rubisco can be 'picky'. When stomata are relatively closed, Rubisco is less 'picky'.

•Thus, there is a link between the degree of discrimination against ^{13}C and stomatal conductance

Since stomatal conductance controls both carbon gain and water loss, C isotope discrimination is directly correlated with WUE.

Total discrimination Δ (‰)

$\Delta = a + (b-a)^* P_i/P_a$ (Read Box 2 pp. 21-24)

Where a = discrimination due to diffusion (4.4‰)

b = discrimination due to Rubisco (~28 ‰)

Linking Δ to WUE:

$WUE = A/E = g_c(p_a-p_i)/g_w(e_i-e_a)$

$= p_a(1-p_i/p_a)/1.6(e_i-e_a)$

Or, equivalently, $p_i/p_a = 1-WUE(e_i-e_a)/1.6P_a$

But $\Delta = 4.4 + 22.6*(p_i/p_a)$

Thus, $\Delta = 4.4 + 22.6*(1-WUE*(e_i-e_a)/1.6P_a)$
Δ is linearly (and negatively) related to WUE!

Independent measures of long term WUE and Δ confirm the linear relationship

Fig. 10.5 Jones and LCP p. 55 fig. 30

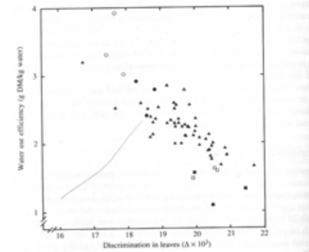
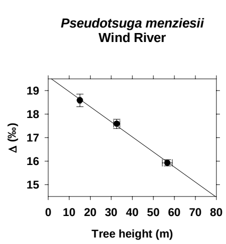


Fig. 10.5. Water use efficiency of whole peanut plants plotted against carbon isotope discrimination measured in dried leaf material. Solid symbols: well-watered plants; open symbols: water-stressed plants; Chico (□ ■); Tifton-8 (○ ●); F2 progeny of Chico × Tifton-8 (▲). (Data from Hubick et al. 1988.)

Δ Can be from short lived materials (sugars) or long term materials (tissue). It can therefore be used for making inferences about WUE at a variety of time scales

Δ Is affected by tree size – hydraulic control over Stomatal conductance?



Thanks for slide Nate McDowell