At higher PPFD levels, photosynthetic CO_2 assimilation eventually reaches a point at which CO_2 uptake exactly balances CO_2 evolution. This is called the **light compensation point**. The PPFD at which different leaves reach the light compensation point can vary among species and developmental conditions. One of the more interesting differences is found between plants that normally grow in full sunlight and those that grow in the shade (**Figure 9.7**). Light compensation points of sun plants range from 10 to 20 μmol m^{-2} s^{-1}, whereas corresponding values for shade plants are 1 to 5 μmol m^{-2} s^{-1}.

Why are light compensation points lower for shade plants? For the most part, this is because respiration rates in shade plants are very low; therefore only a little photosynthesis is necessary to bring the net rates of CO_2 exchange to zero. Low respiratory rates allow shade plants to survive in light-limited environments through their ability to achieve positive CO_2 uptake rates at lower PPFD values than sun plants.

A linear relationship between PPFD and photosynthetic rate persists at light levels above the light compensation point (see Figure 9.6). Throughout this linear portion of the light-response curve, photosynthesis is light-limited; more light stimulates proportionately more photosynthesis. When corrected for light absorption, the slope of this linear portion of the curve provides the **maximum quantum yield** of photosynthesis for the leaf. Leaves of sun and shade plants show very similar quantum yields despite their different growth habitats. This is because the basic biochemical processes that determine quantum yield are the same for these two types of plants. But quantum yield can vary among plants with different photosynthetic pathways.

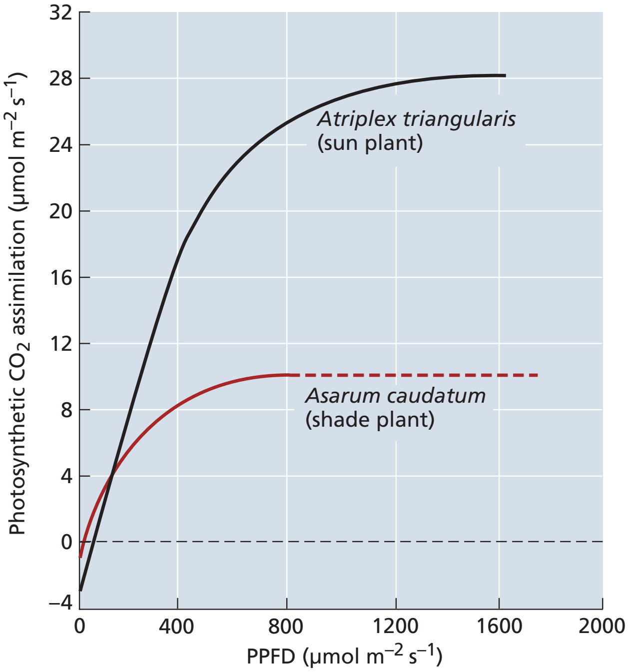

Figure 9.7 Light-response curves of photosynthetic carbon fixation in sun and shade plants. Triangle orache (*Atriplex triangularis*) is a sun plant, and wild ginger (*Asarum caudatum*) is a shade plant. Typically, shade plants have a low light compensation point and have lower maximum photosynthetic rates than sun plants. The dashed line has been extrapolated from the measured part of the curve. (After Harvey 1979.)

Quantum yield is the ratio of a given light-dependent product to the number of absorbed photons (see Equation 7.5). Photosynthetic quantum yield can be expressed on either a CO_2 or an O_2 basis, and as explained in Chapter 7, the quantum yield of photochemistry is about 0.95. However, the maximum photosynthetic quantum yield of an integrated process such as photosynthesis is lower than the theoretical yield when measured in chloroplasts (organelles) or whole leaves. Based on the biochemistry discussed in Chapter 8, we expect the theoretical maximum quantum yield for photosynthesis to be 0.125 for C_3 plants (one CO_2 molecule fixed per eight photons absorbed). But under today's atmospheric conditions (400 ppm CO_2, 21% O_2), the quantum yields for CO_2 of C_3 and C_4 leaves vary between 0.04 and 0.07 mole of CO_2 per mole of photons.

In C_3 plants the reduction from the theoretical maximum is caused primarily by energy loss through photorespiration. In C_4 plants the reduction is caused by the additional energy requirements of the CO_2-concentrating mechanism and potential cost of refixing CO_2 that has diffused out from within the bundle sheath cells. If C_3 leaves are exposed to low O_2 concentrations, photorespiration is minimized and the maximum quantum yield increases to about 0.09 mole of CO_2 per mole of photons. In contrast, if C_4 leaves are exposed to low O_2 concentrations, the quantum yields for CO_2 fixation remain constant at about 0.05 to 0.06 mole of CO_2 per mole of photons. This is because the carbon-concentrating mechanism in C_4 photosynthesis eliminates nearly all CO_2 evolution via photorespiration.

At higher PPFD along the light-response curve, the photosynthetic response to light starts to level off (see Figures 9.6 and 9.7) and eventually approaches *saturation*. Beyond the light saturation point, net photosynthesis no longer increases, indicating that factors other than incident light, such as electron transport rate, rubisco activity, or the metabolism of triose phosphates, have become limiting to photosynthesis. Light saturation levels for shade plants are substantially lower than those for sun plants (see Figure 9.7). This is also true for leaves of the same plant when grown in sun versus shade (**Figure 9.8**). These levels usually reflect the maximum PPFD to which a leaf was exposed during growth.

The light-response curve of most leaves saturates between 500 and 1000 μmol m^{-2} s^{-1}, well below full sunlight (which is about 2000 μmol m^{-2} s^{-1}). An exception to