Does Respiration Reduce Crop Yields?

James N. Siedow, Duke University, North Carolina, USA; Ian M. Møller, Aarhus University, Denmark; Allan G. Rasmusson, Lund University, Sweden

Plant respiration can consume an appreciable amount of the carbon fixed each day during photosynthesis, over and above the losses due to photorespiration. To what extent can changes in a plant’s respiratory metabolism affect crop yields?

Attempts to establish a quantitative relationship between respiratory energy metabolism and the various processes going on in the cell have led to a division of respiration into two components (Lambers 1985). In growth respiration, reduced carbon compounds are metabolized to provide energy for the addition of new biomass. The other component, maintenance respiration, is needed to keep existing, mature cells in a viable state. Utilization of energy by maintenance respiration includes protein and RNA turnover as major components, and estimates indicate that it can represent more than 50% of the total respiratory flux.

There are several empirical examples of relations between plant respiration rates and crop yield. In the forage crop perennial ryegrass (Lolium perenne), yield increases of 10% to 20% were correlated with a 20% decrease in the leaf respiration rate (Wilson and Jones 1982). Similar correlations have been found for other plants, including corn (Zea mays) and tall fescue (Festuca arundinacea) (Lambers 1985). However, later investigations have shown that "selection for low rates of mature leaf respiration is not an appropriate method to select for high-yielding cultivars in perennial grasses" (Kraus and Lambers 2001). More recently, comparisons of genotypes has shown a strong association between plant growth and differences in respiratory metabolite levels, levels of redox carriers, and respiratory rate (Meyer et al. 2007; De Block and Van Lijsebettens 2011).

Although there is a potential for increasing crop yield through reduction of respiration rates, a better understanding of the sites and mechanisms that control plant respiration is needed before such changes can be exploited commercially in a systematic fashion by plant physiologists, geneticists, and molecular biologists (Loomis and Amthor 1999). Furthermore, much remains to be learned about the general applicability of such observations and the conditions under which slower-respiring lines could be at a disadvantage, causing a reduction in crop yields rather than an increase. Also of major importance is that agricultural production is normally strongly restricted by abiotic and biotic plant stress. So, an increase in plant metabolic efficiency that would be beneficial under optimal growth conditions would instead be negative if it hampered the plant’s ability to grow under stress.
Recent studies illustrate the present difficulty of predicting the effect of directed changes at the molecular level on plant productivity:

Nunes-Nesi et al. (2005b) found that the productivity of transgenic tomato plants with a reduced activity of mitochondrial malate dehydrogenase was increased as compared to the wild type. Although the respiratory activity of mitochondria isolated from the transgenic plants was unchanged or higher than in the wild type, the rate of leaf respiration was reduced in the transgenic plants. Photosynthesis was markedly increased in the transgenic lines, possibly linked to increased levels of ascorbate.

Sieger et al. (2005) studied the effect of the alternative oxidase on the growth of tobacco cell cultures. Considering the energy-wasteful nature of the alternative oxidase (see Web Topic 12.3) one might expect that a cell line lacking the enzyme would grow faster than the wild type. Because alternative oxidase has a role in the response of plants to oxidative stress (see Web Topic 12.3 and Web Essay 12.7), a cell line lacking the alternative oxidase would also be expected to handle abiotic stress less well. The results were surprising—a transgenic cell line with a very low expression of alternative oxidase grew as fast as the wild-type cells under normal, nutrient-sufficient conditions, and faster than the wild type under conditions of macronutrient limitation (low phosphate or low nitrogen). It appears that the alternative oxidase is an important factor in modulating the growth rate in response to nutrient availability.

Giraud et al. (2008) investigated the effect of combined stresses in Arabidopsis. A mutant lacking the stress-induced alternative oxidase isoform AOX1a showed no phenotype upon drought treatment under moderate light. However, under a combination of drought and moderately high light conditions (which can easily be envisioned to take place in nature or in the field) the mutant plants were obviously stressed and displayed symptoms of elevated levels of reactive oxygen species. Since mitochondria were not the primary target of the stresses imposed, this investigation also showed how a multitude of cellular processes together enable the plant to fight external stresses.

Plant respiration involves an intricate metabolic network of interacting pathways and complex regulation of gene expression and enzymatic activities. We clearly need to know much more about these interactions before we can predict the effects of changing the expression of single genes on plant productivity. Also, when looking at carbon metabolism overall, including both photosynthetic and heterotrophic metabolism, biotechnological attempts to improve yields have resulted in relatively little progress. This has partly been the consequence of the complexity of metabolism, with perturbations leading to unexpected side effects. However, the effects of genetic changes to carbon metabolism can now be followed in detail using global profiling approaches, and this increased analytical detail aids the specific modification of carbon metabolism for improving yield (Nunes-Nesi et al. 2005a) (see also Web Essay 12.2).

Another important issue for the future is to develop plants that are well adapted for optimal functioning at a higher atmospheric carbon dioxide
concentration and its associated climate effects (higher temperatures, drought, etc.). It has been especially difficult to predict the impact of the atmospheric change (carbon dioxide and temperature) on respiration. This makes the respiratory components of predictive models for future plant growth and the plant’s impact on the future atmosphere less certain (Leakey et al. 2009; Smith and Dukes 2013).