The Impacts of Yield on Nutritional Quality: Lessons from Organic Farming

American Society for Horticultural Science Colloquium
"Crop Yield and Quality: Can We Maximize Both?"
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Abstract

A majority of well-designed studies comparing nutrient density (milligrams of a given nutrient per kilogram of food) in organically and conventionally produced fruits and vegetables show modest to moderately higher concentrations of nutrients in organic produce. Likewise, organic produce is either as flavorful, or more flavorful than conventional produce, and often tends to store better. Physiological factors that may account for these differences include the levels and form of nitrogen applied to crops, the balance of macro and micronutrients in the soil, soil quality, average cell size, glycosylation status, and concentrations of plant secondary metabolites.

I. An Easy Question

Our colloquium poses the important question – **"Crop Yield and Quality: Can We Maximize Both?"**

For the vast majority of agronomic crops and ecosystems, the answer is easy and obvious, and is "No," at least if taste and nutrient density are central to one's definition of food quality. By "nutrient density," I mean the concentration of nutrients in a given food, which is typically reported as milligrams of nutrient per kilogram of food, and may be measured and reported on a fresh or dry weight basis.

American agriculture has excelled in pushing the physiological limits of crops and farm animals through intensification of input use. Geneticists and breeders have also consistently found ways to overcome constraints to higher yields. But these dual, mutually reinforcing success stories sometimes have come at the expense of nutrient density (Davis et al., 2004; Mayer ; Mayer 1997; White et al., 2005; Zhao et al., 2007), organoleptic quality (Roth et al., 2005; Theuer 2006), the environment (Kramer et al., 2006; Reganold et al., 2001b), and in some cases plant and animal health and food

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safety (Baker et al., 2002; Benbrook 5 A.D.; Benbrook 2006a; Benbrook 2005b; Benbrook 2006b; Lu et al., 2006). The realization among agricultural scientists, and a growing number of consumers, that there are costs associated with the unilateral pursuit of higher yields is why we are here today.

Our reviews of published research[1], and the Center's ongoing work with scientists around the country, suggests that for nearly all crops and cropping systems, there is a yield plateau above which nutrient density will begin to decline in most seasons, under most growing conditions. And there are likely other yield plateaus.

The risk of plant or animal health problems increases as yields or production per animal rises. Adverse impacts on the environment often increase in step with yields and production (Kramer et al., 2006; Reganold et al., 2001b). For example, nitrogen use efficiency in corn systems typically declines as yields increase; the health, reproductive performance, and longevity of dairy cows are clearly linked inversely to production levels. High yield production systems are often more vulnerable to pests. Farmers investing in high levels of input use tend to be more risk averse in setting the pest population thresholds that trigger pesticide applications. For these reasons, pesticide use and impacts on nontarget organisms are often higher.

Much of the focus of agricultural research over the last few decades has been on pushing these yield plateaus higher, coupled with minimizing or otherwise dealing with the problems that arise when yields are pushed above one of these plateaus or thresholds. While science and technology have been remarkably successful in pushing these plateaus higher, it has not eliminated them and likely never will, for the vast majority of food produced in the great outdoors. Accordingly, we cannot maximize both yields and crop quality, when quality is defined in terms of nutrient density and taste, in addition to other important parameters like safety, freshness, and storability.

II. What is Crop Quality?

Most scientists agree that crop quality is a complex function of the nutrients in a food; the concentrations of those nutrients (i.e., nutrient density) and the forms in which they exist (particularly glycosylation status); freedom from pathogens, mycotoxins, chemical contaminates, and toxic levels of minerals or phytochemicals; and, organoleptic quality (taste, flavor, aroma, appearance, mouth feel, storage stability). No one has a monopoly on how to measure quality, the weight to place on various quality parameters, or how to deal with gaps in knowledge and data on various food quality indicators.

[1] See the State of Science Reviews and Critical Issue Reports on the Organic Center's website, www.organic-center.org.

We know that the nutritional quality of food for humans rests upon several attributes and constituents in that food, in addition to the traditional nutritional components measured (proteins, fats, carbohydrates, calories, and vitamin and mineral levels). In particular, an array of polyphenols, flavonoids, and antioxidants are clearly of great importance in promoting healthy growth, graceful aging, and in preventing disease (Barbaste et al., 2002; Beecher 2003; Brandt et al., 2004; Galati et al., 2000; Grinder-Pedersen et al., 2003; Knekt et al., 1996; Mayer ; Scalbert et al., 2000; Wang et al., 2002). But not just their levels in a particular food; the form of the nutrients in food can dramatically impact bioavailability, and the mix and balance across nutrients ingested in a given day can alter the individual and combined impacts of nutrients on a person's health.

Moreover, these impacts can vary, sometimes significantly, by age, health status, gender, and human genetics. This is why the science exploring the impacts of diet and food quality on human reproduction and development, and on disease prevalence is so inherently complex and prone to conflicting or confusing results.

The concentration of secondary metabolites in a given apple, tomato, or grain of wheat is highly variable and responsive to exogenous factors and interactions. It is increasingly clear that soil quality, the forms and levels of applied nutrients, particularly nitrogen, and farming system choices impact yields, nutrient density, antioxidant levels, and taste in reasonably consistent ways. The literature contains hundreds of reports showing that individual flavonoid or antioxidant levels can jump or fall one to three-fold as a function of the combination of genetics, soil quality, cropping systems, pest levels and pest management systems, and weather conditions.

While less frequently studied, the form of some nutrients in food also likely changes significantly as a function of the above exogenous factors and farming system choices, in some cases exacerbating impacts on nutrient density, and in other cases ameliorating them. There is much work left to do to sort out these interactions, what drives them, and how to channel them in ways that enhance food quality. To a significant degree, organic farmers and researchers working on organic farming systems are at the forefront of the quest for deeper understanding of these complex interactions.

III. What Does Organic Farming Have to Offer?

Two major factors account for the actual, and potential benefits of organic farming in enhancing food nutrient density: acceptance of somewhat lower yield goals, and improvements in soil quality that enhance plant and farm animal health.

The dominant path to higher yields on conventional farms over the last half-century has been providing higher levels of nutrients to increasingly dense plantings. Compared to most organic and lower-input conventional systems, this path has resulted in fruits, vegetables, and grains that grow relatively fast, reach a larger size at maturity, and have lower levels of at least some nutrients. The quest for higher yields has involved genetic and management interventions to trigger senescence and partition more nutrients to the setting of fruit and grain, as opposed to vegetative growth.

In many cropping systems, one result of the successful pursuit of higher yields via high-N systems is fruit and vegetables with larger average cell sizes. Larger cells contain, on average, lower concentrations of secondary plant metabolites, and cell walls that are more stretched and as a result, more permeable and vulnerable to viruses. The nutrient and antioxidant dilution often observed in high-yield, high-N systems also tends to reduce the richness and intensity of flavors, because increases in sugar content overwhelm other, more subtle flavors. This loss of flavor tends to worsen the earlier fruit is picked.

The beneficial impact of long-term organic farming on soil quality deserves special emphasis in addressing crop yield-crop quality tradeoffs. Scientists studying the impacts of organic and conventional management on yields and crop quality in two long-term trials have recently stressed soil quality as a likely driver explaining the unexpectedly positive performance of organic systems. A team at U.C. Davis has reported significant increases in flavonoid levels in organic tomatoes grown in a long-term cropping systems trial (Mitchell et al., 2007b). An Iowa State University team is reporting higher yields of organic corn and soybeans in another long-term trial (Larson 2007). The U.C. Davis team found that the longer a field was managed organically, the larger the difference in flavonoid levels in organic versus conventional fruit. They attributed this observation to the steady improvement of several soil quality indicators in the organically managed plots, coupled with changes in the levels and form of nitrogen in the organic system.

There is tantalizing, but inconclusive evidence in the literature that suggests that the yield plateau above which nutrient density declines can be increased by improving the balance and bioavailability of macro and micronutrients in the soil. Too much readily available nitrogen, from any source, clearly tends to reduce the plateaus applicable to yields and nutrient density, flavor, plant health, and environmental impacts, regardless of farming systems. Whether soil quality enhancement in conventional or organic systems will consistently and reliably increase these plateaus is an open question that is surely worth pursuing.

Two additional factors play important roles, and in some crops and ecosystems, possibly dominant roles in enhancing food and crop quality under organic management: pest levels and pest management systems, and the diversity of above- and below-ground communities of organisms. Polyphenol levels appear to be particularly sensitive to these factors in many cropping systems.

A growing body of research shows that organic farming increases the concentration of phenolics and antioxidants in food (Barbaste et al., 2002; Beecher

2003; Benbrook 2005a; Brandt et al., 2004; Galati et al., 2000; Herms 1992; Knekt et al., 1996; Mitchell et al., 2007a; Reganold et al., 2001a; Wang et al., 2002; Woese et al., 1997). Differences of 25 percent are common and some up to 300 percent have been documented (Benbrook 2005a). Soon, the Center will release a “State of Science Review” comparing vitamin, mineral, protein, and polyphenol levels in matched pairs of organic and conventionally grown foods. This report draws on a large Access database encompassing the experimental design, analytical methods, and findings of over 80 published studies. Preliminary results include higher phenolics in organic food, and were reported yesterday at this meeting by Dr. Xin Zhao (Zhao et al., 2007), who recently joined the Horticultural Sciences Department at the University of Florida. We believe our study provides a rigorous and up to date assessment of published comparison studies, and will help clarify the positive advantages of organic farming. The Center will update and refine this database, and its applications, as a core part of our work on the impacts of farming systems on nutritional quality.

We also will release next month a “Critical Issue Report” by Brian Halweil on the impacts of crop yields on nutritional quality. This report is intended for a broad audience and integrates information from several types of research into a coherent appraisal of the major and most consistent impacts of higher yields on nutrient density. In short, the report concludes as I began – with few exceptions, it is not possible to simultaneously maximize both crop yields and crop quality. But the effort to do so is ongoing and vital, and important lessons will be learned from careful, rigorous comparisons of organic and conventional farming systems.

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