ONTARIO

Phosphorus and Phytochemicals

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Phosphorus (P) has long been recognized by fruit and vegetable growers as a nutrient important for improving quality. Even in highly fertile soils, P sometimes increases the levels of health-functional phytochemicals like anthocyanins, flavonoids, and lycopene.

Phytochemicals—compounds made uniquely by plants—capture considerable media attention today, because many are linked to health benefits. Sometimes these health-functional compounds go by names such as nutraceuticals, functional food ingredients, etc.

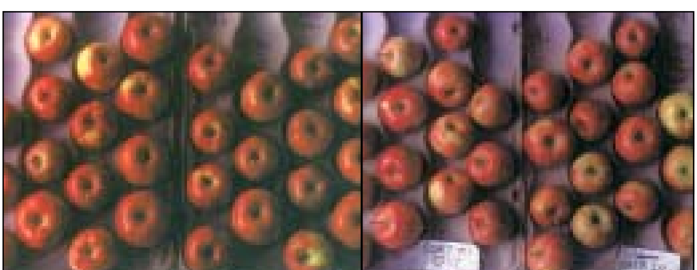
Flavonoids—such as quercetin and catechin—and isoprenoids—such as lycopene and carotene—are strong antioxidants. These phytochemicals are believed to be the principal agents in fruits, vegetables, and their processed products that impart anti-cancer properties and cardiovascular protection to humans.

Consumers are searching for foods rich in these compounds, and often look to organically produced foods or exotic herbal extracts. But the production practices that directly influence their levels in plants are not well known. We conducted research to determine the influence of adding more P than usual on the levels of phytochemicals in tomatoes and apples.

In well-nourished plants, most of the P is inorganic, stored within the cell in vacuoles. Vacuolar P keeps up a constant and rich level in the chloroplast, where biosynthesis begins. Every molecule produced comes out in a phosphorylated form—bonded to a phosphate molecule that gives it the energy it needs for further biosynthesis. It is well known that in a P deficient plant, biosynthesis is inhibited. What is less well known is whether higher levels of P stimulate higher or more specific biosynthesis of phytochemicals.

Apples

We applied P treatments to apple trees in an orchard south of Georgian Bay. The soil in this orchard was rich in P, testing 50 parts per million (ppm) Olsen-P. The grower did not normally apply P fertilizer. In 1999, red color in the apples increased in response to applied P, at rates supplying a total of 4 lb/A (foliar) and 40 to 120 lb/A (soil-applied) of P_2O_5 (**see photo**). The P treatments also increased sweetness (Brix) in both McIntosh and Red Delicious varieties, and farnesene (an aromatic flavor volatile) in Red Delicious only.



With P | Without P

Red Delicious apples at harvest in 1999, with and without soil-applied P.

However, in the McIntosh apples grown in 2000, there was no response to applied P in terms of color, anthocyanins, farnesene, or any other flavor volatiles. The 1999 season ended with warm sunny days and cool nights—conditions which can stimulate anthocyanin production. The 2000 season was more cloudy and not as cool in the nights. Weather conditions appear to influence the responses to added P.

Increased color suggests the activation of the pentose phosphate pathway, from which the precursor for flavonoids (erythrose-4-P, a four-carbon sugar) is derived. Flavonoids have been shown to protect the cardiovascular system from damaging effects of lipid peroxidation. Thus, we concluded that applying high levels of P nutrition may increase the health functionality of apples in some, but not all, weather conditions.

Tomatoes

We grew tomatoes in soils testing rich in P (30 to 50 ppm Olsen-P) at Cambridge, Ontario, in three seasons from 2000 to 2002. Treatments in all years included soil-applied P fertilizer at 45 and 150 lb P_2O_5/A, and foliar treatments supplying 16 lb P_2O_5/A in addition to the soil-applied rate of 45 lb P_2O_5/A. In two of the three years, two additional treatments included rates of zero and 260 lb P_2O_5/A.

Lycopene levels responded differently to added P each year (**Table 1**). In 2000, the year with the highest stress and poorest tomatoes, lycopene increased as the P_2O_5 rate increased to 150 lb/A but then declined at the highest rate. In 2001, the highest rate was omitted, but lycopene increased as applied P increased. In 2002, the highest yielding year, there was no response to applied P. In all years, foliar P produced intermediate levels of lycopene.

Table 1. Applying P influenced lycopene levels in tomato juice.

P applied, lb P_2O_5/A	Lycopene, ppm 2000	2001	2002
0		180 b	182 a
45	61 b	197 ab	180 a
150	77 a	221 a	173 a
260	61 b		161 a
16 (foliar)	69 ab	211 a	176 a

Values followed by the same letter within a column do not differ significantly (p=0.05).

We also measured other quality parameters in the juice and processed sauce, including Brix, acidity, vitamin C, viscosity, and flavor volatiles. Most of these were not affected significantly by applied P, but Brix followed a pattern similar to lycopene. We also found that applied P increased the levels of several anti-oxidant enzymes in 2001. We are continuing research on these enzymes.

Overall, results indicate that even in soils with high P fertility, optimum levels of P are important for tomato quality, but vary depending on the growing season. Further research may identify specific combinations of soil and foliar applications of nutrients that can optimize quality specific to the growing conditions of a particular year.

Discussion

Regulation of nutrient management appears likely to place limits on the use of P fertilizer in the near future. For many horticultural crops, growers apply considerably more P than is removed by the crop. Formal recommendations are often based on scant information and few field calibration trials. Our results and others indicate that, in general, high levels of P are necessary for good quality in fruits and vegetables, but also that excessive applications can potentially limit quality. Since both human health and risk of environmental contamination are at stake, strong research efforts to improve prediction of optimum rates of P application are justified.

The soils in these studies on apples and tomatoes represented the typical high fertility levels that most of today's growers use. If even on these soils P impacts the levels of phytochemicals, its role in soils of lower fertility is undoubtedly stronger.

Growing interest in organic farming practices is driving some producers to manage with lower inputs of soluble mineral fertilizers. A recent study in California reported higher levels of phenolics in blackberries, strawberries, and sweet corn—and higher levels of vitamin C in the latter two

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spring wheat. This same concept could apply for different nutrients and different crops. Although factors other than N can influence yield potential, the value of this approach is that N fertilizer will ultimately be applied based on the specific yield potential of each 4.3 ft^2 area and the potential responsiveness to N for each particular field.

The need to sense biological properties on a small scale was established at OSU. Current work is focusing on the evaluation of statistical properties within each 4.3 ft^2 area, understanding that the nutrient variability within this area will likely be minimal. Fortunately, the sensors developed and used in all of the OSU sensor research are capable of collecting enough data within each 4.3 ft^2 to calculate meaningful statistical estimates. Now, more importantly, these statistical estimates combined with average NDVI have been shown to be useful for mid-season yield prediction and subsequent fertilizer N rate recommendations. Using the algorithm reported earlier, we showed that winter wheat NUE was improved by more than 15% when N fertilization was based on optically sensed INSEY and the RI_{NDVI} compared to traditional practices at uniform N rates. We are not aware of any biological basis to suggest that this approach would not be suitable in other cereal crops.

The sufficiency approach that is being evaluated in the Corn Belt today and that applies fertilizer to all plots when found to be below a theoretical maximum (<95%) does not take into account yield level, or yield potential, and more importantly the quantitative responsiveness to applied N inherent in the response index.

There is ample evidence that wheat potential yield can be reliably predicted from in-season sensor measurements. Basing fertilizer N needs on projected removal (dry matter yield times known concentrations in the grain) should be encouraged since removal amounts are known to vary temporally and spatially. BC

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crops—when managed with practices other than “conventional”. However, in both of the “non-conventional” management systems evaluated, the applied nutrients included large amounts of P. Unfortunately the level of P fertilization in the “conventional” system was unknown. It is possible that the results obtained—attributed to differences among systems in pests and pesticide use—were in fact caused by differences in nutrient levels. More attention to nutrient levels is necessary when making system comparisons. BC

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