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Nutritional Quality of Organic Versus Conventional Fruits, Vegetables, and Grains

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ABSTRACT

Objectives: To survey existing literature comparing nutrient content of organic and conventional crops using statistical methods to identify significant differences and trends in the data.

Design: Published comparative measurements of organic and conventional nutrient content were entered into a database for calculation. For each organic-to-conventional comparison, a percent difference was calculated:

$$(\text{organic} - \text{conventional})/\text{conventional} \times 100.$$

For nutrients where there was adequate data, the Wilcoxon signed-rank test was used to identify significant differences in nutrient content as represented by the percent difference. Mean percent difference values were also calculated for each significant nutrient by study and by vegetable for the most frequently studied vegetables. The nutrient content of the daily vegetable intake was calculated for both an organic and conventional diet.

Results: Organic crops contained significantly more vitamin C, iron, magnesium, and phosphorus and significantly less nitrates than conventional crops. There were nonsignificant trends showing less protein but of a better quality and a higher content of nutritionally significant minerals with lower amounts of some heavy metals in organic crops compared to conventional ones.

Conclusions: There appear to be genuine differences in the nutrient content of organic and conventional crops.

INTRODUCTION

Organic foods are required in a number of alternative treatments, including several alternative cancer therapies. It is widely assumed that any benefit derived from organic foods is due to an absence of pesticide residues. However, prior to the widespread use of pesticides, those in the health care community who advocated organic foods claimed that these foods contained a better arrangement of nutrients as a result of the superior soil management and fertilization practices used by organic farmers. As a corollary, they cautioned that food grown with chemical fertilizers

War II, agricultural chemicals were virtually unused. But by 1995, more than 45 million tons of chemical fertilizers and 770 million pounds of synthetic pesticides were used in U.S. agriculture alone (Terry, 1999; Aspelin, 1999). Ninety-five percent (95%) of crops in the United States are now produced with chemical fertilizers and pesticides (U.S. Department of Agriculture, National Agricultural Statistical Service, Agricultural Statistics Board, 2000), and producing crops using these chemicals has come to be known as conventional agriculture.

There is evidence, however, that this major change in agricultural methods may not have been entirely benign from a nutritional point of view. Coincident with the changes in agricultural practices, there have been recently identified changes in the nutrient composition of fresh fruits and vegetables. Four different analyses of U.S. and British nutrient content data have shown a decline in the vitamin and mineral content of fresh fruits and vegetables over the last 60 years (Klein and Perry, 1982; Bergner, 1997; Mayer, 1997; Jack, 1998). Average declines in nutrient content are shown in Table 1.

How does agriculture affect nutrient composition? Are agricultural chemicals responsible for the decrease in nutrient content? A number of studies over the last 75 years have addressed the question of whether agricultural chemicals and other agricultural methods including organic farming affect nutrient content. The question is still unresolved in part due to the large amount of variability in agricultural data resulting from uncontrollable factors such as rainfall and sunlight, which also influence nutrient content. In addition, few existing studies are exactly alike or even very similar as there are differences in crops grown, fertilization methods used, storage methods if any, etc. These factors can make it hard to interpret data from such studies in any conclusive manner.

Nevertheless, given the relevance of this issue to both alternative medicine and to the food supply in general, it is still useful to take a broad view of the existing data. In that light, the purpose of this study is to examine all of the available comparisons of crops grown organically with those produced conventionally, using computerized and statistical methods to identify differences and trends.

TABLE 1. PERCENTAGE DECLINE IN MINERAL CONTENT OF U.S. AND BRITISH CROPS IN THE LAST SIXTY YEARS*

Mineral	*U.S. 1963–1992 (13 fruits & vegetables)*	*Britain 1936–1987 (20 fruits & 20 vegetables)*
Calcium	−29	−19
Magnesium	−21	−35
Sodium	N/A	−43
Potassium	−6	−14
Phosphorus	−11	−6
Iron	−32	−22
Copper	N/A	−81

N/A, not analyzed.
*U.S. (Berginer, 1997) and British (Mayer, 1997) data.

METHODS

This analysis used all available studies that compared crops produced with organic fertilizer or by organic farming systems to crops produced with conventional fertilizers or farming systems. This analysis focused on fertilizers either alone or within farming systems because fertility management is historically the most fundamental difference between organic and conventional agriculture. Studies of produce from research plots and greenhouses, farm-gate produce, stored produce, and produce purchased at markets were all included. Because there are insufficient data from any one of these types of studies to draw meaningful conclusions, all of the data from the various types were used.

In all, 41 studies were included. Table 2 shows the 41 studies and the nutrients that were measured in each study. These 41 studies reported the results of 22 replicated field trials, 4 simple field trials, 4 greenhouse pot experiments, 4 market basket surveys, and 8 surveys of commercial farms or home growers. For 3 studies, detailed methodology was unavailable. In the majority of studies, data were collected over a time period of several years. All unique comparative data were extracted from these 41 studies for this analysis.

A single comparison consisted of a single nutrient in a single organic fruit, vegetable or cereal grain grown in one growing season

Table 2. Studies Reviewed and Nutrients Measured in Each Study

Study	AL	Bo	Ca	Cd	Cl	Co	Cr	Cu	Fe	Hg	I	K	Li	Mg	Mi	Mn	Mo	Na	Ni	P	Pb	S	Se	Si	Vn	Zn	Ct	B1	B2	B3	B5	B6	C	E	Nt	Qn	Ql
	Nutrient																																				
Ahrens et al. (1983)																											X						X		X	X	X
Barker (1975)																																			X		
Bessenich (1946)																																	X				
Blanc et al. (1984)		X	X					X	X			X		X		X				X						X	X	X	X			X	X				
Brandt and Beeson (1951)								X	X																		X						X				
Chang and Salomon (1978)				X				X	X												X					X											
Clarke and Merrow (1979)			X						X					X				X		X						X	X						X			X	
Dlouhy (1977)																																	X			X	X
Fischer and Richter (1984)																																	X		X		
Hansen (1981)			X									X		X				X		X															X		
Harwood (1984)																																	X				
Kansal et al. (1981)								X	X							X				X						X	X						X				
Lairon et al. (1984a)			X					X	X			X		X		X				X													X		X		
Lairon et al. (1984b)			X					X	X			X		X		X		X		X															X		
Lairon et al. (1984c)			X					X	X			X		X						X															X		
LeClerc et al. (1991)			X					X	X			X		X		X				X						X	X	X	X	X	X	X	X		X		
Linder (1973)																											X										
Mader et al. (1993)			X									X		X						X															X		
Miller and Dema (1958)			X									X		X		X		X		X								X	X	X						X	X
Muramoto (1999)																																			X		
Nilsson (1979)			X									X		X						X							X						X		X		

(continued on page 164)

Table 2. Studies Reviewed and Nutrients Measured in Each Study (*continued*)

	Nutrient																																			
Study	*AL*	*Bo*	*Ca*	*Cd*	*Cl*	*Co*	*Cr*	*Cu*	*Fe*	*Hg*	*I*	*K*	*Li*	*Mg*	*Mi*	*Mn*	*Mo*	*Na*	*Ni*	*P*	*Pb*	*S*	*Se*	*Si*	*Vn*	*Zn*	*Ct*	*B1*	*B2*	*B3*	*B5*	*B6*	*C*	*E*	*Nt*	*Qn*	*Ql*
Peavy and Grieg (1972)			X						X			X		X		X		X		X						X											
Pettersson (1983)																																	X			X	X
Pfeiffer (1951)																											X										
Rauter and Wolkerstorfer (1984c)																																			X		
Reinken (1984)			X		X							X		X				X		X													X		X	X	
Schudel et al. (1979)																																	X		X		
Schuphan (1974)			X						X			X		X				X		X							X						X		X	X	X
Shier et al. (1984)															X																					X	
Smith (1993)	X	X	X	X		X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X											
Stopes et al. (1988)																																			X		
Stopes et al. (1989)																																			X		
Svec et al. (1976)			X									X		X						X													X				
Termine et al. (1984)			X					X	X			X		X		X				X															X		
Termine et al. (1987)			X					X	X			X		X		X		X		X													X		X		
Vogtmann (1984)			X					X	X					X						X													X				
Vogtmann et al. (1984)																																	X		X		
Warman and Havard (1996)														X		X		X		X																	
Warman and Havard (1997)		X	X					X	X			X		X		X		X		X		X				X	X						X	X			
Wolfson and Shearer (1981)																																				X	X
Worthington (1996)								X	X							X										X							X				

AL, aluminum; Bo, boron; Ca, calcium; Cd, cadmium; Cl, chlorine; Co, cobalt; Cr, chromium; Cu, copper; Fe, iron; Hg, mercury; I, iodine; K, potassium; Li, lithium; Mg, magnesium; Mi, minerals; Mn, manganese; Mo, molybdenum; Na, sodium, Ni, nickel; P, phosphorus; Pb, lead; S, sulfur; Se, selenium; Si, silicon; Vn, vanadium; Zn, zinc; Nt, nitrates; Qt, protein quantity; Ql, protein quality; Ct, β-carotene; B_1, vitamin B_1; B_2, vitamin B_2; B_3, vitamin B_3; B_5, vitamin B_5; B_6, vitamin B_6; C, vitamin C; E, vitamin E.

compared to the same nutrient in the same conventionally grown crop grown in the same season, e.g., 0.30 mg of zinc in 100 g of organic cabbage compared to 0.25 mg in an equal amount of conventional cabbage, both grown in the summer of 1986. Some studies reported pooled comparisons that averaged the results for more than 1 year or more than one crop. These comparisons were included in the analysis when single comparisons were not available. All comparisons were used as reported.

A total of 1,297 comparisons were considered for analysis. Of this total, 57 comparisons came from 4 studies that did not report the numerical nutrient content measurements but instead made statements such as "the products of the conventional and organic plots did not differ in content" or otherwise presented the information in a nonnumeric way (Nilsson, 1979; Harwood, 1984; Reinken, 1984; Termine et al., 1984). Because the majority of these 57 comparisons indicated no difference in nutrient content, these comparisons were excluded from determinations of statistical significance and other computations. The remaining 1,240 comparisons were entered into a database for calculation, encompassing 35 vitamins and minerals as well as protein quality and quantity.

For each comparison, a percent difference was computed as follows:

$$\frac{\text{Organic Value} - \text{Conventional Value}}{\text{Conventional Value}} \times 100.$$

These percent difference numbers indicate the percent more or less of a nutrient found in the organic crop as compared to the conventional crop. The percent difference was used to produce descriptive statistics and in tests of significance.

The statistical significance of the difference in nutrient content between organic and conventional crops was calculated for nutrients where there were adequate data. Most nutrients were measured in 3 or fewer studies and a small number of comparisons. The remaining 12 nutrients were measured in 8 or more studies with 39 or more comparisons: calcium, magnesium, potassium, sodium, zinc, copper, manganese, iron, phosphorus, vitamin C, β-carotene, and nitrates. The statistical significance of the difference was computed for these 12 nutrients using the Wilcoxon signed-rank test (Kohler, 1988).

The vegetables in which each nutrient was measured are shown in Table 3. Five vegetables were more frequently studied than other

TABLE 3. THE TWELVE MOST STUDIED NUTRIENTS AND THE VEGETABLES IN WHICH THEY WERE MEASURED

Nutrient	*Vegetables*
Calcium	Beet root, cabbage, carrot, celeriac, kale, leek, lettuce, pepper, potato, spinach, tomato, turnip, apple, pear, currant, corn, wheat
Copper	Cabbage, carrot, celeriac, leek, lentil, lettuce, pepper, potato, spinach, turnip, apple, pear, currant, barley, brown rice, corn, wheat
Iron	Cabbage, carrot, celeriac, leek, lentil, lettuce, pepper, potato, spinach, tomato, turnip, apple, pear, currant, barley, brown rice, corn, wheat
Magnesium	Beet root, cabbage, carrot, celeriac, kale, leek, lettuce, pepper, potato, spinach, tomato, turnip, apple, pear, currant, corn, wheat
Manganese	Cabbage, carrot, celeriac, leek, lettuce, pepper, potato, spinach, turnip, apple, pear, corn, wheat
Phosphorus	Beet root, cabbage, carrot, celeriac, kale, leek, lettuce, pepper, potato, spinach, tomato, turnip, apple, pear, currant, corn, wheat
Potassium	Beet root, cabbage, carrot, celeriac, kale, leek, lettuce, pepper, potato, spinach, tomato, turnip, apple, pear, corn, wheat
Sodium	Beet root, cabbage, carrot, kale, leek, lettuce, potato, spinach, tomato, turnip, apple, pear, corn, wheat
Zinc	Cabbage, carrot, celeriac, lentil, lettuce, pepper, potato, spinach, tomato, apple, pear, barley, brown rice, corn, wheat
β-carotene	Beet leaf, carrot, lettuce, spinach, tomato, corn
Vitamin C	Brussel sprouts, cabbage, carrot, celeriac, corn salad, endive, kale, kohlrabi, leek, lettuce, mangel, pepper, potato, snap beans, spinach, tomato, turnip, currant
Nitrates	Beet root, cabbage, carrot, celeriac, chard, corn salad, endive, kale, leek, lettuce, potato, radish, spinach, turnip

crops: lettuce, spinach, carrot, potato, and cabbage. The mean percent difference was also calculated for significant nutrients for each of these five vegetables.

The nutrient content of the vegetable portion of a daily menu was estimated for both an organic and a conventional diet. It was assumed that both diets met the current recommended dietary intake for vegetables and provided 5 servings of vegetables of the recommended size (U. S. Department of Agriculture, Center for Nutrition Policy and Promotion, 1995): 1 cup of raw leafy vegetables and $^1/_2$ cup of other vegetables. It was also assumed that the five most frequently studied vegetables, as listed above, were consumed. U. S. Department of Agriculture (USDA) nutrient composition data (U. S. Department of Agriculture, Agricultural Research Service, 1999) were used to estimate the nutrient content of vegetables produced with agricultural chemicals because nearly all crops in the United States are produced with these chemicals. The amount of each nutrient in each organic vegetable was estimated, using the percent difference numbers calculated for vegetables in this analysis, as follows:

$$\text{(USDA Nutrient Content Value)} \times \frac{(100 + \text{Percent Difference})}{100}$$

where the USDA value and percent difference are for the same nutrient and vegetable. The total amount of each nutrient in organic and conventional menus was calculated by summing the amounts in the five vegetables.

Data distribution plots were produced for nutrients where the difference in nutrient content was statistically significant. In order to produce a coherent visual display, average percent difference was calculated by study for these nutrients, and these results were plotted for each of these frequently studied nutrients.

Data were analyzed using SAS (SAS Institute Inc., Cary, NC) and plots were produced using NCSS (NCSS Inc., Kaysville, UT).

RESULTS

This analysis was designed to answer several questions for each nutrient considered:

1. Is there a difference in the nutrient content of organic crops and those grown with agricultural chemicals?
2. How much of the time does the difference occur?
3. How big is the difference?

These questions are representative of larger questions such as would a consumer encounter a difference often enough to be affected? And is the difference large enough to be biologically significant?

Of the 12 nutrients that were analyzed statistically, 4 nutrients and 1 toxic substance were significantly different: vitamin C, iron, magnesium, phosphorus, and nitrates. Table 4 shows

TABLE 4. NUTRIENT CONTENT OF ORGANIC VERSUS CONVENTIONAL CROPS: MEAN PERCENT DIFFERENCE, LEVEL OF SIGNIFICANCE, NUMBER OF COMPARISONS, AND NUMBER OF STUDIES FOR STATISTICALLY SIGNIFICANT NUTRIENTS

				Number of comparisons+			
Nutrient	*Mean % difference**	*Level of significance* p	*Range*	*Organic higher*	*Organic lower*	*No difference*	*No. of studies*
Vitamin C	+27.0%	<0.0001	−100%–+507%	83	38	11	20
Iron	+21.1%	<0.001	−73%–+240%	51	30	2	16
Magnesium	+29.3%	<0.001	−35%–+1206%	59	31	12	17
Phosphorus	+13.6%	<0.01	−44%–+240%	55	37	10	18
Nitrates	−15.1%	<0.0001	−97%–+819%	43	127	6	18

*Plus and minus signs refer to conventional crops as the baseline for comparison. For example, vitamin C is 27.0% more abundant in the organic crop (conventional 100%, organic 127%).

+A comparison consists of a single nutrient in a single organic crops grown in one season compared to the same conventionally grown crop from the same season, for example, 0.30 mg of zinc in organic cabbage compared to 0.25 mg of zinc in conventional cabbage, both grown in 1986.

the results for statistically significant nutrients including mean percent difference, level of significance, range of the data, the number of studies for each nutrient, and the number of comparisons where the organic crop had a higher, lower, or equal nutrient content compared to the conventional crop.

For each of the significant nutrients, the organic crops had a higher nutrient content in more than half of the comparisons. For the one toxic compound, nitrates, the organic crop had a lower content the majority of the time. This distribution of results is also evident when the results are compiled by study rather than by individual comparisons. Figure 1 shows the distribution of percent difference results by study for significant nutrients. As shown in Figure 1, most studies report a higher nutrient content or lower nitrate content in the organic crop.

The size of the difference was assessed by calculating a mean percent difference for the nutrient in question. As shown in Table 4, the organic crop has, on average, a higher content of the four significant nutrients and less of the toxic nitrates. For example, the vitamin C content of an organic fruit or vegetable is 27% more, on average, than a comparable conventionally grown fruit or vegetable. In other words, if an average conventional fruit or vegetable contained 100 mg of vitamin C, then a comparable organic one would contain 127 mg. Not too much should be made of the exact numerical differences shown in Table 4 because additional studies could influence the results a

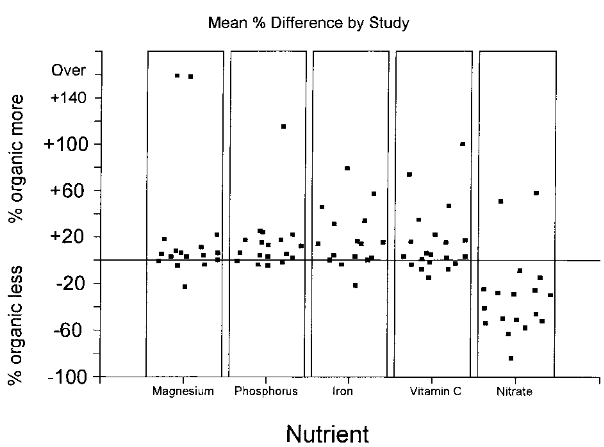

FIG. 1. Distribution of results for selected nutrients.

TABLE 5. DIFFERENCES IN NUTRITIONAL CONTENT BETWEEN ORGANIC AND CONVENTIONAL VEGETABLES: MEAN PERCENT DIFFERENCE FOR FOUR NUTRIENTS IN FIVE FREQUENTLY STUDIED VEGETABLES

	*Nutrient**			
Vegetable	*Vitamin C*	*Iron*	*Magnesium*	*Phosphorus*
Lettuce	+17	+17	+29	+14
Spinach	+52	+25	−13	+14
Carrot	−6	+12	+69	+13
Potato	+22	+21	+5	0
Cabbage	+43	+41	+40	+22

*Plus and minus signs refer to conventional crops as the baseline for comparison. For example, vitamin C is 17.0% more abundant in organic lettuce (conventional 100%, organic 117%).

few percentage points either way. However, these percent difference numbers do indicate the direction and approximate magnitude of observed differences.

The mean percent difference by nutrient was also calculated for individual vegetables. Table 5 shows the results for the five most studied vegetables. Because there are fewer studies and a smaller number of comparisons for individual vegetables than there are for the whole data set, these results reflect more of the variability that is characteristic of agricultural data. Overall, the results for individual vegetables are similar to those for the entire data set shown in Table 4.

Next, an attempt was made to quantify how these differences in nutrient content could affect a person's daily nutrient intake. Estimates of the nutrient content of the vegetable portion a daily menu were made for both an organic and a conventional diet. It was assumed that the five most frequently studied vegetables were consumed: lettuce, cabbage, spinach, carrot and potato. Table 6 shows the quantity of iron, magnesium, phosphorus and vitamin C

TABLE 6. NUTRIENT CONTENT OF AN ORGANIC AND CONVENTIONAL DIET: MILLIGRAMS OF VITAMIN C, IRON, MAGNESIUM, AND PHOSPHORUS IN ONE DAY'S VEGETABLE INTAKE

Diet	*Vitamin C (mg)*	*Iron (mg)*	*Magnesium (mg)*	*Phosphorus (mg)*
Organic	89.2	3.7	80.0	124.0
Conventional	67.9	3.0	68.6	111.8

in the vegetable portion of both organic and conventional menus.

Finally, there are several nonsignificant trends in the data that are worthy of further investigation. First, there appears to be higher amounts of nutritionally significant minerals in organic compared to conventional crops. The organic crop had a higher mean mineral content for all 21 minerals considered in this analysis. Figure 2 shows the mean percent additional mineral content in organic crops by mineral for some of these minerals. In addition, there may be less of the toxic heavy metals in organic crops than in conventional crops. For all four heavy metals considered, the organic crop contained lower amounts of the heavy metals more often than comparable conventional crops. The number of comparisons where the organic crop had less and where the conventional crop had less were 7 and 5 for lead, 6 and 5 for cadmium, 3 and 2 for mercury, and 4 and 1 for aluminum.

A further trend indicates that the quantity of protein may be less but the quality may be better in organic crops than in conventional crops. In all but one of the few measurements that were included in this analysis, the quantity of crude protein was lower in organic compared to conventional crops but the quality was better as measured by essential amino acid content. There is considerable support elsewhere for this difference in protein quantity and quality, some of which will be reviewed in the next section.

DISCUSSION

These results are in agreement with a review of predominantly German comparative literature conducted by the German government (Woese et al., 1995). The results for nitrates and protein quality and quantity agreed with the German review, which found a lower nitrate content in organic vegetables in nearly all cases, and less protein but higher quality protein in organic cereal grains. In addition, the results for vitamin C are similar to those of the German review. The Germans reported that half of the time the vitamin C content of organic and conventional crops was the same, and the other half of the time the vitamin C content was higher in the organic crop. These findings are consistent with a higher average vitamin C content in the organic crop as found in this analysis.

Further supporting evidence for the results of this analysis comes from the known effects of fertilizers and pesticides on soil ecology and plant metabolism. Before reviewing these effects, it is helpful to know something about the differences in organic and conventional fertilizers and fertility management. In organic

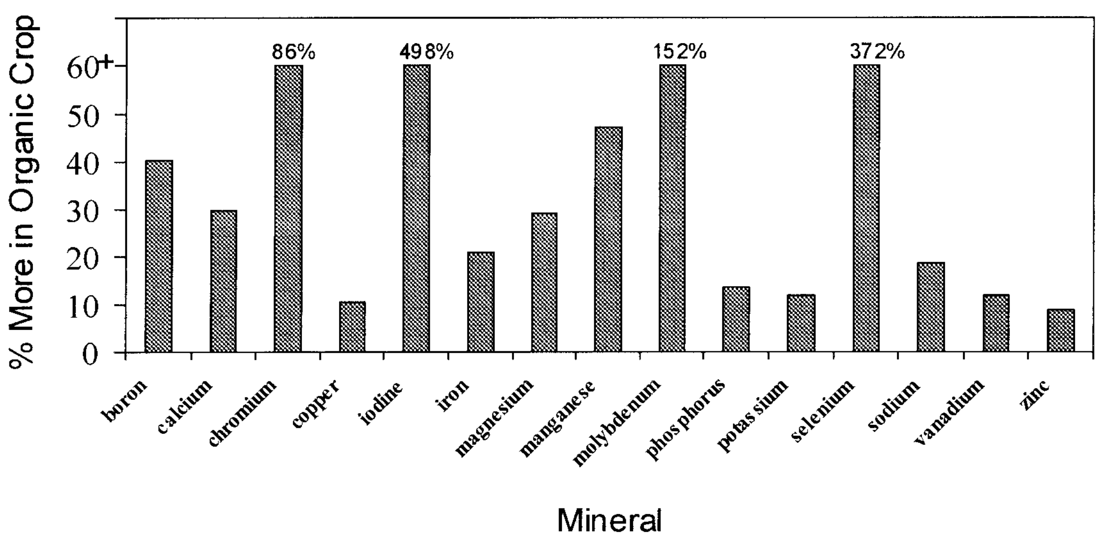

FIG. 2. Mean percent additional mineral content in organic compared to conventional crops.

farming, a number of methods are used to maintain soil fertility. These include: (1) crop rotation, which ensures that one crop does not deplete the soil of the nutrients that it uses most; (2) cover crops to protect against soil erosion; (3) the planting of special crops known as "green manures" that are plowed back into the soil to enrich it; and (4) the addition of aged animal manures and plant wastes, also known as compost, to the soil. The distinguishing feature of these fertility management practices is the addition of organic matter to the soil, in the form of plant and animal wastes, to preserve the soil structure and provide food for soil microorganisms. With these methods, soil nutrients are released slowly over time.

In contrast, chemical fertilizers contain a few mineral substances, principally nitrogen, potassium, and phosphorus. Sometimes trace minerals are also added. These fertilizers dissolve easily in the water that is present in soil. As a result, plants fertilized with chemical fertilizers are presented with large quantities of nutrients all at once, often in excess of their needs. Farmers who use chemical fertilizers control erosion of topsoil through methods such as no-till planting, where weed-killing pesticides are used in place of plowing to prepare a field for planting. With chemical fertilizers, there is no attempt to influence soil structure or to encourage soil microorganisms (Cacek and Lagner, 1986).

These differences in the management of soil fertility affect soil dynamics and plant metabolism, which result in differences in plant composition and nutritional quality. Soil that has been managed organically has more microorganisms (Hader, 1986; Henis, 1986). These microorganisms produce many compounds that help plants, including substances such as citrate and lactate that combine with soil minerals and make them more available to plant roots (Stevenson and Ardakani, 1972). For iron, in particular, this is especially important because many soils contain adequate iron but in an unavailable form (Allaway, 1975). The presence of these microorganisms at least partially explains the trend showing a higher mineral content of organic food crops.

Nitrogen from any kind of fertilizer affects the amounts of vitamin C and nitrates as well as the quantity and quality of protein produced by plants. When a plant is presented with a lot of nitrogen, it increases protein production and reduces carbohydrate production. Because vitamin C is made from carbohydrates, the synthesis of vitamin C is reduced also. Moreover, the increased protein that is produced in response to high nitrogen levels contains lower amounts of certain essential amino acids such as lysine and consequently has a lower quality in terms of human and animal nutrition. If there is more nitrogen than the plant can handle through increased protein production, the excess is accumulated as nitrates and stored predominately in the green leafy part of the plant (Salunkhe and Desai, 1988; Mozafar, 1993). Because organically managed soils generally present plants with lower amounts of nitrogen than chemically fertilized soils, it would be expected that organic crops would have more vitamin C, less nitrates and less protein but of a higher quality than comparable conventional crops.

Potassium fertilizer can reduce the magnesium content and indirectly the phosphorus content of at least some plants. When potassium is added to soil, the amount of magnesium absorbed by plants decreases. Because phosphorus absorption depends on magnesium, less phosphorus is absorbed as well. Potassium is presented to plants differently by organic and conventional systems. Conventional potassium fertilizers dissolve readily in soil water presenting plants with large quantities of potassium while organically managed soils hold moderate quantities of both potassium and magnesium in the root zone of the plant (Bear et al., 1949; Hannaway et al., 1980). Given the plant responses just described, it would be expected that the organic crops would contain larger amounts of magnesium and phosphorus than comparable conventional crops.

Several kinds of fertilizers contain toxic heavy metals that enter the soil and are absorbed by plants. Phosphate fertilizers often are contaminated by cadmium. Also, trace mineral fertilizers and liming materials derived from industrial waste can contain a number of heavy metals (Batelle Memorial Institute, 1999). These heavy metals build up in the soil when these fertilizers are used year after year. As the soil becomes more contaminated, the crops grown on these soils also become more contaminated. When chemical nitrogen fertilizers are added to these soils, plants may absorb even more toxic heavy metals (Reuss et al., 1976; Harmon et al., 1998). Organic farmers only rarely use trace mineral fertilizers and virtually never use fertilizers produced from industrial waste, which are the most contaminated (Organic Crop Improvement Association, 1996; Batelle Memorial Institute, 1999). As a consequence, it might be expected that organic crops would contain lower amounts of toxic heavy metals, but more investigation is required to confirm this expectation.

Furthermore, it is reasonable to ask how the observed differences in nutrient content might affect a person's nutrient intake and health. Estimates of the nutrient content of organic and conventional daily vegetable intake were made, and the organic vegetables had higher amounts of all nutrients shown. For vitamin C, in particular, five servings of the organic vegetables met the recommended daily intake of 75 mg for women and 90 mg for men (Krinsky, 2000) whereas the same vegetables produced conventionally failed to do so. Considering that the recommended intake for vitamin C has been raised twice in the last 30 years, it is possible that the difference seen here could have significant effects on the public health.

However, the health effects that might accrue from these differences in nutrient content have not been assessed to any extent. Animal studies suggest that such functions as reproduction and resistance to infection might be adversely affected by conventionally produced foods as compared to organically produced ones (Linder, 1973; Aehnelt and Hahn, 1978; Voghtmann, 1988; Plochberger, 1989; Velimirov et al., 1992). The one existing human study reported that the percentage of normal sperm increased as the percentage of organic food in men's diets increased (Juhler et al., 1999). Although preliminary, these findings are consistent with the results of the animal studies. Moreover, it should be noted that some of the animal studies included no pesticide usage at all so that the poorer outcome of the conventionally fed animals cannot be entirely attributed to pesticide residues. Soil factors appear to have an effect as well.

In summary, this analysis found more iron, magnesium, phosphorus, and vitamin C and less nitrates in organic crops as compared to conventional crops. In addition, there were several trends showing less protein but of a better quality, more nutritionally significant minerals, and lower amounts of some heavy metals in organic crops compared to conventional ones. More research is needed both to verify these findings and to discover relevant mechanisms in both plants and soil. As with all real-world data, there is considerable variability in agricultural measurements, making it necessary to collect and consider a lot of data in order to identify underlying patterns. Consequently, for most nutrients, there is a need for additional data collection before any further analysis is warranted. Finally, because the data collected to date suggest that there are real differences in nutrient content between organic and conventional crops, more research into the relative health effects is certainly in order.

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