Agriculture and dietary guidelines

John M. Duxbury a, *, Ross M. Welch b

a Department of Soil, Crop and Atmospheric Sciences, 235 Emerson Hall, Cornell University, Ithaca, NY 14853, USA
b USDA Plant, Soil and Nutrition Laboratory, Tower Road, Ithaca, NY 14853, USA

Abstract

Relative to USDA dietary guidelines there is a 30% deficit in vegetable production and a 100% deficit in fruit production in the US. The western US, especially California, dominates current production of both fresh and processed fruits and vegetables. Constraints in land and water resources in California suggest that some shifts in production could occur in the future if production is matched to self sufficiency. Opportunities exist for production to increase in the eastern half of the US where water is abundant, especially for processed products. Even regions with long winters, such as the northeast, could be self sufficient in fruits and vegetables. Past responses of agriculture to producing more healthy products include vegetable oils, low fat milk and greater production of poultry. Crop improvement programs have not included nutrition and health characteristics as a guiding principle and much potential to improve these traits in fruits and vegetables exists. Greater understanding of the effects of environmental and management factors on crop 'quality' is needed and strategies to produce nutritionally consistent products should be developed. © 1999 Elsevier Science Ltd. All rights reserved.

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Relative to dietary guidelines expressed in the USDA food guide pyramid, current agricultural production in the US provides a substantial surplus of sugars and oils, approximately the correct amounts of meat, milk and grains, and substantially less than needed amounts of fruits and vegetables (Fig. 1). The deficit in vegetable production is about 30% of current production, while production of fruits needs to double. These deficits reflect consumer demand rather than constraints on supply. From a resource perspective, it is clear that there are sufficient land and water resources...
in the US for agriculture to supply the current and future populations with sufficient quantities of fruits, vegetables and other food products to meet the dietary guidelines. Achieving these goals may, however, require some geographical shifts in production.

This paper focuses on fruit and vegetable production, documenting the geographic distribution of current production and evaluating constraints and opportunities to increasing production levels. Opportunities to increase the nutritional quality of a range of crop products, including fruits and vegetables, are also discussed.

Regional specialization in production

One state, California, dominates the production of both fruits and vegetables (Figs. 2 and 3) largely because its generally favorable climate and many different climatic zones allow production of a wide range of commodities throughout most of the year. However, little of this would have been possible without the tremendous public investment in supplying water for irrigation. Based on dollar value, California produces more that 70% of three of the top five fruits; 80% of the grapes, 82% of the strawberries and 71% of the peaches. Citrus, the number one fruit, is produced largely in Florida (77% of the oranges and 70% of the grapefruit) with the remainder in California. Half of the apple production, the number three fruit, is in Washington, with New York, Michigan and California all producing around 10%. On a regional basis, the west accounts for two-thirds of the value of all fruits produced in the US, followed by the southeast with 20%, then the northeast and midwest with 6% and 4%, respectively. Fruits from tropical environments cannot be grown in significant amounts in the US and these are largely imported. Bananas are the major tropical
fruit consumed in the US, but other tropical fruits, such as mangos and papayas, are becoming increasingly available and demand for these and other tropical fruits may increase in the future.

Half of the total dollar value of both fresh and processed vegetables is associated with production in California. Florida, Texas and Arizona are significant sources of fresh vegetables during the winter and spring months. These four states, together with Georgia, provide 83% of the fresh market vegetables. Similarly, 80% of the processed vegetables are grown by five states—California, Wisconsin, Washington, Minnesota and Oregon (in order of production). On a regional basis, the western states produce 58% and 63% of the fresh and processed vegetables, respectively. Southern states produce 31% of the fresh vegetables (19% in the SE and 12% in the SW) and mid-western states produce 27% of the processed vegetables; principally sweet corn and peas grown in the states of Wisconsin and Minnesota.

In the last 40 years, US agriculture has become increasingly centralized with regions specializing in the types of agriculture that they are best suited for. Consequently, the production of many foods is far from their points of consumption and their distribution is facilitated by public investment in transportation infrastructure. The interstate highway system is especially important for the transport of fruits and vegetables. Prior to the centralization of agriculture, regions and states were more self sufficient in food production and many states produced greater amounts of fruits and vegetables than they currently do. As an example, Table 1 shows changes in production of selected agricultural products in New York State. Substantial declines in the production of potatoes and apples have occurred since the beginning of the
Fig. 3. Geographic distribution of top five vegetables ($ value) grown in the US (USDA, 1998).

Table 1
Declines in production of selected agricultural products in New York State

<table>
<thead>
<tr>
<th>Crop</th>
<th>Former high (year)</th>
<th>Current production$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potatoes (10^6 cwt)</td>
<td>29 (1904)</td>
<td>7.8</td>
</tr>
<tr>
<td>Dry beans (10^6 cwt)</td>
<td>2.1 (1948)</td>
<td>0.5</td>
</tr>
<tr>
<td>Apples (10^6 bushels)</td>
<td>54 (1896)</td>
<td>26</td>
</tr>
<tr>
<td>Poultry (10^6 broilers)</td>
<td>15 (1956)</td>
<td>1.3</td>
</tr>
<tr>
<td>(10^6 layers)</td>
<td>17.5 (1944)</td>
<td>3.9</td>
</tr>
<tr>
<td>Wheat (10^6 bushels)</td>
<td>15 (1878)</td>
<td>6.5</td>
</tr>
</tbody>
</table>

$^a$Data from New York Agricultural Statistics Service (1997).
20th century, and in dry beans since the 1950s. The production of other food products, such as wheat and poultry, has also declined. The concentration of fruit and vegetable production in a few states is of course also partly driven by the marketing system of food products as supermarket chains prefer guaranteed year round supply from a few wholesalers. This leads to importation year round even when local production is more than adequate to meet the demand. A startling example of this is that 75% of the apples sold in New York City come from Washington State, California or overseas, although production of apples in the state is almost 10 times the annual consumption by New York City residents (Howard, 1995).

**Land and water resources**

The land area devoted to fruit ($3.1 \times 10^6$ acres) and vegetable crop ($3.3 \times 10^6$ acres) production in the US is only 2.5% of the cropland area (excluding hay) so, in principle, there are no land constraints to increasing the production of fruits and vegetables. Current cropland use in the US (Fig. 4) is roughly one-third for production of food grains (principally wheat plus some barley, oats, rice and rye), one-third for production of feed grains (principally corn plus some sorghum) and one-quarter for production of oil seed crops (principally soybeans, which are also used as a feed grain, plus some canola, sunflower and peanuts).

Similarly, the US has abundant renewable water resources (1500 million acre ft) of which only one-quarter is used and only 7% is used consumptively (not returned to surface waters) (USDA ERS, 1997). About 40% of renewable freshwater use is for irrigation of 53 million acres of land. Ten per cent of the water use in the US represents depletion of non-renewable groundwater resources and roughly one-third

![Fig. 4. Distribution of cropland in the US.](image-url)
of irrigated agricultural land in the US uses groundwater resources in a non-sustainable fashion—where use exceeds recharge and water tables are falling.

Although land and water resources in the US are generally abundant, there are great pressures on both of these resources in California, suggesting that this state may not be able to continually increase production of agricultural products as it has done to date. Overall land use in California (Fig. 5) is such that non-agricultural development is coming largely at the expense of farmland. It has been estimated that California will have lost one million acres of agricultural land between 1980 and 2000 (Grossi et al., 1987). Similarly, there is increasing competition for water between urban and agricultural interests. Consumptive use of water in California is more than half of the renewable water supplies under normal precipitation and often exceeds supply in drought years. The pressure on water resources has led to considerable effort to improve the efficiency of water use in agriculture for both water distribution systems and on-farm irrigation practices. Collaborations have developed between urban and agricultural users of water; for example the Metropolitan Water District (MWD) of Southern California supplied almost $240 million to the Imperial Irrigation District (IIR) to line irrigation canals with concrete and to fund implementation of on-farm water conservation measures. In return, the MWD was allowed to use the water savings (130 million m³/yr) for the next 35 years (Moody, 1993).

A major area of groundwater depletion in the US is the great plains region that utilizes water from the Ogallala aquifer. The aquifer is now being depleted at varying rates across the region and irrigation is declining in all states utilizing this resource, especially in Texas. In contrast to the western US, water resources are generally abundant in the eastern US and supplementary irrigation, which can increase yields and cover the risk of drought grew 10–20% in many eastern states between 1980 and 1990 (Bajwa et al., 1992). Water resources are somewhat constrained in the Florida Everglades, where much of the winter vegetable production in this state is
concentrated, as agriculture is being held to water supply and water quality standards (especially with respect to phosphorus) to sustain natural areas of the Everglades. However, the major problem for this area is that the organic soils (muck soils) are gradually being lost as the organic matter in the drained peat deposits is oxidized to carbon dioxide. Probably at least half of this production area will be permanently lost within the next 20 years.

It is often said that a shift in consumption from animal foods to plant foods could significantly reduce the amount of land required for agriculture as only a fraction of the food energy and nutrients in plants are recovered in animal products. However, the situation is quite complex. It is true that calculated energy efficiencies (Table 2) for various grain fed US livestock systems (food energy output/food energy input) are quite low, ranging from 6% to 27% (Reid, 1970). These calculations are valid for monogastric animals, such as poultry or swine, as these are fed grain that could be used directly by humans. But ruminant animals, such as cattle, can use forages and other plant products that humans cannot use directly and they also synthesize proteins that are better quality and more readily digestible than the plant proteins consumed. When efficiency calculations take these factors into account (food energy or protein output/energy or protein input useful for humans) values increase substantially and can be greater than 100% (Table 2) depending on the sources of feed (Oltjen and Beckett, 1996).

Nevertheless, given that 35% of US cropland is used for feed grain production, less reliance on animal products would release some land for other agricultural purposes. With an average energy conversion efficiency for grain fed animals of 10%, only 10% of the land used for feed would be necessary to produce an equivalent amount of energy in plant products for direct human consumption. A 10% reduction in consumption of animal products derived from feeding grain would reduce the land used for feed grain production by 4 million acres. Of this 0.4 million acres would be needed to generate plant products for humans and the remaining 3.6 million acres, roughly half of the land area currently used for fruit and vegetable production, would be available for other purposes. Where land constraints exist, consideration should

<table>
<thead>
<tr>
<th>System</th>
<th>Energy efficiency (%)</th>
<th>Protein efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All outputs</td>
<td>Useable outputs</td>
</tr>
<tr>
<td>All inputs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dairy farming</td>
<td>22–27</td>
<td>96–276</td>
</tr>
<tr>
<td>Pork production</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Egg production</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Chicken meat</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Beef (grainfed)</td>
<td>6</td>
<td>28–59</td>
</tr>
<tr>
<td>Beef (all)</td>
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</table>
be given to development of policies that encourage strategic use of land for food production.

**Increased production of fruits and vegetables in the eastern half of the US?**

Aside from the boundaries that climate places on production of specific crops, there are no technical barriers to increasing the production of fruits and vegetables in many mid-western and eastern states. Barriers that exist for increasing the production of fresh produce are the issues of seasonality and marketing. Increasing the production of processed products would require investment in processing plants and sufficient production to support the processing infrastructure; somewhat the chicken and the egg syndrome. A logical strategy for the future would be for western states, which are major users of increasingly scarce irrigation water, to concentrate on fresh produce and to reduce or eliminate the production of fruits and vegetables for processing as these commodities can, for the most part, be grown in regions where both land and water are more abundant. Such a strategy would maintain the almost year round supply of fresh produce while reducing pressure on limited resources. As can be seen in Fig. 3, geographic separation in the production of vegetables for fresh market and for processing has already happened to some degree, especially with sweet corn. However, 30% of the land in vegetable crop production in California is used to grow vegetables for processing, principally tomatoes.

There are, of course, usually constraints to changing production systems at the farm level as farmers are heavily invested in their current farming system. In general, it is easier to change production systems with annual crops than it is with perennial crops or animal based operations. For example, perennial fruit tree crops require a number of years after establishment before there is significant marketable product. The large investment in establishing production and harvesting and/or storage systems for such crops also makes it difficult to change if excess production capacity develops. Such a situation has arisen with sour cherry production in Michigan. This has led to the development and apparently successful marketing of cherry-burgers; pectins in the cherry enhance texture and moisturize the cherry-burger. And, it seems that cherry-dogs are next! Whether this response to an over-supply problem is viewed as innovative or ridiculous, it clearly illustrates the difficulty faced at the farm level when production capacity exceeds demand. Similarly, changes in animal based operations are becoming increasingly difficult as these operations are becoming fewer and larger; 1000+ head dairy operations and several million head chicken operations with multi-million dollar investments are now commonplace. Nevertheless, agriculture is a dynamic enterprise that has evolved and changed over time and there is no reason to suggest that it will not or should not continue to do so in the future.

**Regional self sufficiency?**

In a survey carried out in the Northeast US, 88% of consumers in the region believed that local fruits and vegetables were fresher, 60% thought they looked better
and 62% said they tasted better than products imported from elsewhere, indicating consumer preference and marketing opportunities for local produce (Wilkins et al., 1996). But can regions with long winters, such as the northeast US, be self sufficient in terms of meeting current dietary recommendations? The answer for the northeast is a qualified yes, however current production in the region is not at all oriented towards this goal. Following the USDA model, a northeast regional food pyramid based on local production has been constructed by Wilkins and Bokaer-Smith (1996). Analysis of model diets showed that adequate amounts of nutrients could be provided year round, even for ovo-lacto vegetarians, but suggests that grains should continue to be imported to the region (Wilkins and Gussow, 1997). Unfortunately, for fresh fruits and vegetables, self sufficiency would require that farmers and consumers adapt to producing and consuming a wide range of greens in the spring and vegetables that store well over the winter. Some of the winter vegetables, such as turnips, rutabagas, cabbage, parsnips, and winter squash may not be widely acceptable to consumers, while others, such as carrots, onions and potatoes are more so. Additionally, choices of fresh fruits during the winter months would be limited to apples and pears.

Agriculture is responsive to health issues

Agriculture has always been responsive to changing consumer demands and market opportunities and there are several examples related to health. Vegetable oils have now largely replaced solid saturated animal fats for cooking following the finding that mono-unsaturated vegetable oils are healthier than saturated animal fats. Canola oil is an example of an improved vegetable oil. Canola was bred from its parent, rapeseed, which contained 40% or so of erucic acid, a nutritionally undesirable long chain fatty acid, in its oil. Plant breeding reduced this to trace levels and developed a desirable mix of 18 carbon unsaturated fatty acids in the oil. In the animal product arena, reduced fat milk now accounts for more than half of the milk purchased by US consumers and new milk marketing orders are changing how milk is valued in many states by including calcium and protein contents in addition to butterfat. The production of chicken and turkey has increased substantially in response to a reduction in consumer consumption of red meat; however, this particular shift has the trade-off of requiring more feed grain production.

Opportunities to improve the nutritional value of crops

Using food groups to portray healthy diets such as is done in the food guide pyramid is an excellent concept, but our knowledge of factors relating to nutrition and health is sufficiently advanced to allow us to be more sophisticated than simply promoting different food groups. The establishment of RDI’s for a range of vitamins and minerals, the fortification of various basic food products such as flour and milk with vitamins and/or minerals, the development of a $5 billion a year vitamin and mineral supplements industry in the US and the projection that the US ‘neutraceut-
'market will become a $500 billion a year industry by 2010 (Furukawa, 1993) indicate that we should be actively seeking to improve the nutritional and health values of agricultural products. This approach has not been broadly embraced by agriculture. Instead, agriculture has measured its success in a narrow economic way, in terms of increasing production and production efficiency and not in terms of well nourished, healthy people.

Crop improvement programs for fruits and vegetables have largely been concerned with such traits as shape and size, firmness, texture, moistness, sweetness, visual appeal and, occasionally, taste. Introducing nutritional quality as a guiding principle has tremendous potential for financial gains to farmers, and health and economic benefits to individuals and society. Of course, agricultural production is only one component of a complex food system where clever product formulation and convenience have attracted large numbers of people in the US to rather unhealthy diets. Nevertheless, a proactive agriculture community in partnership with the food industry could seek to change unhealthy eating habits by developing and promoting healthy foods and healthy diets.

An excellent example of agriculture and the food industry working together is the carrots called short-cuts. These ‘baby’ carrots are actually machine cut and shaped from longer carrots that have been specially bred for:

- more uniform texture by removing the ‘woody’ yellow cortex typical of carrots
- a bright uniform orange color throughout the carrot by increasing the carotenoid content
- increased sweetness
- uniform diameter to reduce loss during processing

These carrots are truly a ‘designer crop’ that has been successfully marketed as a healthy snack food. They do not compete with ‘regular’ carrots and total consumption of carrots has increased by about 20%.

How far the agricultural sector should attempt to improve the nutritional and health values of plant foods is not clear as such efforts can take considerable time and our knowledge of interactions amongst the multitude of plant components during storage, cooking and as a function of meal composition is incomplete. There are large differences in the nutrient content of the edible parts of different plant species and genetic engineering could provide the tools to move desirable quality traits between species. But even without transgenic manipulation, more basic information is needed in order to evaluate the potential for improving the nutritional quality of plant foods and to identify manageable factors that will help to provide nutritionally consistent products. Greater knowledge is need in the following areas:

- the variation in nutrient content amongst cultivars of a given species; i.e. the genetic potential (the G factor);
- the variation in nutrient content of a given cultivar as a function of growing environment (soil type and weather), i.e. the \( G \times E \) interaction.
- the extent to which management practices affect nutrient content, i.e. the \( G \times E \times M \) interaction
- the variation in contents of promoter and anti-nutrient substances in edible plant
products as a function of $G \times E \times M$ and how they affect bioavailability of different nutrients.

Some of the possibilities and challenges for improving the nutritional quality of foods can be illustrated by a couple of examples, one with vitamins and the other with micronutrient minerals. The vitamin C content in apple cultivars grown at the same location has been shown to vary by an order of magnitude (Hansen and Bohling, 1984; Patutina et al., 1974); for a given variety it varies with both location and from year to year at the same location (Trzcinski and Vandermeer, 1975; Trzcinski and Bouckoms, 1973); and spraying trees with a calcium salt increased its content up to three-fold (Bangerth et al., 1974). Surveys of the vitamin A and C content of fruits and vegetables from different geographic regions of the US have found substantial variations indicating a need to understand controlling variables (Vanderslice and Higgs, 1991; Klein and Perry, 1984).

The possibility of improving the micronutrient mineral content of selected staple crops is currently being investigated by a consortium involving several of the CGIAR research centers (CIAT, CIMMYT, IFPRI and IRRI) and several developed country institutions (Universities of Adelaide and Copenhagen and the USDA-ARS Plant, Soil and Nutrition Laboratory, Ithaca NY). This program is aimed at providing more Fe and Zn to the world’s poorest people by targeting the foods that they have access to—rice, wheat, maize, cassava, and dry beans. However, Fe (and likely also Zn) deficiency is also widespread in the US. Surveys of collections of the germplasm base for these staple crops have shown that Fe and Zn contents vary by factors ranging from two to more than five-fold (Table 3). Several conclusions from the work with rice (R. Graham, personal communication) are:

- aromatic rice varieties have higher Fe contents than non-aromatic green revolution varieties that provide much of the world’s rice, and
- some rice varieties retain most of the Fe when milled, while others do not.

A line that has both high Fe content and high Fe retention upon milling has been identified. With dry beans, Fe in intrinsically labeled bean meal has been found to be highly available (65%) to rats across the range of Fe content (52–156 mg/kg) in

<table>
<thead>
<tr>
<th>Crop</th>
<th>Fe (mg/kg)</th>
<th>Zn (mg/kg)</th>
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<tbody>
<tr>
<td>Beans</td>
<td>34–156</td>
<td>20–63</td>
</tr>
<tr>
<td>Maize</td>
<td>7–52</td>
<td>14–36</td>
</tr>
<tr>
<td>Rice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aromatic</td>
<td>16–18</td>
<td>26–35</td>
</tr>
<tr>
<td>Non-aromatic</td>
<td>10–12</td>
<td>17–24</td>
</tr>
<tr>
<td>Wheat</td>
<td>20–59</td>
<td>16–68</td>
</tr>
</tbody>
</table>

Data for beans from CIAT, for maize and wheat from CIMMYT and for rice from IRRI
the beans. Bioavailability was unrelated to either phytic acid (range 1.3–2.3%) or tannin (range from 0.5 to 3 mg/g) contents even though these constituents are generally considered to reduce Fe bioavailability (Welch et al., 1999).

In other studies, foliar application of Zn has been shown to increase the content of Zn in wheat and rice grain two-fold, indicating that crop management practices can also be a tool to improve the nutritional quality of these grains (Duxbury, Bodruzzaman, and Welch; unpublished data). These ‘field fortification’ approaches have the potential advantage that they can be built into agricultural production systems in ways that will reliably provide nutritionally enhanced products in an easily sustainable fashion.

Although many uncertainties still exist with regard to nutrients in plants, the evidence with respect to the health benefits associated with phytochemicals is even less clear. It has been pointed out that health claims associated with a wide range of ‘beneficial’ plant products, including several antioxidants, lignin, pectins, and conjugated linoleic acid are still tenuous (Leveille, 1998). Herein lies the dilemma for agriculture that still remembers the time when nutritionists pushed for the development of high lysine corn only to find that a cheaper alternative was available after a considerable investment in breeding had been made. This ‘failure’ notwithstanding, it is clear that there are great opportunities for agriculture to make real contributions to the nutrition and health of the American public and that of the world’s people.

References


