

# Fertilizing Crops to Improve Human Health: a Scientific Review

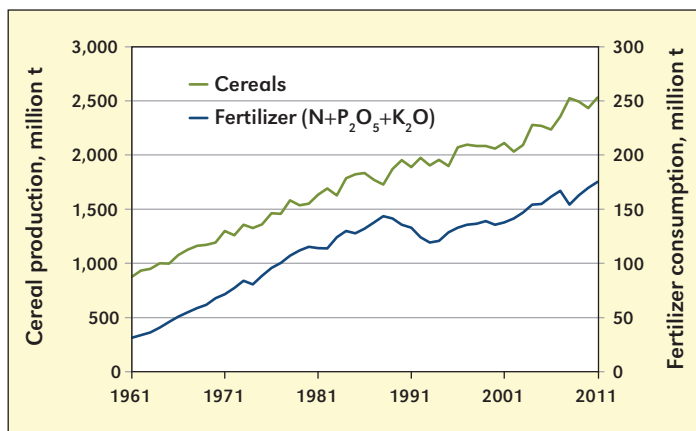
Editors: Tom Bruulsema, Patrick Heffer, Ross Welch, Ismail Cakmak, and Kevin Moran

A large proportion of humanity depends for its sustenance on the food production increases brought about through the application of fertilizers to crops. Fertilizer contributes to both the quantity and quality of the food produced. Used in the right way—applying the right source at the right rate, time and place—and on the right crops, it contributes immensely to the health and well-being of humanity.

Since 1948, the WHO has defined human health as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.” The awarding of the 1970 Nobel Peace Prize to Dr. Norman Borlaug indicates a high level of recognition of the linkage of agricultural sciences to this definition of human health. This article summarizes an upcoming joint publication from IPNI and IFA comprised of 11 chapters in three volumes described below.

## Volume 1: Food and Nutrition Security

**Food security** exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food. Nutrition security means access to the adequate utilization and absorption of nutrients in food, in order to be able to live a healthy and active life (FAO, 2009). Between 1961 and 2008, the world’s population grew from 3.1 to 6.8 billion. In the same period, global cereal production grew from 900 to 2,500 M t (**Figure 1**), with much of the growth due to the increase in world fertilizer use from 30 to over 150 M t. Without fertilizer use world cereal production would be halved (Erisman et al., 2008).



**Figure 1.** Global cereal production and total fertilizer consumption 1961-2011 (FAO 2012; IFA 2012).

By doubling the quantities of new N and P entering the terrestrial biosphere, fertilizer use has played a decisive role in making possible the access of humankind to food. However, not all have access. Chronic hunger still haunted the existence of one-sixth of the world’s people in 2009. By 2050, according to FAO, the human population would require a 70% increase in global agricultural output compared to that between 2005 and

**Common abbreviations and notes:** N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; Mn = manganese; Cu = copper; Fe = iron; Zn = zinc; I = iodine; Se = selenium; IFA = International Fertilizer Association; WHO = World Health Organization; M = million.

2007 (FAO, 2012). Future yield increases expected through genetic improvement will still depend on replenishment of nutrients removed by using all possible sources, organic and mineral, as efficiently as possible.

**Nutrition Security.** In addition to yield, plant nutrition affects other important components of human nutritional needs, including the amounts and types of carbohydrates, proteins, oils, vitamins and minerals. Many of the healthful components of food are boosted by the application of nutrients. Since most farmers already fertilize for optimum yields, these benefits are easily overlooked. Trace elements important to human nutrition can be optimized in the diet by applying them to food crops. Opportunity exists to improve yields and nutritional quality of food crops such as pulses, whose yields and production levels have not kept pace with population growth. Ensuring that such crops maintain economic competitiveness with cereals requires policies that reward farmers for producing the nutritional components of greatest importance to human health.

**Micronutrient malnutrition** has been increasing, partially as a consequence of increased production of staple cereal crops. Other micronutrient-rich crops, particularly pulses, have not benefited as much from the Green Revolution. Having become relatively more expensive, they now comprise a smaller proportion of the diets of the world’s malnourished poor. Biofortification of crops can be an effective strategy for moving large numbers of people from deficient to adequate levels of Fe, vitamin A, and Zn. The choice of genetic or agronomic approaches to biofortification depends on the micronutrient. The two approaches can also be synergistic.

In staple crops, genetic approaches are most effective for Fe and vitamin A, while agronomic approaches including fertilizers can boost the Zn, I, and Se levels in foods. While deficiencies of I and Se do not limit the growth of plants, correction of Zn deficiency can benefit both crops and consumers of crops. Fertilizing cereals with Zn and Se improves both concentration and bioavailability of these trace elements. A large proportion—49%—of soils worldwide are considered deficient in Zn (Sillanpaa, 1990). The proportion of people at risk of Zn malnourishment, while varying regionally, is also substantial (**Table 1**).

## Volume 2: Functional Foods

**Calcium, Mg, and K** are essential macro mineral nutrients for humans. The essential functions of these mineral elements in humans are similar to those in plants, with the striking exception of calcium’s major role in bones and teeth. Their content in plants is influenced by their supply in the soil. Thus, in addition to assuring optimal crop production, fertilization practices may contribute to meeting the requirements for these



**Table 1.** Global and regional estimates of the proportion of the population at risk of inadequate Zn intake (Hotz and Brown, 2004).

Region	Population at Risk, %
N. Africa and E. Mediterranean	9
Sub-Saharan Africa	28
Latin America & Caribbean	25
USA and Canada	10
Eastern Europe	16
Western Europe	11
Southeast Asia	33
South Asia	27
China (+ Hong Kong)	14
Western Pacific	22
Global	21

intake has not been defined, but only 10% of the men and less than 1% of women in the United States take in as much as or more than the adequate intake of 4.7 g/day.

**Carbohydrates, proteins, and oils.** Applying N to cereals adds to the protein they produce, as well as their yields. In rice, while N has its largest effects on yield, it can slightly increase protein and protein quality, since the glutelin it promotes has higher concentrations of the limiting amino acid, lysine, than do the other proteins it contains. In corn (maize) and wheat, protein may increase with N rates higher than needed for optimum yield, but the improvement in nutritional value may be limited by low concentrations of the essential amino acid lysine. An exception is the Quality Protein Maize developed by plant breeding: its lysine concentration remains high when more N is applied. In potatoes, N increases starch and protein concentration while P, K, and S enhance protein biological value. Oil composition of crops changes little with fertilization, though oil production is increased wherever yield-limiting nutrient deficiencies are alleviated.

Management tools that more precisely identify optimum source, rate, timing, and placement of N will help improve the contribution of fertilizer to production of healthful proteins, oils, and carbohydrates. Genetic improvements to N use efficiency may require careful attention to impact on protein quantity and quality in cereals. However, nutrient management practices such as late foliar applications or controlled-release technologies can boost N availability for protein production while keeping losses of surplus N to a minimum.

**Health-functional quality of fruits and vegetables.** Scientific evidence from numerous sources has demonstrated that judicious fertilizer management can increase productivity and market value as well as the health-promoting properties of fruits and vegetables. Concentrations of carotenoids (Vitamin A precursors) tend to increase with N fertilization, whereas the concentration of vitamin C decreases. Foliar K with S enhanced sweetness, texture, color, vitamin C, beta-carotene, and folic acid contents of muskmelons. In pink grapefruit, supplemental foliar K resulted in increased beta-carotene, and vitamin C concentrations. Several studies on bananas have reported positive correlations between K nutrition and

minerals in human nutrition. Calcium deficiencies occur in countries where diets depend heavily on refined grains or rice (e.g. Bangladesh and Nigeria). Adequate Mg intake is not easily defined, but studies suggest a significant number of adults, even in the United States, do not consume adequate amounts. Similarly, a recommended daily allowance for K

fruit quality parameters such as sugars and ascorbic acid, and negative correlations with fruit acidity.

In addition to effects on vitamins, fertilizers can influence levels of nutraceutical (health-promoting) compounds in crops. Soybeans growing on K-deficient soils in Ontario, Canada had isoflavone concentrations about 13% higher when fertilized with K. Potassium has also been reported to promote concentrations of lycopene in grapefruit and in tomatoes. Broccoli and soybeans are examples of plants that can contribute Ca and Mg to the human diet.

When crops like these are grown in acid soils of limited fertility, applying lime can boost the levels of these important minerals. The potent antioxidant pigments lutein and beta-carotene, generally increase in concentration in response to N fertilization. Together with vitamins A, C, and E, they can help lower the risk of developing age-related macular degeneration, which is one of the leading causes of blindness.

### Volume 3: Risk Reduction

**Plant disease.** In cereals deficient in Cu, ergot (*Claviceps sp.*) is an example of a food safety risk caused by a plant disease that can be controlled by application of Cu fertilizer. By immobilizing and competing for mineral nutrients, plant pathogens reduce mineral content, nutritional quality and safety of food products from plants. While many other specific diseases have known plant nutritional controls, there is a knowledge gap on the optimum nutrition for controlling the plant diseases most relevant to food safety. Managing nutrition influences diseases and their control. Strategies to reduce plant disease through plant nutrition include:

- the development of cultivars that are more effective in taking up Mn
- balanced nutrition with optimum levels of each nutrient
- attention to forms and sources suited to the crop (e.g. nitrate versus ammonium, chloride versus sulfate)
- timing, applying N during conditions favoring plant uptake and growth response
- integration with tillage, crop rotation, and soil microbes


**Farming systems.** Organic farmers apply strategies for plant nutrition that differ from those of other producers. Do these differences influence the healthfulness of the food they produce? Owing to the restricted sources for nutrient supply, organic farming cannot provide sufficient food for the current and growing population in the world. Also, because organic production systems rely heavily on ruminant animals and forage crops for the cycling of nutrients, the proportions of food types produced do not match the requirements of healthy diets. An imbalanced dietary composition can cause health problems as a result of insufficient supply of essential nutrients or excessive supply of other food constituents.

The composition of foods produced does show small changes explained by plant physiological responses to differences in N supply. Vitamin C is increased, but A and B vitamins, protein and nitrate are reduced under organic farming. Higher levels of nitrate in conventionally grown foods do not threaten and may be beneficial to human health. Despite the great interest in food quality among supporters of organic agriculture, focussing on food supply and dietary composition is most important for human health.

**Remediating radionuclides.** When soils become contaminated with radionuclides, as for example after accidents with nuclear reactors in Chernobyl or Fukushima, limiting plant uptake becomes an important goal for protecting human health. Studies on soils from the Gomel region of Belarus showed that levels of radiocaesium ( $^{137}\text{Cs}$ ) and radiostrontium ( $^{90}\text{Sr}$ ) in crops declined in response to increasing soil exchangeable K, with K applied as either fertilizer or manure. These radionuclide levels also declined with addition of dolomitic limestone, and N and P fertilizers. The involvement of rural inhabitants in processes of self-rehabilitation and self-development is a way to improve people's life quality on radioactive contaminated territories.

## Summary

The foregoing demonstrates the very large role fertilizer plays in improving crop attributes relevant to the health of humankind.

Given the important role of fertilizers in promoting food and nutritional security, it becomes all the more important to invest in research aimed at optimizing the benefits associated with their use. Research needs to support the adoption of 4R Nutrient Stewardship ensuring that the right source is applied at the right rate, at the right time, and in the right place. This concept—embraced by the fertilizer industry—defines “right” as that most appropriate for addressing the economic, social, and environmental aspects of sustainability, all three of which are critical to sustaining human health. Coupled with appropriate strategic changes to farming systems toward production of a better balance of foods to address the true nutritional needs of the human family, an emphasis on 4R Nutrient Stewardship in agronomic research and extension will enhance the benefits and minimize the potential negative impacts associated with fertilizer use. 

*T. Bruulsema is Director, IPNI Northeast North America Program (e-mail: Tom.Bruulsema@ipni.net); I. Cakmak is Professor at Sabanci*

*University, P. Heffer is Director, Agriculture Service at IFA; K. Moran is Director of Yara's Foliar and Micronutrient Competence Centre; and R. Welch is with the Robert W. Holley Center for Agricultural and Health at Cornell University.*

## Author Acknowledgment

**Volume 1:** T. Roberts and A. Tasistro - Food sufficiency: role of plant nutrition in supporting food security; H. Bouis, E. Boy, and J.V. Meenakshi - Micronutrient malnutrition: causes, prevalence, consequences and interventions; R. Welch and R. Graham - Perspectives on enhancing the nutritional quality of food crops with trace elements; G. Lyons and I. Cakmak - Agronomic biofortification of food crops with micronutrients. **Volume 2:** F. Nielsen - Calcium, magnesium and potassium in food; C. Grant and T. Bruulsema - Protein, oil and carbohydrate composition of foods; M. Oke and G. Paliyath - Fertilizer applications and nutraceutical content in health-functional foods; J. Jifon, G. Lester, W.M. Stewart, K. Crosby, D. Leskovar, and B. Patil - Fertilizer use and functional quality of fruits and vegetables; **Volume 3:** D. Huber - Plant nutrition and health risks associated with plant diseases; H. Kirchmann and L. Bergstrom - Human health issues associated with cropping systems; I. Bogdevitch, N. Mikhailouskaya, and V. Mikulich - Fertilization as a remediation measure on soils contaminated with radionuclides  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$ .

## References

- Erismann, J.W., M.A. Sutton, J. Galloway, Z. Klimont, and W. Winiwarter. 2008. *Nature Geoscience* 1:636-639.
- FAO. 2012. <http://faostat.fao.org/site/339/default.aspx> and <http://www.fao.org/worldfoodsituation/wfs-home/csdb/en/>. Verified April 2012.
- FAO. 2009. The State of Food Insecurity in the World 2009. Food and Agriculture Organization of the United Nations. [www.fao.org/docrep/012/i0876e/i0876e00.HTM](http://www.fao.org/docrep/012/i0876e/i0876e00.HTM).
- Hotz, C. and K.H. Brown. 2004. *Food Nutr Bull* 25(1): S94-204
- IFA. 2012. <http://www.fertilizer.org/ifa/HomePage/STATISTICS>. Verified April, 2012.
- Sillanpaa, M. 1990. *FAO Soils Bulletin* 63. Food and Agricultural Organization of the United Nations, Rome.



**Symposium on Fertilizing for Crop Qualities that Improve Human Health** ASA/CSSA/SSSA International Annual Meetings - Tuesday 23 October 2012

**Sponsored by:** SSSA Divisions S4 (Soil Fertility and Plant Nutrition) and S8 (Nutrient Management and Soil & Plant Analysis), International Fertilizer Industry Association (IFA), and International Plant Nutrition Institute (IPNI).

The World Health Organization defines human health as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.” Agriculture

produces foods that nourish human health. Sustainable fertilizer use must increasingly focus on the improvement of that health-sustaining role, towards a goal of healthy and productive lives for all in the context of a burgeoning world population.

We invite all participants of the ASA/CSSA/SSSA International Meetings in Cincinnati to attend this symposium, which will focus on the linkages between fertilizer use and crop attributes most closely connected to human health, exploring how the benefits can be optimized through 4R Nutrient Stewardship. 