Using Agriculture As A Tool For Better Health

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Why Does Agriculture Exist?

- To produce food and fiber and provide livelihoods to farmers and profits to the agricultural and food industries alone?
- Why do we need “food”? – Nutrients!
- Agriculture is the primary source of all essential minerals and vitamins required for human life!
- Farmers are nutrient providers!
- If food systems, based in agriculture, cannot provide all the essential nutrients in adequate quantities to sustain human life during all seasons, diseases ensue, societies suffer and development efforts stagnate.
A downward spiral that ends in death

1. Poverty and Illness

2. Inadequate Food/Inappropriate Diets

3. Malnutrition and increased susceptibility to illness

4. Sickness and loss of livelihoods

Figure from WHO, 2000
Some Major World Risk Factors Causing Deaths

Malnutrition accounts of $\approx 30$ million deaths per year (about 1 death per second)
Agricultural technologies can be directed at improving the “healthiness” of foods to meet human needs, but this require the use of
Holistic Food System Perspectives to Assure Sustainable Impact
Complexities of Food Systems

RESOURCES

- agronomic practices
- farming system diversification
- genetic improvement
- communication & education
- food-related behaviors

Production

Acquisition

Utilization

ENVIROMENTS

Economic

Biophysical

Social

Policy

HEALTH, WELL-BEING
Food Systems, Diet and Disease

• Global food systems are failing to provide adequate quantities of essential nutrients and other factors needed for good health, productivity and well being for vast numbers of people in many developing nations.

• *Green revolution* cropping systems have resulted in reduced food-crop diversity and decreased availability of many micronutrients.

• Nutrition transitions (double burden of malnutrition) are causing increased rates of chronic diseases (e.g., obesity, cancer, heart disease, stroke, diabetes, osteoporosis) in many nations.

• Holistic, sustainable improvements in the entire food system are required to solve the massive problem of malnutrition and increasing chronic disease rates in developed and developing countries.

• Agricultural systems are a major factor affecting human health
Global Food Systems’ Problems

• Agriculture’s primary focus has been on production alone, with little concern for nutritional or health-promoting qualities of products.

• Nutritionists tend to emphasize unsustainable medical approaches to solve malnutrition problems – supplements – food fortificants.

• These strategies do not address the underlying causes of malnutrition - dysfunctional food systems based in agricultural systems that do not have a goal of promoting human health.

• Simplistic views are the norm – looking for “silver bullet” approaches for solutions.

• Agriculture and human health have never been generally recognized as closely linked disciplines.
Box 1: Pathways through which agriculture may impact nutrition

Policy & Governance

Agricultural interventions/practices
- Agricultural inputs e.g. crops/animal/fish breeding, technology, fertilisers, irrigation

Impacts/outcomes related to nutrition
- Nutritional status (anthropometry and biomarkers)
  - Farmers, agricultural workers, (pregnant) women, children, infants, populations in fragile states/humanitarian crises, urban consumers, other high risk groups

Indirect impacts/intervening factors
- Health/education status & wellbeing
- Health care & education e.g. national investment in services, household practices
- Economic outcome e.g. household income, national growth

Climate & Environment

Agricultural practices e.g. cropping/horticultural/fish/animal raising practices, input use, time allocation

Food consumption & intake e.g. household food expenditure, food consumption & dietary diversity, individual food & nutrient intake & dietary diversity; infant & young child feeding practices

Food environment availability, nutrient quality, affordability, acceptability

Culture, Gender & Equity

Food value chain e.g. storage, processing, distribution, retailing

Rachel Turner blog, 2012
Early History of Agriculture-Human Nutrition Linkages in USA

- **Henry Wallace** (Sec. Agriculture, 1933-1940) & Bank Jones Act 1935
- U.S. Plant, Soil & Nutrition Laboratory (USPSNL) built in 1938 on Cornell University Campus
  - Charter - to understand the movement of nutrients from soils to plants to animals to humans to enhance the nutritional quality of agricultural products and human health
  - **Leonard Maynard** – first Director of USPSNL and Director of the School of Nutrition at Cornell University
- **Sir Albert Howard** (father of organic agriculture) - 1945
“related subjects as agriculture, food, nutrition and health have become split up into innumerable rigid and self-contained little units, each in the hands of some group of specialists. The experts, as their studies become concentrated on smaller and smaller fragments, soon find themselves wasting their lives in learning more and more about less and less. The result is the confusion and chaos now such a feature of the work of experiment stations and teaching centers devoted to agriculture and gardening. Everywhere knowledge increases at the expense of understanding. The remedy is to look at the whole field covered by crop production, animal husbandry, food, nutrition, and health as one related subject, and then to realize the great principle that the birthright of every crop, every animal, and every human being is health.” – March, 1945

“Western civilisation is suffering from a subtle form of famine – a famine of quality.”– November, 1947
**The Known 43 (51) Essential Nutrients for Sustaining Human Life**

<table>
<thead>
<tr>
<th>Air, Water &amp; Energy</th>
<th>Protein (amino acids)</th>
<th>Lipids-Fat (fatty acids)</th>
<th>Macro-Minerals</th>
<th>Trace Elements (9) (17)</th>
<th>Vitamins (13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(3)</td>
<td>(9)</td>
<td>(2)</td>
<td>(7)</td>
<td>(9) (17)</td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td>Linoleic acid</td>
<td>Na</td>
<td>Fe</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>Linolenic acid</td>
<td>K</td>
<td>Zn</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>Carbohydrates</td>
<td></td>
<td>Ca</td>
<td>Cu</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>Histidine</td>
<td></td>
<td>Mg</td>
<td>Mn</td>
<td>K</td>
<td></td>
</tr>
<tr>
<td>Isoleucine</td>
<td></td>
<td>S</td>
<td>I</td>
<td>C (Ascorbic acid)</td>
<td></td>
</tr>
<tr>
<td>Leucine</td>
<td></td>
<td>P</td>
<td>F</td>
<td>B1 (Thiamin)</td>
<td></td>
</tr>
<tr>
<td>Lysine</td>
<td></td>
<td>Cl</td>
<td>Se</td>
<td>B2 (Riboflavin)</td>
<td></td>
</tr>
<tr>
<td>Methionine</td>
<td></td>
<td></td>
<td>Mo</td>
<td>B3 (Niacin)</td>
<td></td>
</tr>
<tr>
<td>Phenylalanine</td>
<td></td>
<td></td>
<td>Co (in B12)</td>
<td>B5 (Pantothenic acid)</td>
<td></td>
</tr>
<tr>
<td>Threonine</td>
<td></td>
<td></td>
<td>Cr</td>
<td>B6 (Pyrooxidine)</td>
<td></td>
</tr>
<tr>
<td>Tryptophan</td>
<td></td>
<td></td>
<td>Si</td>
<td>B7/H (Biotin)</td>
<td></td>
</tr>
<tr>
<td>Valine</td>
<td></td>
<td></td>
<td>B</td>
<td>B9 (Folic acid, folacin)</td>
<td></td>
</tr>
</tbody>
</table>

*Numerous other beneficial substances in foods are also known to contribute to good health.*
The Ugly Face of Micronutrient Malnutrition

Zinc Deficiency
Vitamin A Deficiency
Iodine Deficiency
Ca Deficiency
Iron Deficiency
Rickets
Micronutrient Malnutrition
Causes....

• More severe illness
• More infant and maternal deaths
• Lower cognitive development
• Stunted growth
• Lower work productivity

And ultimately -

• Lower GDP (e.g. an estimated >5% annual loss in Pakistan)
• Higher population growth rates
Worldwide Prevalence of Anemia (i.e., Fe Deficiency) in Pregnant Women

Over 2 billion iron deficient people

(WHO, 2008)
Over 800 million afflicted

WHO (2004)
Countries categorized by degree of public health importance of vitamin A deficiency

April 1995

> 200 million children afflicted
Link Between Zn-Deficient Soils (Crops) & Zn Deficiency in Humans

Wide Deficiency – 
Medium deficiency –

> 1 billion people

Zn-Deficient Crops
Zn-Deficient Humans

Figure from A. Green, 2009
Some Other Known Human Micronutrient Deficiency Problems

- Selenium deficiency
- Scurvy (vitamin C deficiency)
- Beriberi (thiamine/B$_1$ deficiency)
- Rickets (both vitamin D & Ca deficiencies)
- Pernicious Anemia (cobalamine/B$_{12}$ deficiency)
- Folic acid deficiency
Effects of Eating Starchy Staple Crops on Stunting in Children

Percentage of children under five years of age who are stunted

Share of average dietary energy supply derived from cereals, roots and tubers

FAO, 2013
Percentage Change in Crop Nutrients at Elevated [CO$_2$] Relative to Ambient [CO$_2$]

Myers et al., Nature 2014
Effects of Elevated CO$_2$ on Elements in C3 plants

Loladze, *eLife* 2014
Change in The Prevalence of Iron Deficiency Globally

Data from WHO, 2002
Dietary Iron Density and % Anemic Women in S. Asia

Dietary Iron Density (mg Fe per kcal)

% Anemic Women (below 12g/dL blood)

South Asia

Dietary Iron Density

% Anemic Women

Year

Most Important Food Crops Globally

rice + wheat + maize = 56%

Comparative Nutritional Quality of Fonio to White Rice

- Very high biological value of protein; rich in methionine and cystine
- Rich in minerals
- One of the world's best tasting cereals
- World's fastest maturing cereal

Data from National Research Council, NAS, 1996
Historical Trends in Fe & Zn in Grain of Hard Red Winter Wheat Varieties in USA (1873 to 2000)

(From Garvin et al., J. Sci. Food Agr. 2006)
% Changes in Cereal & Pulse Production & in Populations Between 1965 & 1999

(FAO data, 1999)
# Micronutrients in Whole Cereal Grains and Legume Seeds (Pulses)

<table>
<thead>
<tr>
<th>Plant Food</th>
<th>Fe</th>
<th>Zn</th>
<th>Mn</th>
<th>Cu</th>
<th>Mo</th>
<th>Cr</th>
<th>Ni</th>
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<tbody>
<tr>
<td></td>
<td>(µg g⁻¹ dry weight)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cereals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brown rice</td>
<td>20</td>
<td>14</td>
<td>11</td>
<td>2.4</td>
<td>0.78</td>
<td>0.088</td>
<td>-</td>
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<tr>
<td>Whole soft wheat</td>
<td>39</td>
<td>22</td>
<td>35</td>
<td>4.5</td>
<td>-</td>
<td>0.370</td>
<td>0.31</td>
</tr>
<tr>
<td><strong>Legumes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mung bean</td>
<td>87</td>
<td>41</td>
<td>14</td>
<td>13.0</td>
<td>3.20</td>
<td>0.251</td>
<td>2.04</td>
</tr>
<tr>
<td>Black gram</td>
<td>139</td>
<td>36</td>
<td>19</td>
<td>7.9</td>
<td>0.16</td>
<td>0.530</td>
<td>3.43</td>
</tr>
<tr>
<td>Cowpea</td>
<td>67</td>
<td>45</td>
<td>16</td>
<td>6.3</td>
<td>1.47</td>
<td>0.272</td>
<td>3.44</td>
</tr>
<tr>
<td>Soybean</td>
<td>97</td>
<td>43</td>
<td>26</td>
<td>15.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Red kidney bean</td>
<td>64</td>
<td>30</td>
<td>12</td>
<td>6.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
## Effects of Polishing and Milling on Rice Grain Micronutrient Concentrations

<table>
<thead>
<tr>
<th>Micronutrient</th>
<th>Brown Rice</th>
<th>Polished Rice</th>
<th>% Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron (mg kg(^{-1}))</td>
<td>20</td>
<td>5</td>
<td>75</td>
</tr>
<tr>
<td>Copper (mg kg(^{-1}))</td>
<td>3.3</td>
<td>2.9</td>
<td>12</td>
</tr>
<tr>
<td>Manganese (mg kg(^{-1}))</td>
<td>17.6</td>
<td>10.9</td>
<td>62</td>
</tr>
<tr>
<td>Zinc (mg kg(^{-1}))</td>
<td>18</td>
<td>13</td>
<td>30</td>
</tr>
<tr>
<td>Biotin (μg kg(^{-1}))</td>
<td>120</td>
<td>50</td>
<td>58</td>
</tr>
<tr>
<td>Folic Acid (μg kg(^{-1}))</td>
<td>200</td>
<td>160</td>
<td>20</td>
</tr>
<tr>
<td>Niacin (mg kg(^{-1}))</td>
<td>47</td>
<td>16</td>
<td>66</td>
</tr>
<tr>
<td>Pantothenic Acid (mg kg(^{-1}))</td>
<td>20</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Riboflavin (mg kg(^{-1}))</td>
<td>0.5</td>
<td>0.3</td>
<td>40</td>
</tr>
<tr>
<td>Thiamin (mg kg(^{-1}))</td>
<td>3.4</td>
<td>0.7</td>
<td>80</td>
</tr>
<tr>
<td>Vitamin B(_6) (mg kg(^{-1}))</td>
<td>6.2</td>
<td>0.4</td>
<td>94</td>
</tr>
<tr>
<td>Vitamin E (IU kg(^{-1}))(^{b})</td>
<td>20</td>
<td>10</td>
<td>50</td>
</tr>
</tbody>
</table>

\(^{a}\)Dry weight basis.

\(^{b}\)IU = International Unit.
## Copenhagen Consensus 2008 Global Challenges

### Ranked Top Five World Challenges

<table>
<thead>
<tr>
<th>SOLUTION</th>
<th>CHALLENGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Micronutrient supplements for children (vitamin A and zinc)</td>
<td>Malnutrition</td>
</tr>
<tr>
<td>2  The Doha development agenda</td>
<td>Trade</td>
</tr>
<tr>
<td>3  Micronutrient fortification (iron and salt iodization)</td>
<td>Malnutrition</td>
</tr>
<tr>
<td>4  Expanded immunization coverage for children</td>
<td>Diseases</td>
</tr>
<tr>
<td>5  Biofortification</td>
<td>Malnutrition</td>
</tr>
</tbody>
</table>

### Malnutrition and Hunger

The expert panel examined the following solutions to this challenge: micronutrient supplementation (Vitamin A and Zinc), micronutrient fortification (iron and salt iodization), biofortification (agricultural improvements through research and development), de-worming (which also improves education), and nutritional education campaigns. The panel ranked solutions to this challenge very highly, because of the exceptionally high ratio of benefits to costs. Micronutrient supplements were the top-ranked and fortification was the third-ranked solution, with tremendously high benefits compared to costs.
G-8 Action on Food Security and Nutrition
($3 billion pledged; May 18, 2012)

To improve nutritional outcomes and reduce child stunting, the G-8 will:

- Actively support the Scaling Up Nutrition movement and welcome the commitment of African partners to improve the nutritional well-being of their populations, especially during the critical 1,000 days window from pregnancy to a child’s second birthday.

- We pledge that the G-8 members will maintain robust programs to further reduce child stunting.

- Commit to improve tracking and disbursements for nutrition across sectors and ensure coordination of nutrition activities across sectors.

- Support the accelerated release, adoption and consumption of bio-fortified crop varieties, crop diversification, and related technologies to improve the nutritional quality of food in Africa.

- Develop a nutrition policy research agenda and support the efforts of African institutions, civil society and private sector partners to establish regional nutritional learning centers.
What Farmers Require to Grow More Nutritious Crops

Provide them the knowledge and tools needed to grow more nutrient-dense crops allowing increased nutrient output of farming systems.

Provide the tools needed to prove their crops are more nutritious and healthy such as analytical services for testing crops for nutrients (e.g., minerals, vitamins) and health promoting substances (e.g. antioxidants).

Provide incentives to attract more farmers into growing “health” promoting crops (e.g., Norway).

Make it profitable.
Agricultural Approaches to "Healthier" Food Crops

- Field Site Selection – (e.g., soils high in Se, Zn, etc.)
- Agronomic Practices
  - macronutrient fertilizers
    - nitrogen, phosphorus, potassium, sulfur, calcium, magnesium
    - effects protein, fats, vitamins, antinutrients, etc.
  - micronutrient & trace element fertilizers
    - Zn, Se, Co, Ni, I, Mo, Li, Cl - effective in increasing amount in plant seeds and grains
    - Fe, Cu, Mn, B, Cr, V, Si - not very effective in increasing seed or grain levels
- farming system (no-till, organic matter, soil amendments)
- Cropping systems – design to maximize nutrient output
  - crop rotations - effects micronutrient content
  - use nutrient-dense varieties of food crops (HarvestPlus)
  - diversification – soil health and human health
- Utilize indigenous plant foods and diversify food systems
- Genetically modify food crops to improve nutrient output and the “healthiness” of crops from farming systems
P & Zn Fertilizer Effects on Zn Levels in Pea Seeds
Effects of Crop Rotations on Wheat Grain-Cu

Effects of Maize Intercropping on Fe Deficiency in Peanuts

Mono-cropping  Intercropping

(Zuo et al., Plant and Soil, 2000)
Effect of Intercropping (Maize-Peanut) on Fe Levels in Peanuts

(Zuo et al., Plant and Soil, 2000)
Farming Benefits of Micronutrient Element-Enriched Seeds (e.g. Zn)

- Better seed viability
- Greater seedling vigor
- Denser stands (less soil erosion)
- Lower seeding rates (lower cost to farmers)
- Larger root absorptive surface (better water & nutrient use efficiency)
- Better resistance to disease
- Better plant survival
- Increased plant & seed yield
- Improved livestock health
## Impact of Micronutrient Enriched Wheat Grain on Seedling Performance in 9 Farmers’ Fields

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Seed Type</th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Enriched</td>
<td>Control</td>
<td>Farmer</td>
</tr>
<tr>
<td>Seedling Emergence- %</td>
<td>78</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>Biomass @ 30 days - mg</td>
<td>9.7</td>
<td>7.8</td>
<td>6.9</td>
</tr>
<tr>
<td>Root Health Grade b</td>
<td>2.8</td>
<td>3.9</td>
<td>4.3</td>
</tr>
</tbody>
</table>

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*a* Unenriched seed grown at the same time as the enriched seed  
*b* On a 1-9 scale, where 1 is best and 9 is worst

Data from John Duxbury
Effects of Micronutrient-Enriched Seed on Wheat (Kanchan) Grain Yields from Farms in Bangladesh

24% > in grain yield (0.69 t/ha) seen on 47 farms over 4 years.

(Data from Duxbury et al., unpublished data)
Se Map of 48 U.S. States

- **Low** - approximately 80% of all forage and grain contain 0.05 mg kg⁻¹ of Se.
- **Variable** - approximately 50% contains > 0.1 mg kg⁻¹ of Se.
- **Adequate** - 80% of all forages and grain contain > 0.1 mg kg⁻¹ of Se.
- Local areas where Se accumulator plants contain > 50 mg kg⁻¹ of Se.

Map developed by Drs. Joe Kubota & William H. Allaway
Using the Selenium Fertilizer Tool to Improve Selenium Status of the Finish People

Adding Se to fertilizers greatly > Se in cereal grain

Adding Se to fertilizers greatly > Se eaten each day

Resulted in a doubling of the blood-Se levels in the whole Finish population

From: Combs, 2005
Effects of Zinc Fertilization on Wheat Yield & Grain Level

<table>
<thead>
<tr>
<th>Zn application methods</th>
<th>Zn concentration (mg kg⁻¹)</th>
<th>Increases in yield by Zn Fertilizer (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Whole shoot</td>
<td>Grain</td>
</tr>
<tr>
<td>Control</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Soil</td>
<td>19</td>
<td>18</td>
</tr>
<tr>
<td>Seed</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Foliar</td>
<td>60</td>
<td>27</td>
</tr>
<tr>
<td>Soil + foliar</td>
<td>69</td>
<td>35</td>
</tr>
<tr>
<td>Seed + foliar</td>
<td>73</td>
<td>29</td>
</tr>
</tbody>
</table>

Using both soil and foliar Zn fertilizers can maximize grain yields and grain-zinc

Yilmaz et al., 1997
Food Systems Approach to IDD

Effects of Iodination of Irrigation Water
Long Ru, China

Importantly, also ≈ 30% increase in livestock productivity!
Using iodized salt can not achieve this benefit.
The root cause of I deficiency is not enough I in the soil!

Data from Cao, et al., 1994
Biofortification - an Additional Weapon to Fight Malnutrition

Supplementation

Commercial Fortification

Dietary Diversity

“Biofortification”
HarvestPlus
Program Strategy

Develop micronutrient dense staple crops using the best traditional breeding practices and modern biotechnology to achieve provitamin A, iron, and zinc concentrations that can have measurable effects on nutritional status of target populations (i.e., the poorest of the poor)
Congratulations to Dr. Howarth Bouis

2016 WORLD FOOD PRIZE LAUREATE

For his pioneering work to end global hunger and malnutrition by developing micronutrient-rich crops through biofortification.
Where Biofortification Started In 1993

Robin Graham, Ross Welch & Howdy Bouis
U.S. Plant, Soil & Nutrition Laboratory
Cornell University
Biofortification Strategies

- Plant Breeding
- Agronomic tools
- Genetic Engineering
Advantages of Biofortification

• Targets the poor who eat high levels of food staples
• Rural-based: where 75% of the malnourished populations live
• Cost-effective: research at a central location can be multiplied across countries and time
• Sustainable: investments are front-loaded, low recurrent costs
Questions for Success

• Can breeding increase nutrient levels to high enough levels to have health impacts?

• Will the extra nutrients be absorbed at sufficient levels to improve micronutrient status?

• Will farmers adopt and will consumers buy/eat in sufficient quantities?
Agriculture’s Agenda For Better Health

Item 1: Declare a goal of agriculture to produce high quality food that promotes human health and well-being in sustainable ways.

Item 2: Design seeds, cropping, livestock & aquiculture systems that help achieve primary goal—design for maximum bioavailable nutrient output of farming systems.

Item 3: Genetically modify food crops, increasing nutritional and health while promoting crop productivity.

Item 4: Use agronomic practices (e.g., cropping systems and fertilizers) to improve nutrient output of farming systems.

Item 5: Define sustainable agriculture, as agriculture that yields “healthy foods” for healthy and productive people!