Link Between the Application of Micronutrients to Crops and Human Health

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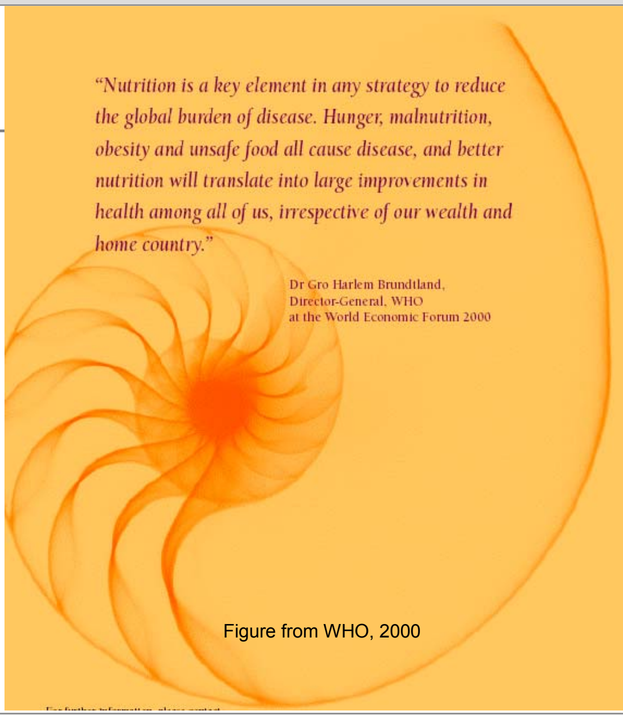


Figure from WHO, 2000

A downward spiral that ends in death

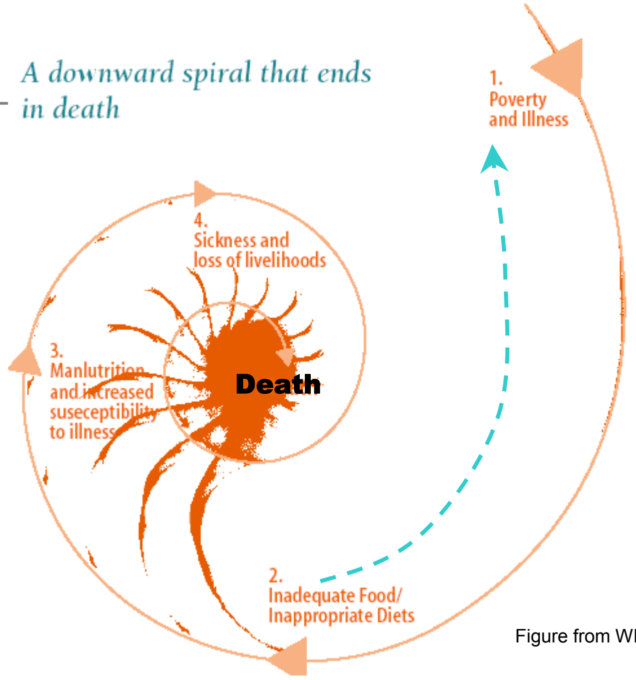
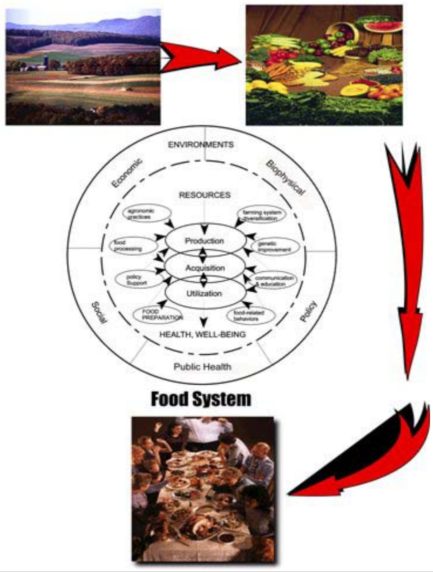


Figure from WHO, 2000



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



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 micronutrients.
- Nutrition transitions are causing increased rates of chronic diseases (cancer, heart disease, stroke, diabetes, osteoporosis) in many developing 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.
- How can agriculture contribute to sustainable solutions?

Global Food Systems' Problems

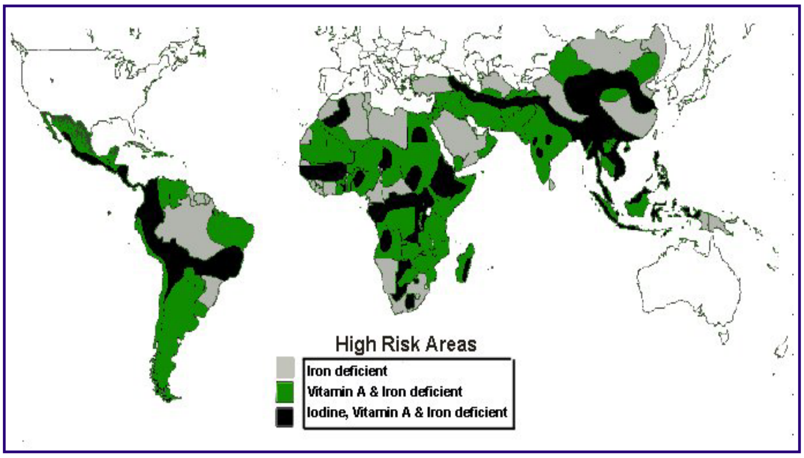
- Agriculture's primary focus is on production alone, with little concern for nutritional or health-promoting qualities.
- Nutritionists tend to emphasize unsustainable medical approaches to solve malnutrition problems
  - supplements
  - food fortificants
- Simplistic views are the norm – looking for "silver bullet" approaches for solutions

The Known 50 Essential Nutrients for Sustaining Human Life*

Water & Energy (2)	Protein (amino acids) (9)	Lipids-Fat (fatty acids) (2)	Macro-Minerals (7)	Micro-Elements (17)	Vitamins (13)
Water	Histidine	Linoleic acid	Na	Fe	A
Carbohydrates	Isoleucine	Linolenic acid	K	Zn	D
	Leucine		Ca	Cu	E
	Lysine		Mg	Mn	K
	Methionine		S	I	C (Ascorbic acid)
	Phenylalanine		P	F	B_1 (Thiamin)
	Threonine		Cl	B	B_2 (Riboflavin)
	Tryptophan			Se	B_3 (Pantothenic acid)
	Valine			Mo	Niacin
				Ni	B_6 (Pyridoxal)
				Cr	Folate
				V	Biotin
				Si	B_{12} (Cobalamin)
				As	
				Li	
				Sn	
				Co (in B_{12})	

*Numerous other beneficial substances in foods are also known to contribute to good health.

Global Micronutrient Deficiencies



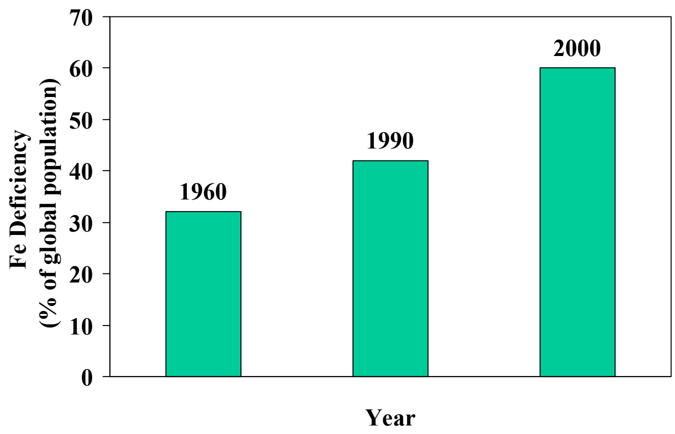
> 3 billion people afflicted

(Map from USAID)

Iron Deficiency Anemia

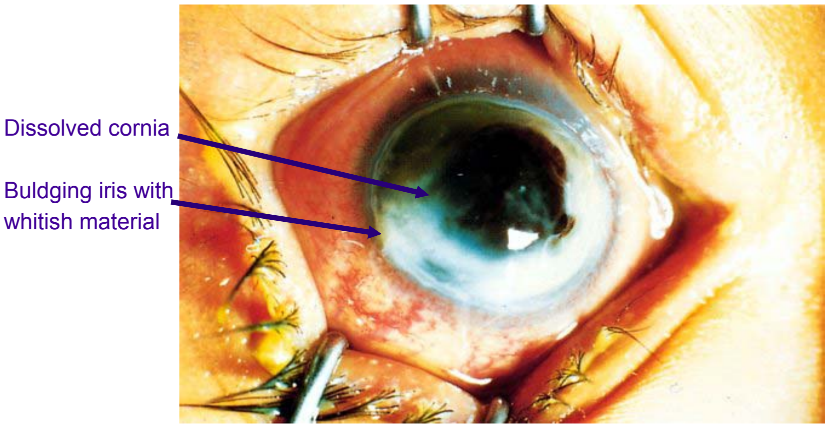
Picture from World Health Organization

Change in Prevalence of Iron Deficiency Globally

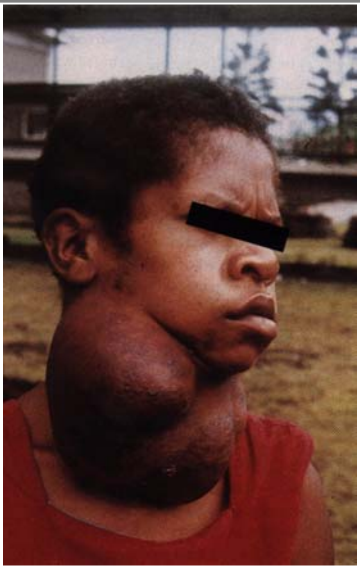


Data from WHO, 2002

Vitamin A Deficiency in a 3-year-old Indonesian Child



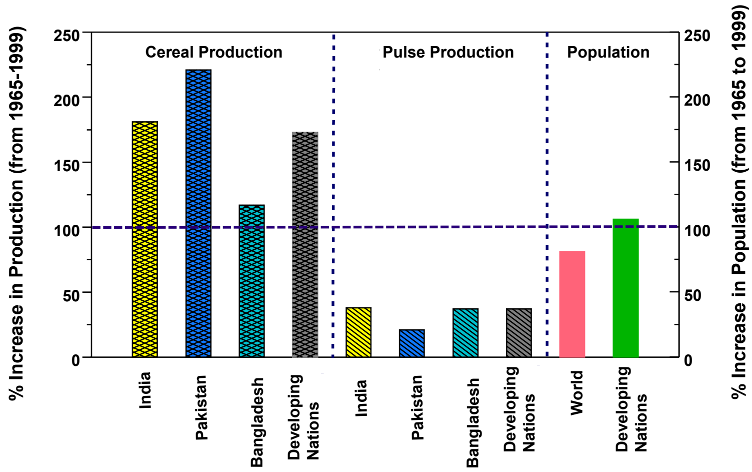
Iodine Deficiency Goiter



Calcium Deficiency Rickets in Bangladeshi Children

New disease in Bangladesh; also reported in Nigeria

% Changes in Cereal & Pulse Production & in Populations Between 1965 & 1999



(FAO data, 1999)

Micronutrients in Whole Cereal Grains and Legume Seeds (Pulses)

	Plant Food	Fe	Zn	Mn	Cu	Mo	Cr	Ni
		($\mu g\ g^{-1}$ dry weight)						
Cereals	Brown rice	20	14	11	2.4	0.78	0.088	-
	Whole soft wheat	39	22	35	4.5	-	0.370	0.31
Legumes	Mung bean	87	41	14	13.0	3.20	0.251	2.04
	Black gram	139	36	19	7.9	0.16	0.530	3.43
	Cowpea	67	45	16	6.3	1.47	0.272	3.44
	Soybean	97	43	26	15.5	-	-	-
	Red kidney bean	64	30	12	6.8	-	-	-

Effects of Polishing and Milling on Rice Grain Micronutrient Concentrations[a]

Micronutrient	Brown Rice	Polished Rice	% Removed
Iron ($mg\ kg^{-1}$)	20	5	75
Copper ($mg\ kg^{-1}$)	3.3	2.9	12
Manganese ($mg\ kg^{-1}$)	17.6	10.9	62
Zinc ($mg\ kg^{-1}$)	18	13	30
Biotin ($\mu g\ kg^{-1}$)	120	50	58
Folic Acid ($\mu g\ kg^{-1}$)	200	160	20
Niacin ($mg\ kg^{-1}$)	47	16	66
Pantothenic Acid ($mg\ kg^{-1}$)	20	10	50
Riboflavin ($mg\ kg^{-1}$)	0.5	0.3	40
Thiamin ($mg\ kg^{-1}$)	3.4	0.7	80
Vitamin B_6 ($mg\ kg^{-1}$)	6.2	0.4	94
Vitamin E ($IU\ kg^{-1}$)[b]	20	10	50

[a]Dry weight basis.
[b]IU = International Unit.

(Data from Lockhart & Nesheim, 1978)

Agricultural Approaches to "Healthier" Plant Foods

- **Field Site Selection**
- **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 effective in increasing seed or grain levels**
- **Cropping systems**
  - **legume-cereal rotations -effects micronutrient content**
  - **use micronutrient-dense varieties of food crops**
  - **increase production of vegetables, fruits, & legumes**
- **Utilize indigenous plant foods and diversify food systems**
- **Genetically modify food crops to improve nutrient output of farming systems**

Effects of Zn Fertilization on Yield & Zn Concen. of Wheat Grain

Zn Treatment (mg/kg soil)	Grain yield (g/plant)	Zn concen. (mg/kg)
0	1.00	9.1
0.05	2.20	9.9
0.2	2.24	14
0.8	2.51	83
3.2	1.70	145

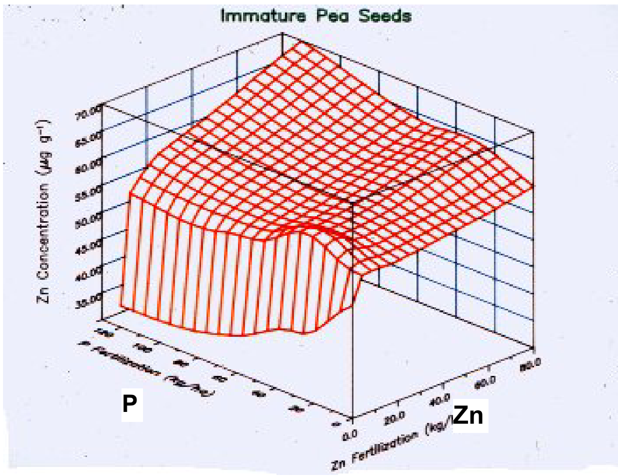
Data from Rengel et al. (1999)

Effects of Zn Application Method on Wheat Grain-Zn

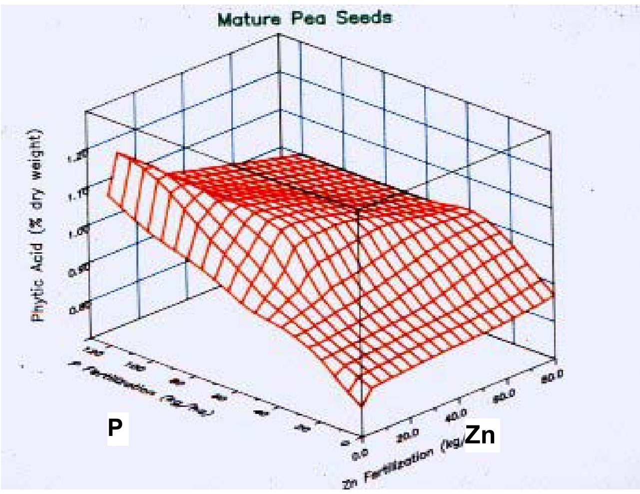
	Variety Gerek-79	Variety Bezostaja-1	Variety Gerek-79	Variety Bezostaja-1
Treatment	Yield (t/ha)	Yeild (t/ha)	Zn (mg/kg)	Zn (mg/kg)
Control	0.74	0.81	9	10
Soil appli.	2.70	2.34	17	17
Seed appli.	2.05	1.96	11	8
Foliar appli.	1.47	1.55	30	28
Soil + foliar	2.71	2.33	34	38
Seed + foliar	2.77	2.38	34	25
LSD (5%)	0.45	0.74	6	9

Data from Yilmaz et al. (1997)

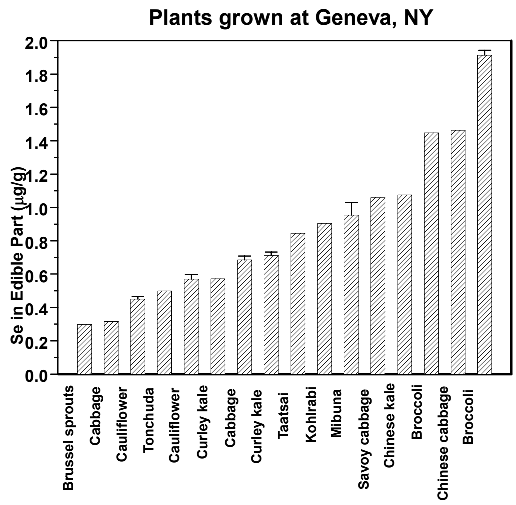
P & Zn Fertilizer effects on Zn levels in pea seeds



Zn and P fertilizer Effects on Phytic Acid in Pea Seeds

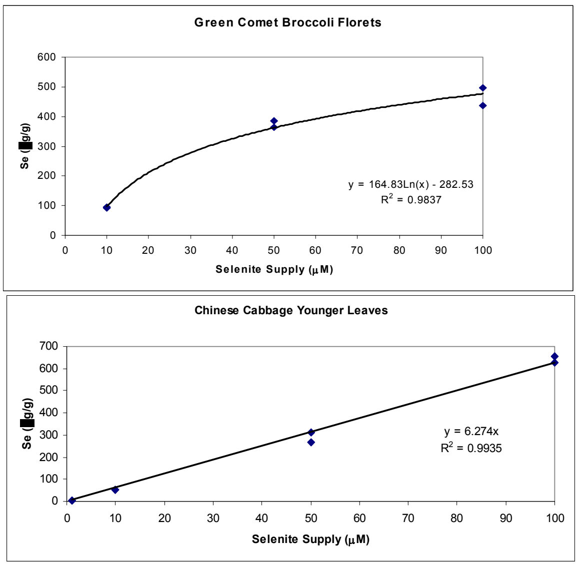


Se Accumulation in *Brassica* Species Supplied 1 μg/ g Se (as Selenite) in Potting Mix



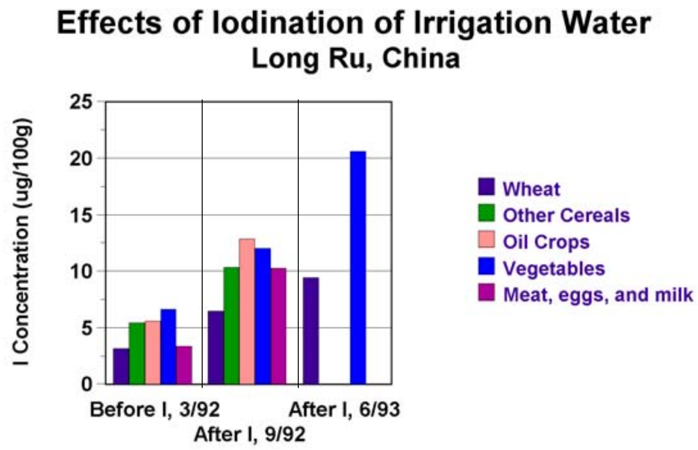
(unpublished data from Welch, 2004)

Effect of Selenite Supply on Se Concentration in *Brassica* Species



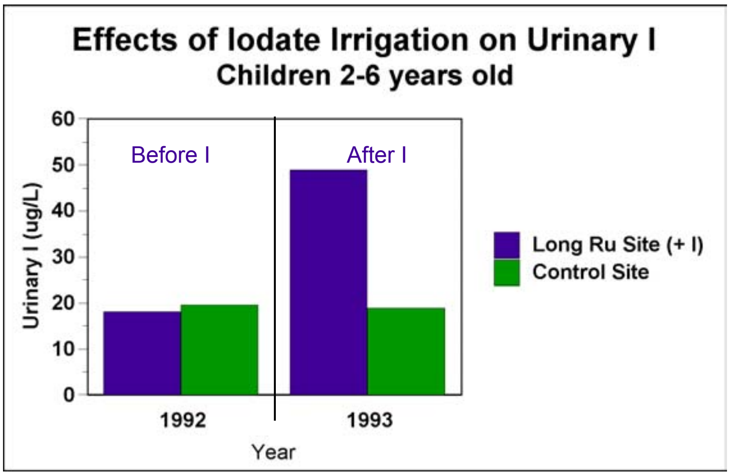
(unpublished data from Welch, 2004)

Food Systems Approach to Iodine Deficiency Disorders



Cao, et al., 1994

Food Systems Approach to IDD



Cao, et al., 1994

Large Genetic Potential to Improve the Micronutrient Efficiency of Crops

- Historically, plant breeders did not select for micronutrient efficient traits in food crops
  - used most fertile soils in selection process
  - resulted in high yielding varieties that require high inputs to maximize yields
- Within "wild" relatives and land races of crop plants large variation exists to improve micronutrient efficiencies in crop plants
- Limitation to breeders is the ability to screen genotypes for micronutrient efficiency traits
- HarvestPlus program - CGIAR, etc.

Zn Efficiency in Wheat Cultivars

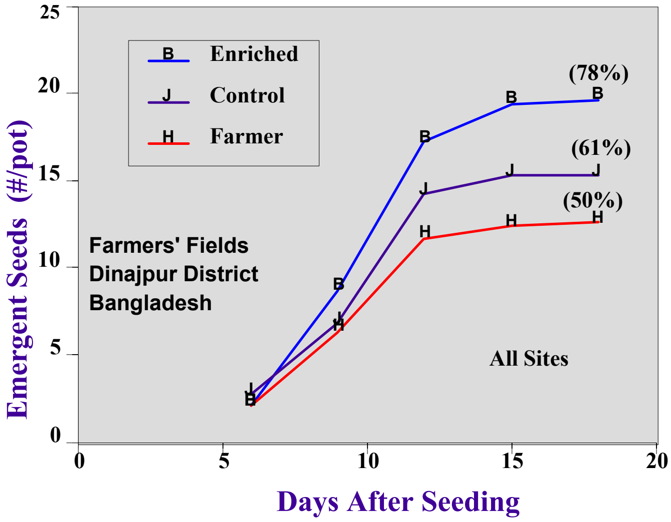
Genotype	Grain Yield		RE	Grain-Zn	
	-Zn	+Zn		-Zn	+Zn
	(t/ha)		(%)	(mg/kg)	
Excalibur	1.43	1.76	81	8	25
Warigal	1.00	1.22	82	13	26
Kite	0.95	1.37	69	10	24
TJB*MKR	0.63	1.30	48	12	30
Kamilaroi	0.45	1.29	35	9	23
LSD	0.3			3	

LSD = (G*Zn)
RE = (100)*(-Zn yield / +Zn yield)

Agronomic Benefits of Micronutrient Element-Enriched Seeds (e.g. Zn)

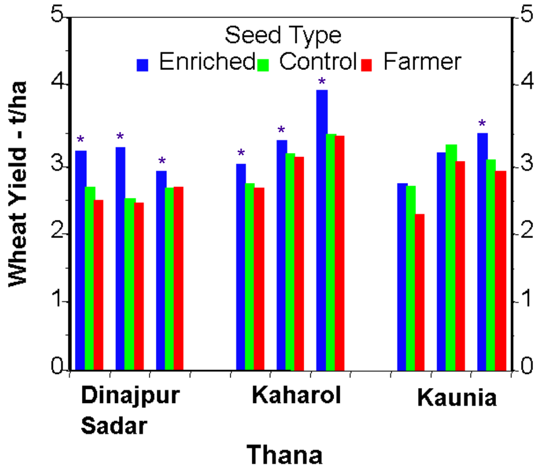
- Better seed viability
- Greater seedling vigor
- Denser stands (less soil irrosion)
- Lower seeding rates (lower cost to farmers)
- Larger root absorptive surface (better water & nutrient use efficiency)
- Better resistance to disease
- Better plant survival
- Increased plant & seed yield

Effects of Micronutrient-Enriched Grain on Wheat Seedling Emergence



(data from Duxbury, 2000)

Effects of Micronutrient-Enriched Seed on Wheat (Kanchan) Grain Yields from 9 Farms in Bangladesh



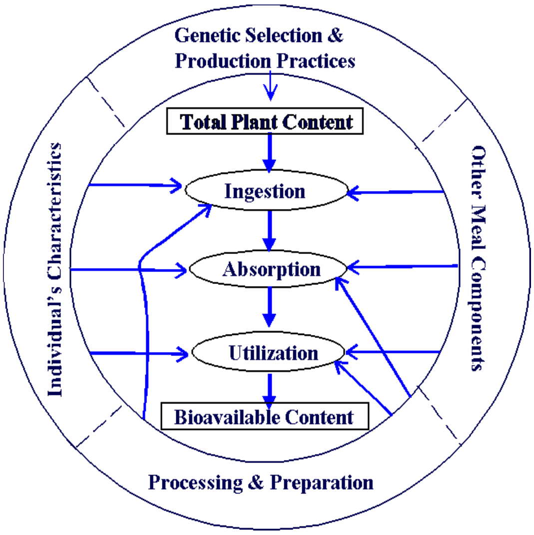
(Data from Duxbury, 2001)

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

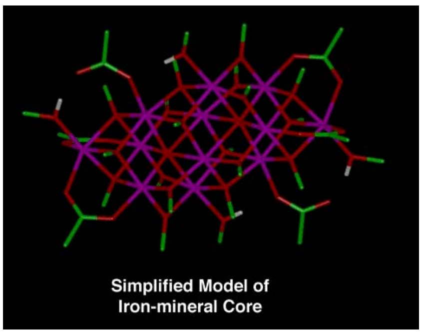
The Importance of Bioavailability

- Bioavailable amount of a micronutrient in a meal, not the total amount, is the critical factor for human health
- Definition – the amount of a nutrient in a food that can be absorbed from a typical diet and utilized in the body
- Most staple plant foods (cereal grains and legume seeds) fed alone contain very low levels of bioavailable Fe and Zn (e.g., about 5%) because of the antinutrients they contain (phytate, polyphenols, etc.)
- Increasing the bioavailability of micronutrients from 5% to 30% would have the same effect as increasing their total amounts in staples by 6 fold

Complexities of Bioavailability



Structure of Ferritin



Bioavailable Fe in Intrinsically ^{55}Fe-labeled Soybeans[1] Fed to Women

Feeding day	Soy soup	Soy muffin
	(% absorbed)[2]	(% absorbed)[2]
Day 14	25.9	28.7
Day 28	24.5	27.0

[1]Soybeans (Tokyo variety) contained 30-50% of their total Fe as ferritin and 2.1% phytic acid.

[2]Mean of 18 subjects with depleted Fe stores

Data from Murray-Kolb et al., 2002

Agriculture's Agenda For Better Health

- Make human health and well being an explicit goal of agricultural systems in addition to productivity & environmental goals
- Re-diversify cropping systems & design for maximum nutrient output
- Make more use of indigenous micronutrient-dense edible plant species, small livestock, & fish
- Use agricultural practices (e.g., fertilizers) that increase the bioavailable micronutrient output of farming systems
- Breed for and select for bioavailable micronutrient-dense staple food crops with micronutrient efficiencies
- Genetically modify plants to increase nutritional & health promoting factors
- Redefine sustainable agriculture to include adequate nutrient output for healthy & productive lives