Fertilization, Plant Nutrition and Food Quality

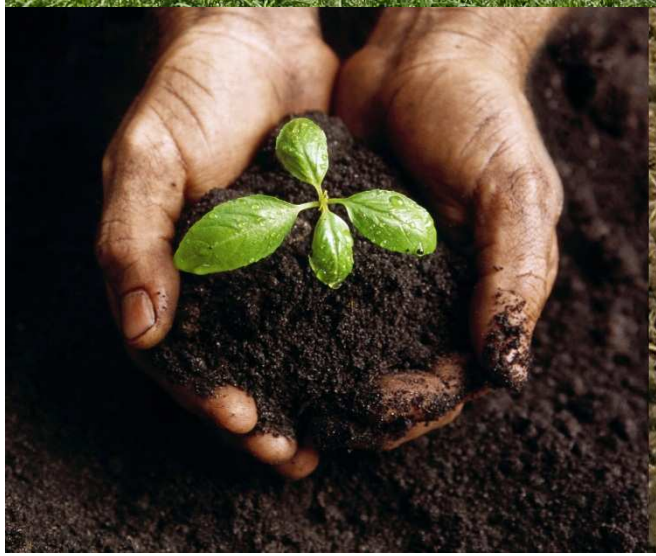
Cynthia Grant
AAFC - Brandon Research Centre
Cynthia.grant@agr.gc.ca

Canada

Nutrient Management Plays A Critical Role in Sustainable Crop Production

- Required to optimize crop yield and profitability
- Maintain soil quality through organic matter input and nutrient balance
- Efficient use can optimize crop yield and quality while reducing risk of environmental damage

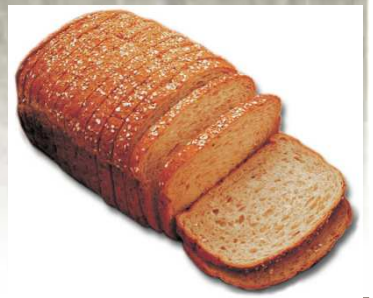
Poor Nutrient Management Can Lead to Low Crop Yield and Quality and Loss of Soil Fertility



Nutrient Management Can Also Affect Functional and Nutritional Quality of Crops

Functional Quality is the Ability to Produce the Desired Product

- High flour yield
- Bread-making quality of wheat
- Good “bite” of pasta
- Desirable texture of rice
- Ethanol yield of maize
- Oil yield from soybean and canola
- High yield of haze-free beer for barley



Nutritional Quality is the Ability to Meet the Nutritional Needs of the Human Diet

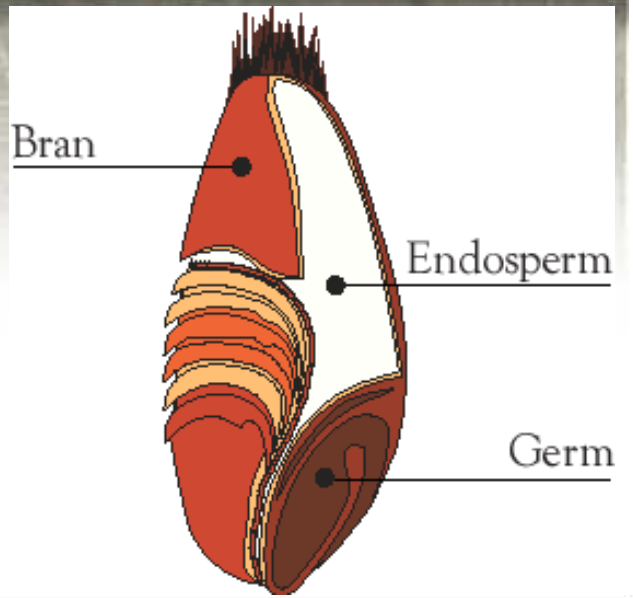
- Fatty acid profile of oils
- Glycemic index of carbohydrates
- Protein content and amino acid balance
- Trace element concentration and availability
- Low levels of contaminants and anti-nutritional factors

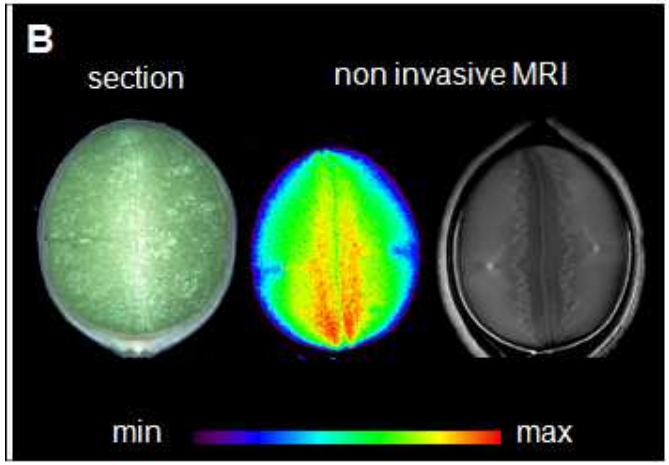
Crops are Important Sources of Nutrients in the Human Diet

- Plants provide proteins, carbohydrates, oils, vitamins, trace elements and a range of neutraceutical compounds
- Rice is the staple food for over half of the world's population
- Wheat provides about 20% of the food calories
- Maize is an important staple in Asia, Africa, Latin America and parts of the former Soviet Union
- Soybean is important protein source in vegetarian diets

Storage of Protein, Carbohydrates, Oil and Trace Elements in the Seed Affects Nutrition

- Cereal grains are about 60 to 75% starch and 7-14% protein
  - Starch is primarily located in the endosperm
  - Protein in the aleurone layer and surrounding starch granules in the endosperm
  - Minerals, vitamins and fibre concentrated in the bran and aleurone layers
  - Oil concentrated in the cereal germ
- Canola and soybean seeds store mainly oil and protein rather than starch
- Processing affects retention of components

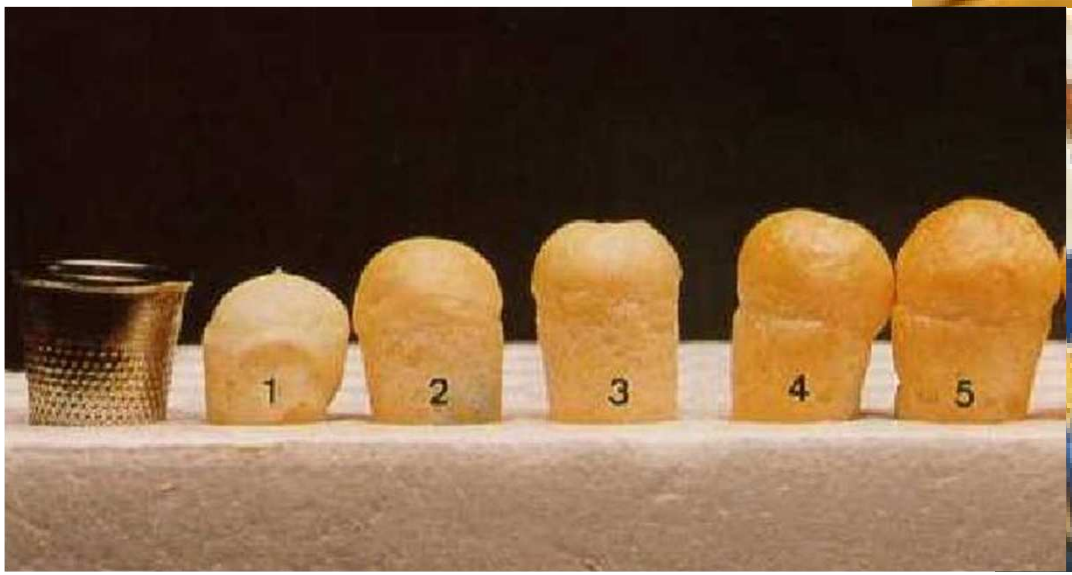




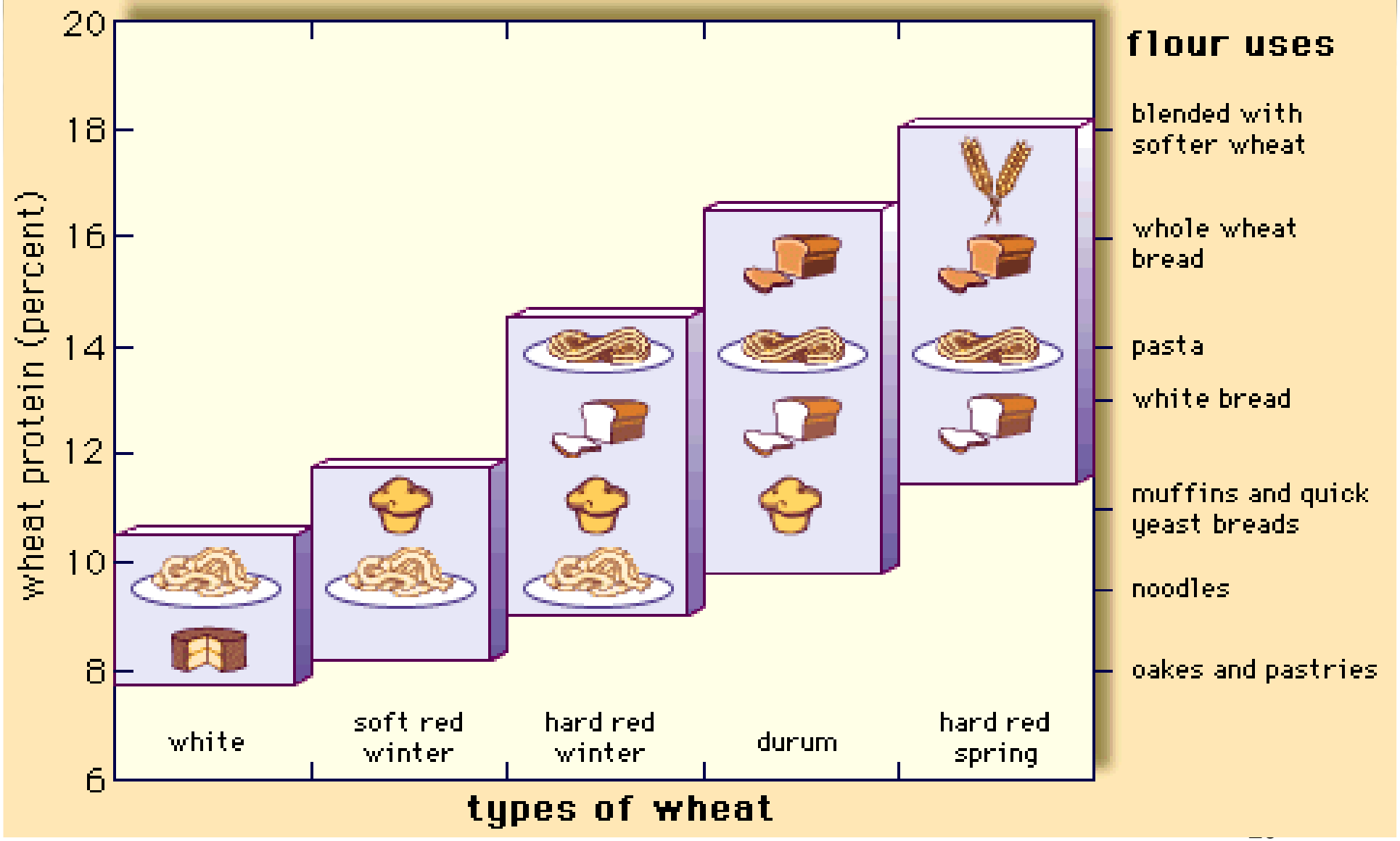
Lipid distribution in soybean

http://www.ipk-gatersleben.de/abt-molekulare-genetik/heterosis/forschungsprojekte/imaging-and-quantification-of-lipid-in-living-seed/

Protein Affects Functional Quality of Crops



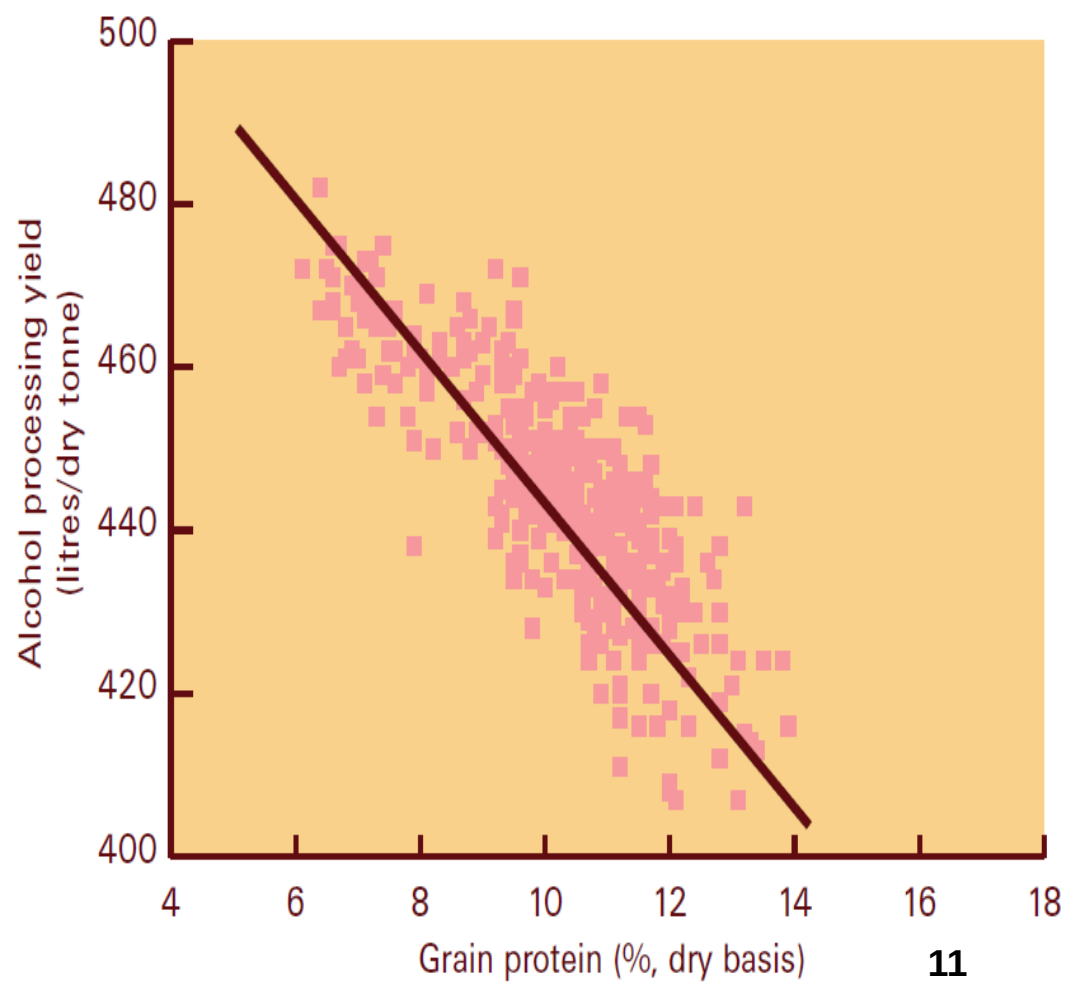
Higher Protein Content Required for Stronger Bread and Pasta Dough and Lower for Softer Cakes and Cookies



wheat: flour protein content and uses. Art. *Encyclopædia Britannica Online*. Web. 22 Jun. 2012. <http://www.britannica.com/EBchecked/media/160/The-protein-content-and-major-food-uses-of-certain-varieties>.

Highest Ethanol Yield Occurs with Low Protein

- Related to direct replacement of starch by protein
- Ethanol production increases by about 7 liters/dry tonne for every 1% decrease in grain protein



publications.hgca.com/publications/documents/.../PP14.pdf

SWRI, 2003-2005

Target Proteins to Meet Functional Requirements

- High protein for bread and pasta
- Moderate to lower protein for pastry, cakes, cookies and beer
- Low protein for ethanol and oil yield





Protein Plays a Important Role in Nutrition

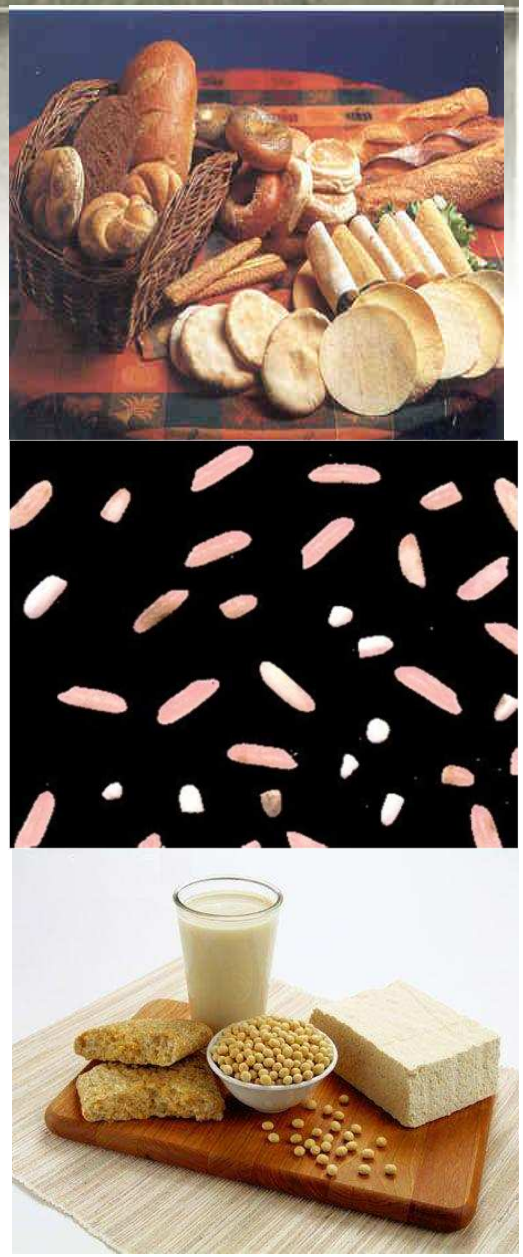
- Critical in all tissues, enzymes and certain hormones
  - Growth, cell reproduction and repair
  - 25,000 proteins coded in the human genome
- Should be 10 to 35% of dietary calories
  - Lack leads to nutritional deficiencies
  - Excess can lead to kidney problems

- Especially important for children and pregnant or lactating women
- Eight or nine essential amino acids must be supplied by food

WHO
***whqlibdoc.who.int/trs/WHO_TRS_935_eng.pdf*13**

Protein and Plant Products

- Cereals contribute about 25% of dietary protein in developed countries and more in countries with low animal protein consumption
  - Rice contributes about 29% of the protein in developing countries
- Potato is major protein source in potato-based diets
- Soybean is an important contributor to protein, especially in vegetarian diets



Diet Must Supply the Essential Amino Acids

- Animal proteins are complete sources
- Plant proteins may lack essential amino acids
  - Cereals are usually low in lysine and threonine, but fairly high in cysteine and methionine
  - Rice has higher lysine content than maize and wheat
  - Potatoes contain high lysine with methionine being the first limiting amino acid
  - Soybean contains high total protein, but methionine and cysteine are limiting
- Combining cereal and soybean protein improves the amino acid balance

Concentration of protein and proportion of selected amino acids in the protein in soybean meal, wheat, maize and rice.

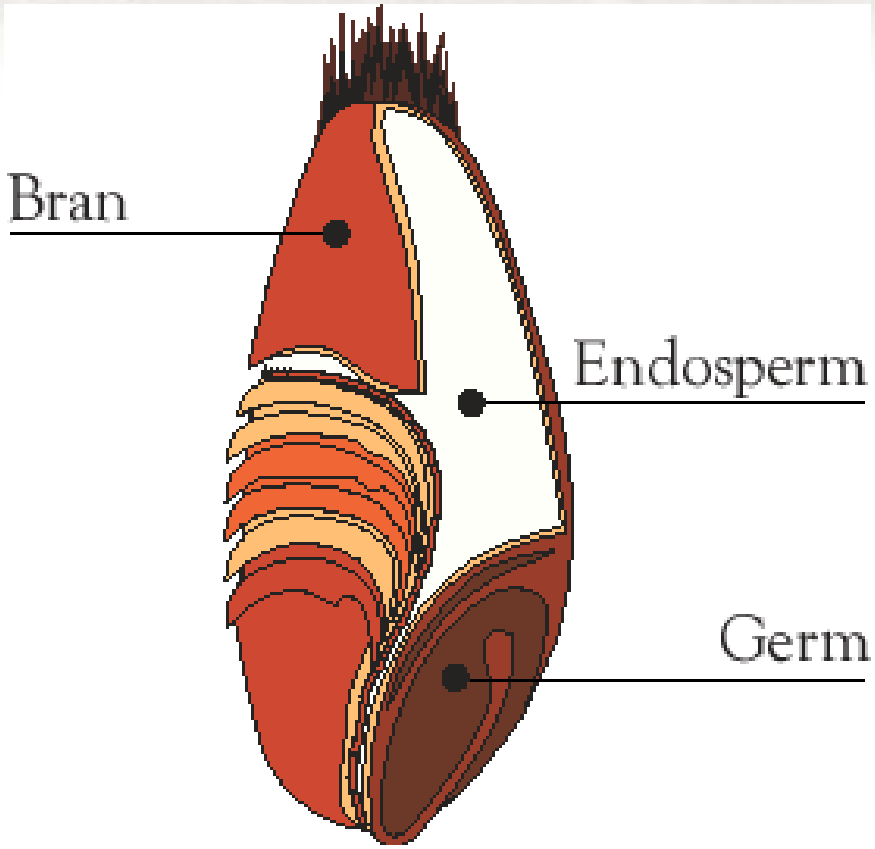
	Soybean (meal)	Wheat	Maize	Rice
Crude protein	44	14	9	7
Methionine	0.01	0.02	0.02	0.02
Cysteine	1.14	1.50	0.85	0.88
Lysine	4.03	1.06	1.59	1.73
Threonine	0.64	1.11	1.30	1.00
Tryptophan	0.35	0.44	0.20	0.31
Arginine	5.48	3.53	6.71	7.38
Isoleucine	0.61	0.87	0.72	0.53
Leucine	1.68	1.83	3.41	1.90
Valine	0.62	0.65	0.41	0.75

Protein Content Depends on:

- Nitrogen taken up by the plant
  - About 17% of protein is made of N
  - Supply from soil and fertilizer application
- Movement of N to the grain
- Grain yield through which the N is distributed

Cereals are Primarily Starch and Protein

- About 60% starch
- About 14% protein
- Remainder consists of minerals, oils, water, and other minor constituents
- Protein concentration reflects the balance between the amount of protein and starch that the plant produces
- As protein increases, starch decreases and visa versa



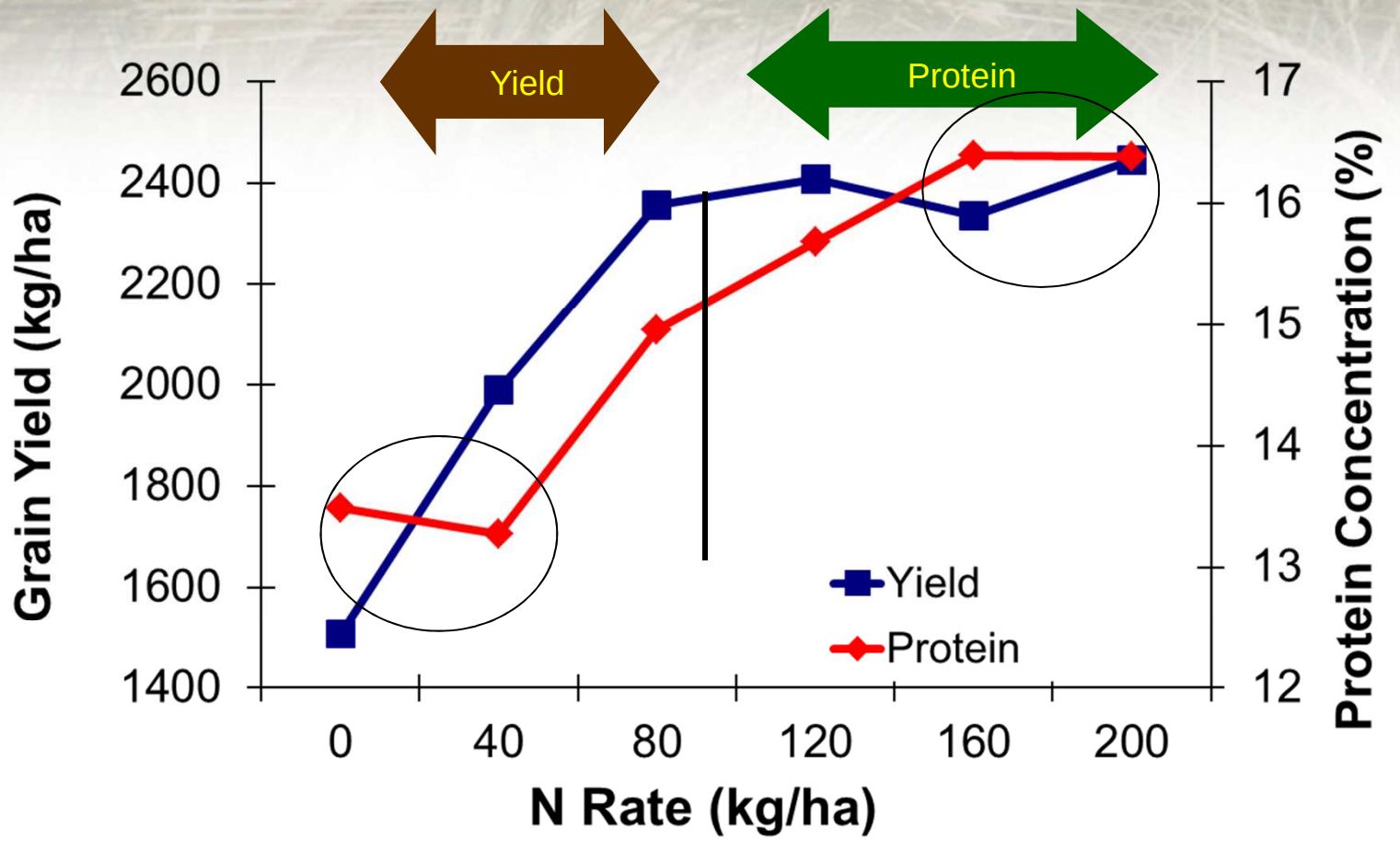
Dilution and Protein Content

- Key factor affecting protein concentration
- Protein concentration generally falls if yield increases *at a constant N level*
  - Improved growing conditions
  - High yielding cultivars
  - Early seeding
- Protein “diluted” by increased yield

Nitrogen Can increase Both Yield and Protein Content

- Usually most limiting nutrient
- Nitrogen increases yield by creating metabolism and sink for carbohydrate storage
- Protein produced is distributed through stored carbohydrate
- Protein concentration affected by amount and timing of N supply relative to yield

N Fertilization Influences Both Grain Yield and Protein

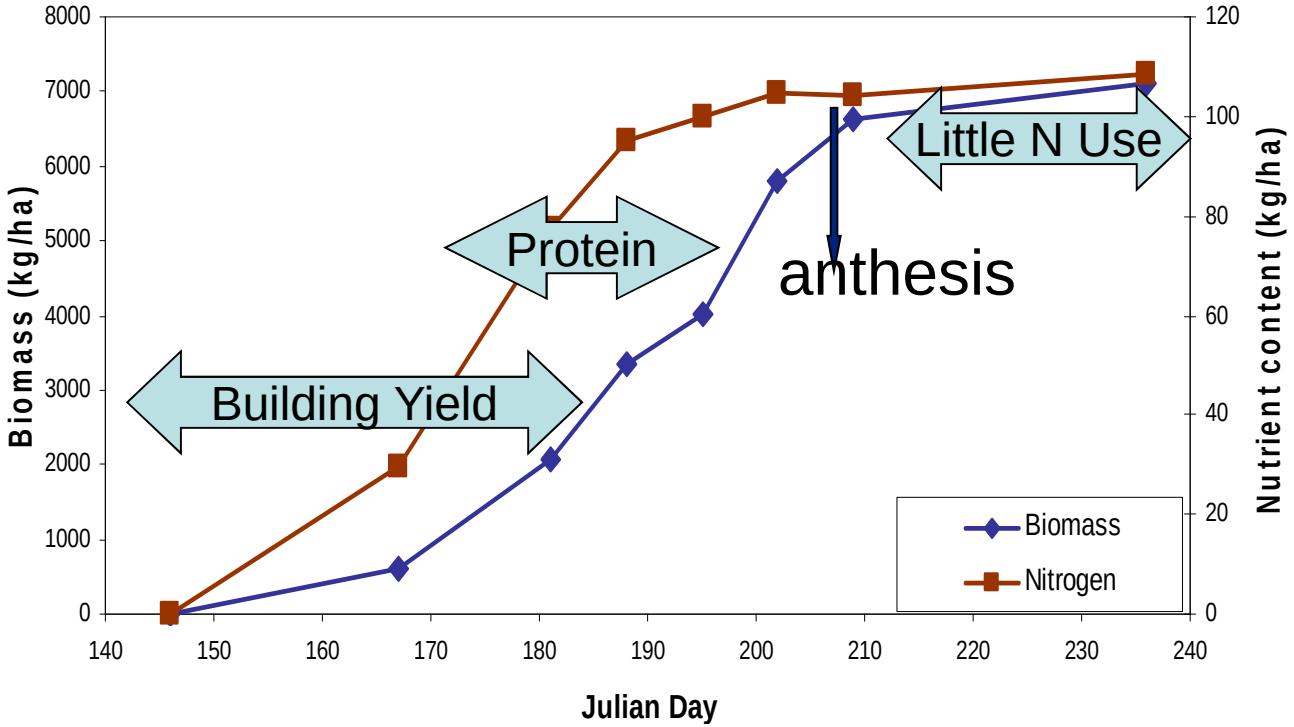


N supply relative to yield potential is critical

Target N applications to yield potential and protein targets

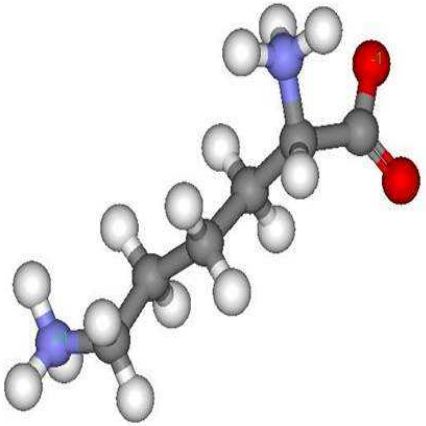
Timing of N Supply Also Affects Protein Concentration

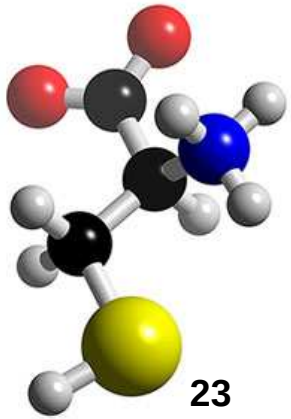
- Early supply builds yield by affecting tillering and kernel number
- Late supply builds protein but has little effect on yield
  - More protein is distributed through stable yield
- In-crop applications, in-season mineralization and slow-release products may increase protein concentration



Fertilization can Affect Amino Acid Balance

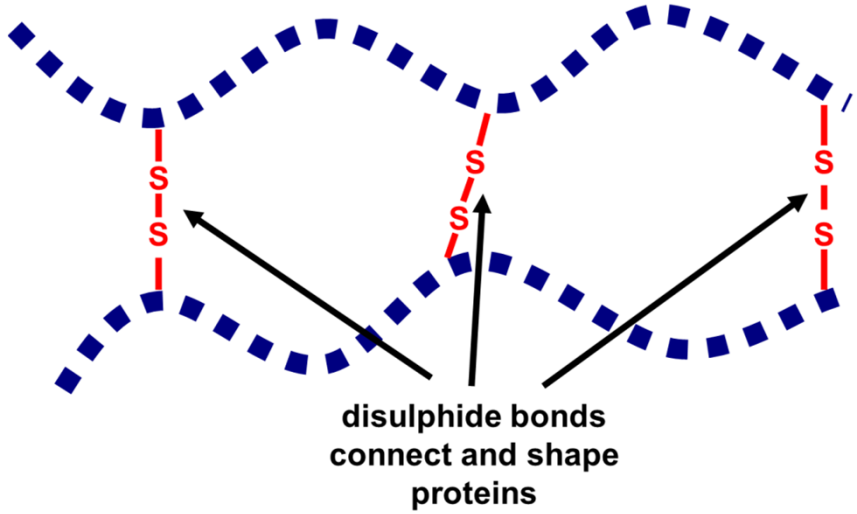
- N fertilization increases glutens in wheat and zeins in maize
  - Low in lysine, so nutritional benefit may be less than increase in protein
- In rice, N fertilization increased the glutelin ratio and decreased phytic acid content
  - Increase lysine content gives better nutrient value
  - Lower phytic acid increases nutrient availability
- S fertilization increases S-containing essential amino acids, cysteine and methionine





Sulphur Fertilization and Bread Quality

- S-containing amino acids are important for bread-making
- S in gluten forms cross linkages in dough that traps CO_2 and makes bread rise



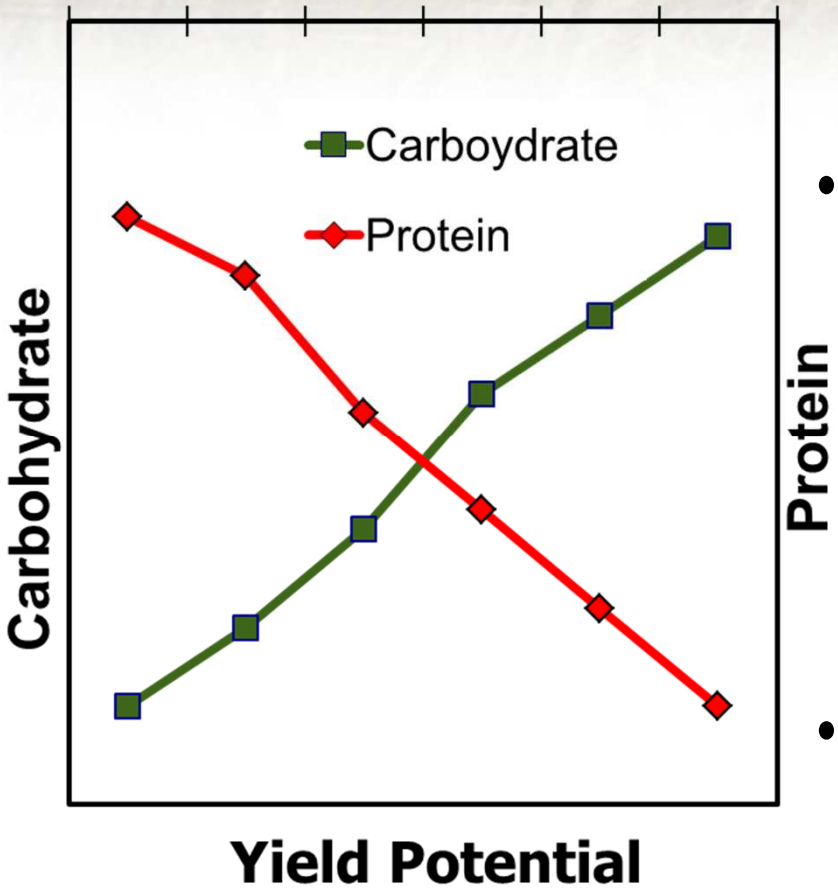
Potato Protein Concentration and Quality are Also Affected by Fertilization

- Protein content increases with N application but biological value decreases
  - Proportion of asparagine increased while essential amino acids declined
- S fertilization increased biological value by increasing methionine and cysteine
- P and K application reduced total protein content but increased biological value

Carbohydrates

- Should be 45 to 65% of the calories in the diet
  - As much as 80% in developing diet
  - Usually 45-50% in industrialized countries
- Digestible forms are primarily a source of energy
  - Starch provides about 20 to 50% of the energy in countries with high carbohydrate intake
- Non-digestible forms are important as dietary fibre
- Cereals provide over 50% of the carbohydrate in the diet

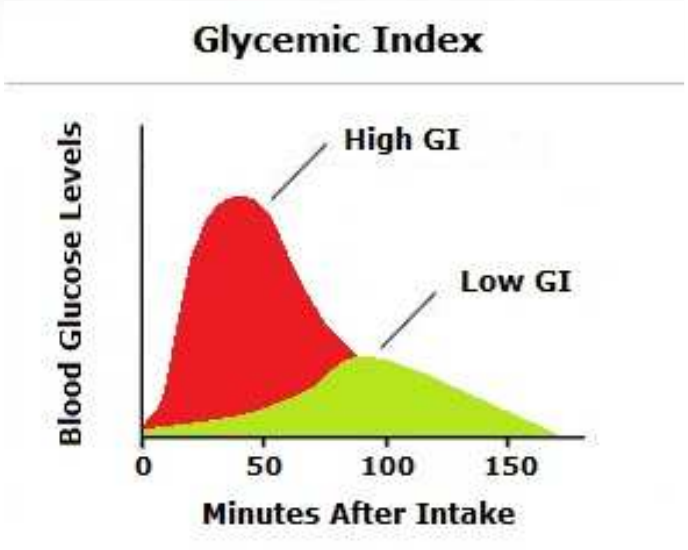
Negative Relation Between Carbohydrate and Protein Concentration



- Numbers have to add up to 100% so one increases at the expense of the other
- If yield potential relative to N supply increases, carbohydrate percentage increases and protein decreases
  - Yield increase is mainly due to carbohydrate
- Nitrogen application will increase protein concentration and decrease carbohydrate concentration

Carbohydrate Quality

- Glycemic index (GI) is important indication of carbohydrate quality in the diet
  - Rate at which starch is digested to release energy
  - Lower GI means slower release and more stable blood sugar over time
  - Glycemic response affected by other factors, including other components in the diet

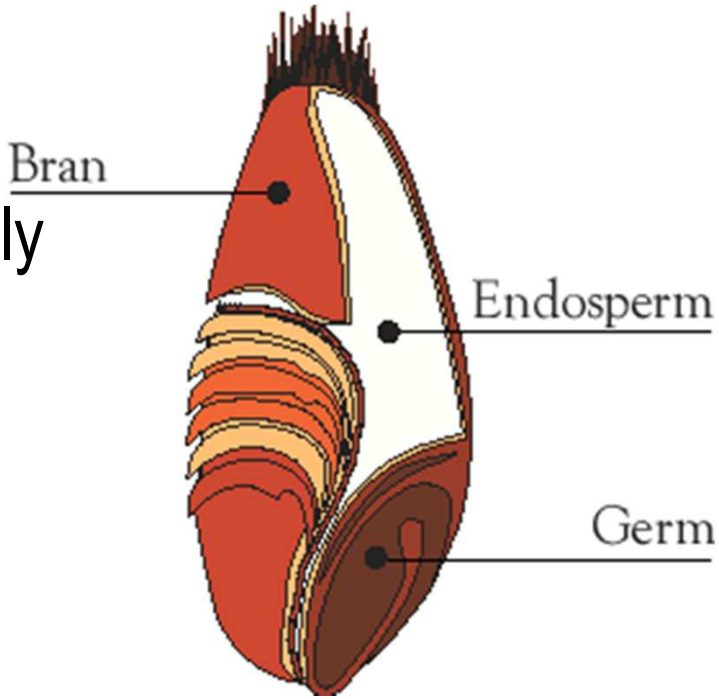


Importance of Carbohydrates as Fibre Source

- Fibre can reduce risk of coronary heart disease, stroke, hypertension, diabetes, obesity and some gastrointestinal problem
- Insoluble fibre
  - Adds bulk to the diet
  - May help bind and excrete carcinogens
- Soluble fibre
  - May lower serum cholesterol
  - Regulates blood glucose and insulin levels

Carbohydrate Quality

- Whole grains are important fibre sources
- Fibre is concentrated in the bran
  - Removing the bran layer removes much of the fibre
- White flour and polished rice are relatively low in fibre
  - White flour has about 0.6% cellulose while whole wheat flour has over 2.4%

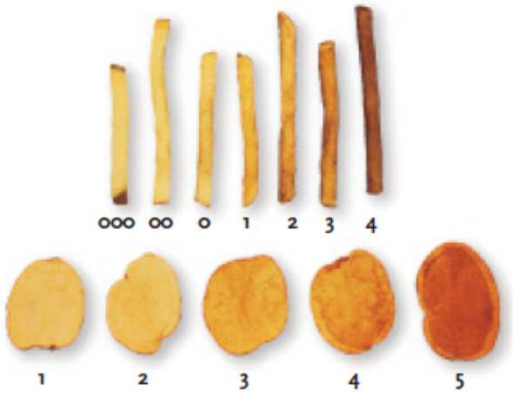


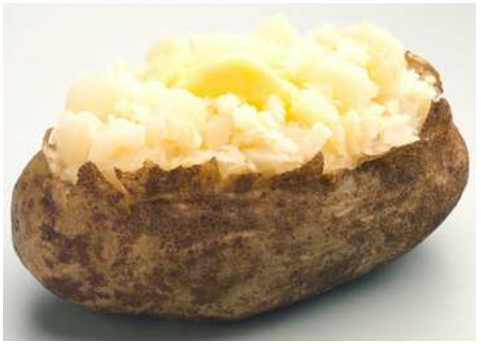
Carbohydrate Quality

- Rice is mainly used as energy source in the form of starch
- Starch characteristics affect sensory quality of rice
  - Firmness of cooked rice increases with the amylose content and number of long chains in the amylopectin
  - Low or intermediate amylose gives dry, fluffy rice with soft texture
  - Long amylopectin chains give better quality starch granules that resist breakdown during cooking

Starch Content of Potatoes Is Key Quality Factor

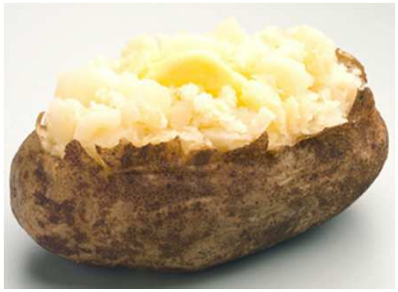
- Starch content and specific gravity influenced potato texture
  - High starch and specific gravity produces fluffy, dry texture for baking
  - Lower starch and specific gravity are better for boiling
- Excessive sugar causes over-browned during frying due to Maillard reaction
- Tuber sugar and starch are usually inversely related



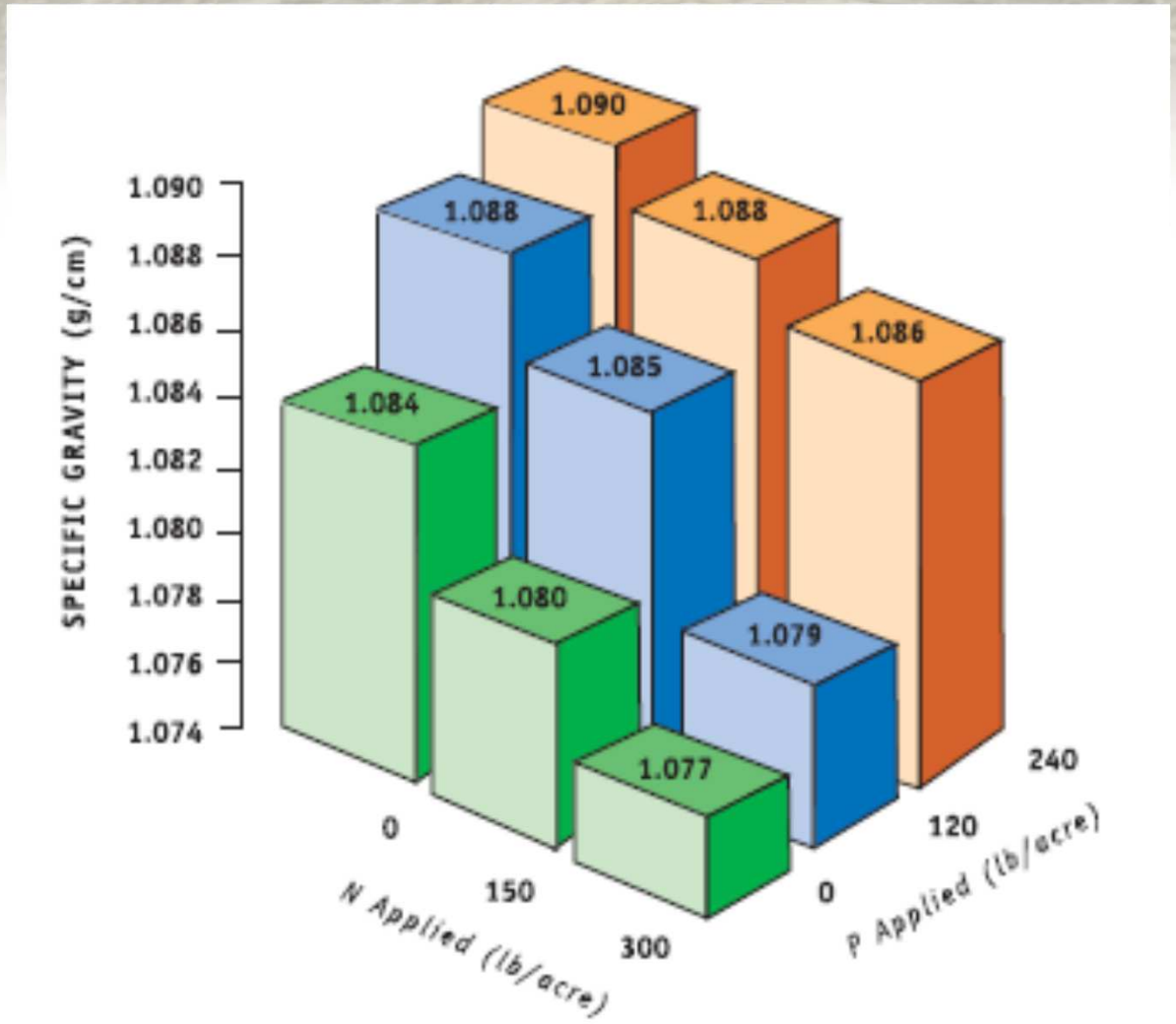


Starch Content of Potatoes Is Affected By Nutrient Supply

- Nutrient levels that maximized yield also provided highest starch levels
  - Correcting N, P, K, or S deficiency improved starch content
- Excess N and K can decrease starch and specific gravity
  - Excess N can delay tuber bulking and maturity
  - Excess K can increase moisture retention and decrease specific gravity



N and P fertilization can interact in their effects on specific gravity



Stark and Love
Chapter 16 Tuber Quality

Healthy Oils in the Diet Also Come From Plants

- Soybean and canola (rapeseed) are the two main annual oilseed crops
- Maize is also used for oil
- Soybean is also a major protein source

Oils and Fats

- Important part of cell membranes, mitochondria and intracellular organelles
- Should be 20 to 35% of the calories in the diet
  - Often only 8-10% in developing countries
  - Over 36% in the United States
- Lack of oil in the diet can limit the absorption of vitamin A and plant carotenoids

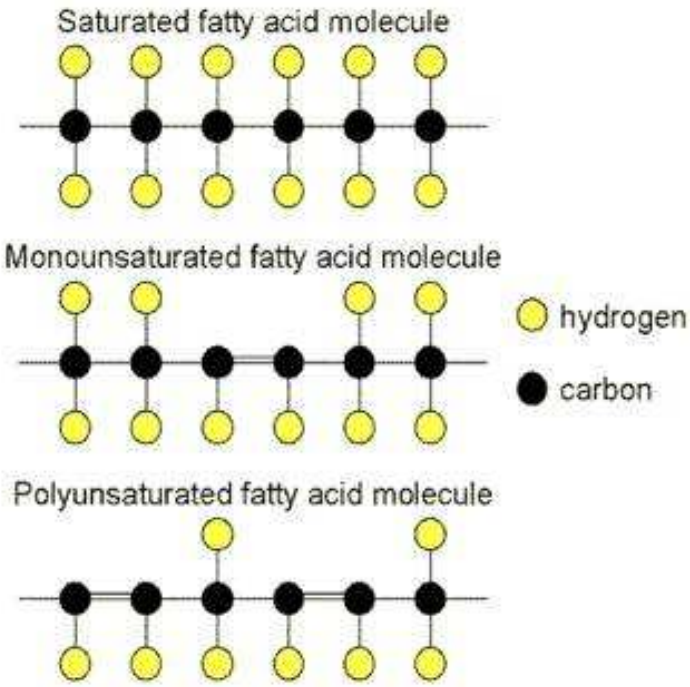
  - http://www.fao.org/docrep/W0073E/w0073e04.htm#P2096_237138

Roles of Oils in the Diet

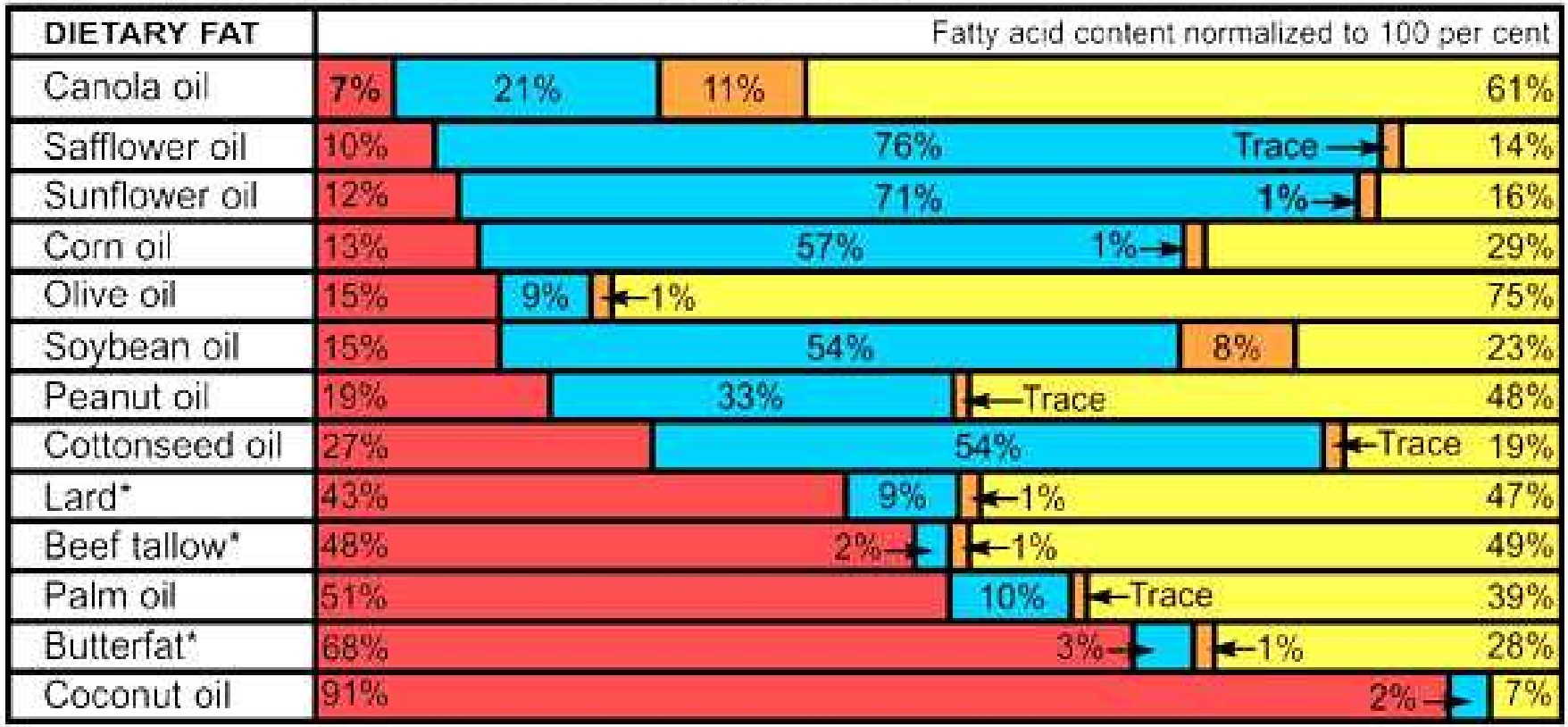
- Saturated fatty acids in the diet increase the risk of coronary vascular disease
- Omega-3 polyunsaturated fatty acids are associated with reduced risk of heart disease
- The unsaturated fatty acids linoleic acid and α-linolenic acid are essential fatty acids required for health
  - Omega 3 and omega 6 essential fatty acids
  - α-linolenic acid (ALA), is present in flaxseed, soybean, and canola oil

Mono and Polyunsaturated Oils Have Health Benefits

- Most fat in the diet should come from unsaturated sources
- Monounsaturated and polyunsaturated fats
  - Improve blood cholesterol levels
  - Lower risk of heart disease
  - Improve insulin levels
  - Better blood sugar control



Comparison of Dietary Fats



* Cholesterol Content (mg/Tbsp): Lard 12; Beef tallow 14; Butterfat 33. No cholesterol in any vegetable-based oil.

Source: POS Pilot Plant Corporation, Saskatoon, Saskatchewan, Canada June 1994

SATURATED FAT

MONOUNSATURATED FAT

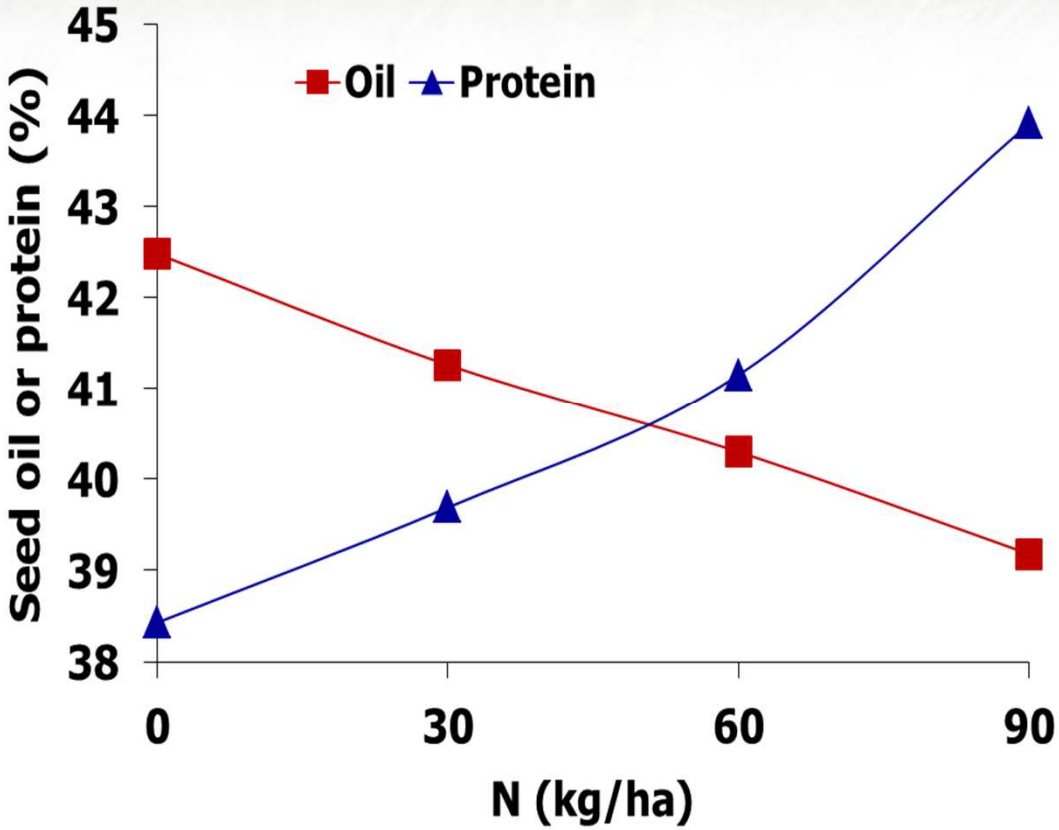
POLYUNSATURATED FAT

Linoleic Acid

Alpha-Linolenic Acid (An Omega-3 Fatty Acid)

CANOLA COUNCIL OF CANADA 400-167 LOMBARD AVENUE WINNIPEG MANITOBA CANADA R3B 0T6

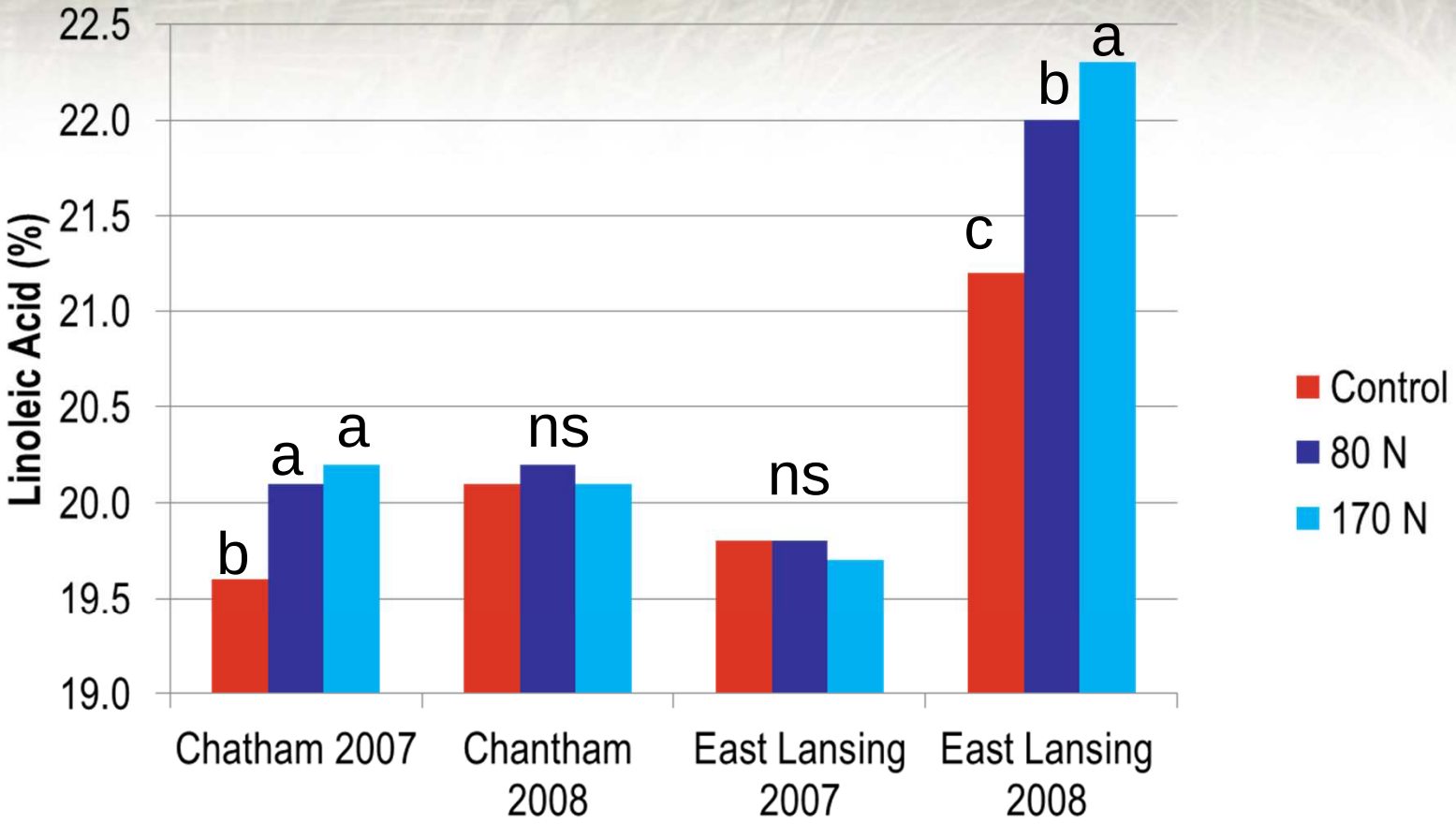
Nitrogen Increases Protein but Decreases Oil in Canola



Impacts of P, K and S Fertilization on Oil Content are Small

- K may slightly increase oil concentration and decrease protein in canola and soybean
- P seems to have little to no effect on oil concentration
- S has been reported to increase oil concentration of canola on S-deficient soils
- However, increasing yield with P, K or S will increase total oil yield per hectare
- Little information on effects of fertilization on fatty acid composition

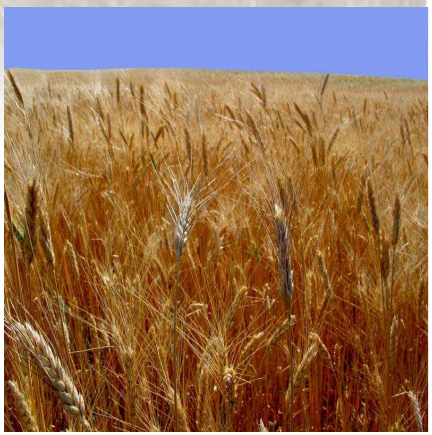
N Fertilization Increased the Linoleic Acid Concentration of Canola In Some Site-Years



Gao et al. 2010

Trace Elements Affect Food Quality

- Deficiencies of nutrient trace elements like iron, zinc and selenium are major human health issues
  - Increasing their content can improve human health and the value of our crops
- Excess cadmium, arsenic and other trace elements can cause health problems and trade restrictions
  - Reducing their content can improve human health and maintain market share

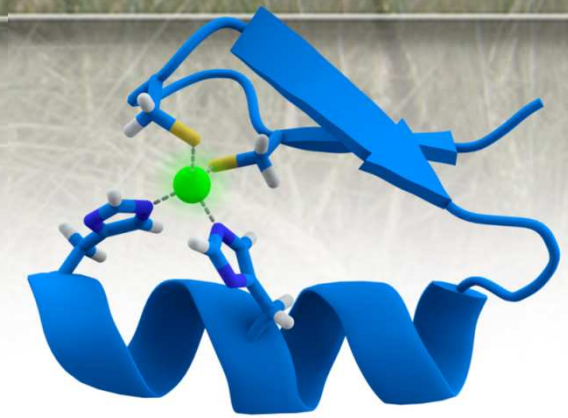


Trace Element Deficiency is a Major International Health Issue

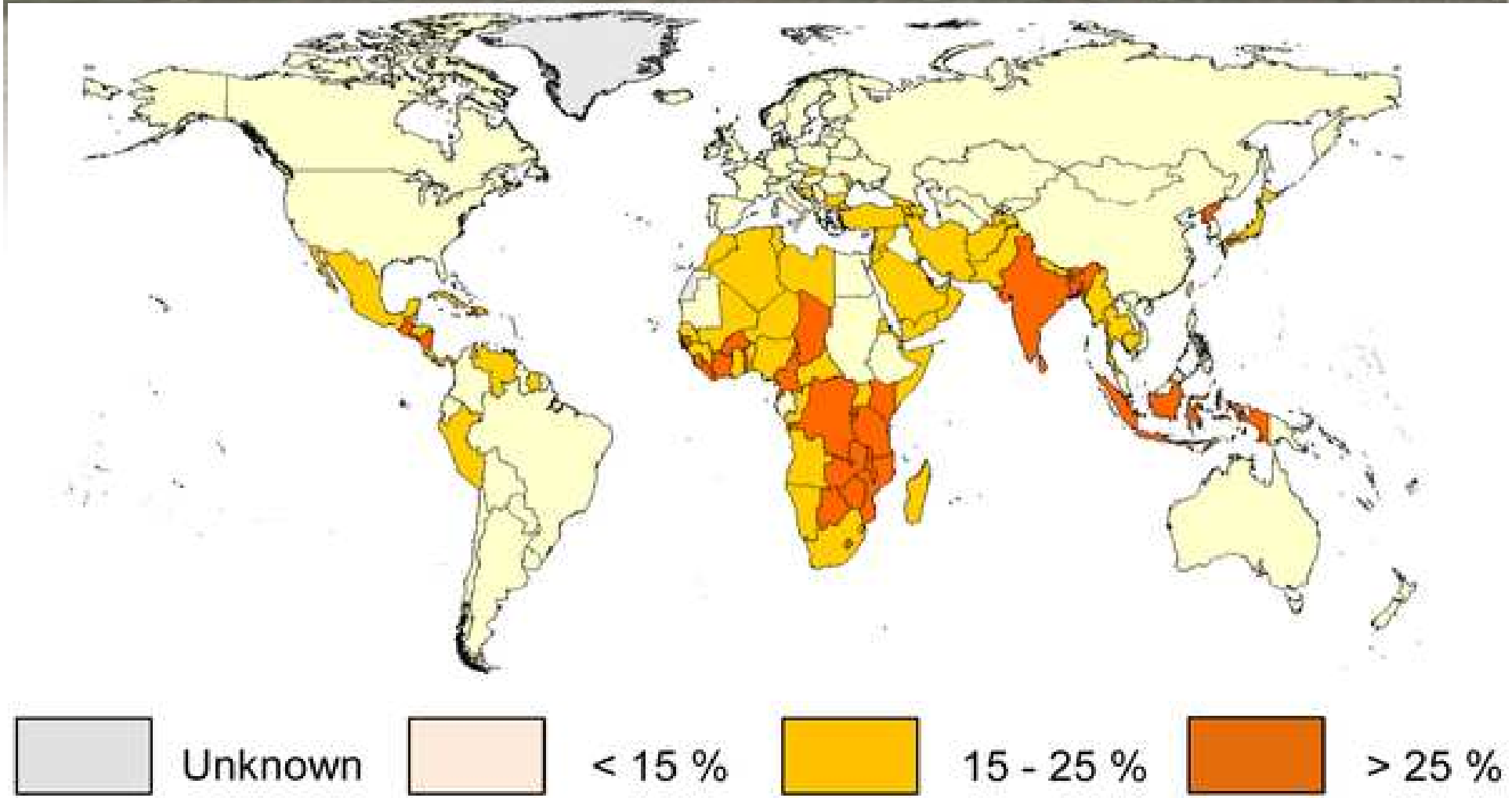
- "Green Revolution" has increased caloric supply
- Micronutrient deficiencies are wide-spread and increasing
  - 40% of world population deficient in iron, vitamin A and iodine
  - Selenium and zinc of concern
  - Increased infant mortality
  - Increased sensitivity to disease and heavy metal toxicity
  - Blindness
  - Anemia
  - Neural tube defects
  - Reduced cognitive performance

Role of Zinc in Human Nutrition

- Component of several hundred enzyme systems
- Synthesis and degradation of carbohydrates, lipids, proteins and nucleic acids
  - Metabolism of other micronutrients
- Essential role in polynucleotide transcription and hence genetic expression
- Central role in immune system
- Particular important in infants, children, adolescents and pregnant women



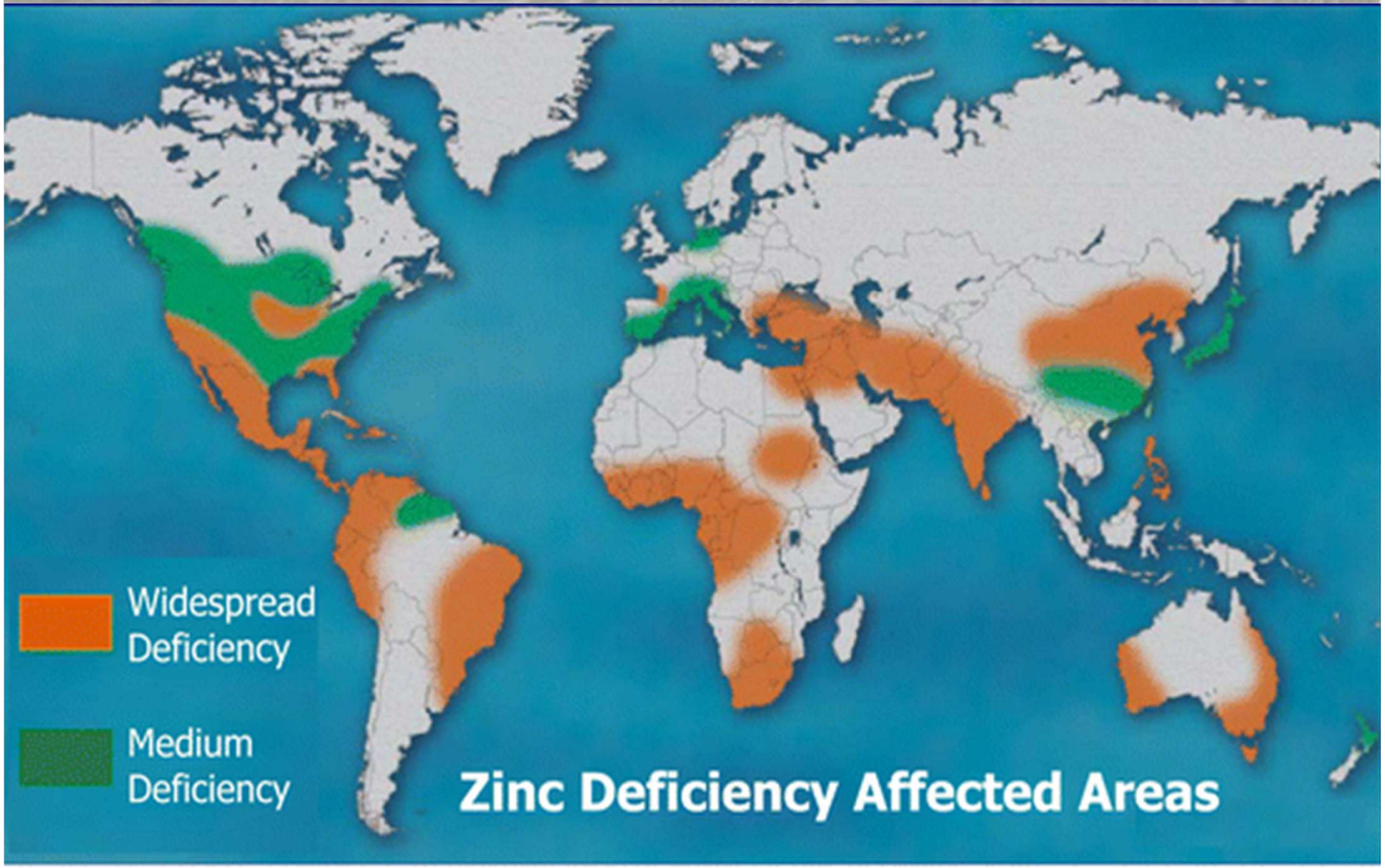
Estimated Country-Specific Prevalence of Inadequate Zinc Intake



Wessells KR, Brown KH (2012) Estimating the Global Prevalence of Zinc Deficiency: Results Based on Zinc Availability in National Food Supplies and the Prevalence of Stunting. PLoS ONE 7(11): e50568. doi:10.1371/journal.pone.0050568
http://www.plosone.org/article/info:doi/10.1371/journal.pone.0050568

PLOS | ONE

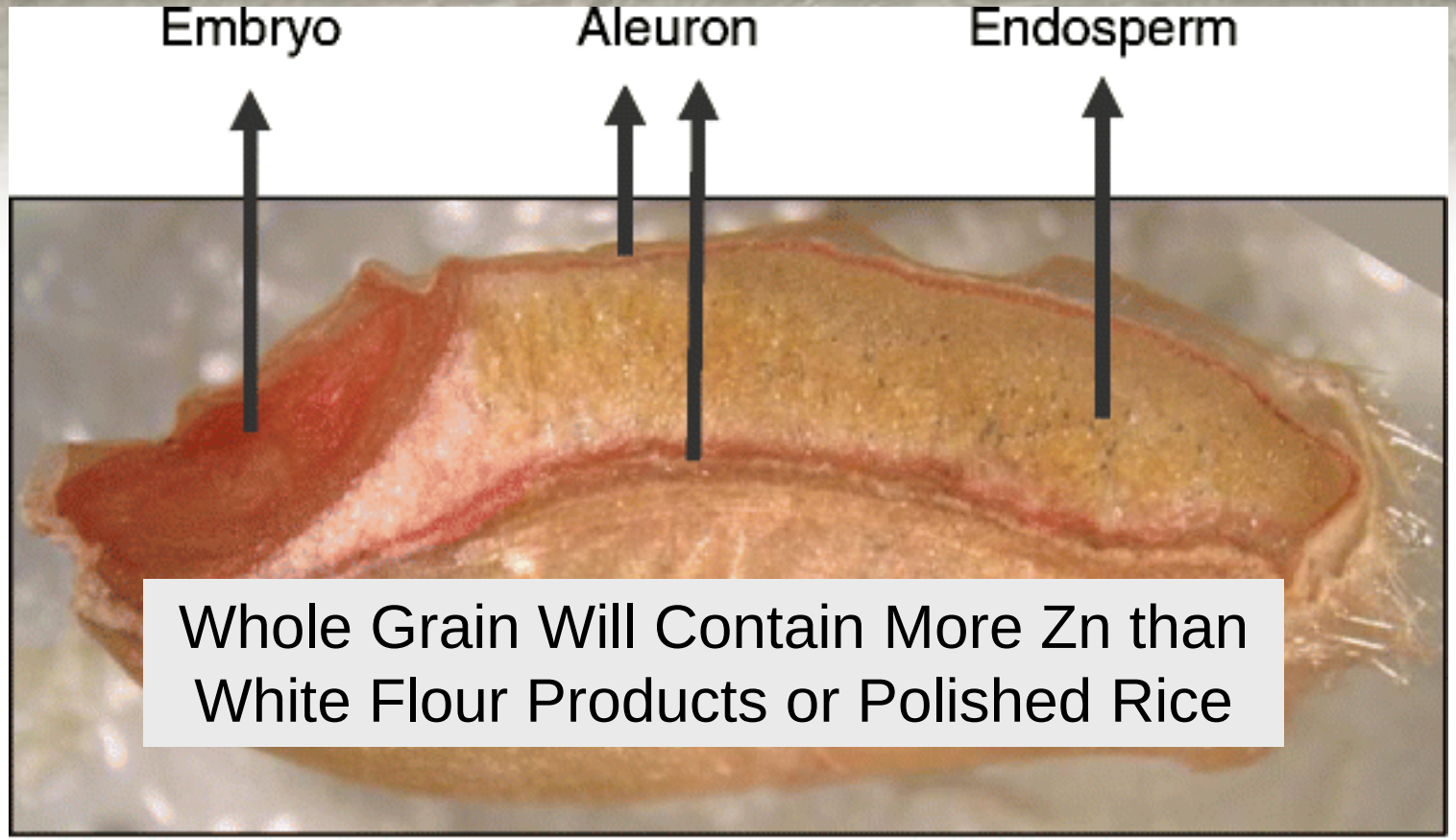
Areas of Zinc-Deficient Soils in the World (Alloway 2008)



Zinc in Crop Nutrition is Linked to Zinc in Human Nutrition

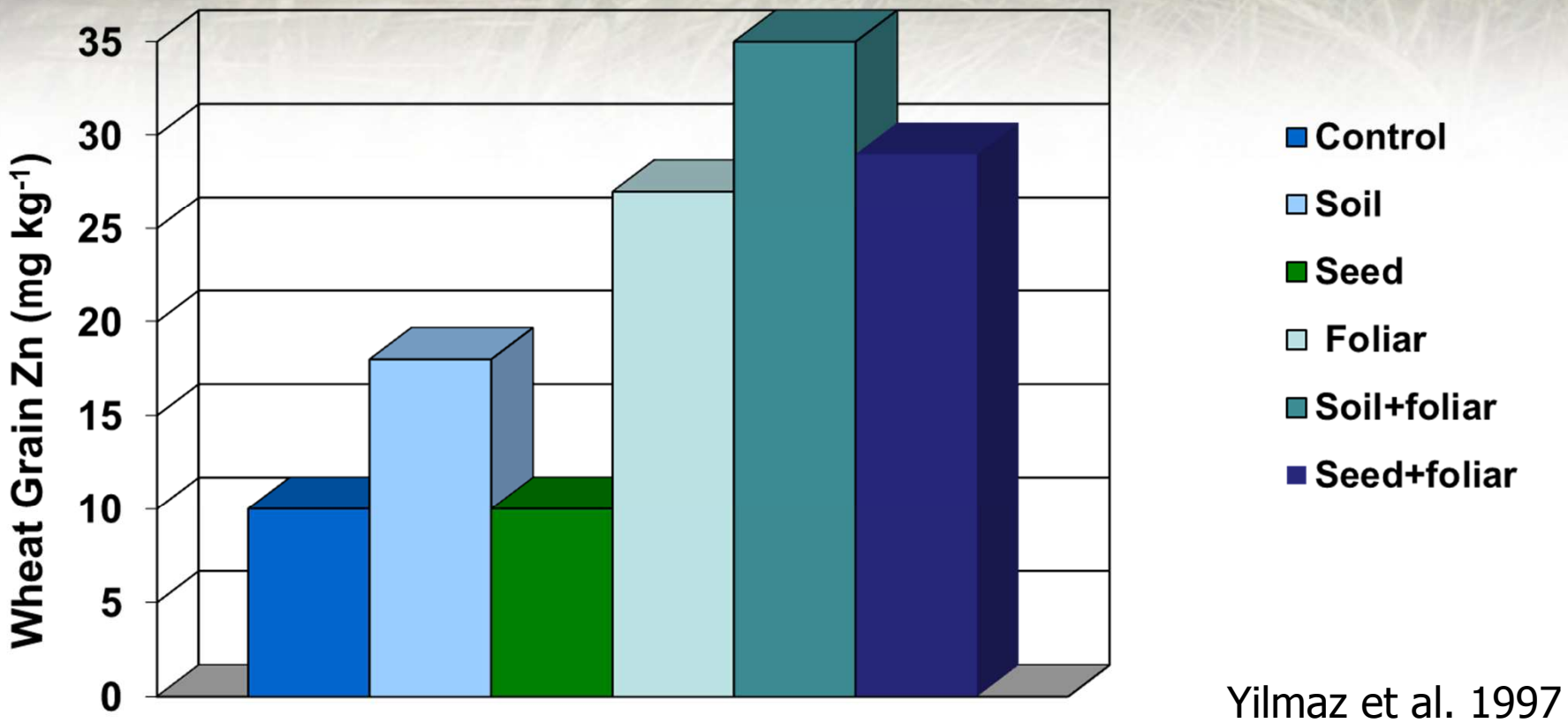
- Whole grain cereals, pulses and legumes are important sources of Zn in the diet
- Often below the target Zn concentration of 40 to 60 mg kg^{-1} in wheat grain
- Breeding and agronomic practices underway to increase Zn and many other critical nutrients in crops
  - HarvestPlus program is playing a major role in this
- Potentially can increase both crop yield and nutritional value in Zn-deficient soils

Zinc Concentration is Higher in the Embryo and Aleurone Layer of Wheat than in the Endosperm



Cakmak 2008. http://link.springer.com/article/10.1007/s11104-007-9466-3/fulltext.html

Zinc Fertilization Can Increase Seed Zn Concentration

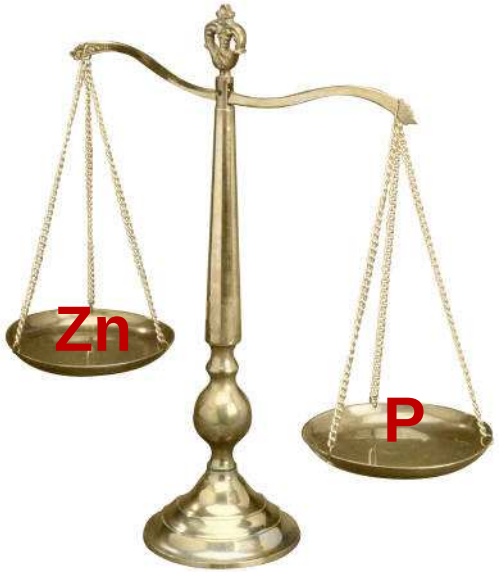


Yilmaz et al. 1997

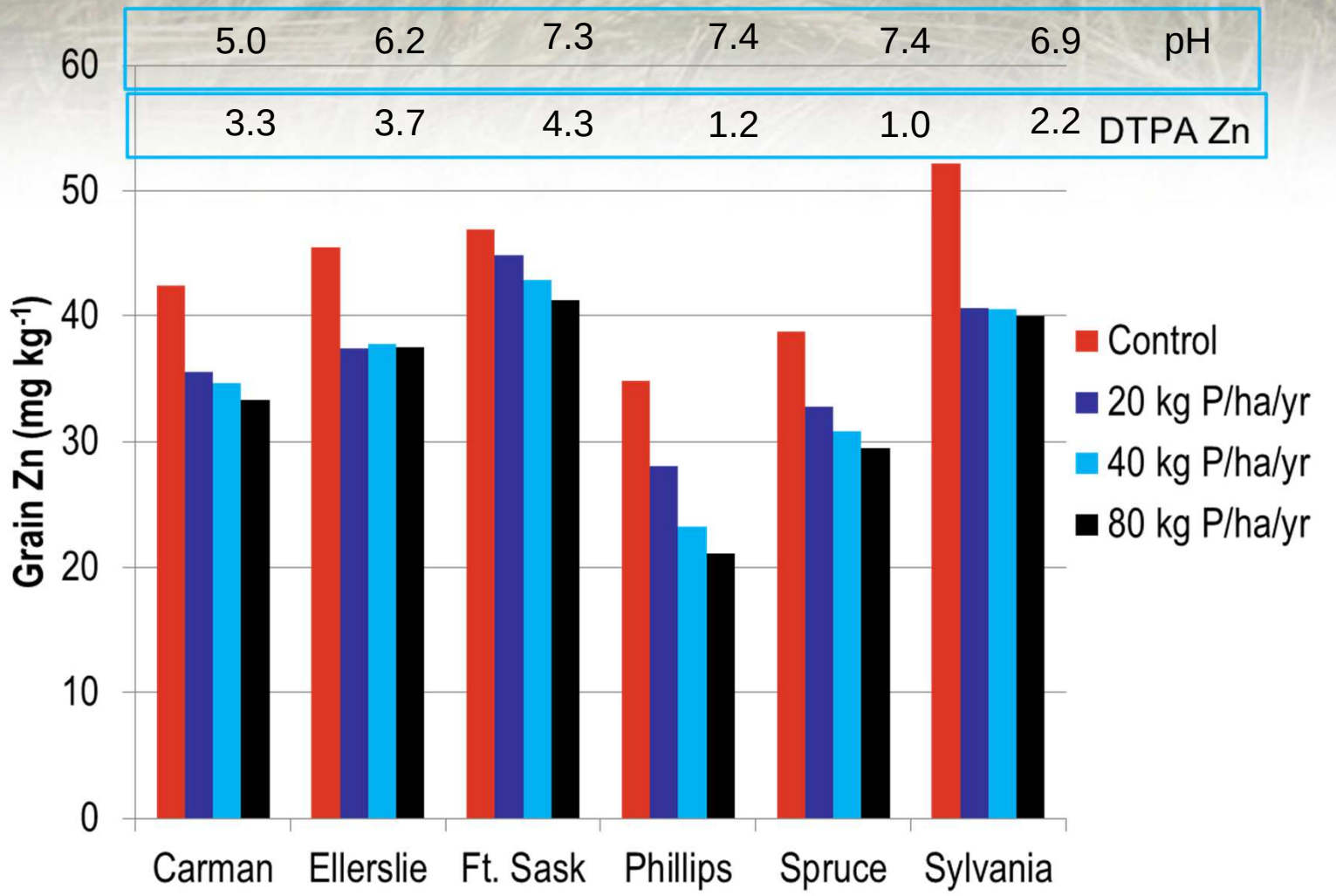
Can also increase crop yield on Zn deficient soils for a two-fold benefit

Phosphorus Fertilization Can Reduce Zinc Availability for Crop Uptake and Human Nutrition

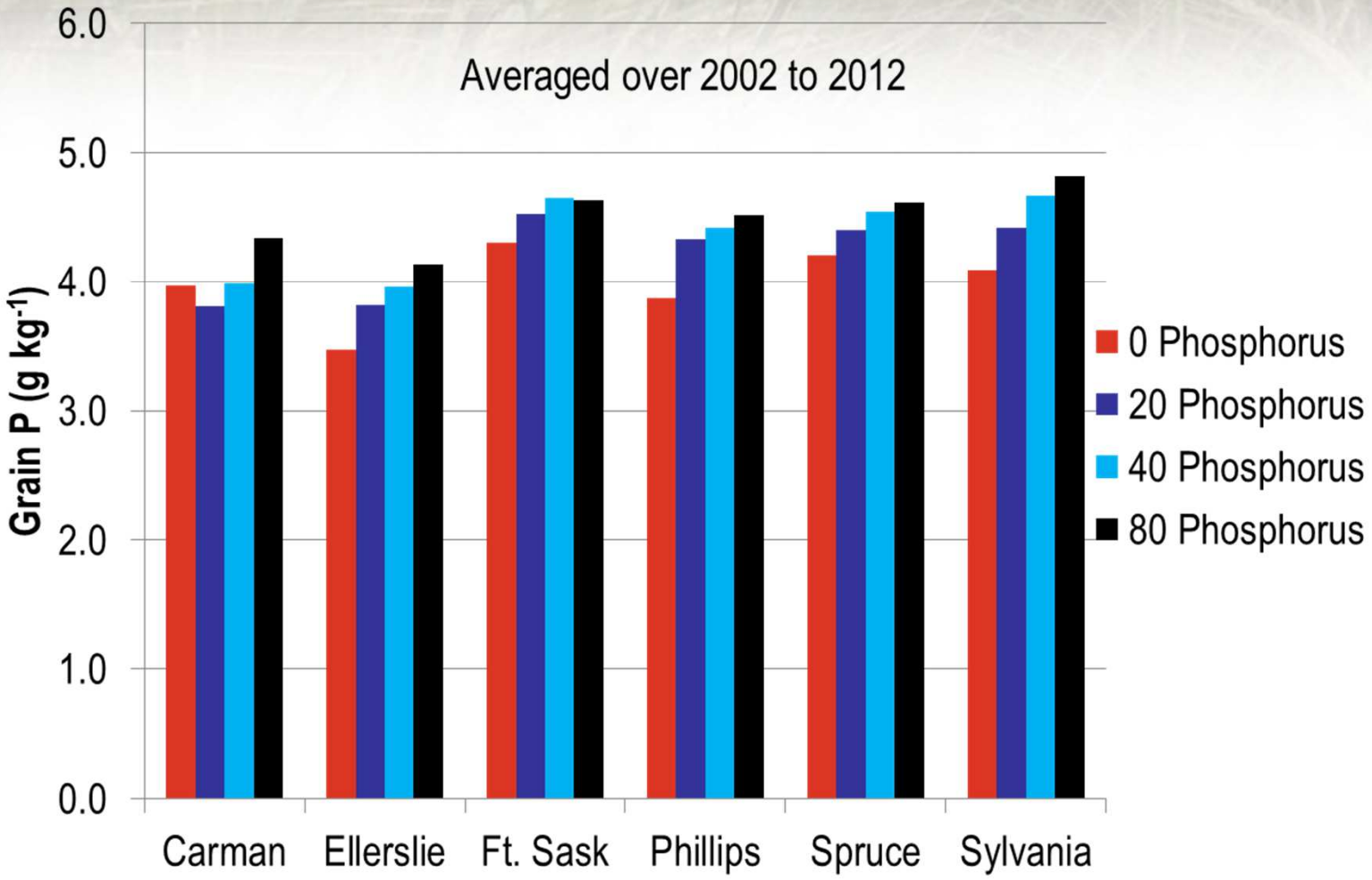
- Phosphorus-Zn interaction can reduce Zn uptake and translocation in the plant
- Phosphorus is stored in cereals as phytate
  - Total P and phytate are closely correlated (Raboy et al. 1991)
  - Increasing P fertilizer can increase phytate concentration in wheat
- Phytate will reduce Zn absorption by gut
- High levels of P fertilization may have double effect on Zn availability
  - Decrease actual Zn concentration in grain
  - Decrease Zn:phytate ratio



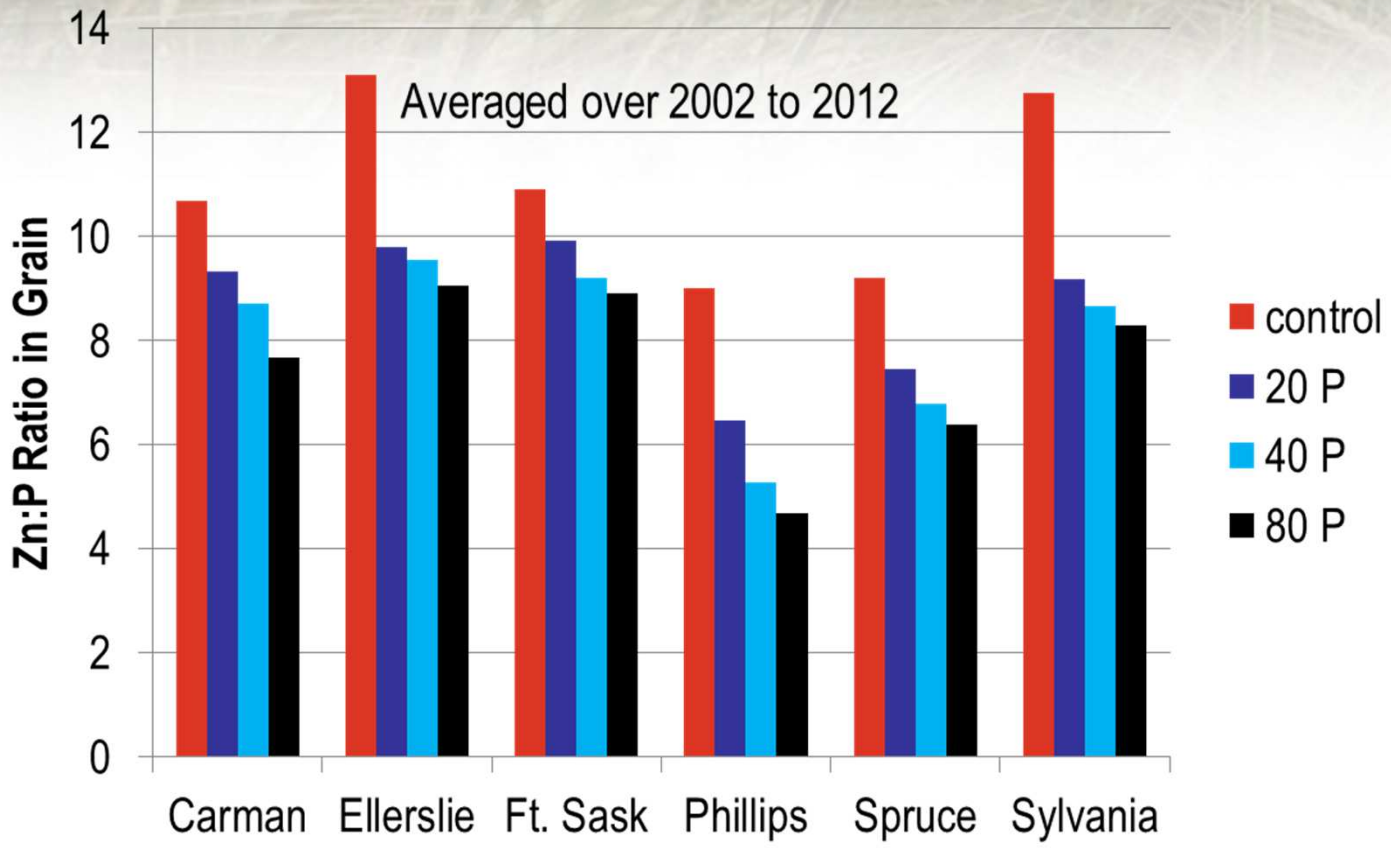
P Application Decreased Zn, Especially on High pH and Low Soil Zn Soils



Grain P also Increased with P Application



Ratio of Zn:P Decreased with P application



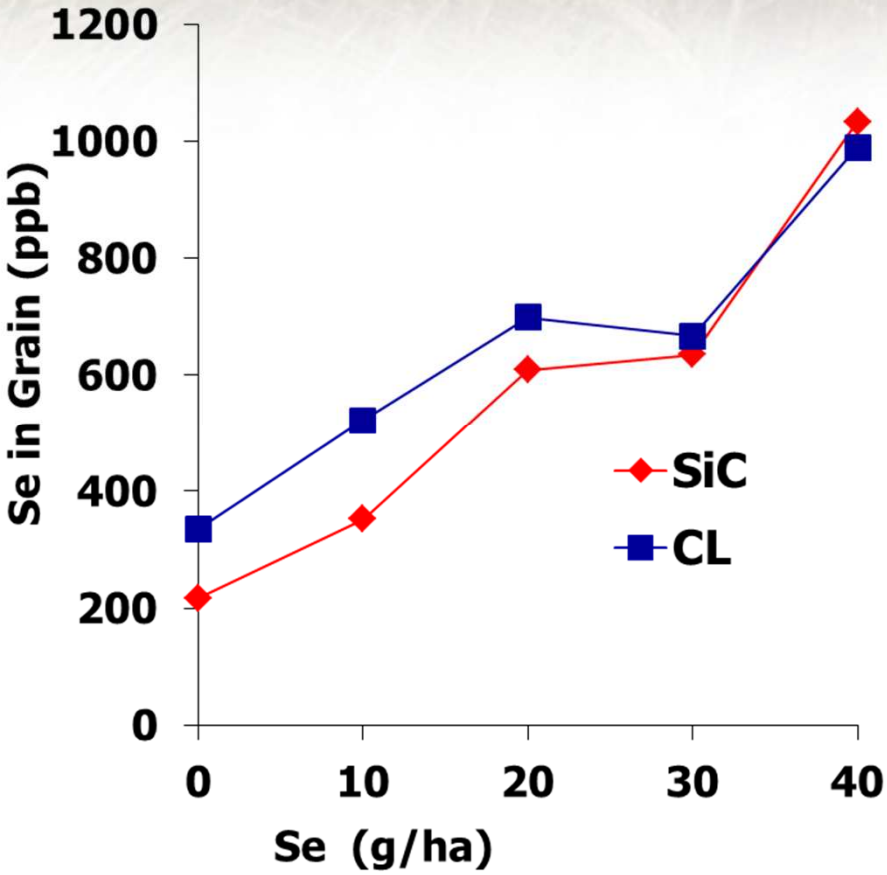
High P reduced both concentration and potential availability of Zn

Selenium Deficiencies Are Common in Many Regions

- Low Se levels have been measured in livestock feed in Latin America, including Brazil
- Many diets are low in Se
  - Se is an important antioxidant
  - Evidence that increasing Se can cause health effects such as reduced cancer risk and reduced cardiovascular disease
  - Supplementation may be beneficial, even when diet is marginal
  - Excesses may be dangerous, so balance is important

Effect of Se Seed-Coating on Se Concentration in Durum Grain at Two Locations (1999)

- Se concentration can be increased easily with Se applications as seed-coat or fertilizer
- Finland and New Zealand add Se to fertilizer
  - Improved livestock productivity and human health
- UK is assessing methods of increasing Se in crops since average intake is too low



Excess Trace Elements Are Also of Concern in the Human Diet – Especially Cd, As and Se

- Limits for grains traded internationally are set by Codex Alimentarius of the FAO (United Nations) and WHO
- Vegetables, fruits, cereals, potatoes and leaf vegetables have a limit range of 0.050–0.2 mg kg^{-1} total cadmium (fresh weight).
- There are no Codex maximum limits for arsenic and selenium
  - China has set limits for grains, vegetables, fruit and pulses for arsenic ranging from 0.05 to 0.2 mg kg^{-1} and selenium from 0.05 to 0.3 mg kg^{-1}

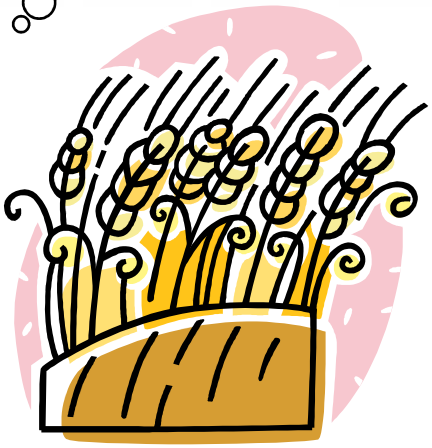
Factors affecting Trace Element Concentration of Crops

Soil Characteristics

Soil concentration

Irrigation and water management

weather



Crop Rotation

Crop Genetics

Tillage and agronomic management

Fertilizer management

Plant-Soil Barrier Affect Risk of Trace Elements

- Most elements are too insoluble to cause problems for plants or people
  - Cr, Hg, F, Pb, Ag, Ba, Zr, V
- Most elements become toxic to the plant before they reach concentrations that will be harmful to the people consuming them
  - Zn, Cu, Ni, Mn, B, not usually a risk in plant products
  - Pb can be a problem from consumption of dirt or dust on the plants or directly by children
  - Cd and Se may be a problem in some staple crops
  - As may be a concern in rice grown or cooked with high As water

Major Concern is with Staple Crops

- Crops such as wheat, potatoes, and rice that make up major portion of diet
- Intake and risk from the diet is associated with long-term accumulation
  - Related to concentration in the food multiplied by amount consumed
  - If amount of item consumed is low, the health risk is low
    - Consumer perception may still affect the market even when there is no real health risk
- Quality of overall diet affects Cd absorption
  - Trace element deficiency increases risk
  - More nutritionally balanced, diverse diet decreases risk

Cadmium is of Concern in a Number of Crops

- Naturally present in soils
- Added in fertilizers, soil amendments and industrial contamination
- Health concerns over chronic toxicity from long-term consumption of Cd in food
  - Kidney problems, Itai-itai disease, possibly cancer (debatable)
- Restrictions have been placed on level of Cd in foods and fertilizers

Many Crops Can Accumulate High Cd

- Durum wheat - major staple crop
- Soybean – high consumption in some countries
- Leafy vegetables, carrots
- Sunflower –low level of consumption
- Flax – low consumption but viewed as “health food”




Rice is of Special Concern

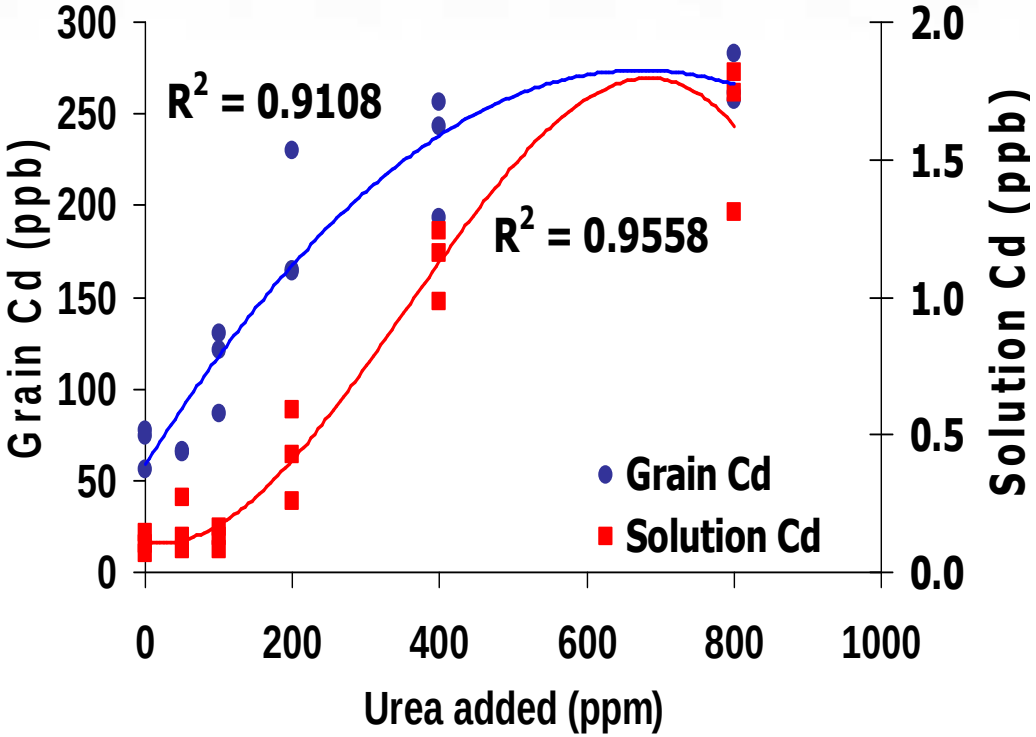
- Rice can accumulate high Cd
- Major source of Cd in diet
  - Inorganic As form is more toxic than organic forms
- Cd in rice is highly bioavailable
  - Rice is low in Zn and Fe
    - Zn and Fe will restrict absorption of Cd by gut
    - Trace element deficiency increases risk
- Often subsistence rice-based diets are poorly diversified
  - Lacking in meat, dairy, and other nutrient-dense plant products
  - High degree of local consumption accentuates risk in contaminated regions

Fertilizer Management Can Influence Cd and As Concentration

- Addition of Cd in fertilizer
- Effects on soil or rhizosphere chemistry
  - pH, osmotic strength, exchange reactions
- Competition for plant uptake
- Effects on plant growth
  - rooting, transpiration, translocation, dilution

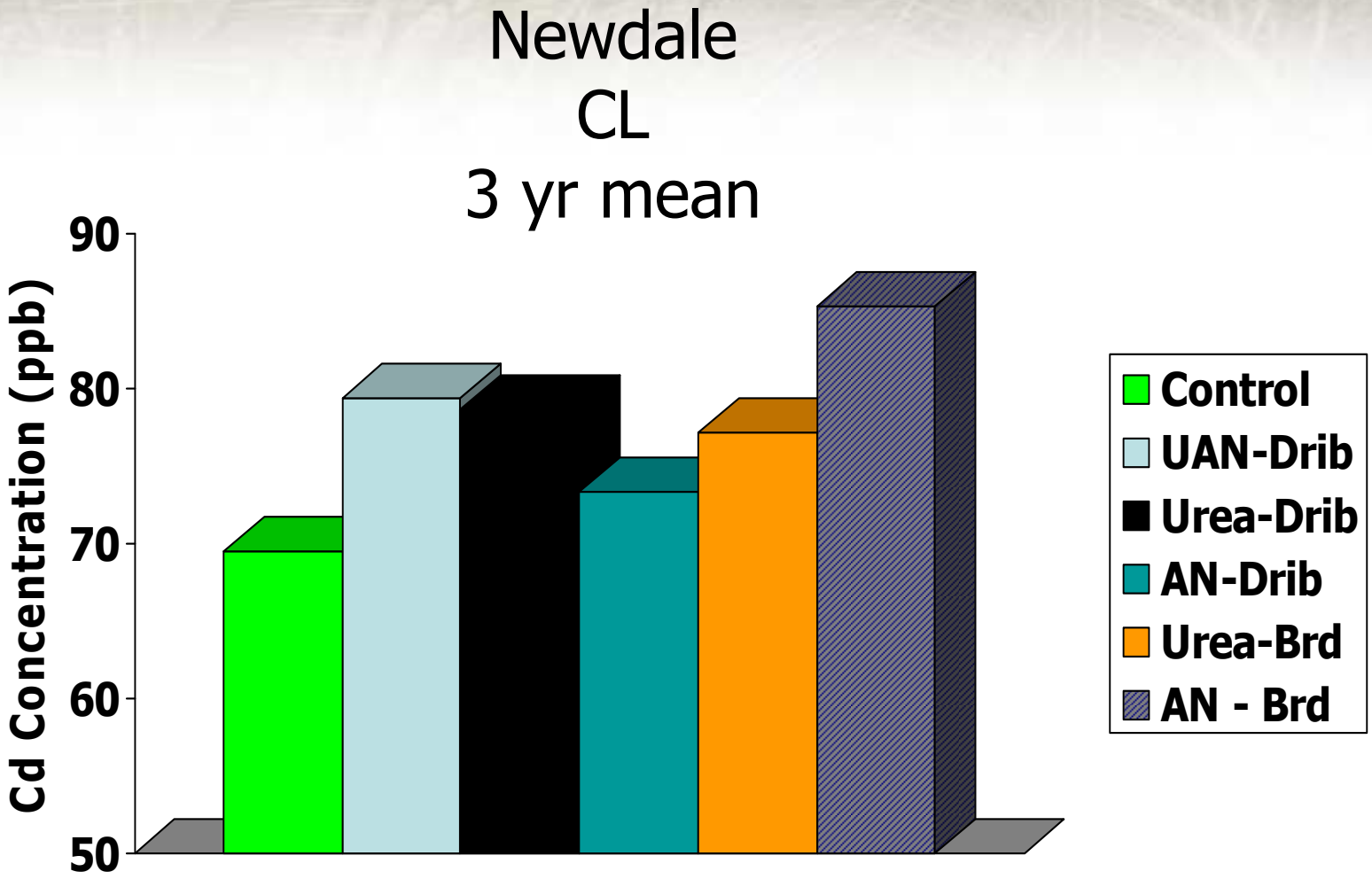
Nitrogen Fertilizer is Often Needed to Optimized Cereal Production

- N fertilization can increase both soil solution Cd and durum wheat grain Cd concentration in pot studies



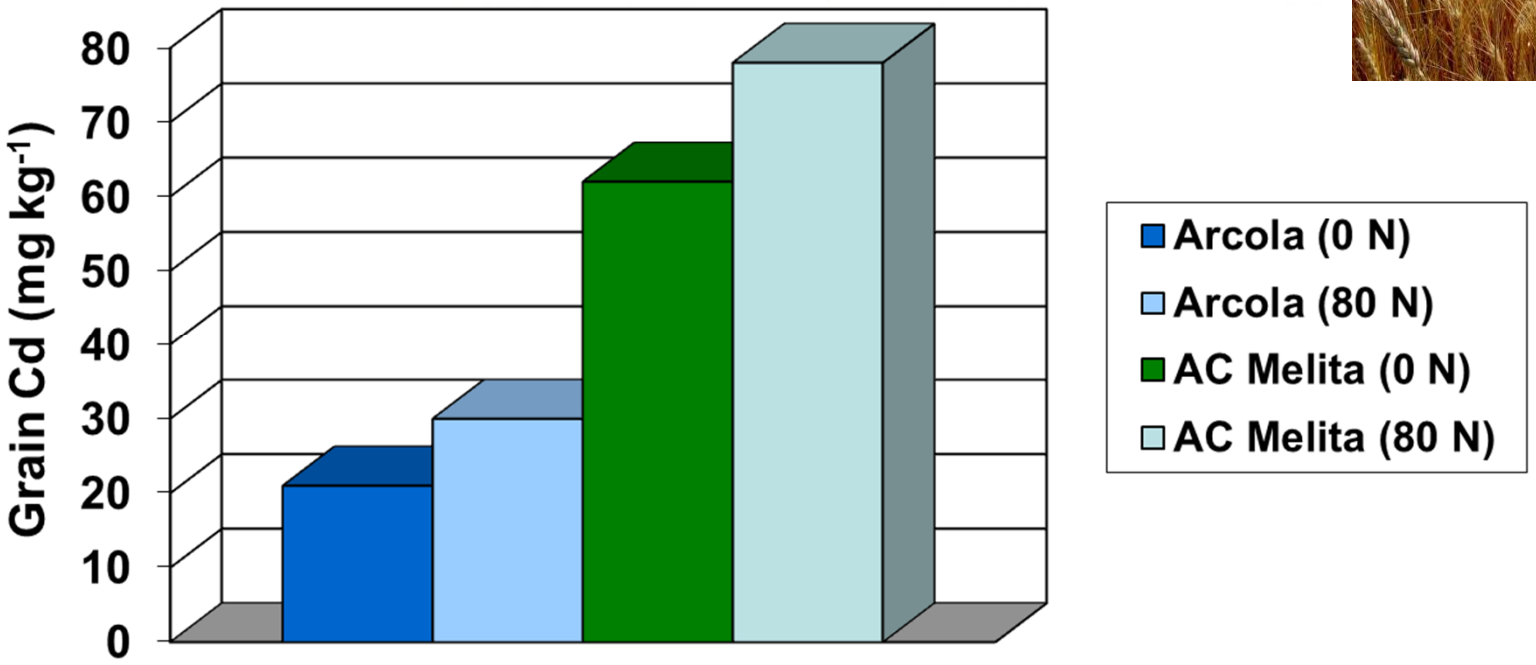
Mitchell 1999

Nitrogen Fertilizer Increased Cd Concentration Under Field Conditions



Gao et al. 2012

Nitrogen Effect Was Consistent Across Cultivars



Perelli, Mitchell et al. (2010)

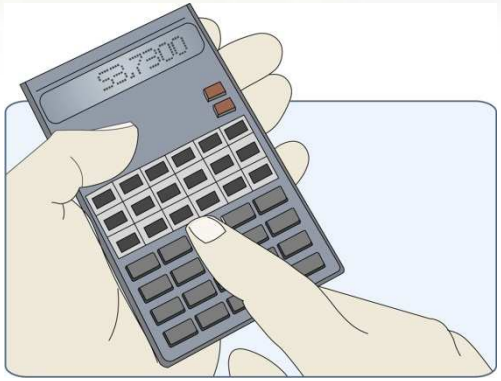
Phosphate and Cadmium Concentration of Sedimentary and Igneous Rocks

Source	Average P_2O_5 Wt %	Average Cd (ppm)	Range Cd (ppm)
Morocco	33	26	10-45
Togo	37	58	48-67
Florida	32	9	3-20
Idaho	32	92	40-150
Senegal	36	87	60-115
Finland	40	<2	-
Russia	39	1.25	0.3-2.0

http://www.fertilizer.org/ifa/Home-Page/LIBRARY/Publication-database.html/Cadmium-Content-of-Phosphate-Rock-and-Fertilizers.html

Cadmium in Phosphate May Accumulate in Soils From Long-term Applications

- Phosphate fertilizers contain cadmium
- Accumulation = Addition - losses
- Addition is affected by
  - Cd concentration in fertilizer
  - Rate of phosphate addition
  - Frequency of application
- Losses are mainly by crop off-take
- Phytoavailability of Cd may also be affected by soil characteristics and management

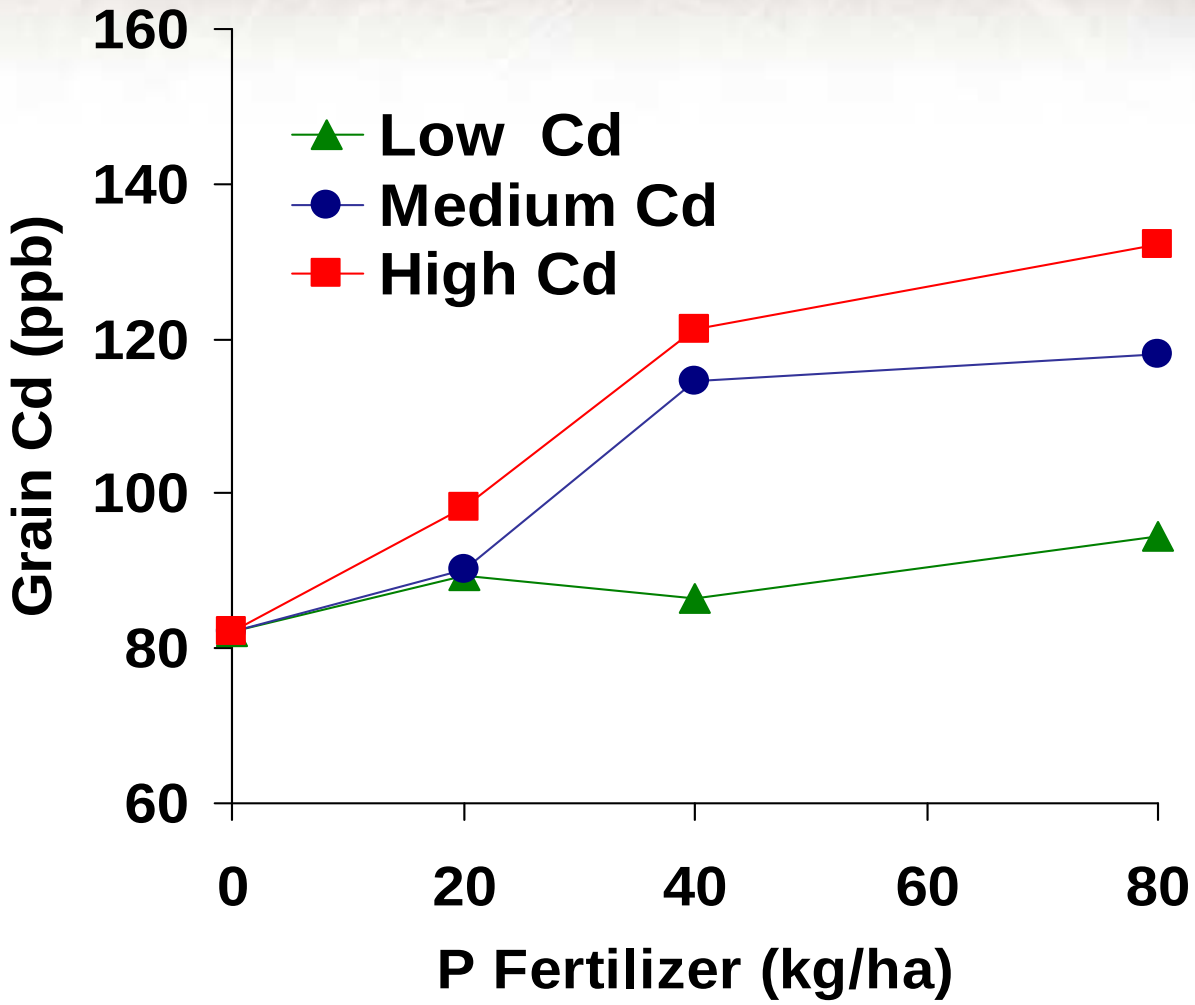


Sheppard, S.C., C.A. Grant. M.I. Sheppard, R. de Jong and J. Long. 2009. Risk indicator for agricultural inputs of trace elements to Canadian soils. J. Environ. Qual. 38(3): 919-932.

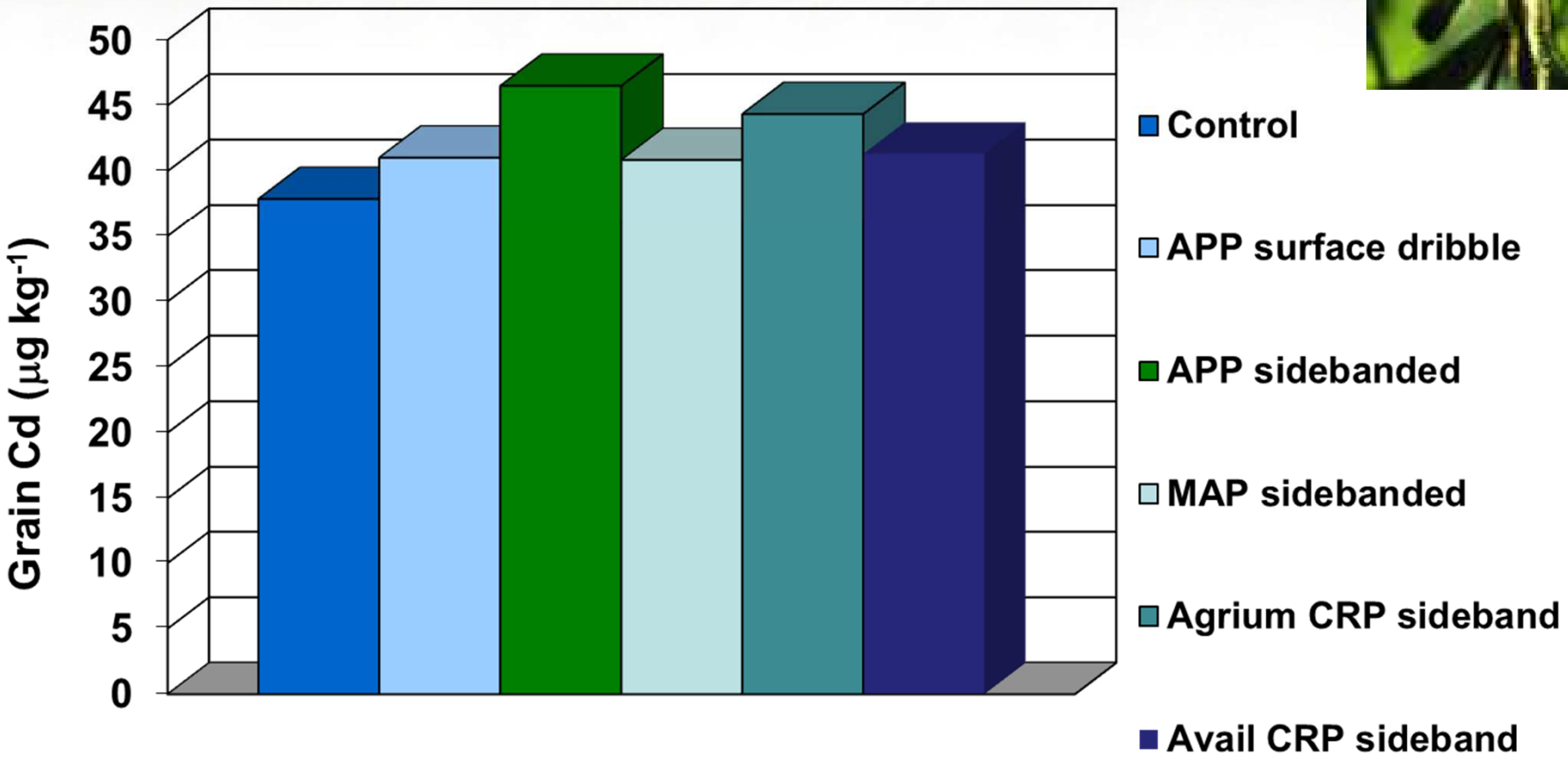
Cd Concentration of Durum Wheat Increased with P Application Rate and Cd Concentration

2008

Averaged over field sites
Seven years of application

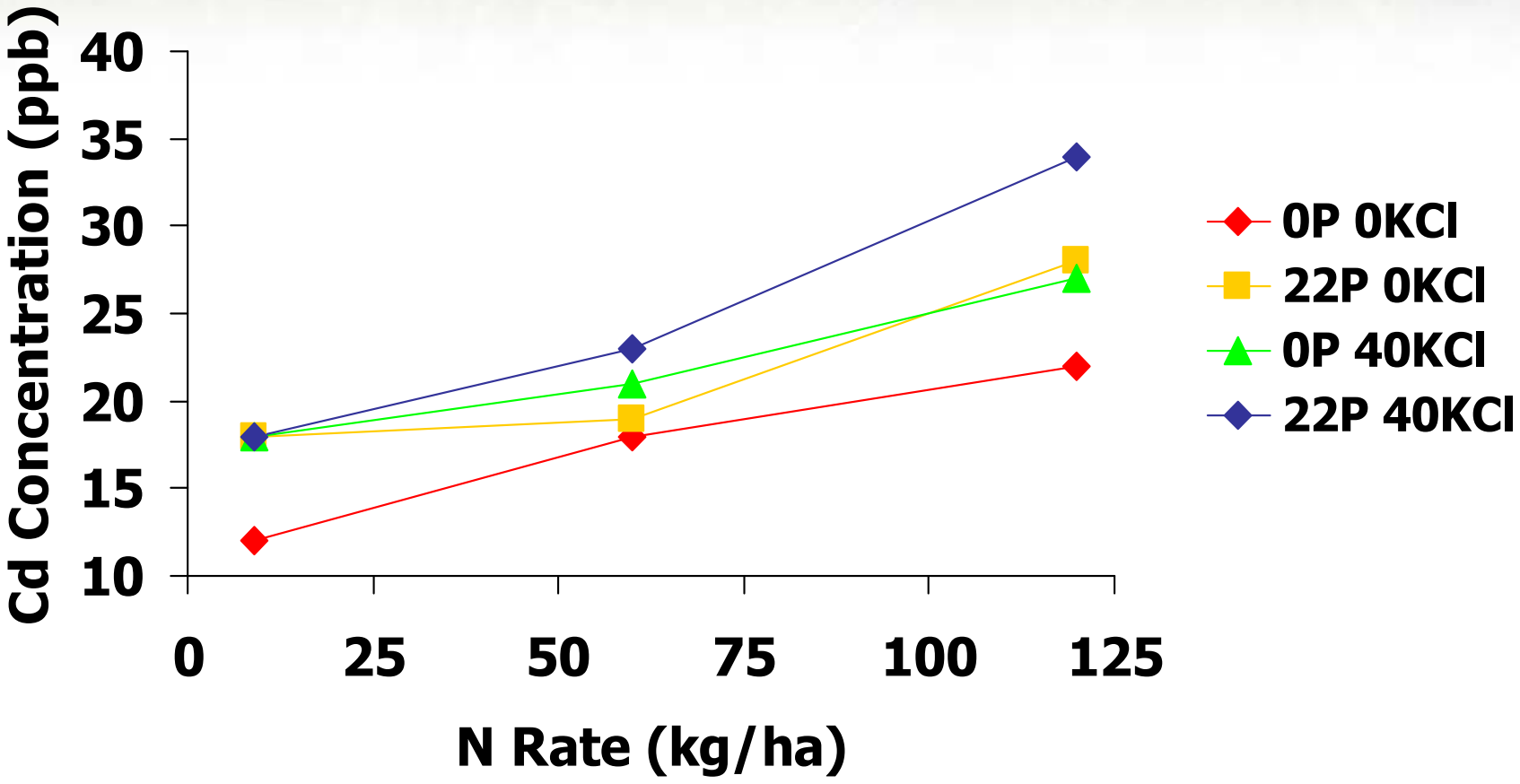


Phosphorus Fertilization Slightly Increased Seed Cd in Soybean Under Field Conditions



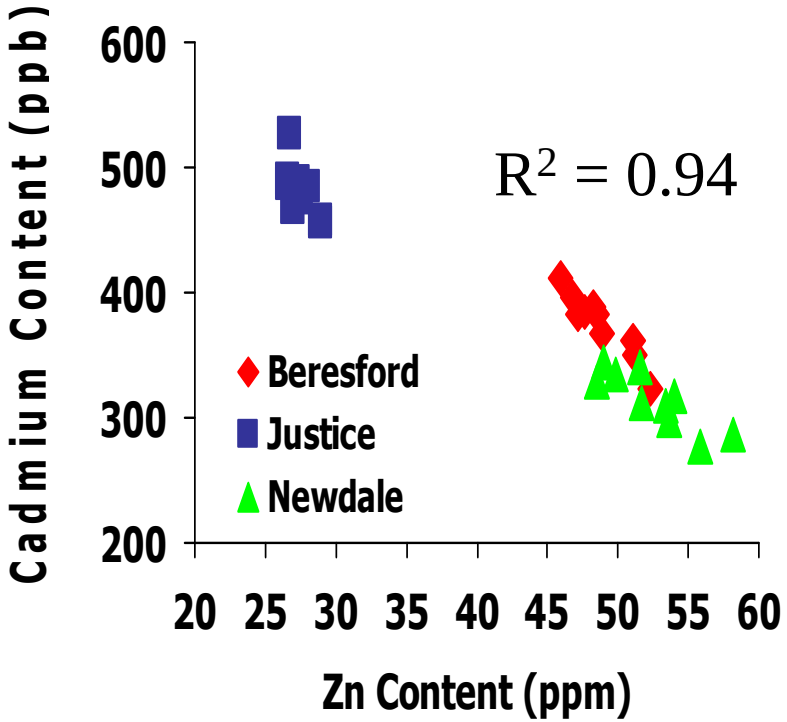
Grant (unpublished)

KCl, P and N Also Increased Cd Concentration of Barley Under Field Conditions

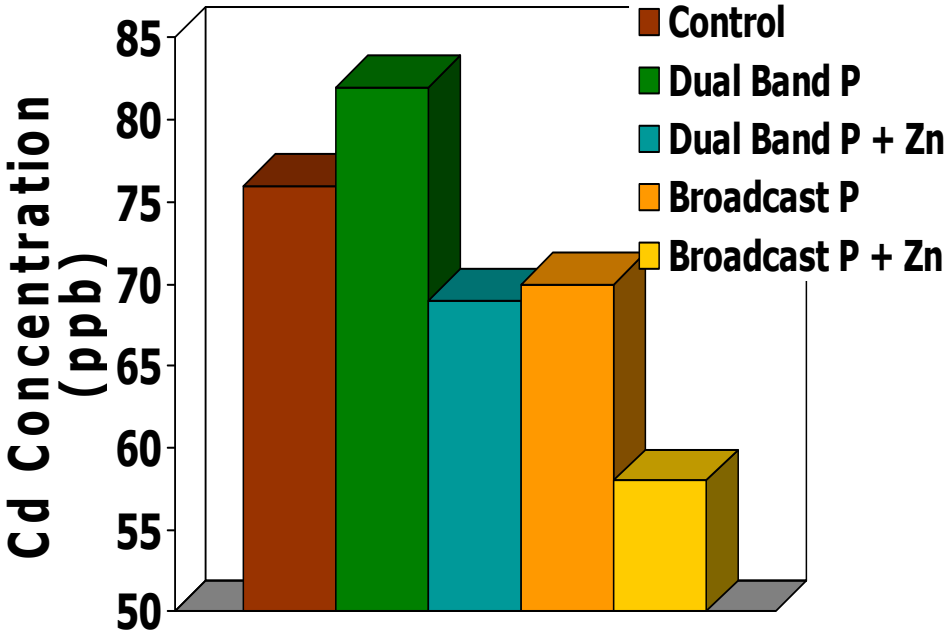


Application of Zn can Decrease Grain Cd Concentration under Field Conditions

Flax



Durum Wheat



Arsenic

- Geogenically elevated As_i in water is widespread in Asia
- Crops can accumulate As_i from soil
- Rice is a major source of As_i in the food chain
  - 50% or more of daily intake
  - Anaerobic paddy conditions enhance availability
  - Rice takes up As_i through phosphate and Si pathway

Arsenic in Rice Made Headlines in 2012

- Media testing of US rice showed high total levels
  - Did not discriminate between forms in the rice
  - Calls for As limits to be placed on US rice
- Inorganic As is primary concern
  - Organic forms are much less bioavailable
  - Dimethylarseninic acid (DMA) is major organic component

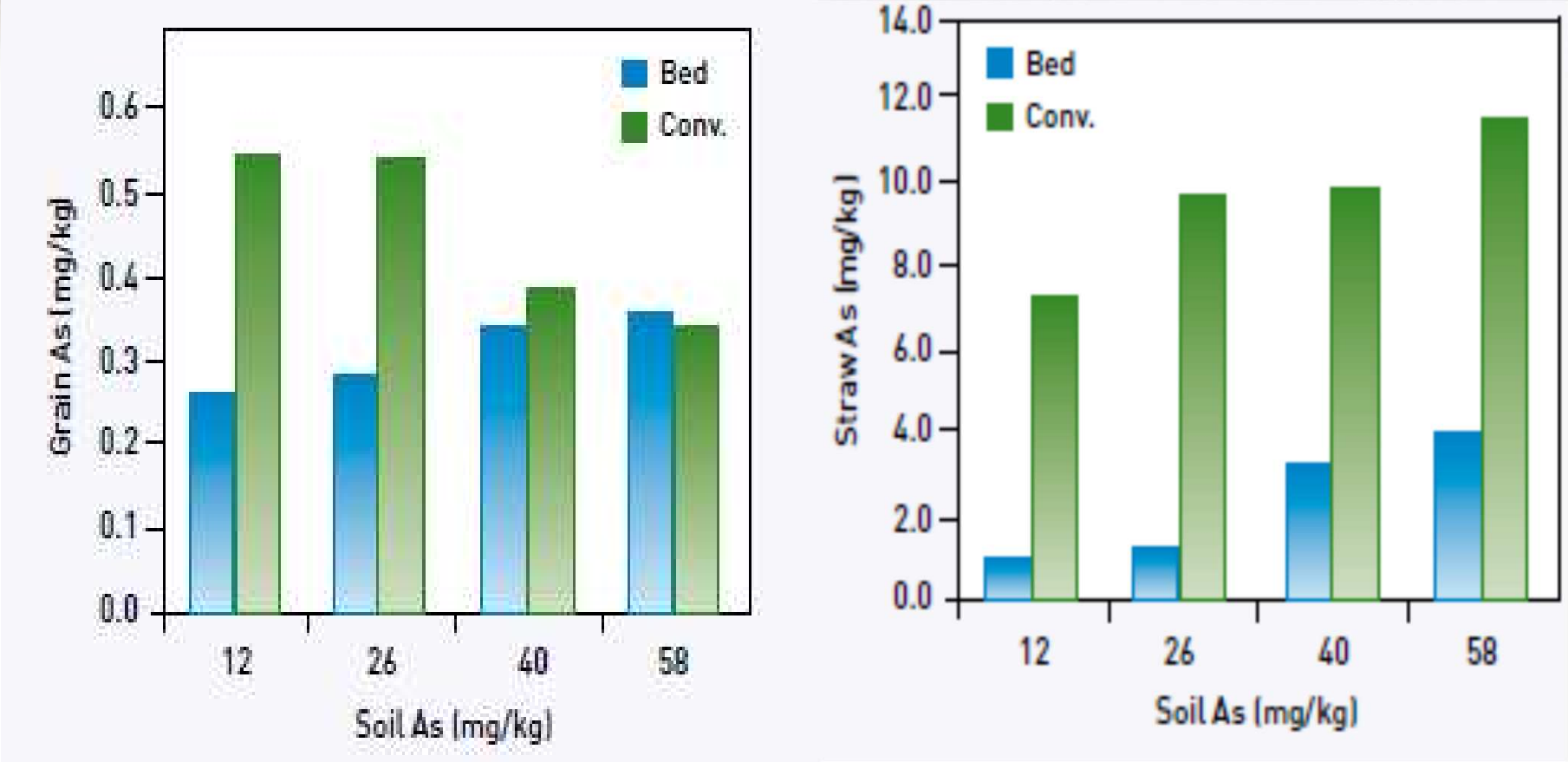
Growing rice in raised beds can reduce As availability

- Higher redox potential in the raised beds causes adsorption of As onto oxidized Fe surfaces, reducing availability.
- Arsenic in the arsenate form in oxidized soils is suppressed by phosphate, unlike the arsenite that is in flooded soils
- Yield of rice on raised beds is less affected by soil As levels than in conventional paddies

Duxbury et al. (2007)

FAO-Cornell project

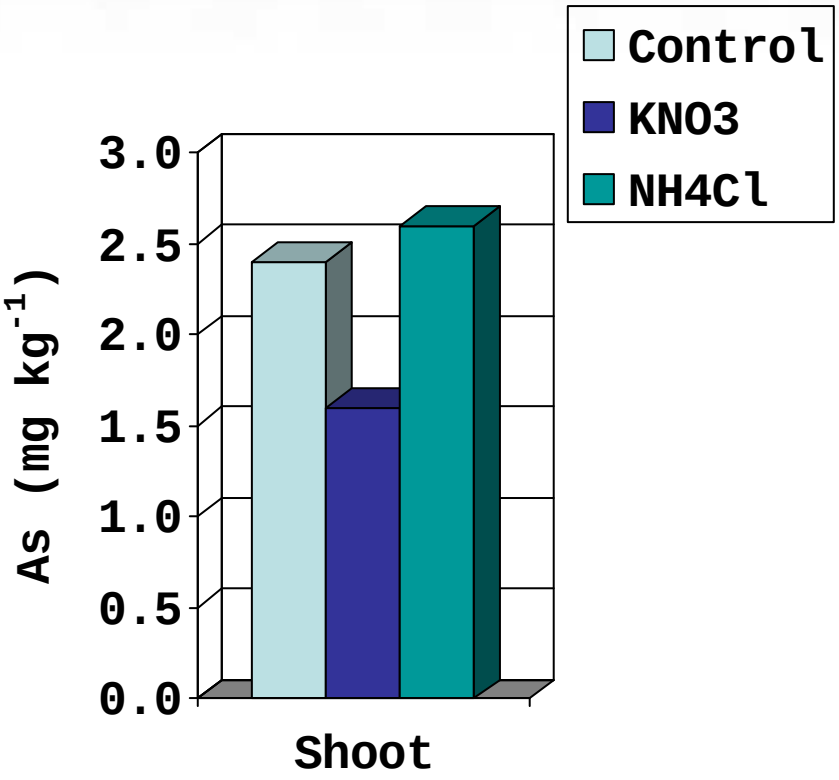
Arsenic in Both Grain and straw was Lower in the Raised Beds than Conventional Paddies



Duxbury et al. (2007)
FAO-Cornell project

Arsenic in Rice May Also be Affected by N Application

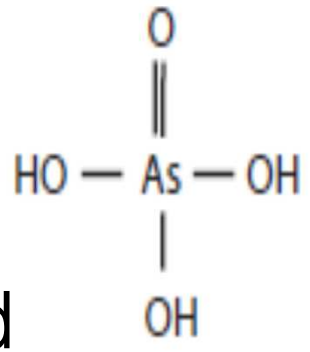
- Lower concentration of As when N was added in the nitrate form in pot studies
  - Nitrate stimulated As co-precipitation of or adsorption to Fe (III) minerals in the soil
- Nitrate fertilization may be able to reduce As levels
  - Needs field testing



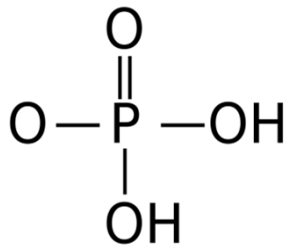
Chen et al. (2008)

Phosphate Fertilizer and Arsenic

- Oxidized arsenic species arsenate acts as phosphate analogue
  - Enters plant through phosphate co-transporters
  - Phosphate will compete with arsenate for plant uptake
- BUT: phosphate also competes with arsenate and arsenite for adsorption on Fe-oxides
  - Reduces As adsorption and increases availability
- Phosphate status of plant affects
  - Phytosiderophore secretion by plant
  - Plaque formation
  - Feedback regulation of arsenate uptake by P transporters

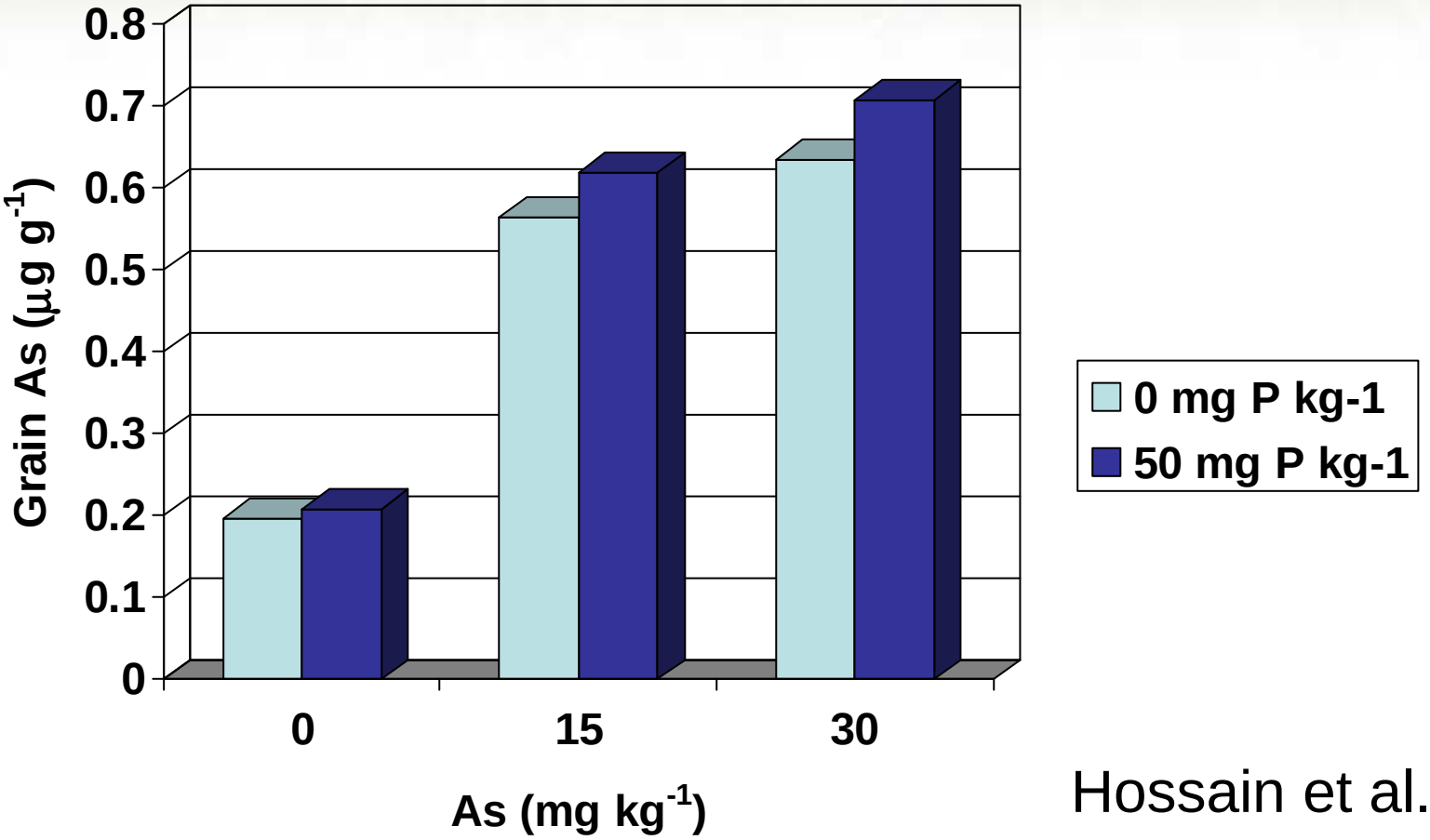


Arsenate



Phosphate

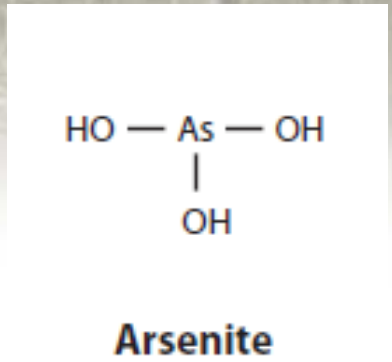
In Pot Studies, P Application Increased Grain As Concentration in Rice Under Flooded Conditions



Hossain et al. 2009

Silicon Application can Reduce As Accumulation in Rice

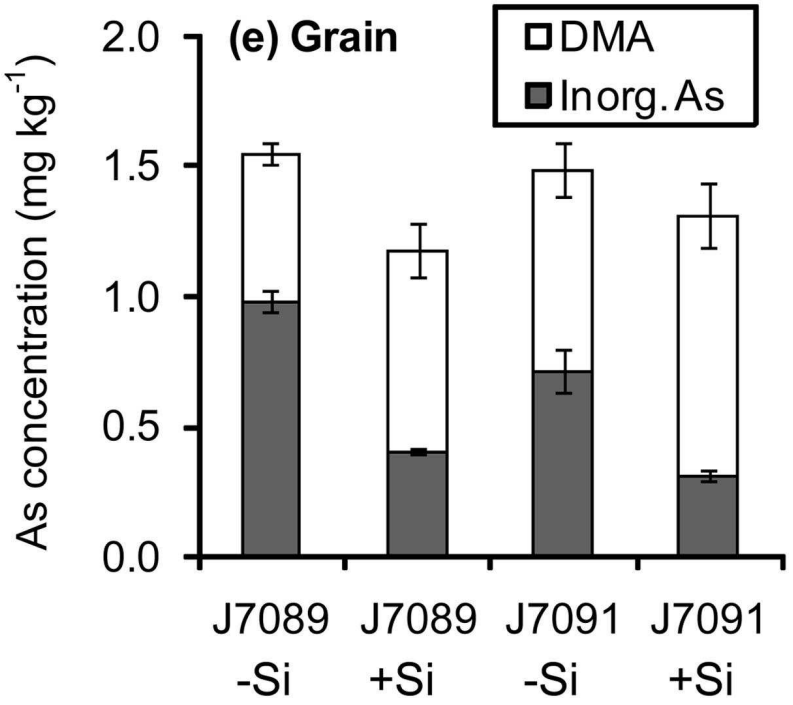
- Rice is a strong Si accumulator
  - Aids in stress resistance
  - Si is often used as fertilizer to increase rice yield
  - Well-water is often low in Si
- Arsenite is taken up and transported by Si pathway
  - Si and arsenite compete for uptake and efflux transporters
- Si fertilization reduces As uptake
  - As accumulation lower in shoots and to a lesser extent in grain
  - Win-win scenario



Arsenite

Silicon application reduced As concentration and proportion of inorganic As in rice grain in pot studies

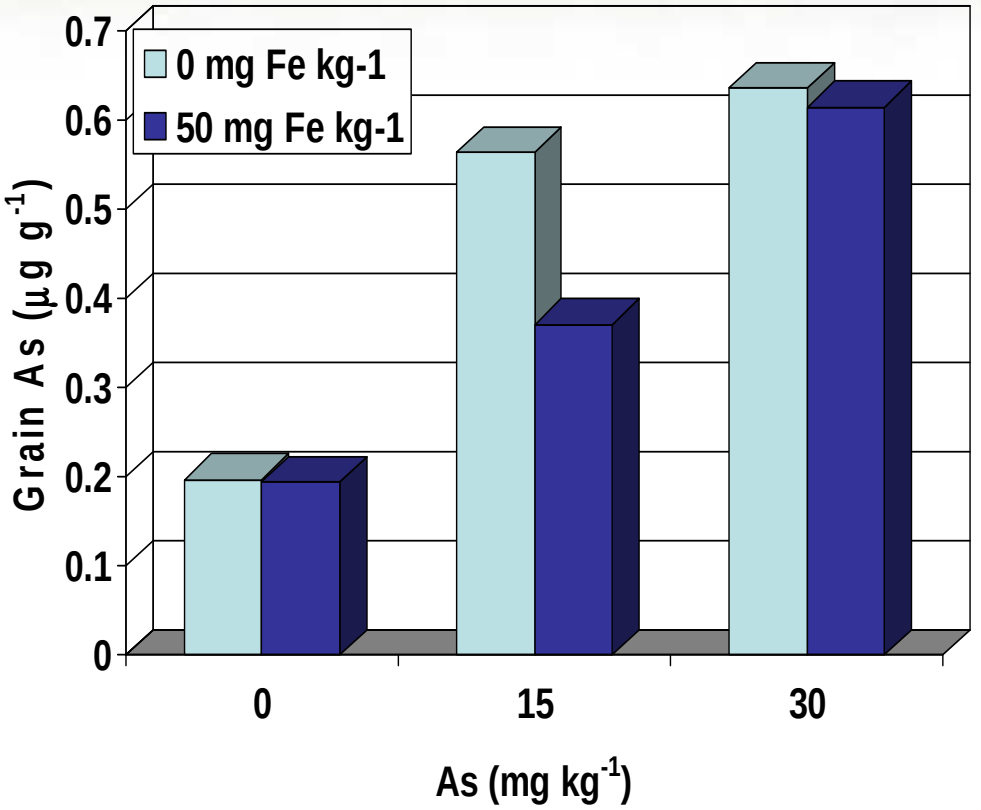
- Si decreased inorganic As but increased DMA
  - Greater effect in reducing toxicity than in reducing total concentration
- Si fertilization also increased grain and straw yield



Li et al. (2009)

Iron May Decrease Accumulation of As in Rice

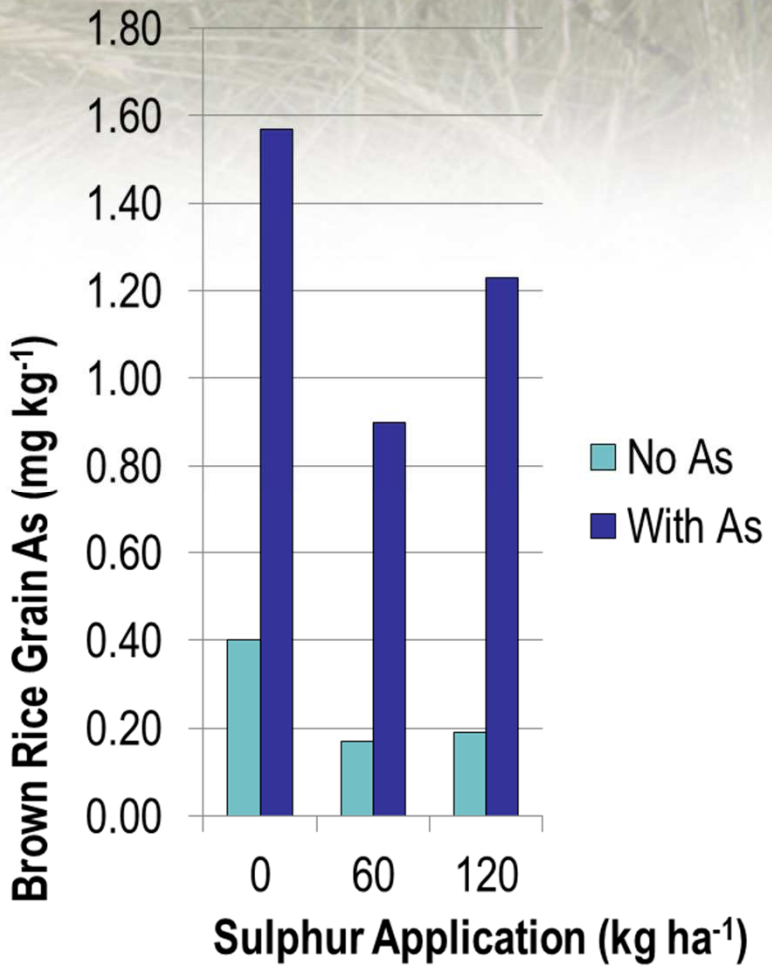
- Fe-oxide plaque at the root surface can be a source or sink for As
- Application of Fe^{2+} can increase plaque formation and increase As adsorption
  - Decrease available As for uptake



Hossain et al. 2009

Sulphur May Also Reduce As Accumulation in Rice

- Increases plaque formation in rhizosphere
  - Increases As trapped on root surface
  - Inhibits As translocation from root to shoot to grain
- Induced glutathione formation and As-phytochelatin complexes
  - Sequesters As in vacuole and decreases translocation to grain
- Possibly forms As_2S_3 or FeAsS precipitates



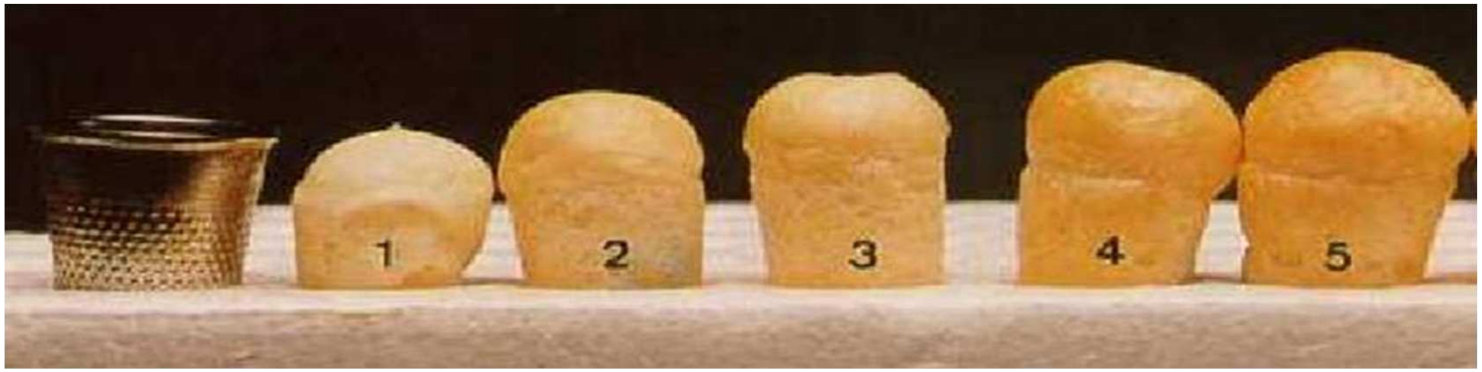
Fan et al (2013)

Summary

- Crops are important sources of protein, carbohydrate, oils and trace elements in the human diet
- May also be a significant source of harmful heavy metals
- Manage to increase beneficial traits and reduce harmful ones

Summary

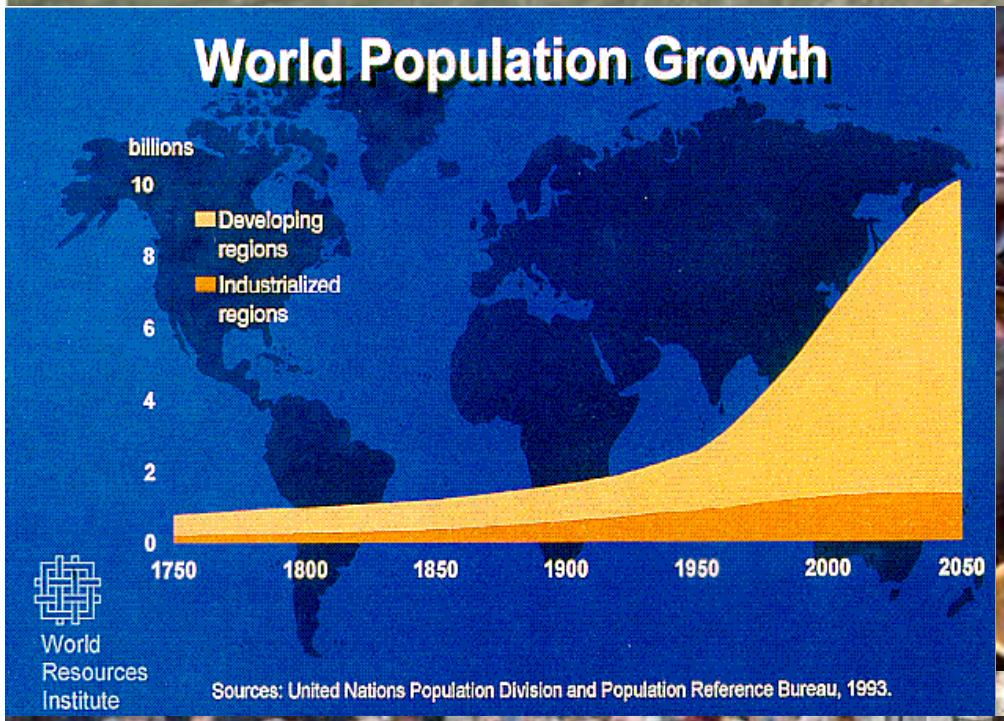
- Nutrient management will affect both crop yield and quality
  - Functional quality
  - Nutritional quality
- Major impacts on protein content and amino acid composition
- Affects oil and carbohydrate concentration
  - Lesser effect on fatty acid and starch quality



Summary

- Concentration of beneficial trace elements can be increased by nutrient management
  - Zn and Se in particular
- Harmful trace elements As and Cd can also be affected by nutrient management
  - Fertilization can increase or decrease As and Cd concentration

The World's Population is Projected to Rise to Over 9.1 Billion by 2050



Summary

- Efficient nutrient management is critical in providing an adequate and high quality diet for the increasing world population


Thank You