Principles of Micronutrient Use

Integrating Micronutrients into Global Fertilizer Practice.

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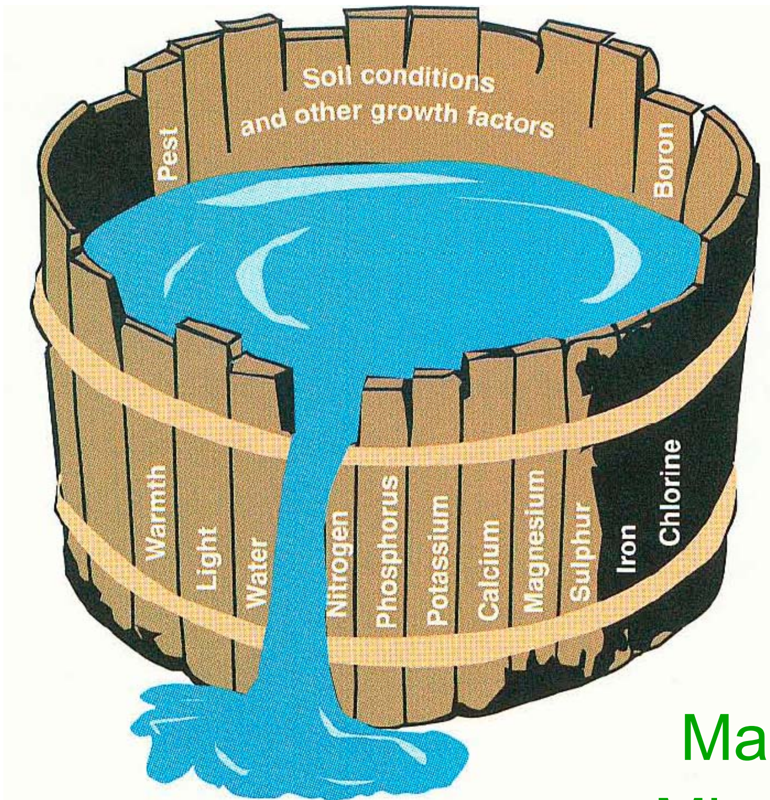
Outline

- Micronutrient State of the Globe
  - Nutrient budgets, deficits and downhill trends
  - New Demands (Micronutrients for Health, High Value Crops, Sustainability)
- The Challenges of Micronutrient Supply and Use
  - Soils Supply Processes
  - Plant Uptake Processes
- An Approach
  - Risk Mapping
  - New Products and Challenges
- Conclusion
  - Integrating Micronutrients into Global Fertilizer Practice

The Law of Minimum



".. It is by the minimum that crops are governed, be it lime, potash, nitrogen, phosphate, magnesium, or any other mineral constituent; it regulates and determines the amount or survival of the crops."

Justus Von Leibig, 1863

Macronutrients: N, P, K, Mg, Ca, S

Micro: B, Fe, Cu, Mn, Cu, Ni, Zn, Mo

Global Micronutrient Use:

Focus on the Developing World

- Very little data available for global micronutrient use
  - Micronutrient providers are scattered and highly diversified
  - Huge number of products with differential effectiveness
- Paradigm: Micronutrients are only needed if a clear deficiency is noted.
  - Very little maintenance application
  - Almost no crop micro-nutrient budgeting

Is there a problem?

Global Status of Micronutrients: *Is there a Problem?*

Nutrient Budget Approach (Smalling et al, 1997)

(Nutrient Budget = Inputs-Outputs)

- Inputs:
  - Fertilizers
  - Organic materials
  - Atmospheric Deposition
  - Sedimentation by irrigation and flooding
- Outputs
  - Harvested Products
  - Crop Residue removal
  - Solute leaching
  - Runoff and Erosion

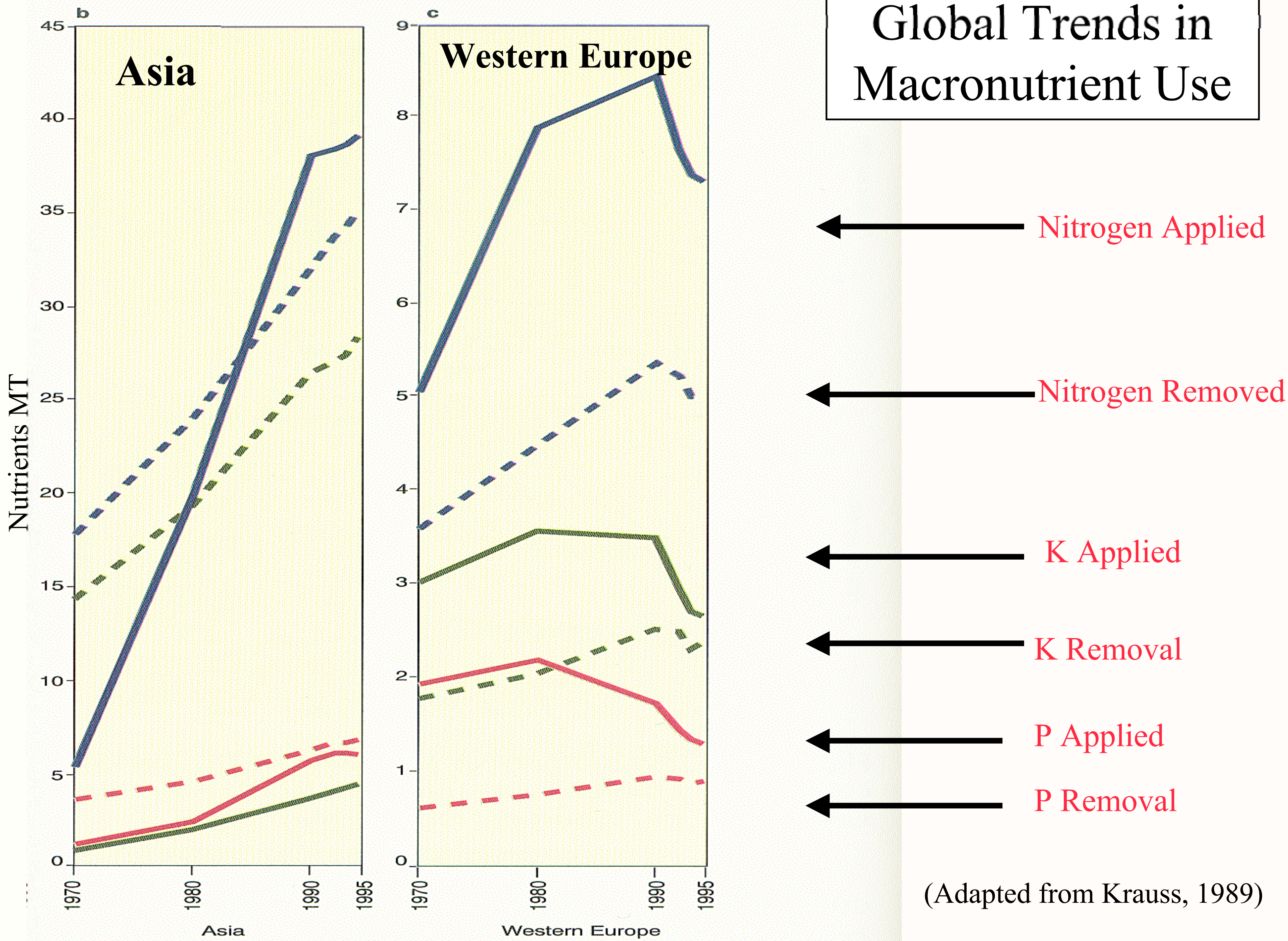
Presence and Extent of Micro Nutrient Deficiencies

Global Status of Micronutrients:

Budget Deficits and Downhill Trends

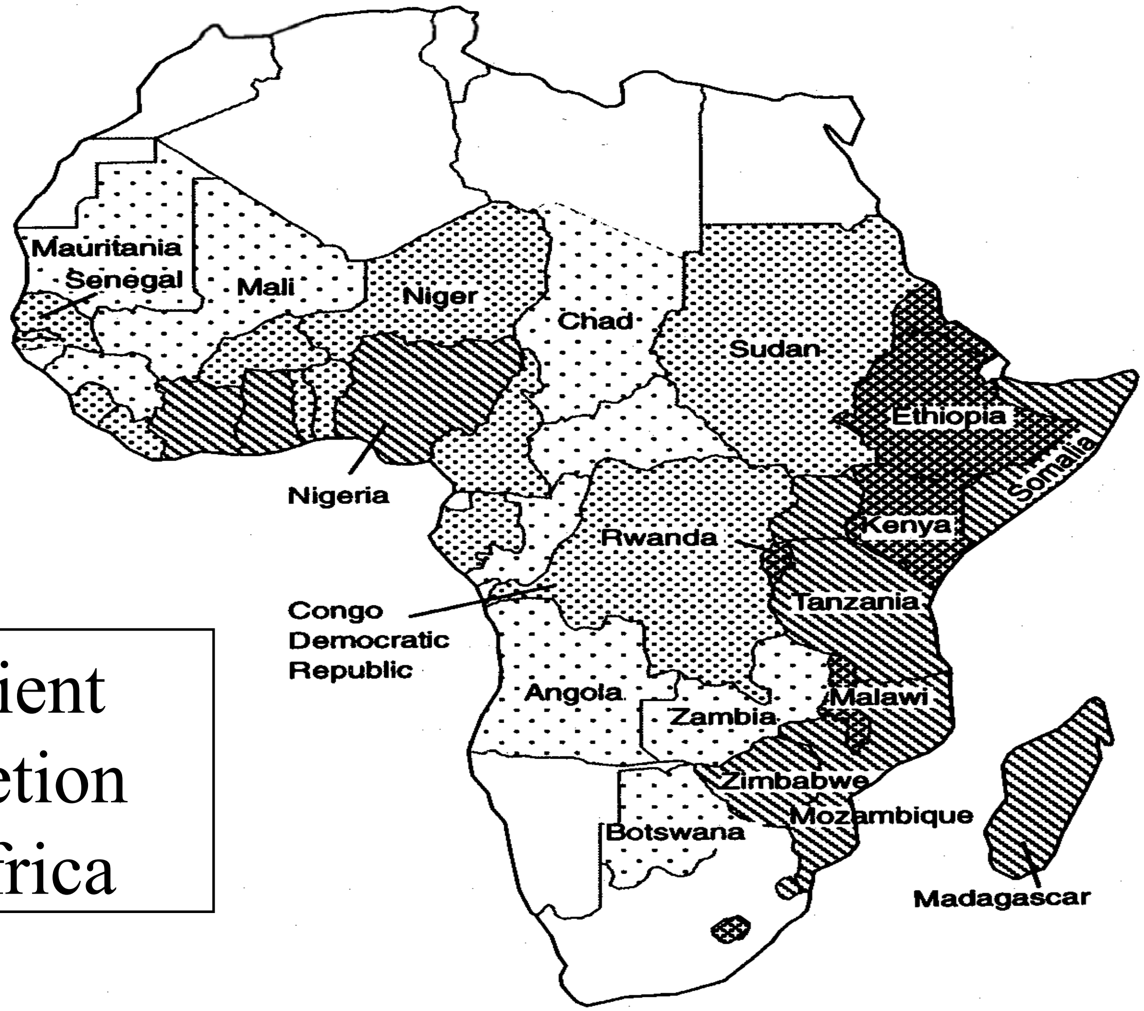
- Inputs Declining
  - Fertilizer Use (limited data)
    - Micronutrients rarely used in developing countries and generally used in developed countries only after deficiencies occur
    - High analysis N,P,K has fewer contaminants
  - Availability of organic manures is declining (Migration to cities, increase in cropping area)
  - Atmospheric deposition is now minor (predominantly industrial sources)
  - Sedimentation input is significant in some regions only (Bangladesh, Egypt)
- Outputs Increasing
  - Harvested Products and exported residues
    - Dramatic increase in yields in all environments except Africa (Green Revolution)
    - Shift toward high value crops, increases demand and export in leafy tissues
  - Runoff and Erosion (local effect as a result of land degredation).

Global Trends in Macronutrient Use



(Adapted from Krauss, 1989)

Nutrient Depletion In Africa



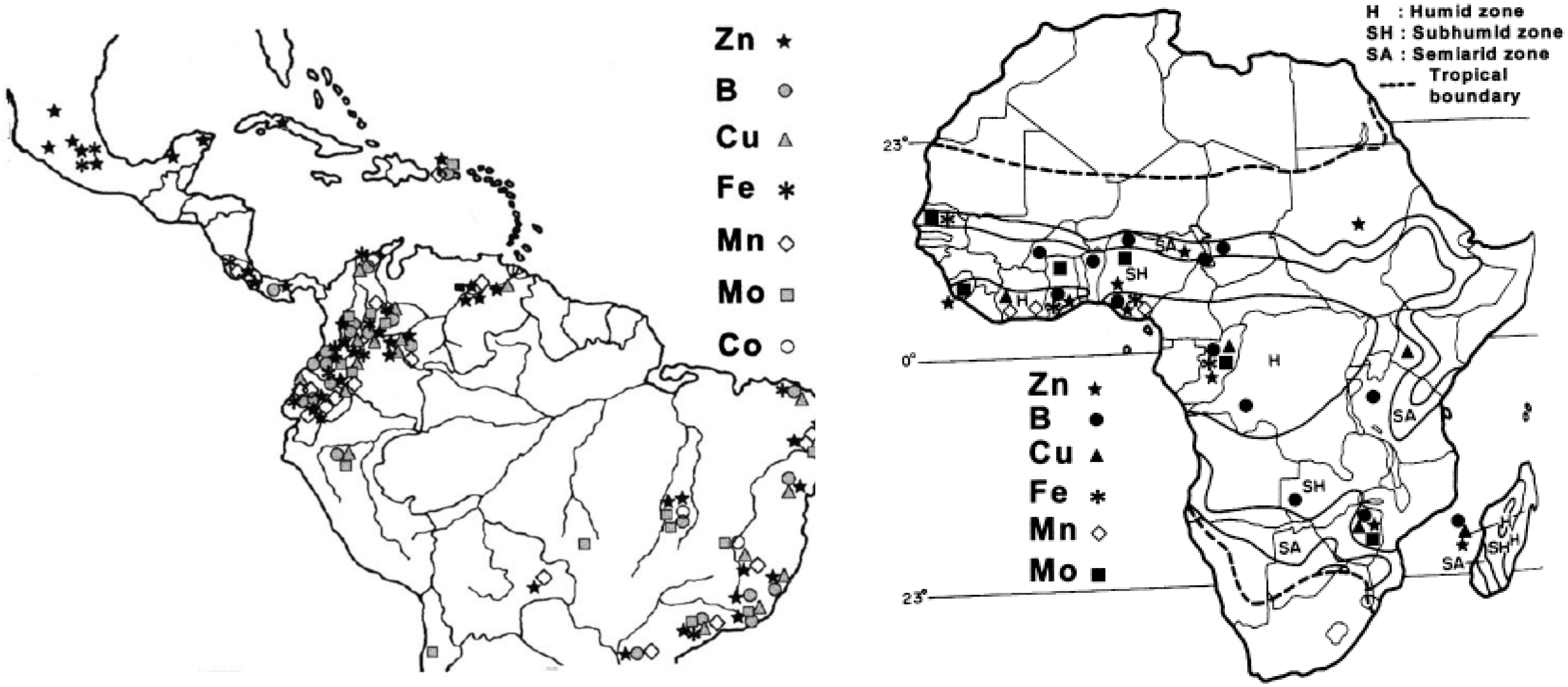
(Smalling et al 1997)

Nutrient depletion (kg ha^{-1} yr^{-1})

	N	P	K	Micronutrients
Low	< 10	< 1.7	< 8.3	?
Moderate	10 to 20	1.7 to 3.5	8.3 to 16.6	?
High	20 to 40	3.5 to 6.6	16.6 to 33.2	?
Very high	≥ 40	≥ 6.6	≥ 33.2	?

Limited Documentation of Micronutrient Deficient Areas

J.G. White, R.J. Zasoski / Field Crops Research 60 (1999) 11–26



Sillanpää, M., 1982. Micronutrients and the nutrient status of soils: A global study. FAO Soils Bulletin 48.
Sillanpää, M., 1990. Micronutrients assessment at country level: An international study. FAO Soils Bulletin 63
Katyal and Vlek, 1985: Liu Zeng 1991.

Occurence of Deficiency Symptoms is Increasing

Zinc Deficiency in Rice

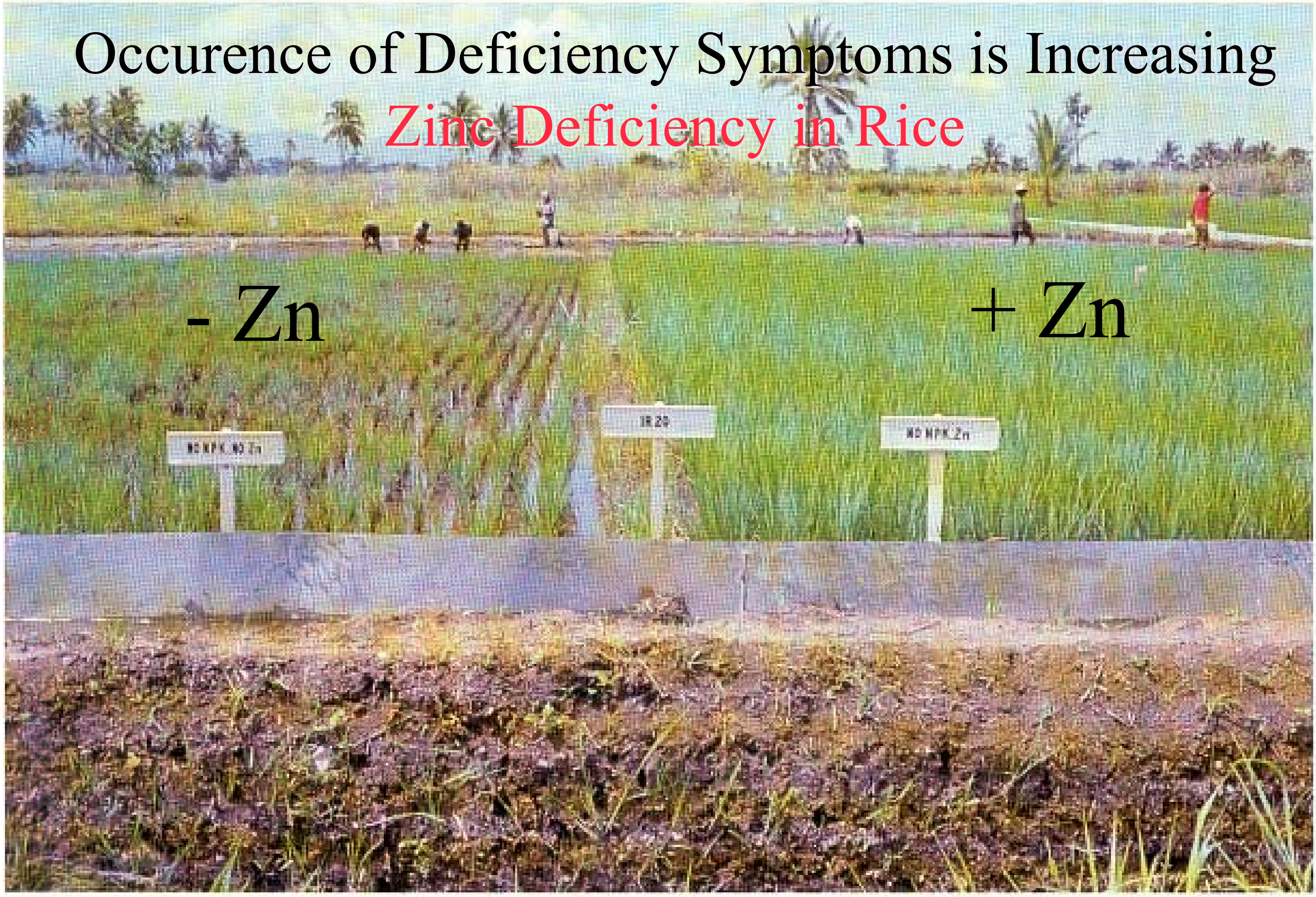
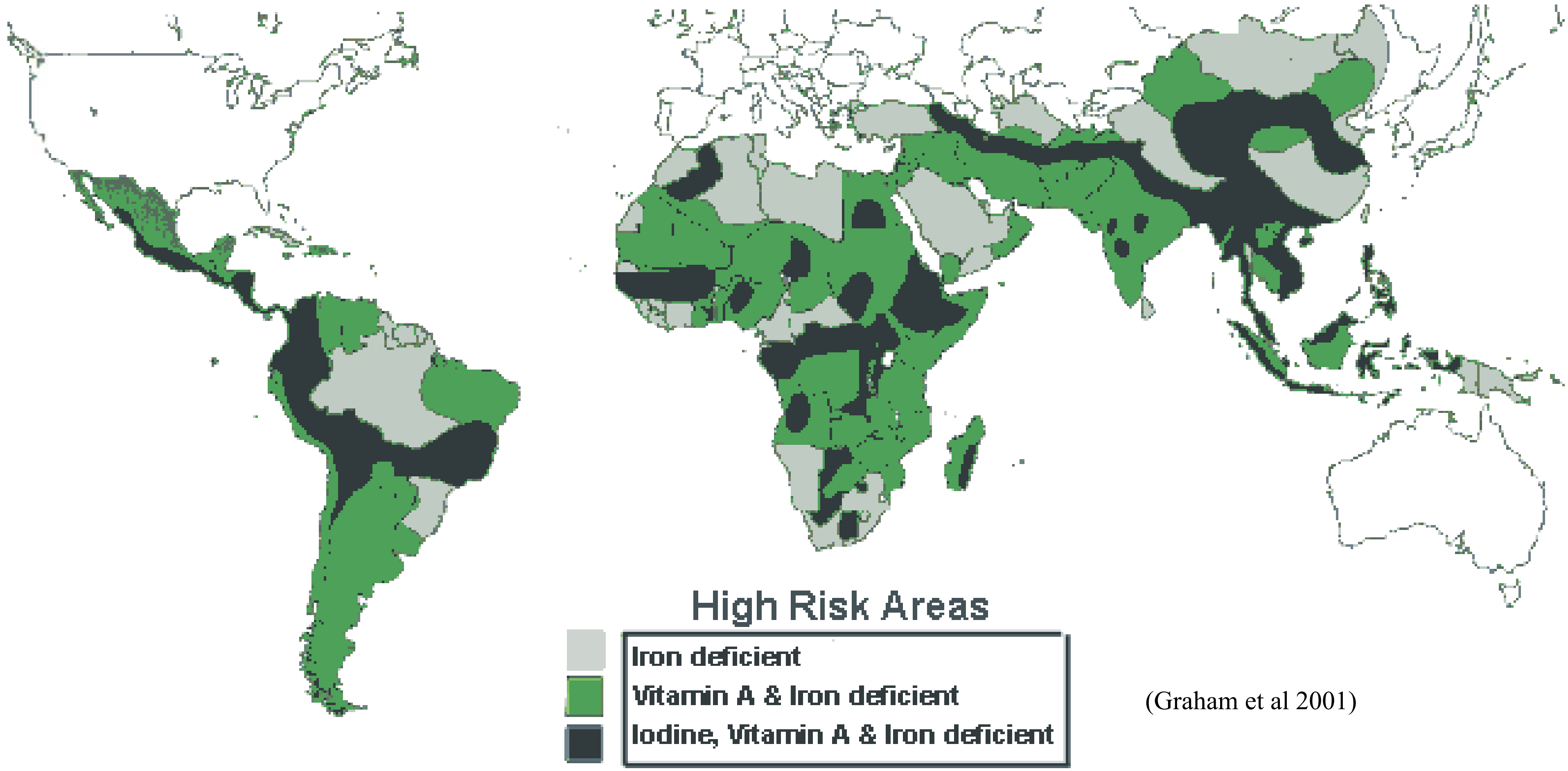


Fig. 2.10 Spectacular differences between Zn treated and untreated rice. Plot on the right received Zn and grew normally, while the one on the left did not receive Zn and failed to yield any grain (Photo by J.C. Katyal)

Human Dietary Deficiencies Indicators of Soil Deficiency



(Graham et al 2001)

Global Status of Micronutrients:

Balanced Nutrition is Compromised

- Micronutrient status globally is declining
  - Little replacement over many years
  - Increased withdrawal
  - Less Organic Material and cleaner N, P, K
- Demand is increasing
  - Increased demand for quality and high value crops
    - Developing World is increasing horticultural production
    - Developed world is increasingly seeking nutrient rich foods
  - Demand for low pesticide food products will require more careful nutrient management and balance.
  - Increased demand for Human Consumption and Health Needs

Does it matter, can it be corrected, will it be worthwhile?

The Principles of Micronutrient Analysis, Supply and Use

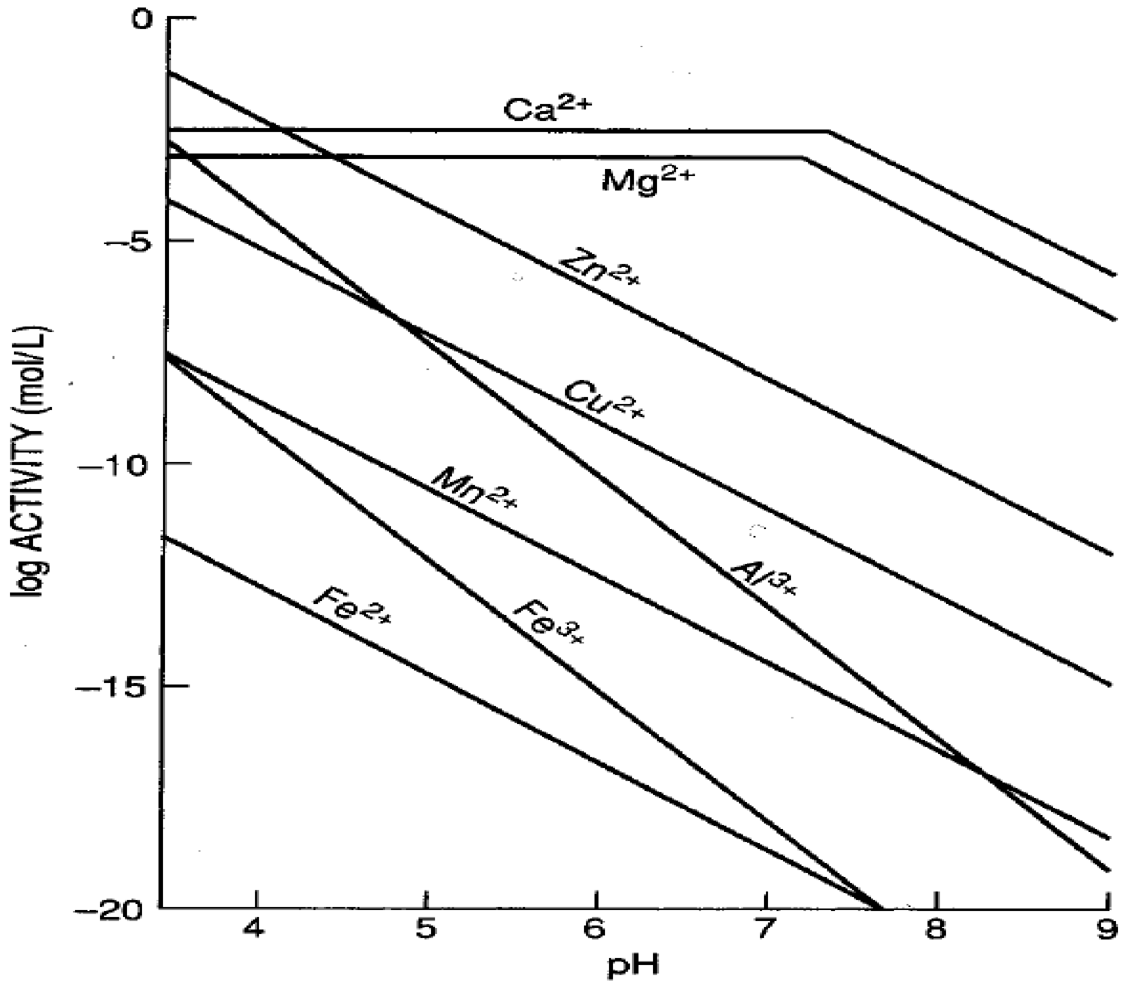
- Soil Supply
- Plant Uptake
- Analytical Challenges
- Principles of Correction

Most commonly limiting micronutrients worldwide are Zn, B, Fe, and Mn.

Soil Processes Controlling Zn, Mn, Fe Availability

- Mineral content of soil
  - Parent material, weathering.
  - Except in sands, total mineral content is usually not low.
- Concentration of soluble Metal^{2+} in solution
  - High pH decreases solubility in the soil
  - Lime content and oxide enhance fixation
  - Reducing conditions enhance solubility

Fe, Mn, Cu, Zn Solubility



Soil pH is a critical determinant of Fe, Mn, Cu, Zn availability

Soil Processes Controlling B Availability

Quantity:

- Derived from saline deposits or volcanic minerals (Ulexite, Coulmanite etc)
- Present in soil organic matter (Crop residues, Manures, composts)
- Waste and Drainage water

Solubility:

- Some fixation in clay soils (yellow/grey) and in high OM soils (>30%, Peat Soils)
- Leachable from acid soils and light textured soils
- Irrigation water is often main B source and, if pure, can contribute to B leaching.

Determining Soil Nutrient Status

In the absence of a detailed soil sample can nutrient status be determined?

- Soil Classification, Weathering and Minerology
  - Total Nutrient Content
  - Potential Solubility (inconsistent value)
- Soil physical and chemical properties
  - Ph, eH, lime, oxides, OM%, CEC
- Water sources (surface, well, recycled), est. leaching fractions

Problem

While soil classification is available for much of the World at varying scales, this alone is inadequate to predict nutrient availability,

however,

Soil and plant analysis, however, is expensive and impractical for much of the world.

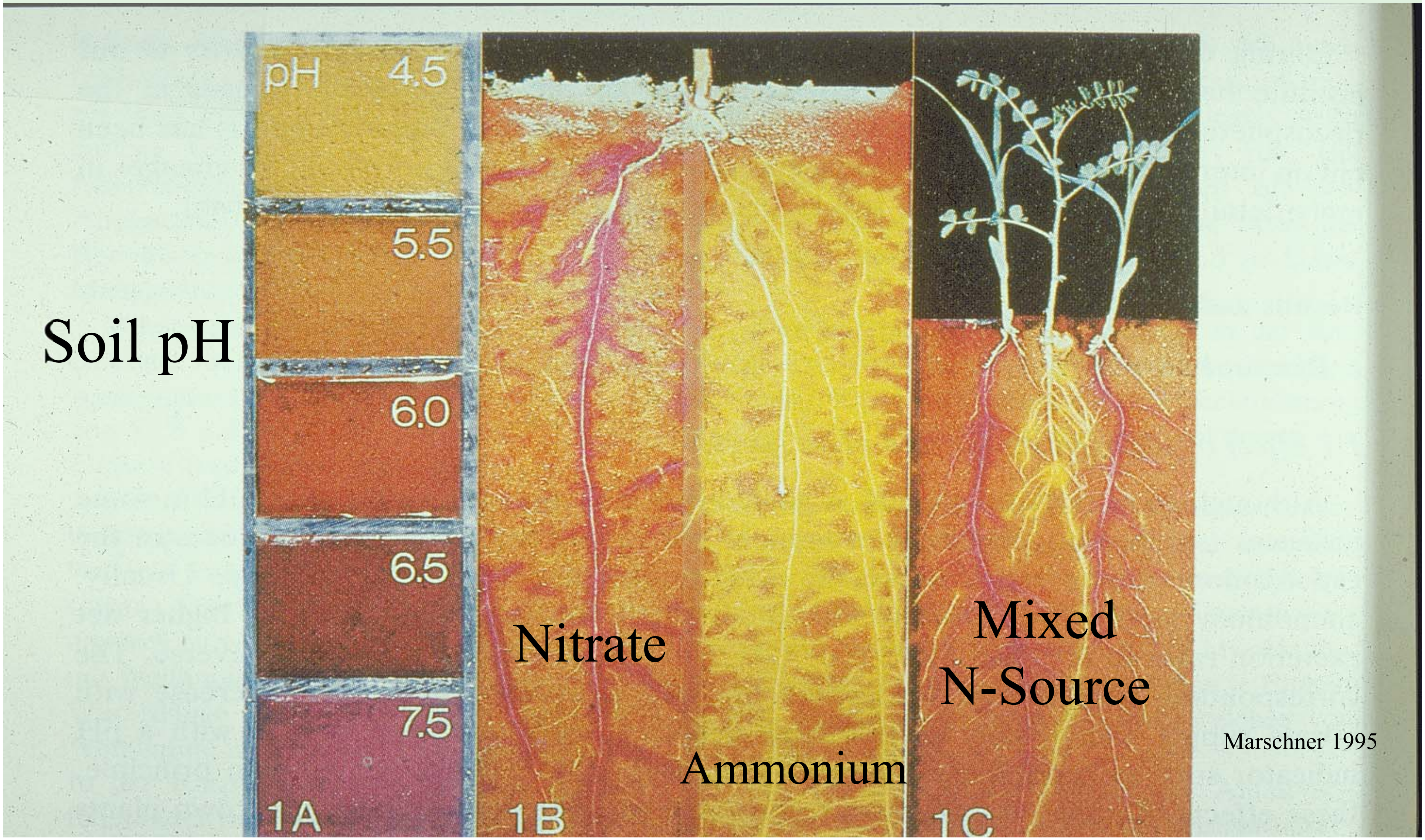
Plant Micronutrient Uptake

General Principles

- Nutrients are taken up in solution via an energy dependent and regulated process.
  - Active root growth and metabolism is required.
- Mn, Zn, Cu, Ni, Fe have restricted diffusion in soils, hence:
  - Root distribution and root fineness are critical for uptake of these element
- Boron is provided by mass flow
  - Requires availability of water and favorable environment (transpiration)
- For Mn, Zn, Fe: Species vary greatly in ability to tolerate poor soils, species do not differ in nutrient demand.
- For B: Species vary dramatically in uptake, internal demand and internal efficiency of use.

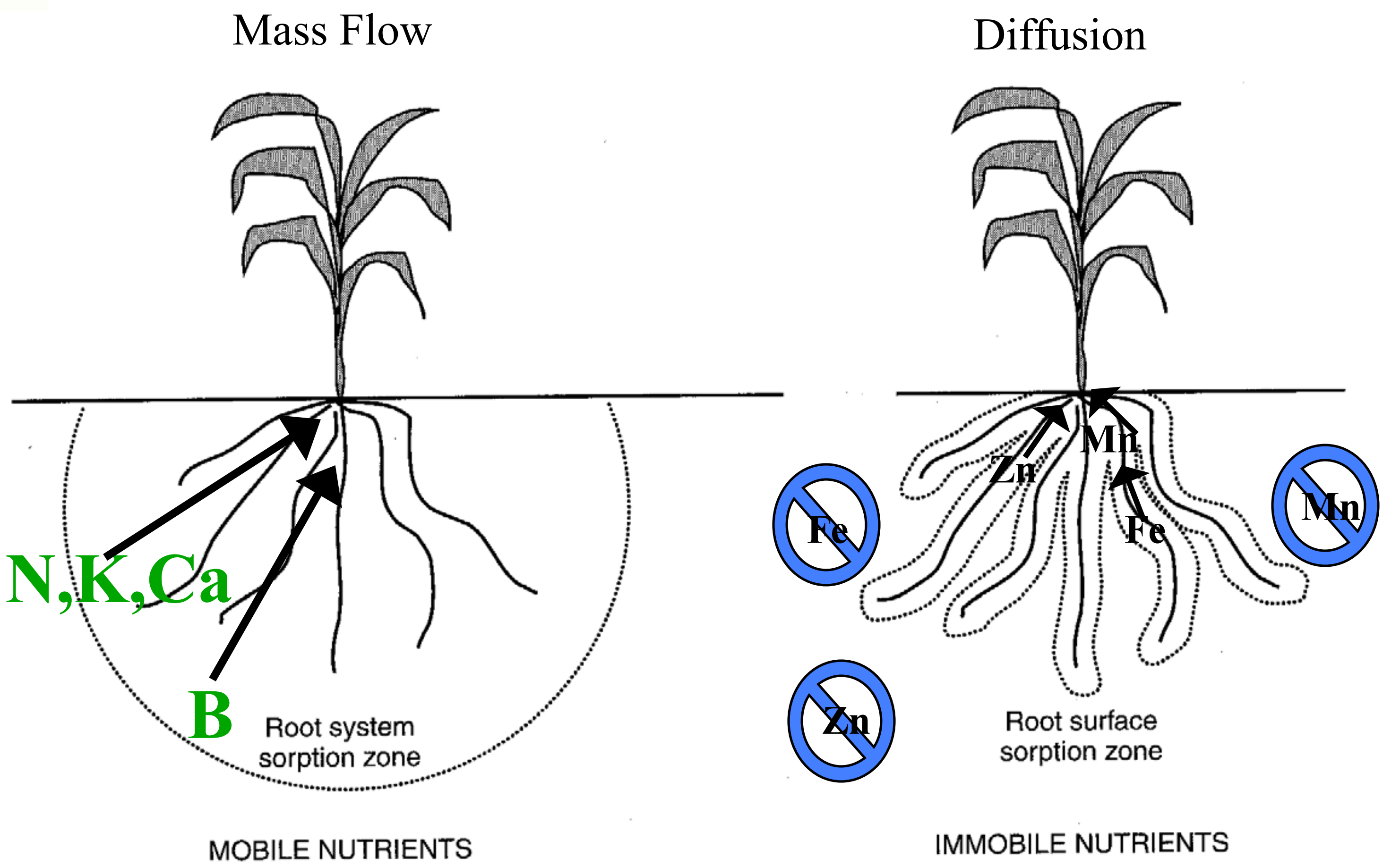
Plants Can Alter Their Rooting Environment

-Altered soil pH influences micronutrient uptake
-Species vary in their capacity to affect soil pH
-Fe deficiency and Nitrogen source can alter soil pH

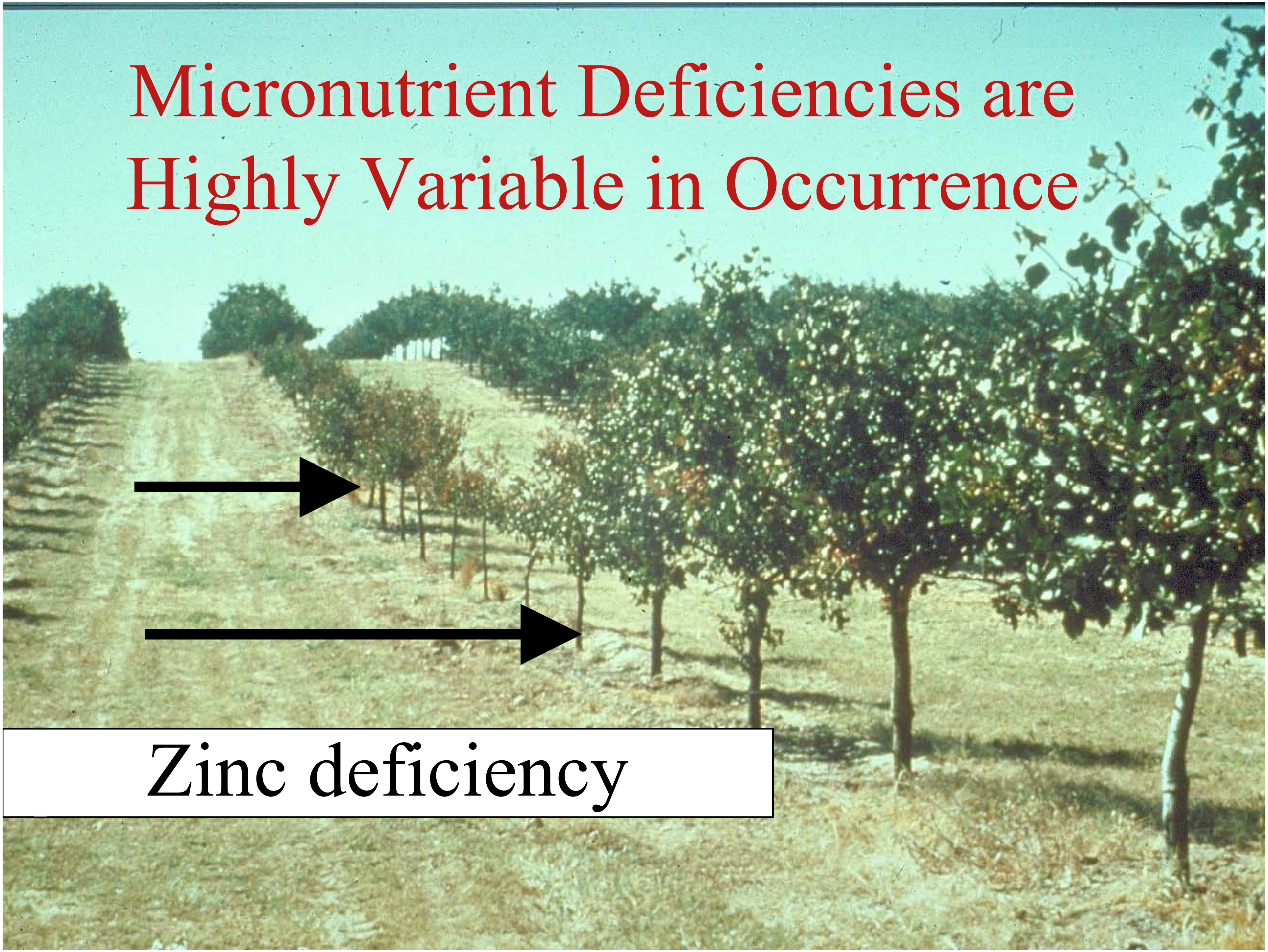


Marschner 1995

Diffusion versus Mass Flow



Micronutrients (excluding B and Cl) are immobile in the soil and can only be obtained from soil in close proximity to the root surface. Root growth and root patterns (fineness, depth etc) influence uptake.


Micronutrient Deficiencies are
Highly Variable in Occurrence
Zinc deficiency

Summary

Global Micronutrient Status

- Micronutrient deficiencies will become increasingly prevalent and important limits to yield and quality.
- Determining the local extent of the problem is difficult since soil and plant analysis are often unavailable.
- Existing soils data and crop budgeting analysis can help, but this requires knowledge of soil science and plant nutrient.

Challenges

Provision of cost effective decision making tools

Develop cost effective solutions

Decision Making Tools

When and Where will Micronutrient Deficiencies impact Plant and Human Health?

- Nutrient budget analysis (Inputs minus outputs)
- Better utilization of available resources
  - Soil surveys and crop analysis
  - Regional trials, tissue analysis
  - Remote Sensing and GIS technologies
- Consideration of human and crop specific demands
- Knowledge of soil supply and plant nutrition principles

Challenge: To Create an Integrated Micronutrient Risk Analysis

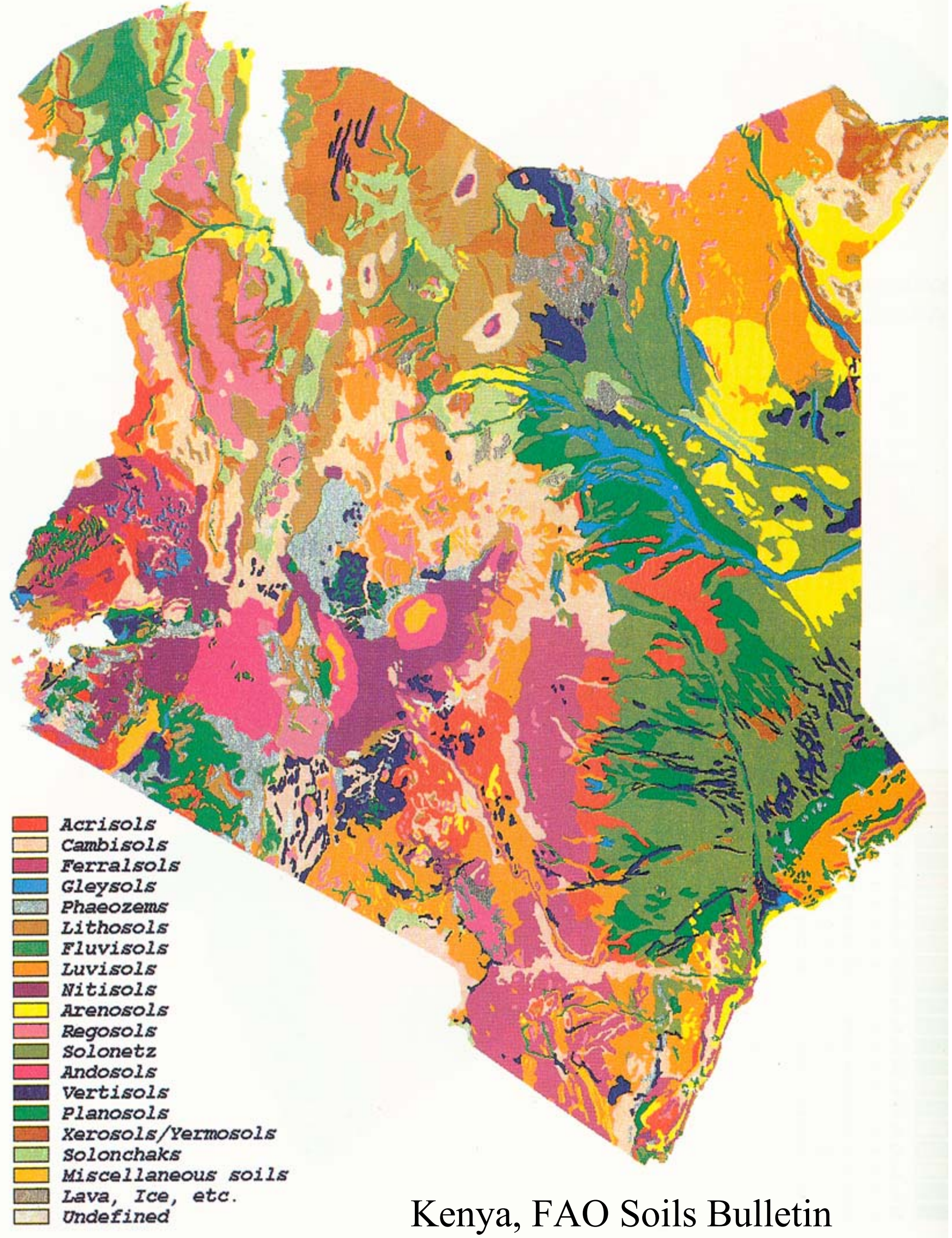
Micronutrient Risk Analysis

A Micronutrient risk analysis can be derived from:

- Existing soils and geology data
- Agroclimatic, cropping and yield data
- Available soil and plant sampling data
- Soil and plant nutrition principles
- Application of modelling procedures to map, predict, verify micronutrient deficiencies and risk.

Soils and Geological Maps Exist for Much of the World.

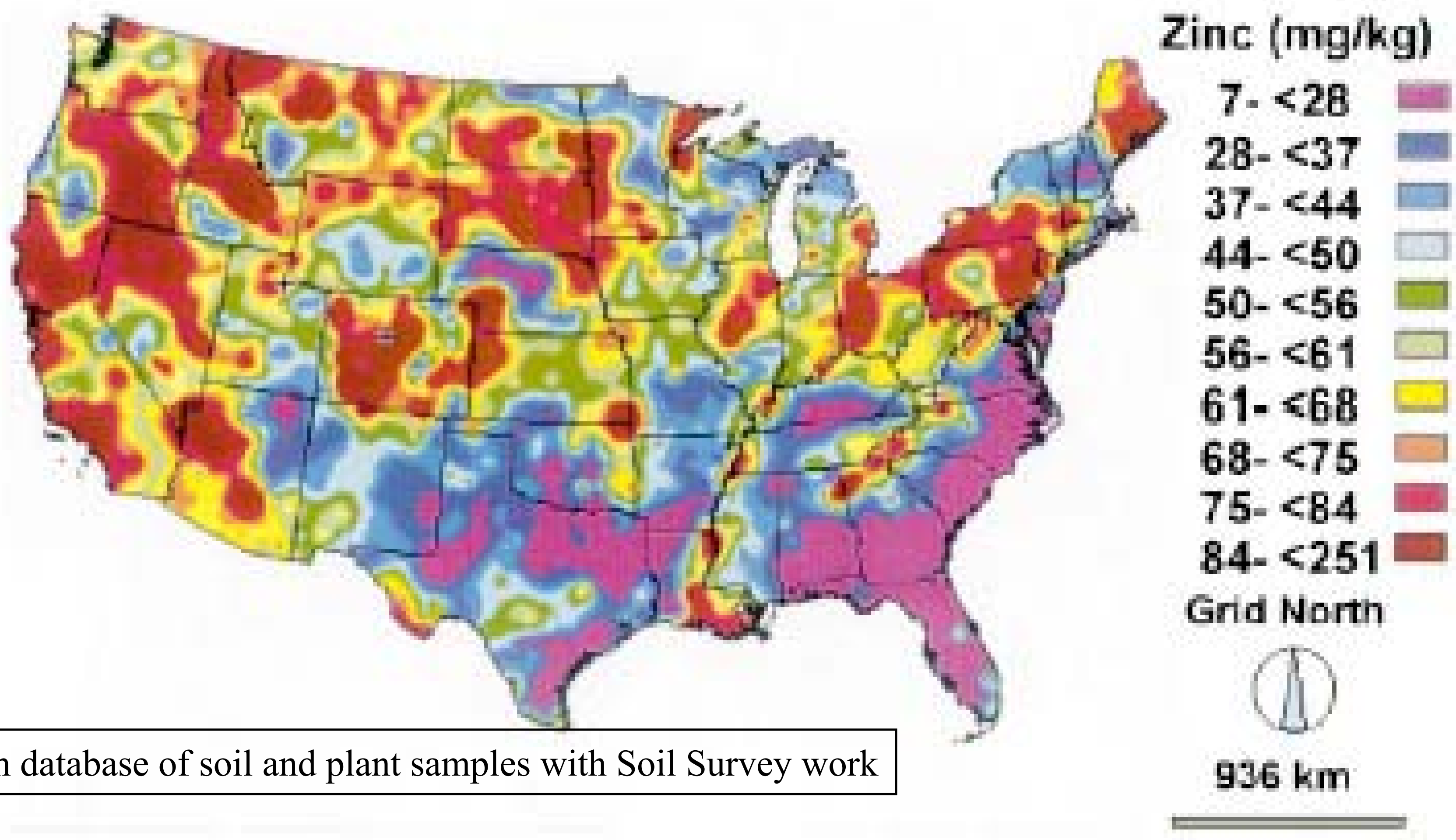
Agroclimatic Zones
Historic Plant and Soil Samples
Cropping Systems and Yield
Remote Sensing



Kenya, FAO Soils Bulletin

Distribution of Zinc in surface soils of the USA

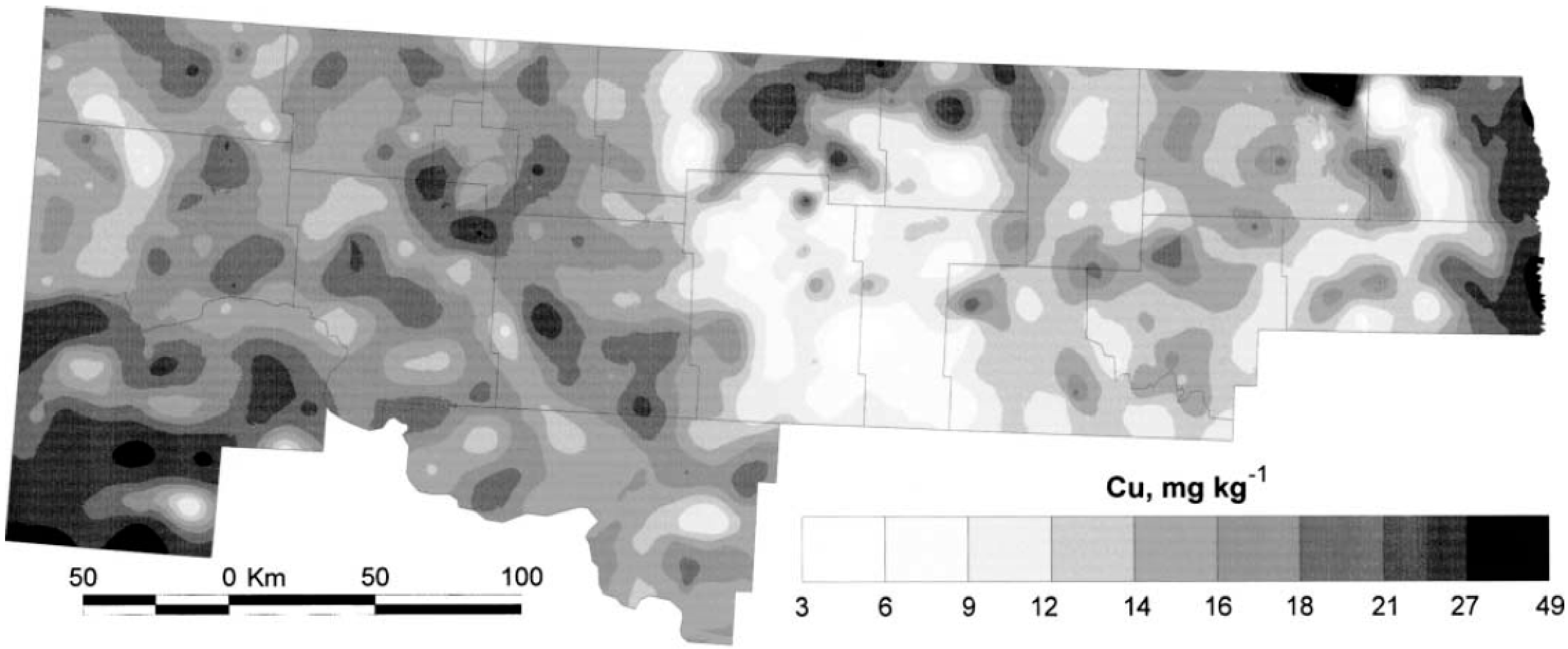
(from White et al, 1997)



From database of soil and plant samples with Soil Survey work

Integrated Nutrient Risk Mapping

Combining Soil Survey Data, CEC, available and focused soil analyses



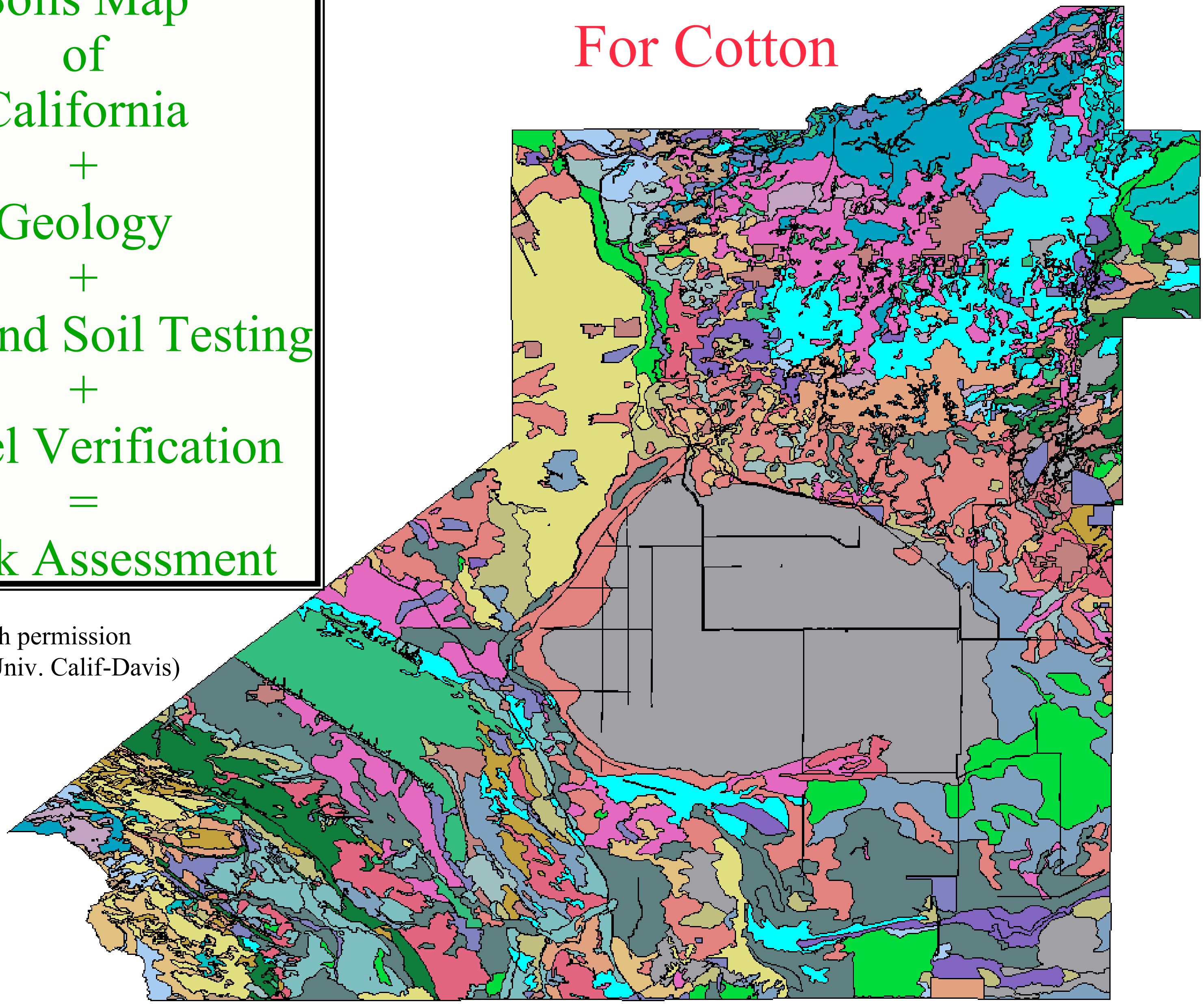
Soil copper risk map.

Generated from soil survey work, total soil Cu at 815 sites and cation exchange capacity (CEC) at 911 sites in North Dakota, USA (Wu et al 2003).

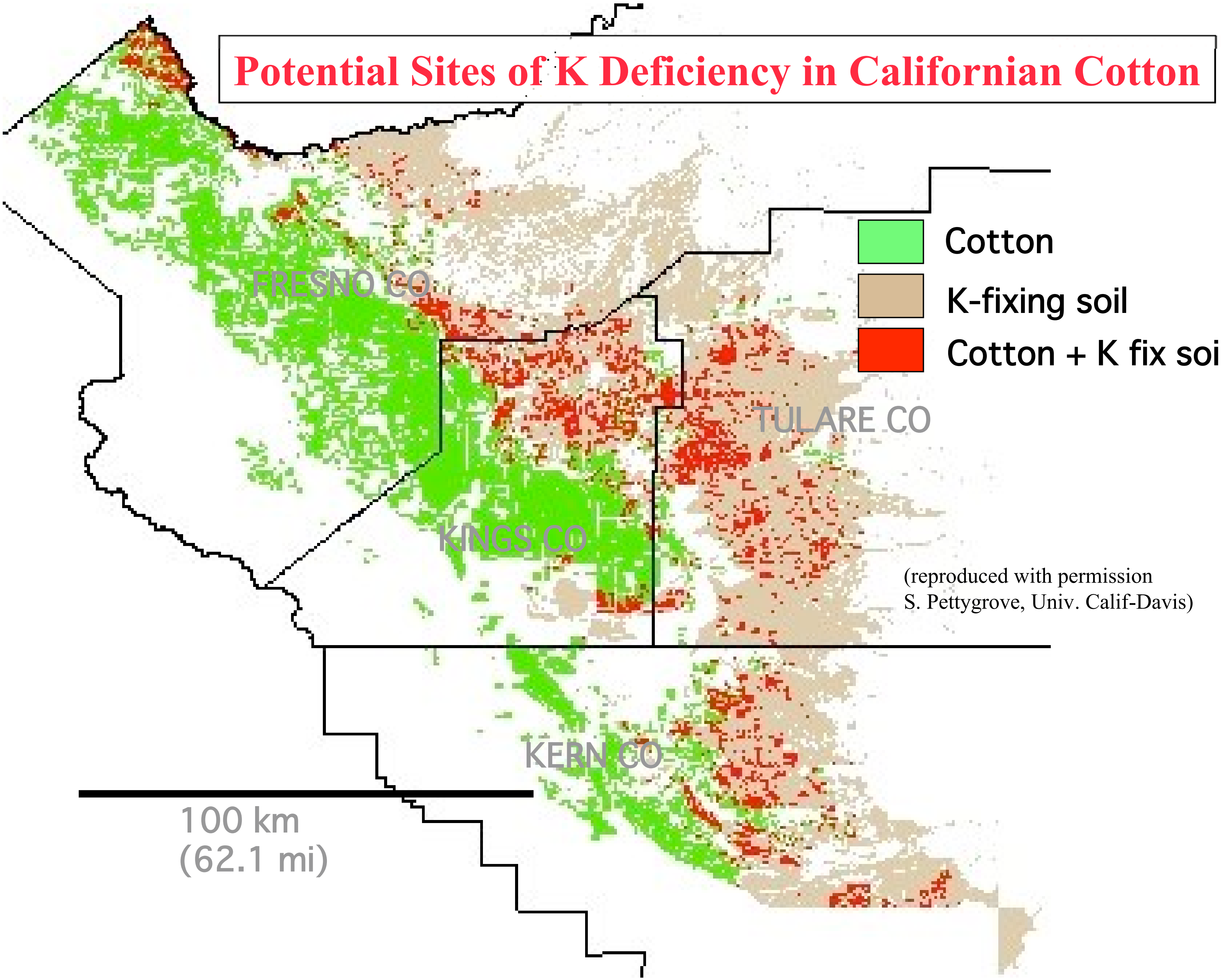
Potassium Risk Assessment For Cotton

Soils Map
of
California
+
Geology
+
Plant and Soil Testing
+
Model Verification
=
K risk Assessment

(reproduced with permission
S. Pettygrove, Univ. Calif-Davis)



Soils Map of Kern County, California



Potential Sites of K Deficiency in Californian Cotton
Cotton
K-fixing soil
Cotton + K fix soil
FRESNO CO
TULARE CO
KINGS CO
KERN CO
100 km
(62.1 mi)
(reproduced with permission
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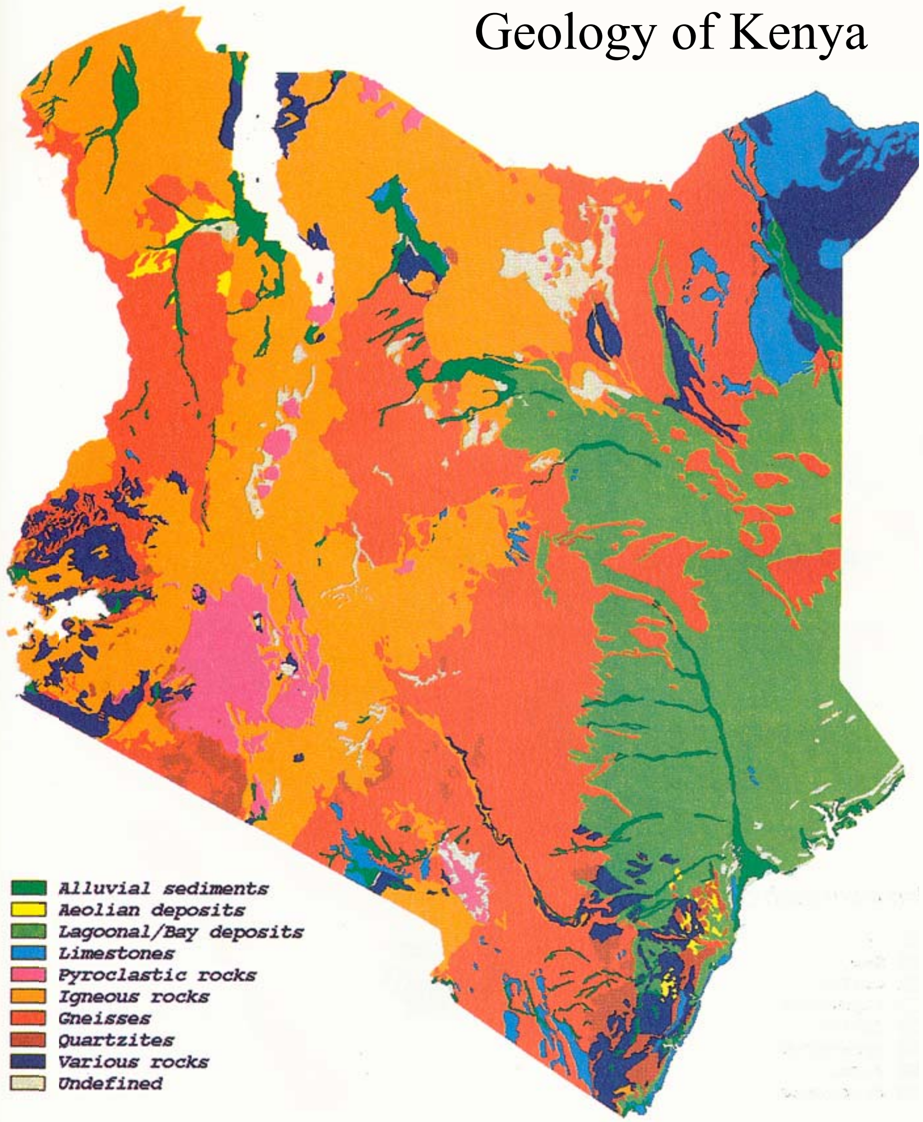
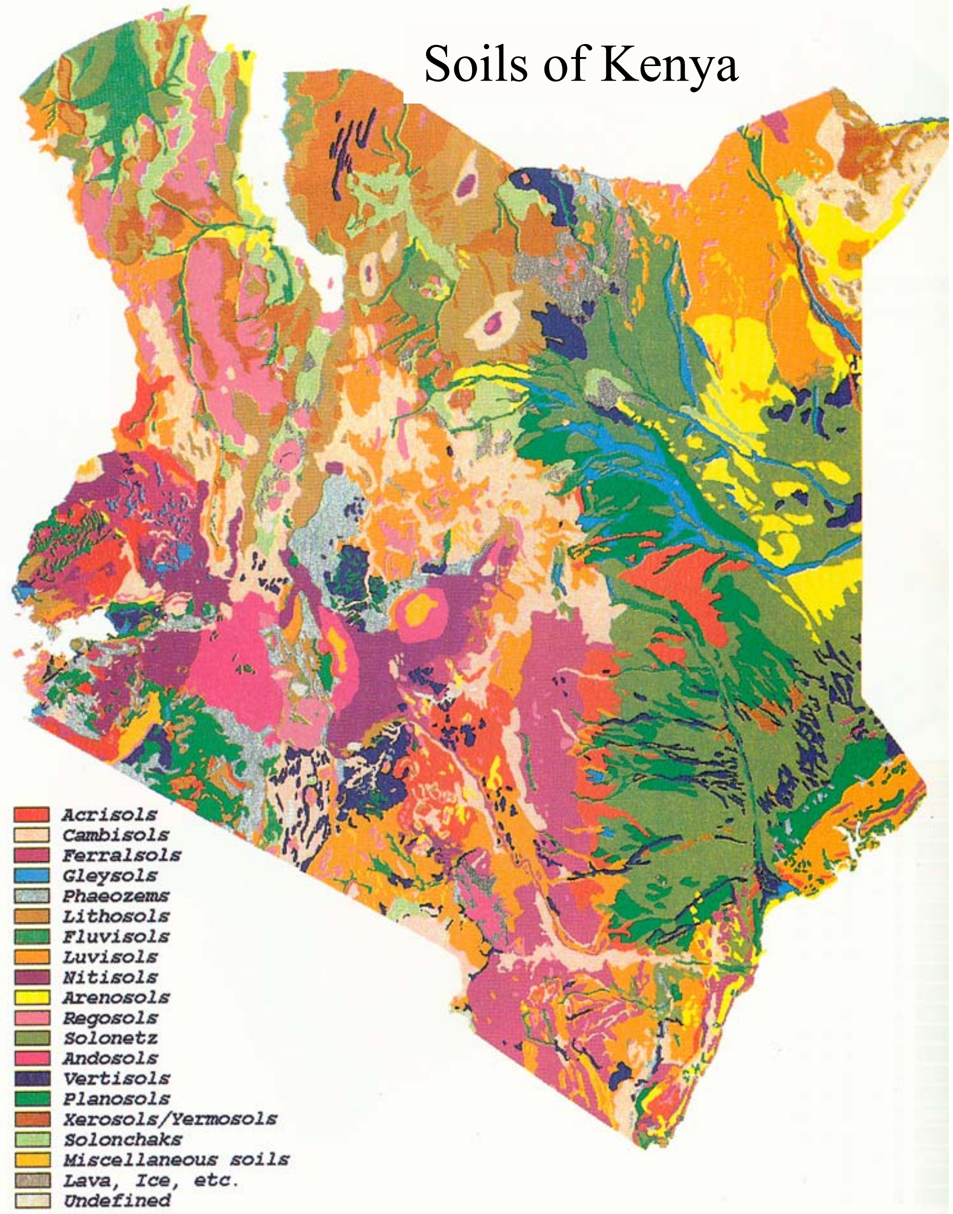
Creating Micronutrient Risk Assessment Maps





Designing Cost Effective Solutions

(If a substantial micronutrient risk exists how can we address it?)

Systems Approach

- Develop an Integrated Plant Nutrient Management Program (FAO)
  - Breeding for micronutrient efficiency
  - Cropping systems
  - Soil and plant analysis
  - Organic matter retention
  - Erosion and other environmental considerations

Technology Development

- Fertilizers (technology, distribution)
- Knowledge

Balancing inputs and outputs for the sustainability of the Food System.

Designing Cost Effective Solutions

(*Increased use of Micronutrient fertilizers*)

- Constraints of current micronutrient products:
  - Expensive, high degree of crop specificity, technically complex, complex distribution systems.
  - Limited local production capability.
  - Beaurocratic, Economic and Political Limitations

- Perception becomes Reality:
  - Micronutrients are not required routinely → Expensive and 'technical' products → Micronutrients are not required routinely. *(Reality: Micronutrients are essential elements)*
  - Inappropriate use of micronutrients will result in productivity losses and environmental damage. *(Reality: Very Unlikely, except B)*

Micronutrients must be included as part of any balanced fertilization program

Improved Micronutrient Technology

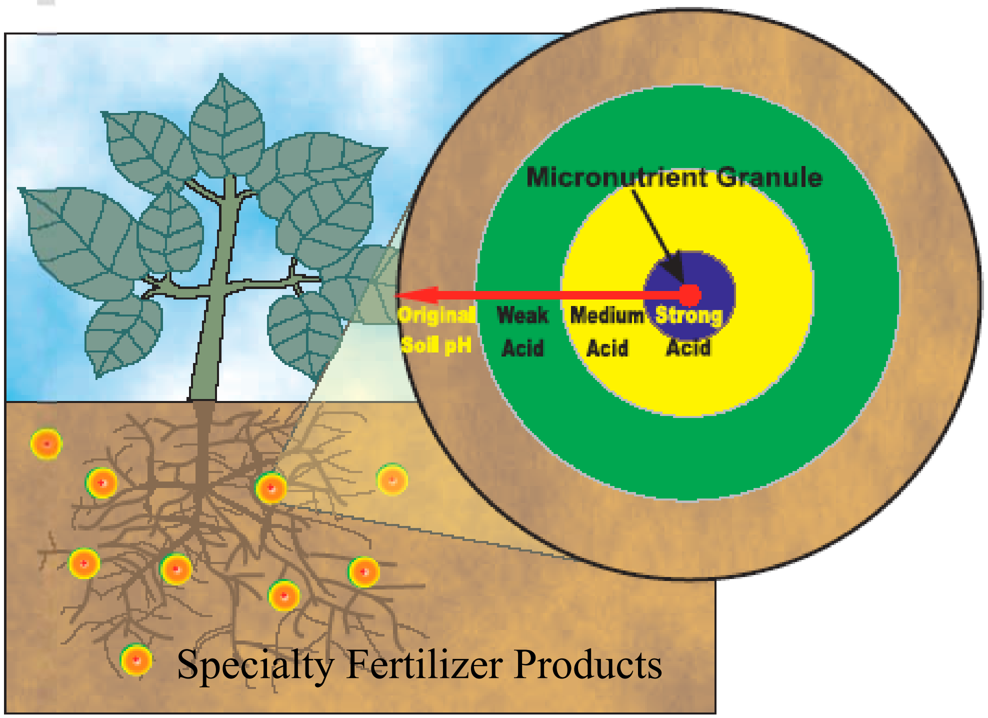
(current products are inadequate)

- Cost Considerations (current, predominantly specialized products are too expensive and difficult to integrate into low input farming systems)
  - Develop complete fertilizer products (N,P,K plus indicated macros and micros)
  - Reduced specialization.
  - Integrated supply and distribution chain
- Technical Considerations
  - Solubility of added nutrients (maintaining solubility and minimizing fixation)
  - Placement of micronutrients to ensure root availability.
    - Complete fertilizers versus bulk blending
  - Developing easy to use, low knowledge base solutions

Development of New Products

Compound Fertilizer Products: Multilayered, Multielement Slow Release, Acid Releasing, Chelates

Constraints: High Cost, Not fully integrated into normal N,P,K distribution chains

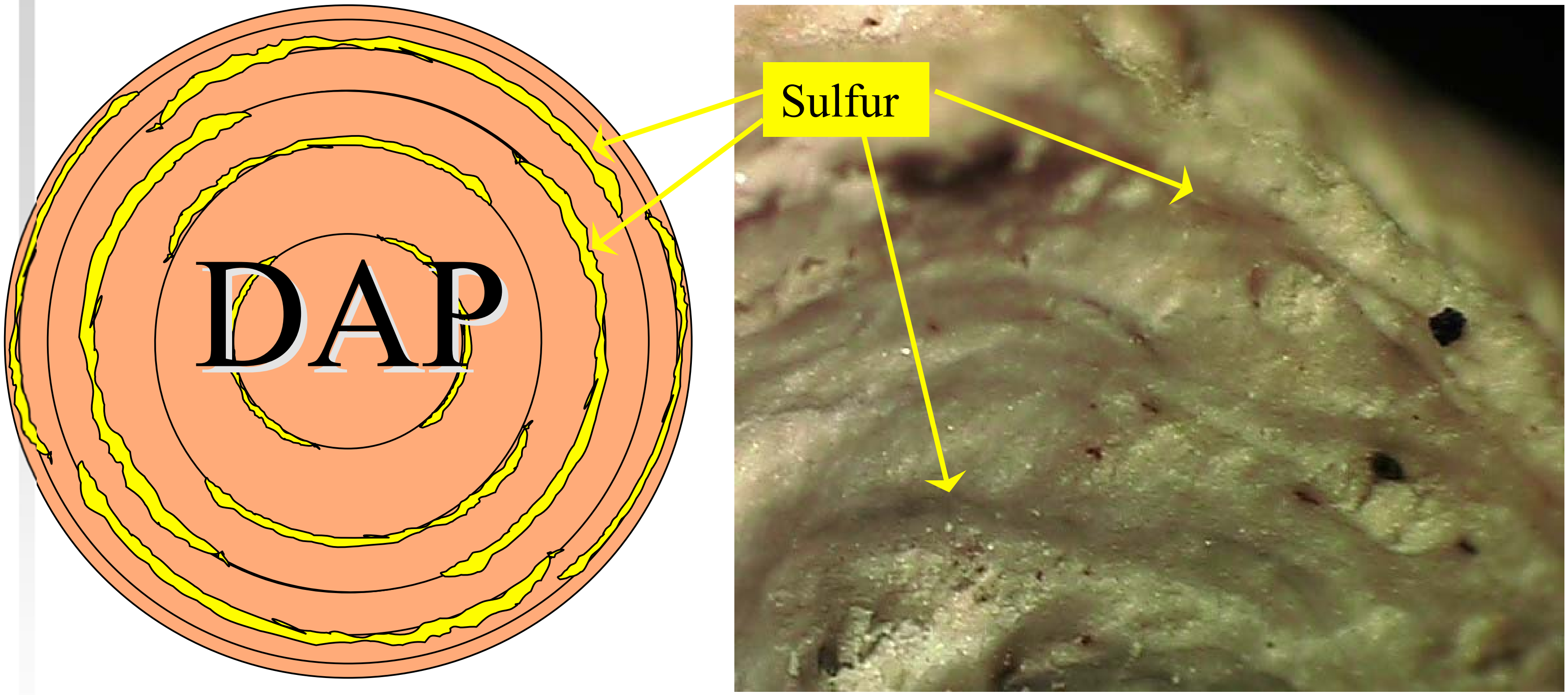


SFP Micronutrients control the pH around each individual granule

- SFP micronutrients contain a complex of ingredients to control the pH around each individual granule.
- Now you can lime your soils for optimum uptake of N, P and K while providing an acid micro environment for the greatest availability of the micronutrients.
- The acid environment around *SFP* micronutrients protects them from fixation, keeping them much more available than sulfate, chelate or oxysulfate products.

Development of Composite Fertilizers

(e.g. Cargill MicroEssentials™ S-15)



40x

Cross Section of S15 Granule

Cargill

Conclusions

Problem:

- Micronutrient deficiencies will become increasingly important constraints to crop yield human health and sustainability.

Risk Analysis:

- Use of existing soils, geological data with crop budgeting analysis and plant and soil testing can be used to establish a risk analysis.

Solution: (technology, politics, economics, will)

- Technological and political solutions are required if micronutrients are to be integrated into global fertilizer strategy.

Underpinning Requirement:

- Knowledge of soil science and the physiology of nutrient use will remain essential to all that we do.


Thank You
Nickel Deficiency in Pecan