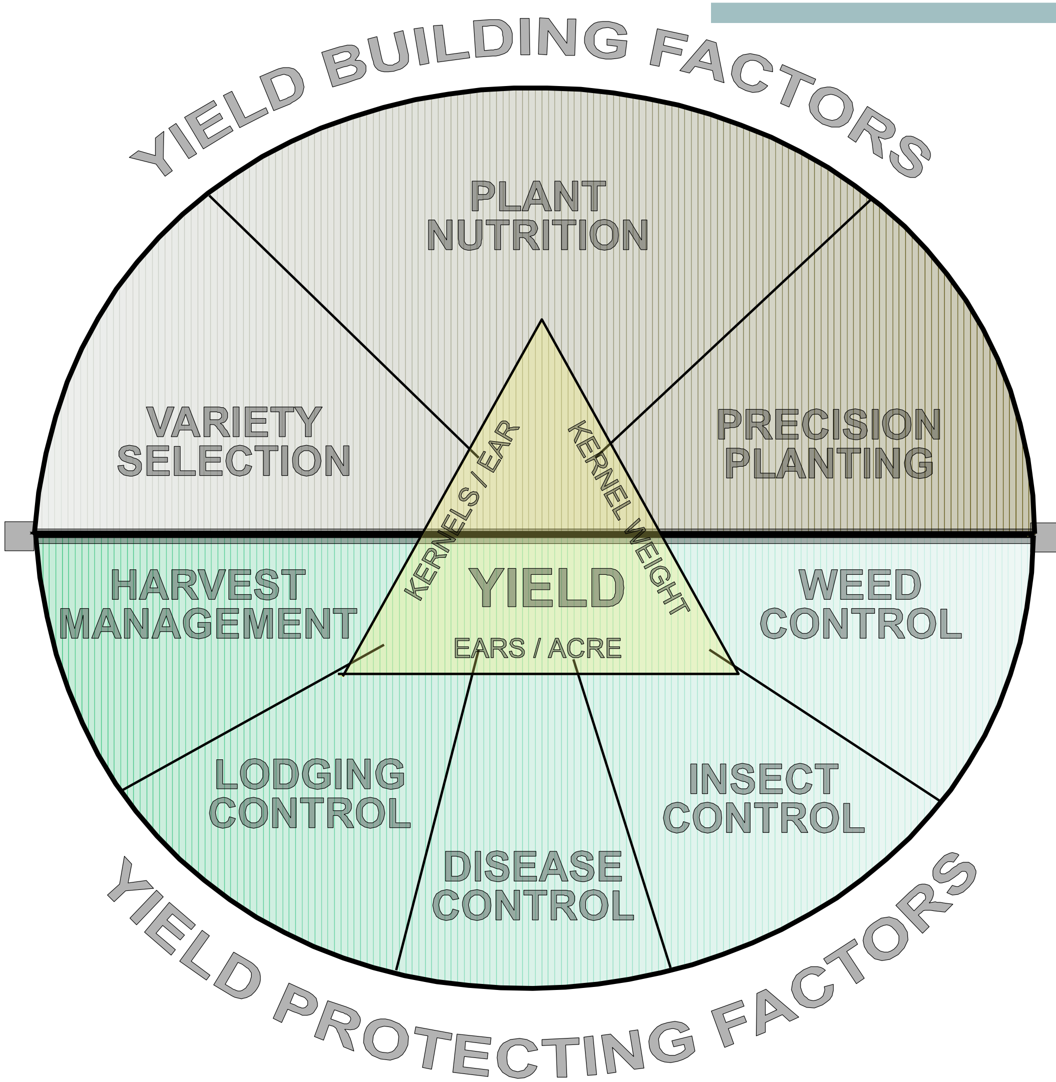
High Yield Systems: Thoughts on Fertility Programs for the Future

Fluid Technology Roundup
Indianapolis, IN

What are high yields?
Is high, “high” for all environments?

- 300 bu/acre corn
- 125 bu/acre soybean
- 15 ton/acre alfalfa
- 5 bale/acre cotton

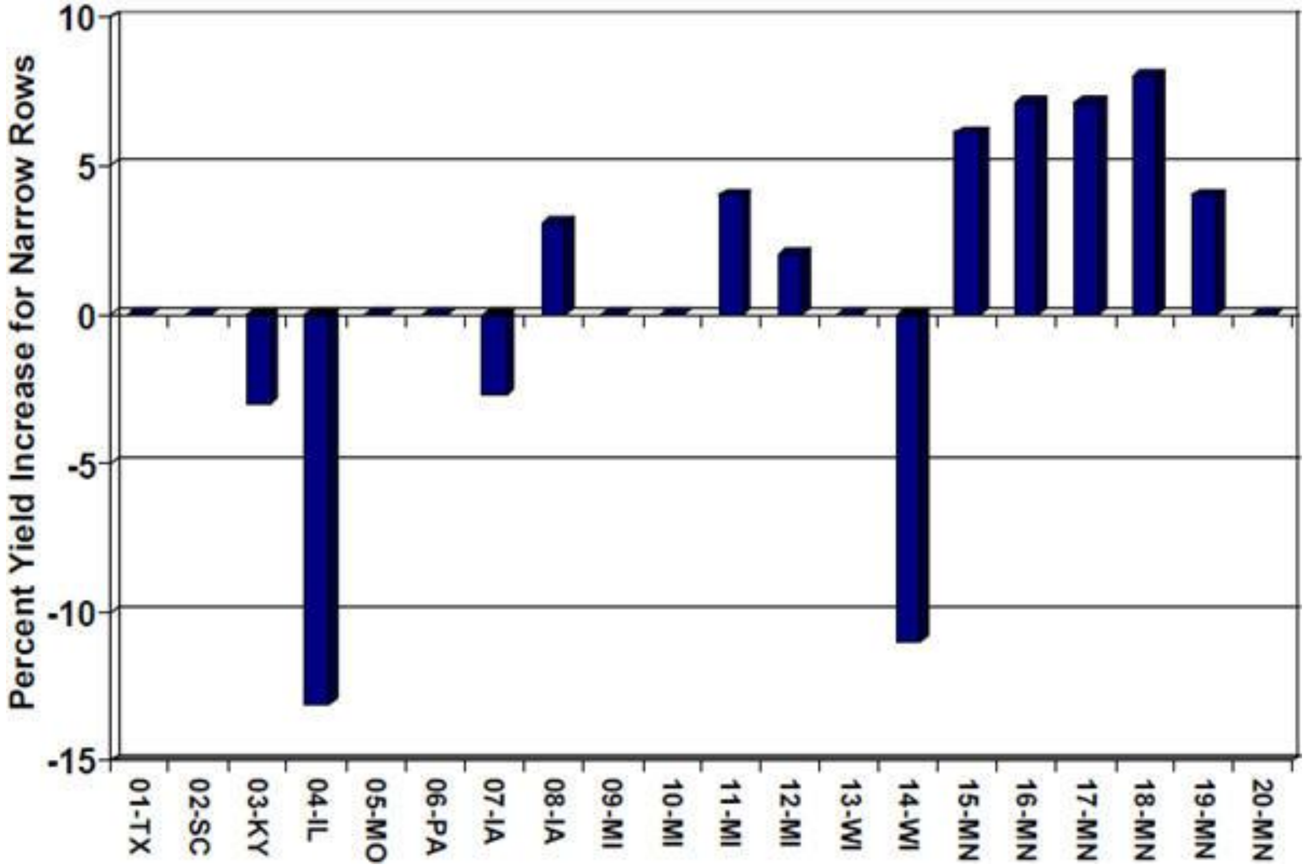


Agronomy for Building a High-Yield Production System

High Yield System Requirements

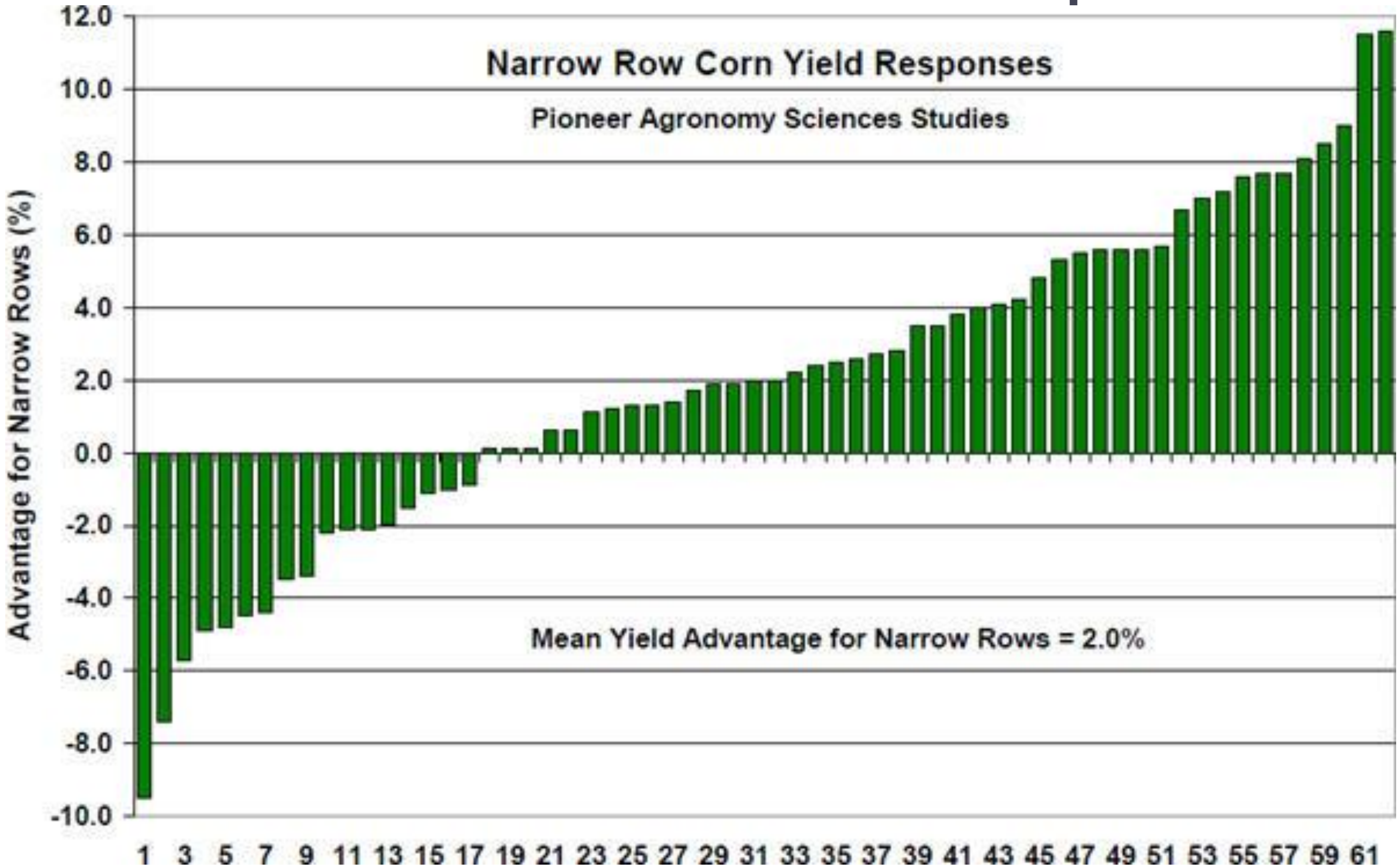
- Genetics
  - Yield potential is not limited by the physiological capacity of the plant.
- Plant Populations
  - Significant recent work with different row widths and plant spacing to more efficiently use resources at a specific site.

Corn Yield Response to Narrow Rows Pioneer Summary



S.Butzen and S. Paszkiewicz. 2010. Narrow row corn production—when does it increase yields? Crop Insights Dec. 2. http://www.pioneer.com/home/site/us/agronomy/library/template.CONTENT /guid.9248FD75-1F2D-1D60-F460-E207FF6F2792

Pioneer Agronomy Science
Narrow Row Corn Yield Responses



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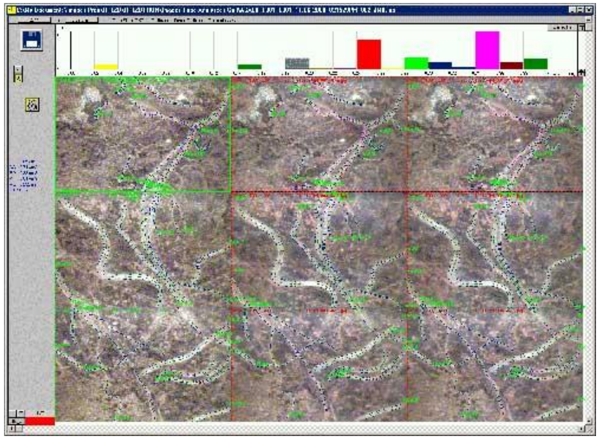
Summary – Pioneer Review

- Studies over 13 years showed "considerable" variability
- Most consistent responses found in northwest Corn Belt states, i.e. MN, ND and SD
- Hybrid by row width interaction rare
- Where narrow row corn increased yields, probable that narrow rows
  - Improved efficiency of light interception*
  - Increased moisture extraction*

*Data not available to prove or disprove the reasons for the responses.

High Yield System Requirements for Specific Soils

- Moisture availability
  - Total amount and time
- Rooting depth
- Volume of soil explored
- Moisture movement
  - How far?
  - How fast?

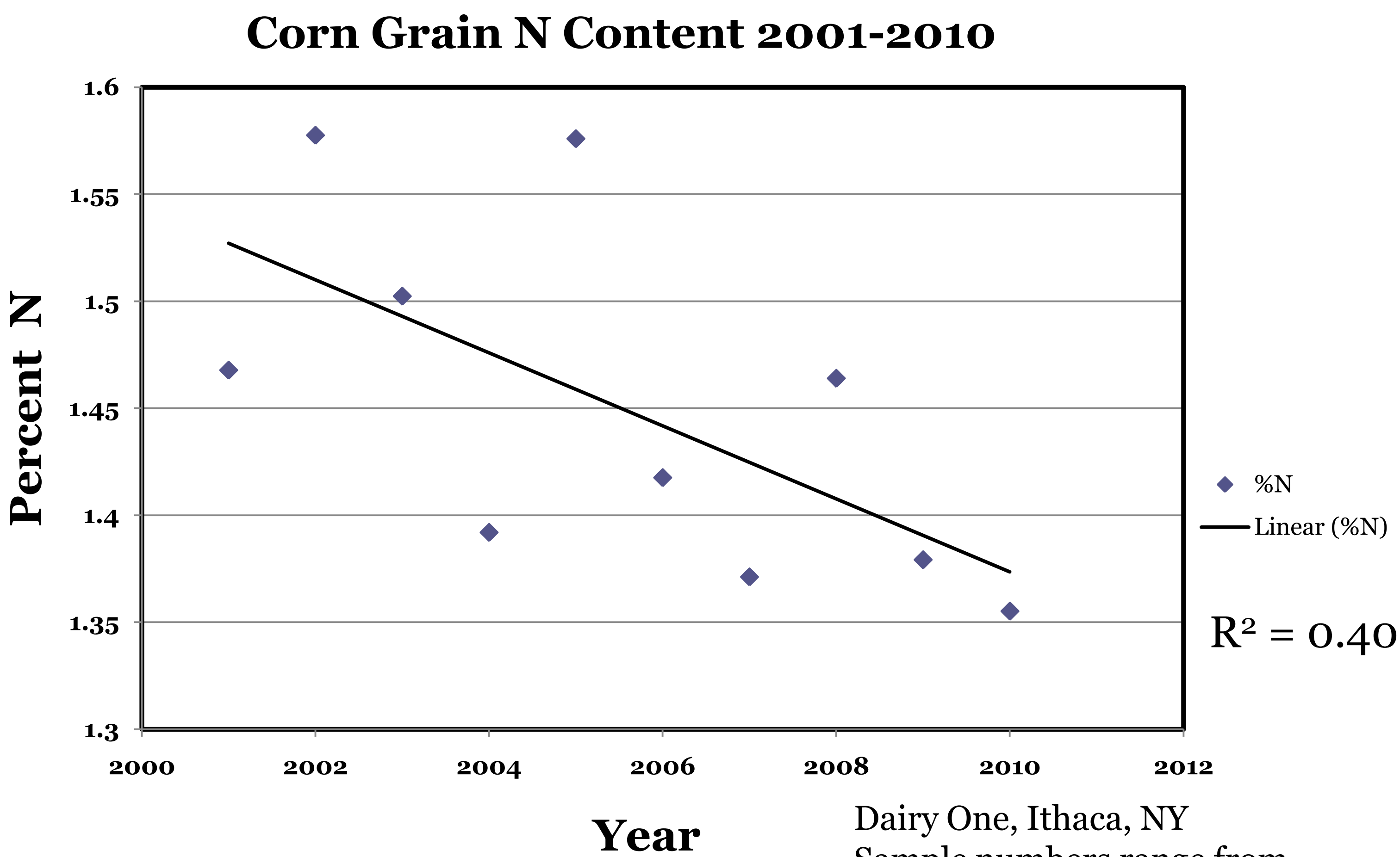


Estimated Nutrient Uptake For Corn at Two Yield Levels

Yield	N	P_2O_5	K_20	Mg	S
bu/ac	----------uptake (lbs/acre)*-------------				
220	290	125	290	72	36
300	395	170	385	98	49

*Uptake values for 220 bu/ac from "Plant Food Uptake for Southern Crops, IPNI, Norcross, GA. Uptake values for 300 bu/acre estimated as a linear increase from the 220 bu/acre values.

Corn Grain N Contents



Dairy One, Ithaca, NY
Sample numbers range from 566 to 1493 per year

Nutrient Removals Can be Estimated for Various Crops at Various Yield Levels: But How Do We Make the Uptake happen?






Plant Nutrition

- Availability of adequate amounts of essential elements
- Environment for uptake **rates** to support necessary growth
  - Growing season length remains same;
  - Nutrient uptake rates must double if yields increase from 150 to 300 bu/acre for corn, and grain nutrient contents are maintained.

Plant Nutrient Uptake

- Root system distribution
  - Soil volume explored
- Nutrient concentrations in soils
- Soil textures
- Moisture content of soil
- Mechanical strength (bulk density)
- Soil temperature
- Atmospheric CO_2 concentrations
- Microbial populations and activity
- ???????

Plant Roots Respond to Differences in Nutrient Concentrations

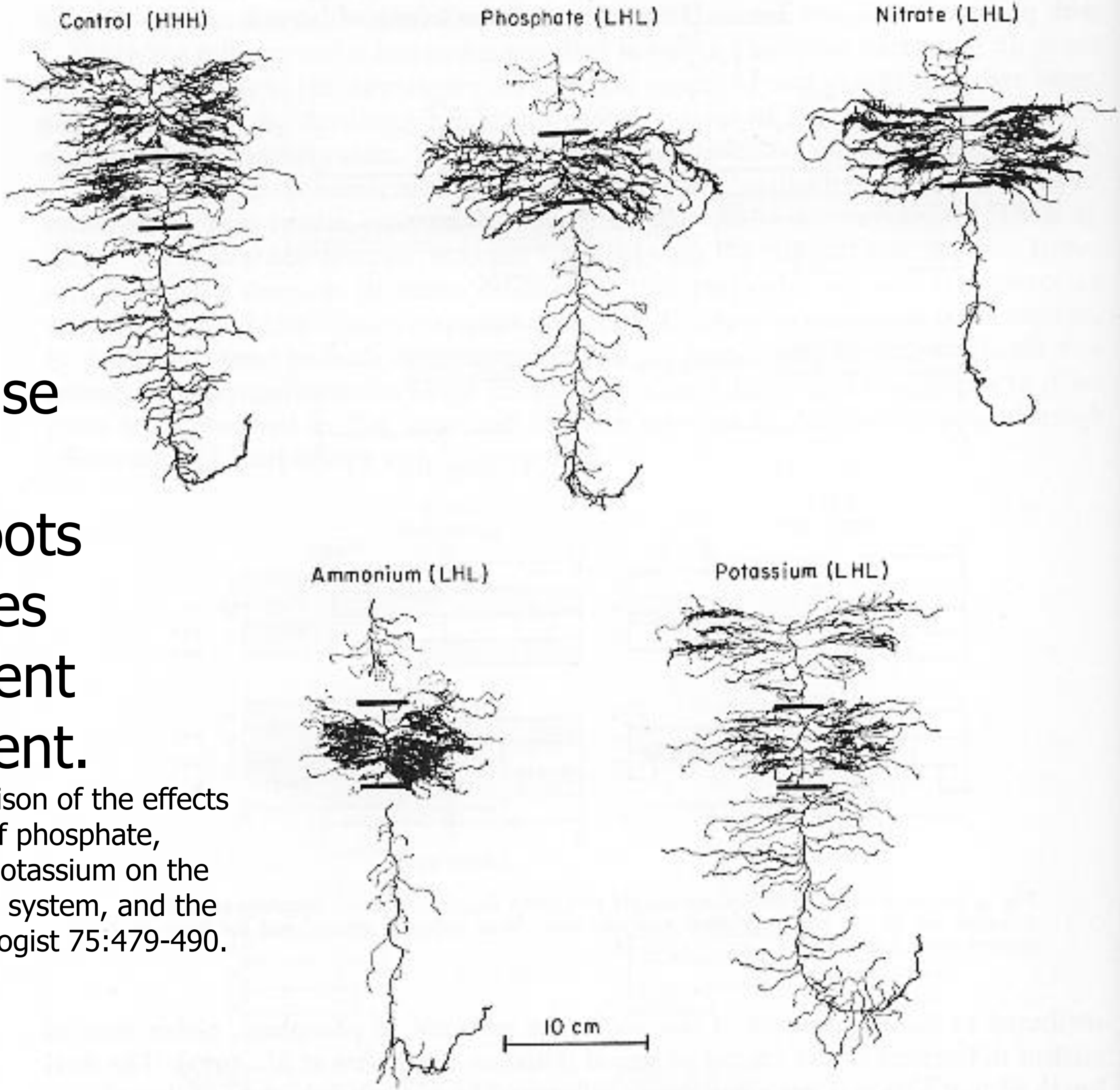
Table 2.11. Distribution of Barley Roots in a Loam Soil with NPK Fertilizer Placed at Different Depths (Gliemeroth, 1955)

Depth of Soil Layer, cm	Proportion of Total Weight of Roots, %		
	Fertilizer in 0- to 18-cm Layer	Fertilizer in 18- to 36-cm Layer	Fertilizer in 36- to 54-cm Layer
0–18	50	35	27
18–36	30	45	33
36–54	19	20	40

*Landw. Forsch. Sonderheft 6:69-85. Cited by C. A. Black, 1984.

Response Of Plant Roots to Zones of Nutrient Enrichment.

Drew, M. C. 1975. Comparison of the effects of a localized supply of phosphate, nitrate, ammonium and potassium on the growth of the seminal root system, and the shoot in barley. New Phytologist 75:479-490.



Corn Root Distribution with Age (Mengel and Barber, 1971)

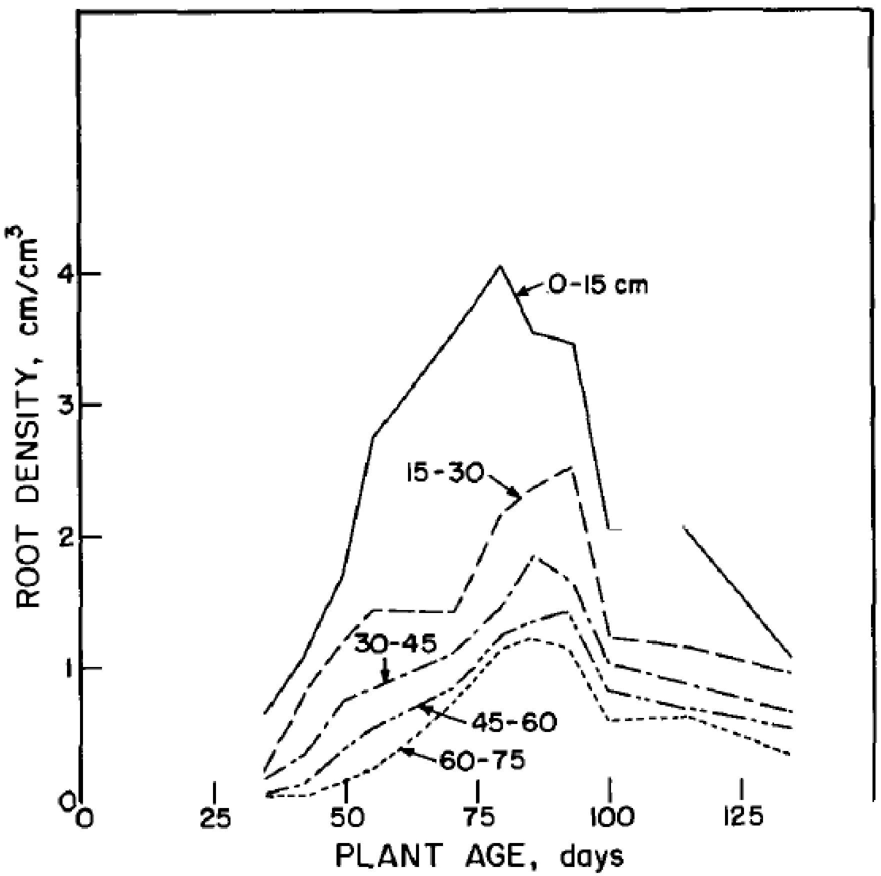


Fig. 1. Relation of plant age to root density at five soil depths during corn growth in 1971.

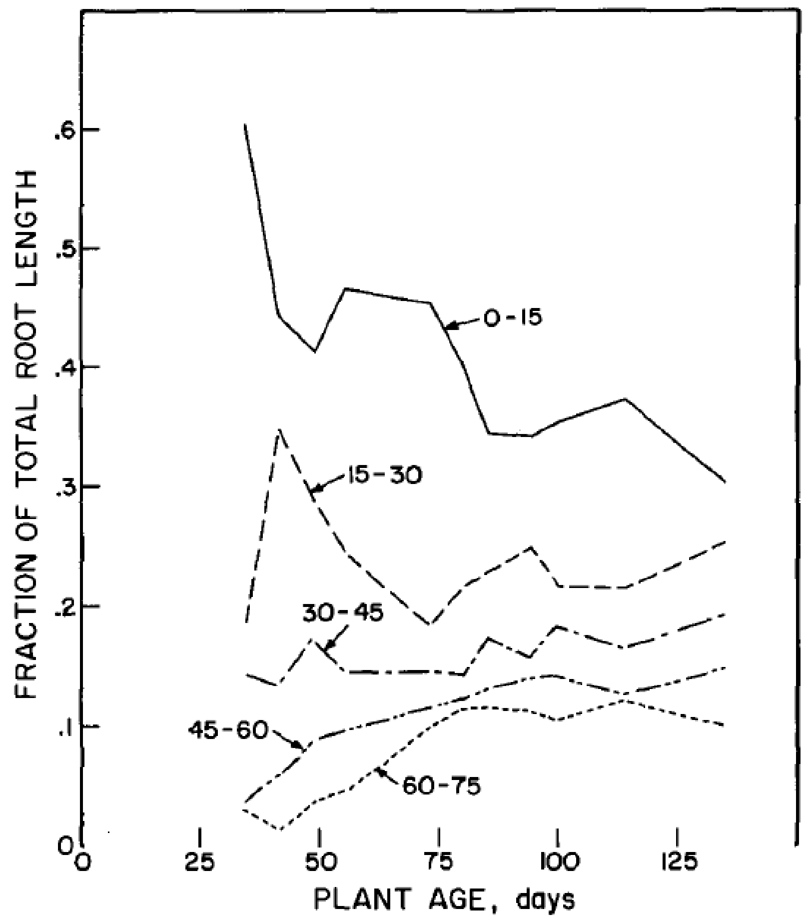


Fig. 2. Relation of plant age to the decimal fraction of the roots present in each of five soil depths during corn growth in 1971.

Corn Root Distribution with Age
(Mengel and Barber, 1971)

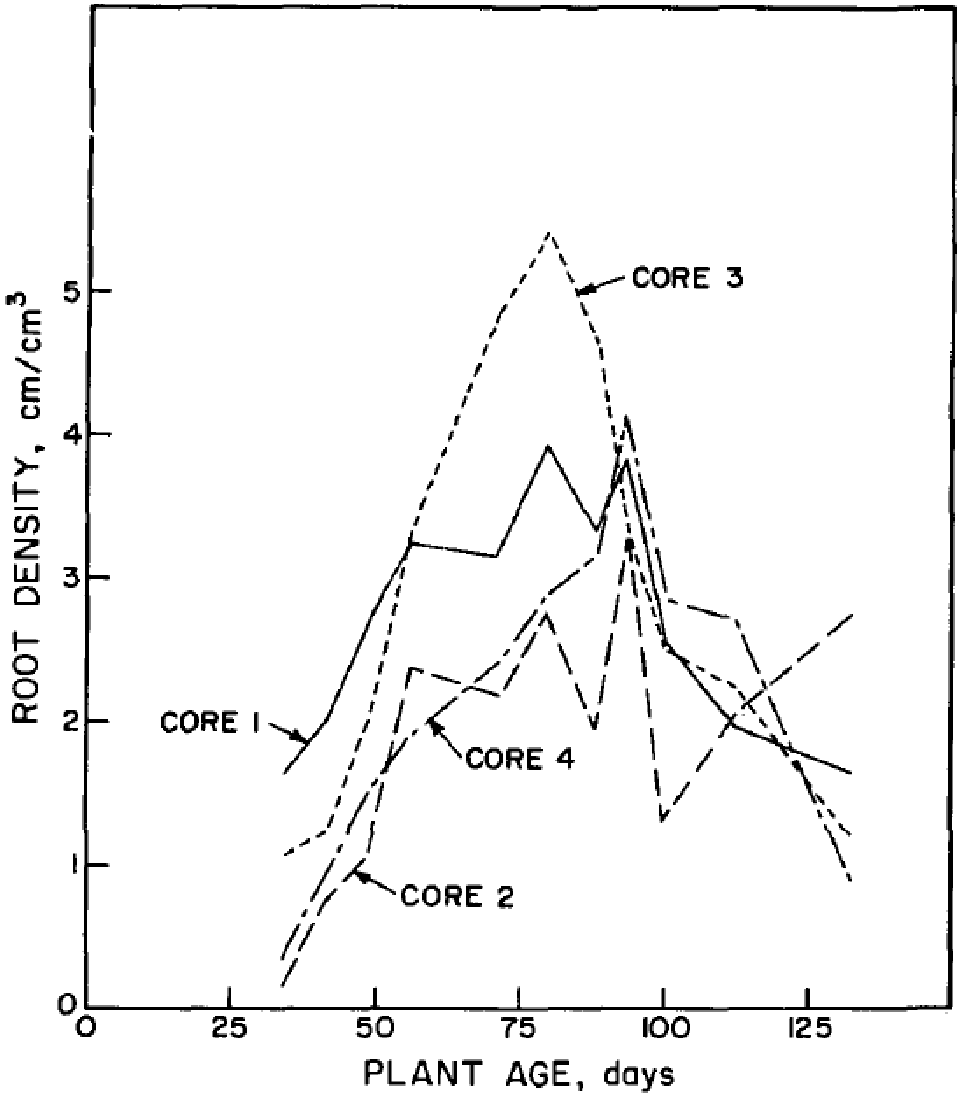


Fig. 3. Relation between core location and root density in the 0 to 15 cm depth zone for corn grown in 1971. Core 1, directly under the plant; core 2, midway between the rows; core 3, midway between plants in the row; core 4, midway between cores 2 and 3.

Movement of Nutrients to Root Surface

- Soil Nutrient "Bioavailability"
- Three components of nutrient movement
  - Root interception
  - Mass flow
  - Diffusion

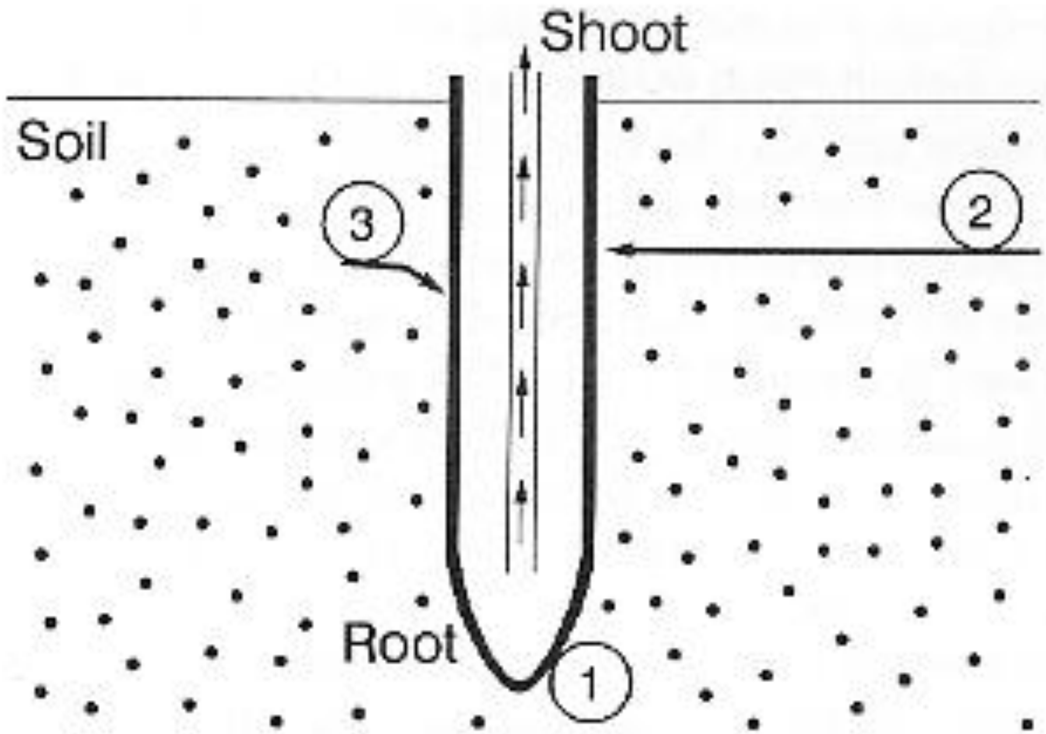


Fig. 13.1 Schematic presentation of the movement of mineral elements to the root surface of soil-grown plants. (1) Root interception: soil volume displaced by root volume. (2) Mass flow: transport of bulk soil solution along the water potential gradient (driven by transpiration). (3) Diffusion: nutrient transport along the concentration gradient. ● = Available nutrients (as determined, e.g., by soil testing).

Mass Flow of Nutrients

- Driven by transpiration
- Estimates are calculated by:
  - Nutrient concentration in soil solution
  - Amount of water transpired per unit weight of shoot issue
    - Transpiration coefficient (300—600 l H_2O per kg shoot dry weight for corn) or (36—72 gals/lb)
    - Or water transpired per acre of a crop

Diffusion of Nutrients

- Calculations
  - diffusion coefficient – Rate that each nutrient ion moves in response to root uptake
  - Difference between total nutrient uptake and the total supplied by root contact and mass flow is the amount supplied by diffusion

Table 13.2
Nutrient Demand of a Maize Crop and Estimates on Nutrient Supply from the Soil by Root Interception, Mass Flow, and Diffusion[a]

Nutrient	Demand (kg ha^{-1})	Estimates on amounts (kg ha^{-1}) supplied by Interception	Mass flow	Diffusion
Potassium	195	4	35	156
Nitrogen	190	2	150	38
Phosphorus	40	1	2	37
Magnesium	45	15	100	0

[a]From Barber (1984).

Measured for 150 bu/acre crop, are the relative amounts the same for a 300 bu/acre crop ?

Concentration of Nutrients in Soil Solution

- Mass flow and diffusion are main mechanisms for nutrient movement to plant roots
  - Higher the nutrient concentration in soil solution, the faster the transport of nutrients
  - The reason that band applications are effective (also reduce fixation reactions for P)
- Mass flow and diffusion occur in soil solution
- Interrelated to root growth
  - Growing roots shorten the distance nutrients must move in the soil

Concentration of Nutrients in Soil Solution

- Concentration of a specific nutrient varies:
  - Moisture and aeration
  - pH
  - Cation exchange capacity
  - Soil organic matter content
    - Nutrients that are mineralized
    - Nutrients held on cation exchange sites
    - Organic acids and other compounds that influence nutrient solubility

Concentration of Nutrients in Soil Solution

- Indicator of mobility of nutrients
  - Toward root surface
  - Vertical direction (potential for leaching in humid climates)
- Phosphorus occurs in relatively low concentrations
  - P strongly interacts with surfaces of clay minerals
  - Mobility is enhanced by complexation with organic molecules – Benefit depends on soil and location
  - Organic matter and microbial activity increase concentration and mobility of phosphate

Bio-Geochemistry of Nutrient Availability in Soils

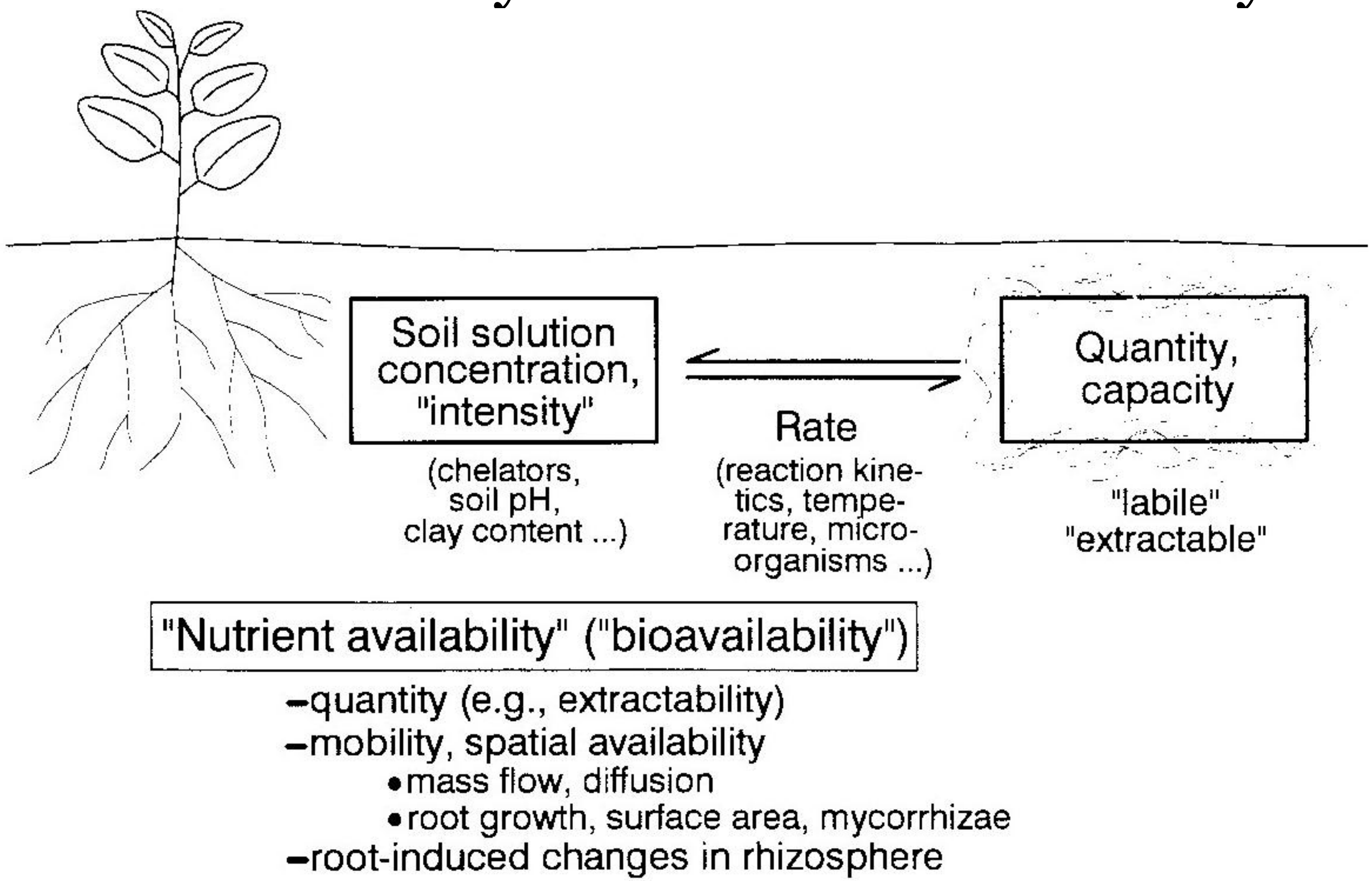


Fig. 13.12 Intensity/quantity ratio of nutrient availability, and factors determining the 'bio-availability' of mineral nutrients. (Marschner, 1993.) Reprinted by permission of Kluwer Academic Publishers.

Where and how can we make changes in this system to increase nutrient uptake efficiency and increase yields?

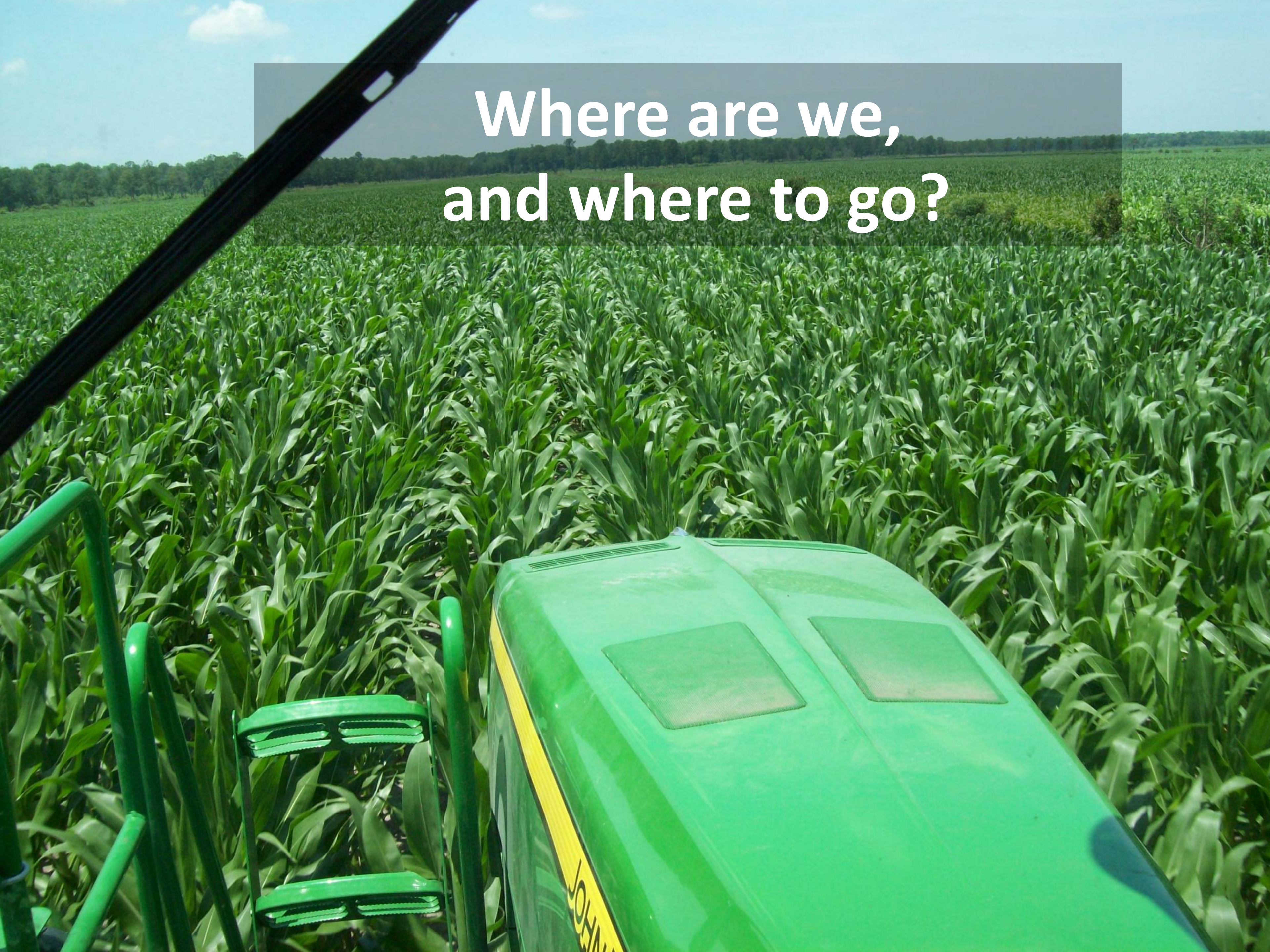
High Yielding Crops

- Total nutrient requirements
- Rate of nutrient availability

Nutrient Requirements

- Sources
- Placements
- Timings
- Environmental concerns

Where are we, and where to go?



Producing More with Less

- Agro-ecosystems that can produce the needed food in perpetuity
- Agro-ecosystems that do not degrade associated natural systems and perhaps enhance “eco-system services.”
  - Clean water
  - Clean air
  - Carbon and nutrient cycling
  - Bio-diversity

Agricultural Ecosystems Realities

- Increased food production
  - Quantity and quality of food production
  - Increased demand associated with income rises in many countries.
- Less land per person
- Less fresh water per person
- Impact of agricultural practices on water and air quality???

The Fertilizer Industry

Specific Technological Developments

- Defining essential elements for plant nutrition
  - Late 1800's and early 1900's
  - Carbon, Hydrogen, Oxygen – From air and water
  - "Mineral Nutrients"
    - N, P, K, Ca, Mg, S – Macronutrients
    - Zn, Cu, Fe, Mo, Mn, B, Cl, Ni

Technological Developments In the Fertilizer Industry

- Acid treatment of phosphorus sources
  - Patented by Lawes in England in 1842 – Superphosphate
- Haber Bosch Reaction for Producing Ammonia
  - Industrial Scale Production – BASF 1913
- Potash mining
  - Mining in several areas of Germany in the 1860's
    - KCl, K_2SO4
  - Large scale Canadian production in 1960's
- Triple superphosphate
  - 1890's with major production after 1950
- Ammonium phosphates
  - First introduced in the United States in 1916 by American Cyanamid
  - Large scale fertilizer production in 1960's

Importance of Food Production Systems and Agricultural Sciences

- Fertilizers account for 50% of increased food production in the world today
- Do we live longer (even with our "bad" diets" in the developed world)?
- Can not argue that science has increased the carrying capacity of the planet since "hunting and gathering" era
  - Medicine
  - Sanitation
  - Education
  - FOOD PRODUCTION!!

Developing Fertility Programs for the Future

- Develop the agronomic systems to produce “high” yields for specific environments.
  - Will initially be done with excessive nutrient concentrations in soils
- Define the rates of nutrient uptake needed to achieve the yields
  - Lbs per acre per day at different plant growth stages
- Define the soil volumes and root lengths needed in specific soil horizons to achieve most efficient uptake
  - Enables determination of optimum nutrient placement(s)
  - Associated with moisture availability and utilization

Developing Fertility Programs for the Future

- Develop new nutrient source molecules
  - Reduce fixation by soil
  - Minimize leaching
  - Maximize transport rates that match plant growth patterns and nutrient needs
- Determine how to finance!!!
  - NFDC is gone
  - Major research restructuring at Land Grants
  - USDA budget expected to decline
  - Industry has not had R&D funds in past

Why?

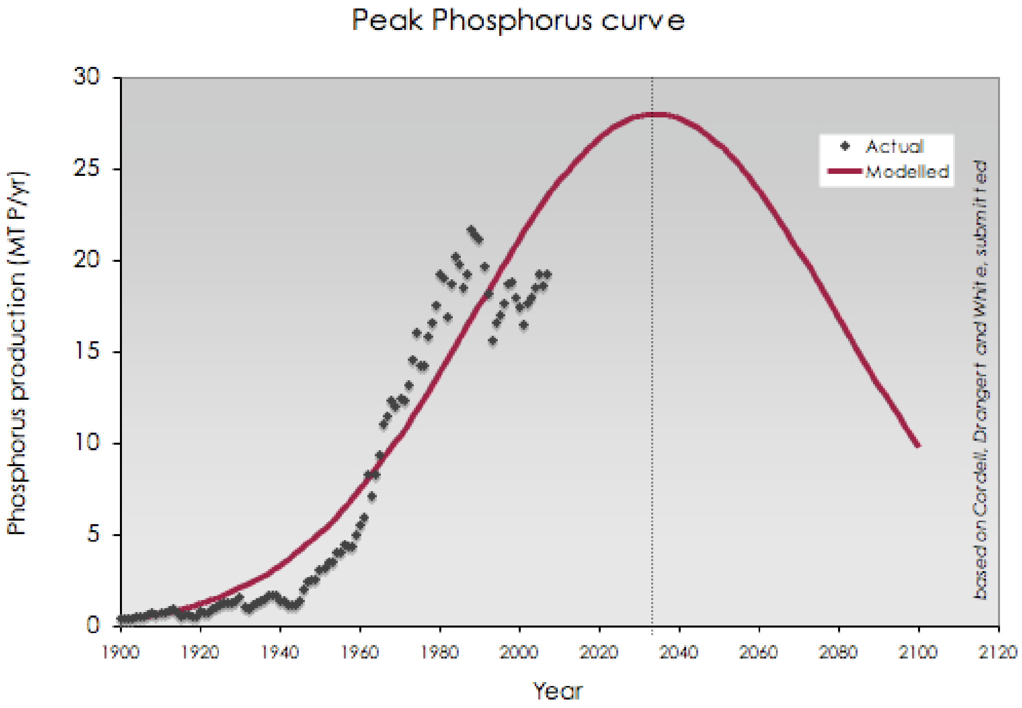
- Enlightened self-interest
  - Increased grain yields = Increased N use?
  - Increasing N use
    - At what rate relative to yield increases?
    - Is N use efficiency of 25 to 50% acceptable?
  - Example:
    - Maize in North China Plain*
      - Average N application: 249 kg N/ha (56 to 600 kg N/ha)
      - Average yield: 6 – 8 t/ha (120 to 160 bu/ac)
      - Soil nitrate levels: 275 kg N/ha (0-90 cm depth); 213 kg N/ha (90-180 cm depth)
      - 49% of 80 groundwater samples exceeded 45 mg NO_3 / L

*Cui, et al. 2008. Agron. J.; Meng et al. 2010, Field Crops Research (in review).

Phosphorus

- Peak* Phosphorus Discussion

***30 or 200 years, same problem**



*Cordell et al. 2009. Global Envir. Change 19:292-305

Fertilizer Development for the Future

- Virtual Fertilizer Research Center
  - http://www.ifdc.org/Alliances/VFRC
    - Fertilizers critical to world food security
    - Efficiency of currently used fertilizers is low
    - Fertilizers produced with non-renewable resources
      - Natural gas
      - Ores
    - Majority of current fertilizer sources developed between 1930 to 1960 by the National Fertilizer Development Center (TVA) which no longer exists

Fertilizer Industry Focus

- Efficiency
  - Mining
  - Production
    - "De-bottlenecking"
    - Decreased energy use per unit of production
    - Decreased water use
  - Transportation and distribution
  - Financing
- Focus has created an extremely effective system for producing and distributing fertilizers throughout the world – Fertilizer is truly a "globalized" industry

Future Scientific Involvement For a Sustainable Fertilizer Industry

- New energy sources to reduce carbon footprint and cost of production
- More effective use of essential nutrients
  - N -- Plenty of N_2 in atmosphere
  - P –200 (or 30?) years of phosphate rock reserves
  - K – Plenty (but is that a reason to not use it efficiently)
- Issue is what are we doing with what we make and what are the collective “we” doing to “our environment” as we use these nutrients.
  - I can also make the argument that our effects with nutrients are negligible compared to the effects of many “consumer” goods that are being made today.

Future Scientific Involvement For a Sustainable Fertilizer Industry

- Increase the capture of nutrients applied to fields to produce crops
  - N use efficiency – 33 to 65%
  - P use efficiency – 14 to 50%
  - K use efficiency – Balanced fertilization!
- Refine the values for nutrient concentrations of food grains that optimize human and animal nutrition.
  - Determine the fertilizer sources that can supply these nutrients to various crops in specific locations

Future Scientific Involvement For a Sustainable Fertilizer Industry

- Increased yield levels
  - 4 R's program
    - Do we have the right source, rate, place and time for 18.9 tons/ha (300 bu/acre) corn?
    - Amounts of nutrients if we maintain the same nutrient content in the grain
    - Same growing season, increased nutrient uptake rates
      - Transport through soil
      - Uptake through roots
      - Other ways to get needed nutrients to plants efficiently

Future Scientific Involvement For a Sustainable Fertilizer Industry

- Nutrient recovery and reuse
  - Livestock wastes
  - Municipal wastes
  - How many times can your company sell the same phosphate, nitrogen, and K molecules?
- EPA Targeted Watersheds and NRCS Mississippi River Basin Initiative
  - N, P, and Sediment Reduction in Water
  - Millions of dollars but most, if not all, is for cost-share of practices.
  - How do we get the investment in research?

http://www.acwa-rrws.org/watershed.html

RIVER STEM
Raccoon River
Buena Vista County
200 miles +/-
Joins the Des Moines River in the city of Des Moines
Middle Raccoon
Carroll County
76 miles +/-
Joins the Raccoon near Van Meter
South RaccoonGuthrie County
50 miles +/-
Joins the Middle Raccoon near Redfield
3,600 square miles / 2.3 million acres
74% of the land area is farmed; corn / soybeans on 1.7 million acres
47 registered feedlots
127 unregistered feedlots
54 permitted animal feeding operations
40 municipal wastewater treatment plant

Ag Partners LLC (Des Moines River & Raccoon River)
Albert City, Iowa |
Dedham Cooperative Association (Raccoon River)
Dedham, Iowa
Farmers Cooperative Company (Des Moines River & Raccoon River)
Ames, Iowa | www.fccoop.com
First Cooperative Assoc. (Raccoon River)
Cherokee, Iowa | www.first.coop
Gold-Eagle Cooperative (Des Moines River)
Goldfield, Iowa
Heartland Co-op (Des Moines River & Raccoon River)
West Des Moines, Iowa | **Key Cooperative (Des Moines River)**
Helena Chemical Company-Midwest Division (Raccoon
New Cooperative, Inc. (Raccoon River)
Fort Dodge, Iowa | www.newcoop.com
Pro Cooperative (Des Moines River & Raccoon River)
Gilmore City, Iowa | www.procooperative.com
Crop Production Services (Raccoon River)
Wall Lake, Iowa |
Van Diest Supply (Des Moines River & Raccoon River)
Webster City, Iowa | www.vdsc.com
West Central (Des Moines River & Raccoon River)
Ralston, Iowa | www.westcentral.coop

PARTNERSHIPS

Our partners make this work possible.

Thanks to:

National Laboratory for Agriculture and the Environment | www.ars.usda.gov

Des Moines Water Works | www.dmww.com

Lake Panorama Association | www.lakepanorama.org

Racoon River Association

US Geological Survey | www.usgs.gov

Agriculture Clean Water Alliance

http://www.acwa-rrws.org/index.html

SUSTAINABILITY and GROWTH

- Economic
  - Demand (not just need for food) is increasing.
  - Industry appears to be entering a period of greater economic return due to increased demand
  - Investment in research and development for new molecules and technologies is needed for “long-term” economic sustainability of our farmers and our businesses.

SUSTAINABILITY AND ACCEPTANCE

- Social
  - Food production is essential for society, and we as an industry have done "good things" in terms of supply, quality and safety.
  - Perhaps we have been "to good" at our jobs and thus we are under appreciated. (GET OVER IT!)
  - The un-intended consequences of our production systems sometimes put us in conflict with society.
  - Continued efforts needed on education of society about what we do, as well as our being socially aware of our actions.

SUSTAINABILITY AND STEWARDSHIP

- ENVIRONMENT
  - Continue reducing the environmental impacts of nutrients
  - Most, if not all, gains in reducing environmental impacts of nutrients should increase fertilizer production efficiency and crop production efficiency.
    - Quantification of the increases in efficiency should have a value that can be shared by the fertilizer industry and growers, i.e. more value in the system.
  - We must be seen as proactive in this area, or we have the potential to be regulated greatly in specific areas.