Soil Sampling and Testing

Basic Concepts, Use, and Interpretation

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Soil Testing

- Soil testing is a widely use to assess the crop-availability of nutrients
- Fertilization guidelines for macronutrients P and K, secondary nutrients, and micronutrients are based on soil testing
- Sometimes soil nitrate testing is used to complement N fertilization guidelines based on other criteria

What is a Soil Test?

- Soil tests estimate probable nutrient sufficiency and response to fertilization
- Only a small fraction difficult to define for sure is available at a certain time
- Try to estimate from a tiny sample, in few minutes, an amount proportional to what may be available during a season
- Various tests can be used for a nutrient, and may measure different amounts

Soil Testing Elements

- A representative soil sample
- A testing method adequate for a region:
  - Chemical extraction of the nutrient
  - Measuring extracted nutrient
    - The extractant often defines a soil test with the exception of P tests (ICP)
- Field calibration with yield response
  - Give a meaning to soil-test results
- Laboratory testing quality

Updated Soil Sampling Publication

CROP 3108 - December 2016

One of the most important steps in soil testing is collecting soil samples. The soil sample is the first part of the soil testing process and the foundation for information derived from laboratory analyses, soil test interpretations, and recommendations. Soil sampling is also the largest and most

recommended sampling times and cannot be used with suggested interpretations. Field research calibrations for phosphorus (P), potassium (K), and pH soil tests are based on samples collected in the fall or spring. Recent research suggests that samples taken in late spring or early summer, before around the V6 growth

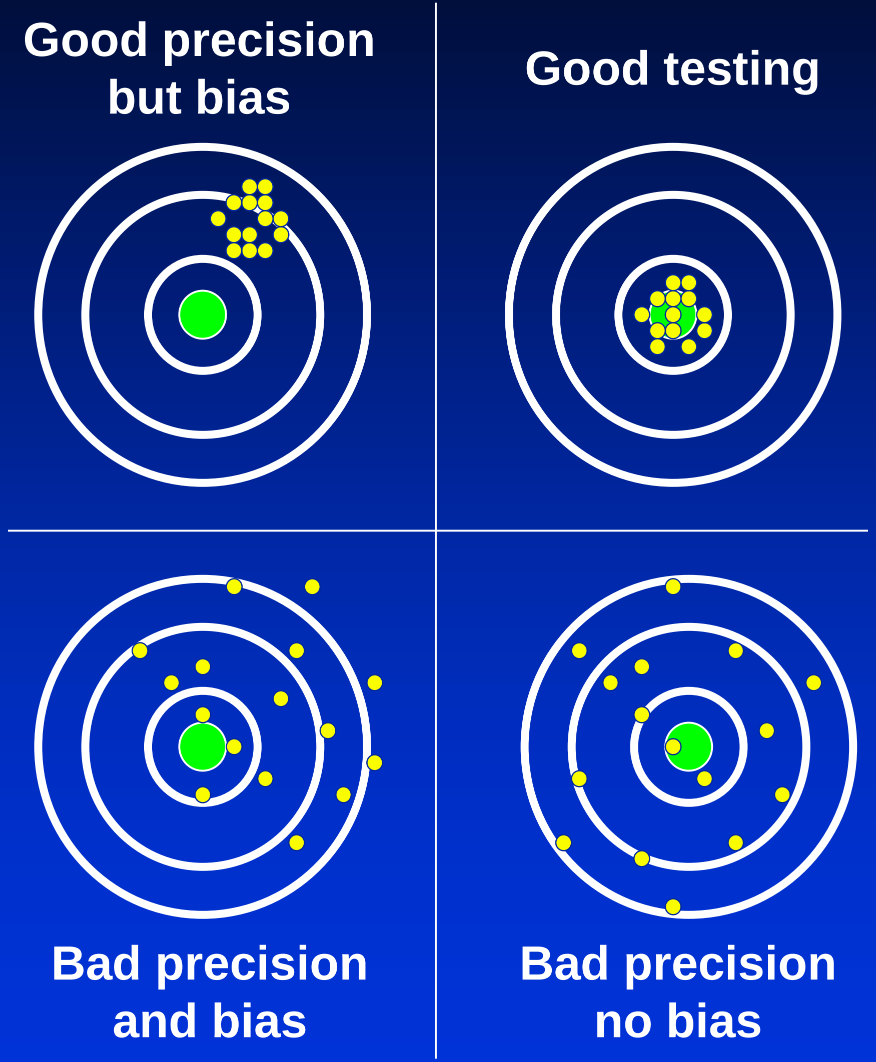
Soil Testing Potential Errors

- Laboratory errors:
  - Is the entire soil sample ground?
  - Analytical error
  - Laboratory bias
- Soil sampling in the field is the most common and important source of error
  - Number of samples per field or zone
  - Number of cores per sample
  - Subsampling when more than about 12 6-inch cores are collected

Laboratory Testing Quality

Precision of the measurement
Uncertainty

Accuracy of the measurement
Bias



Soil Testing Proficiency

- Several states certify soil testing laboratories
- Voluntary enrollment in Iowa, but DNR and NRCS requires use of certified labs
- The state uses the North American Proficiency Testing Program (NAPT)
  - Administered by the SSSA
  - Quarterly submission of blind samples
  - The program has reduced lab bias

What Do We Measure?

Fast **Slow**

Solution ↔ **Exchangeable K / labile, reactive P / < readily available >** ↔ **Nonexchangeable K forms / low solubility or insoluble P forms / << More available — Less available >>**

- **For P:** no clear correspondence between "plant available" and chemical forms
- **For K:** tests measure exchangeable and soluble forms, but some forms of non-exchangeable K become available too
- **Many factors affect the equilibrium between readily available and less available forms**

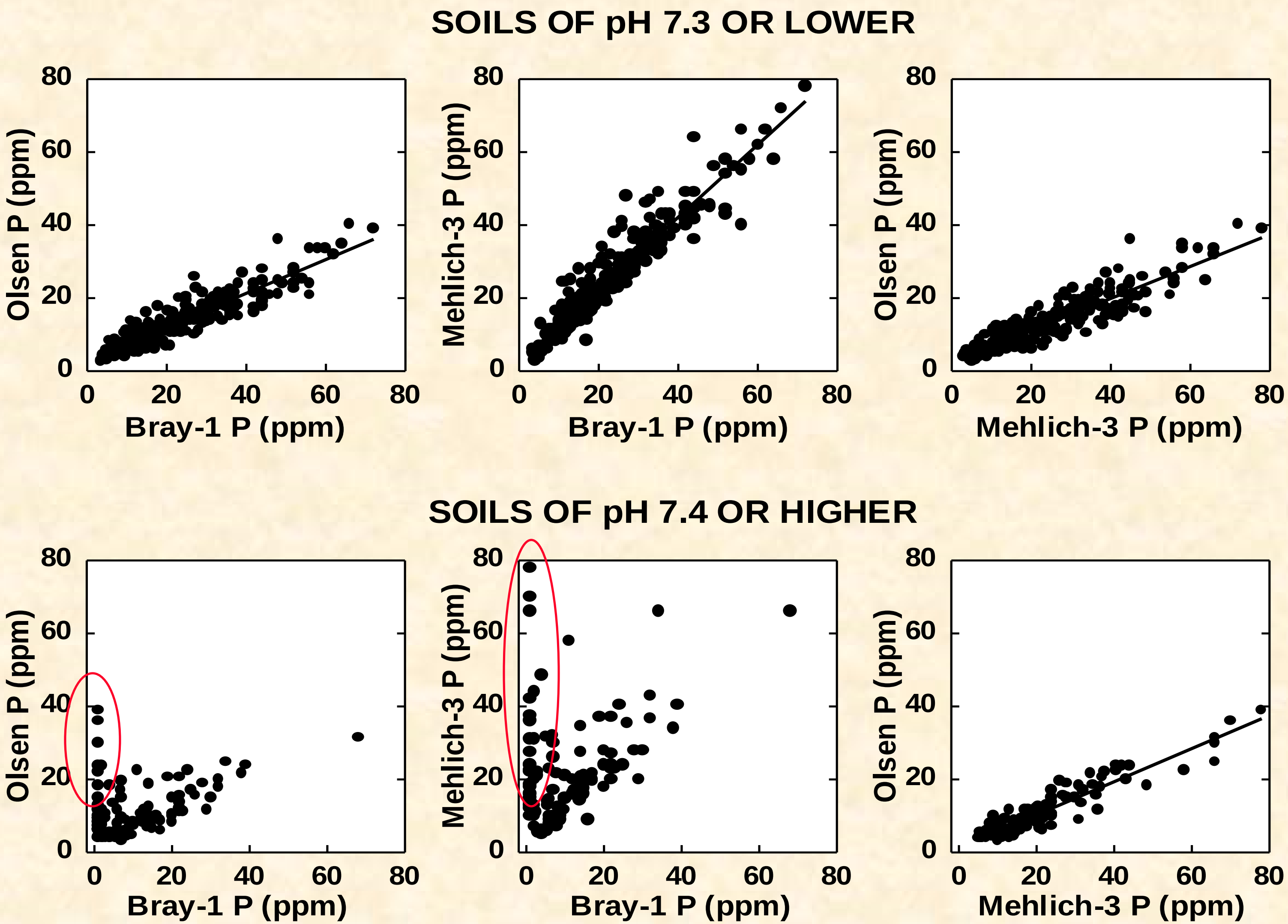
P Extraction and Determination

- Common P extractive solutions
  - Bray-1: HCl + NH_4F (weak acid)
  - Olsen: $NaHCO_3$ (alkaline, pH 8.5)
  - Mehlich-3: $CH_3COOH + NH_4F + NH_4NO_3 + HNO_3$ + EDTA
- Determination of extracted P
  - colorimetric, measures ortho P only
  - ICP, inductively coupled plasma, measures al forms of dissolved P
  - the ICP measures more P in extracts

P Soil Testing and pH

- The Bray-1 test often underestimates available P in highly calcareous soils
  - Badly with > pH 7.3 and > 4-5% $CaCO_3$
  - The weak acid solution is diluted
- The Olsen test is the classic method recommended for calcareous soils
- The Mehlich-3 measures about the same P than Bray-1 in acid to neutral soils, but works better in Iowa calcareous soils

Matching Soil Tests to Soil Types

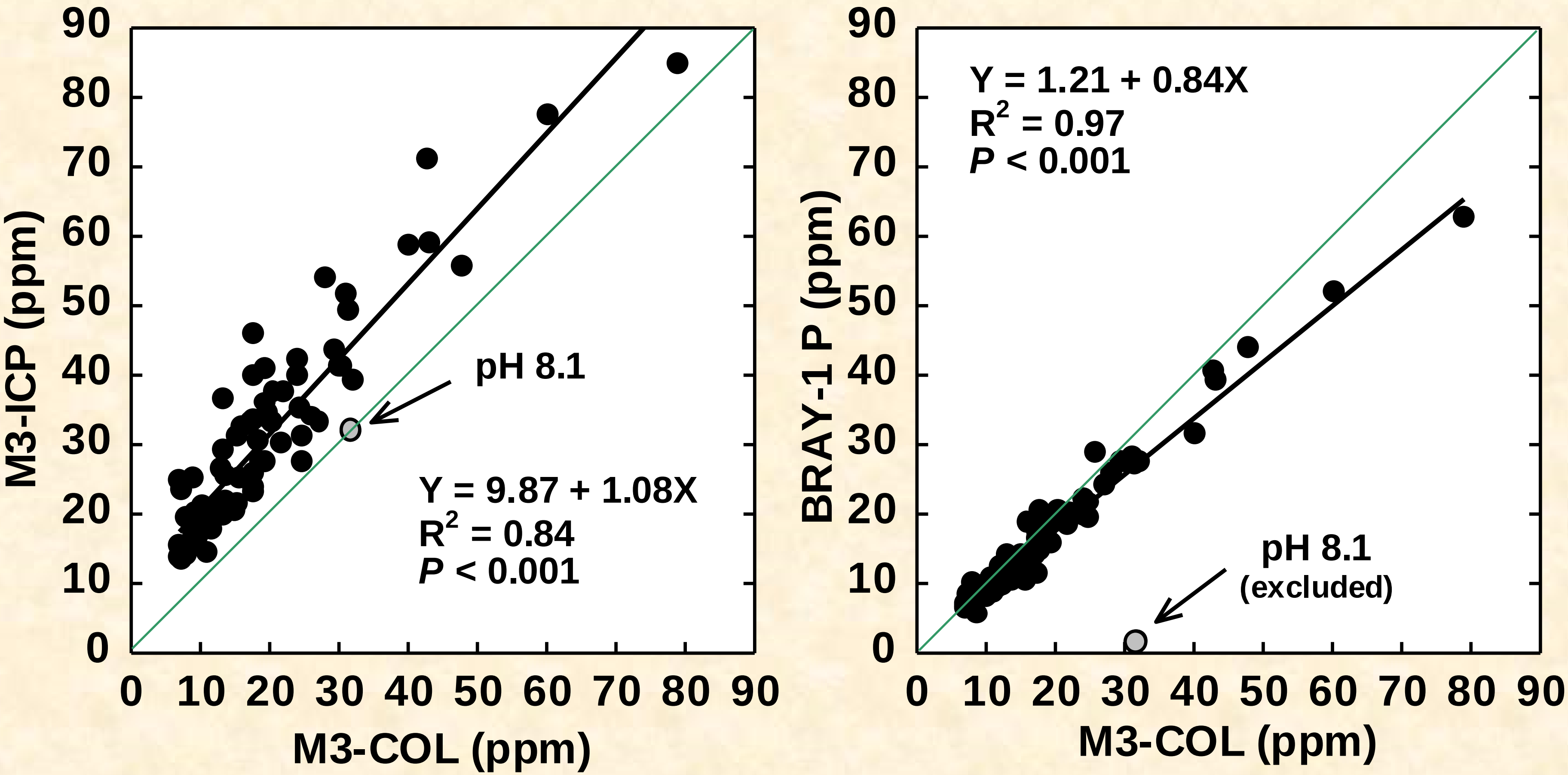


Mallarino, 2003

The ICP Confusion for P

- Colorimetry was used to measure orthophosphate P by all test methods
- As ICP instruments became cheaper, some labs began using ICP (inductively coupled plasma) for the M3 P because it can be used for other elements
- The ICP uses a very hot flame that breaks down all compounds, measures more P in all soil extracts, additional P mostly comes from simple organic P forms

Relationships Between P Tests



Mallarino, 2003

K Extraction and Determination

- Common K extractive solutions
  - 1 *M* ammonium acetate and Mehlich-3
- Determination of extracted K
  - Atomic absorption (low temp flame)
  - ICP (very high temp flame)
- These K extractants and determination methods give the same K test results
- Very different test results for K testing of dried or undried soil samples

The Moist Soil Test for K

- The common testing methods use soil samples dried at 35-40 C
- Only the lab sample handling differs from the dry test, not the analysis
- Two versions, which give same results
  - As is field-moist testing
  - Soil/water slurry to facilitate handling
- Interpretations since the fall 2013 in ISU PM 1688 extension publication

Interpretation of Soil Tests

- The amount of nutrient measured is only proportional to what a plant can absorb, soil tests are indices
  - Various soil tests can be used for one nutrient and measure different amounts
    - For example, the Olsen P test extracts about 60% less than the Bray-1 or M3
- A soil test value cannot be directly used to make fertilizer recommendations and directly translated to lb/acre of fertilizer

Meaning of a Soil Test Value

- Only in dry areas total profile nitrate-N sometimes can be directly related to plant needs and fertilization needs
- Use of soil-test units such as lb/acre are very misleading and should not be used. Use concentrations (such as ppm)
- Soil-test results should be calibrated with field response trials for different crops, contrasting soil types, and conducted at least two or three years

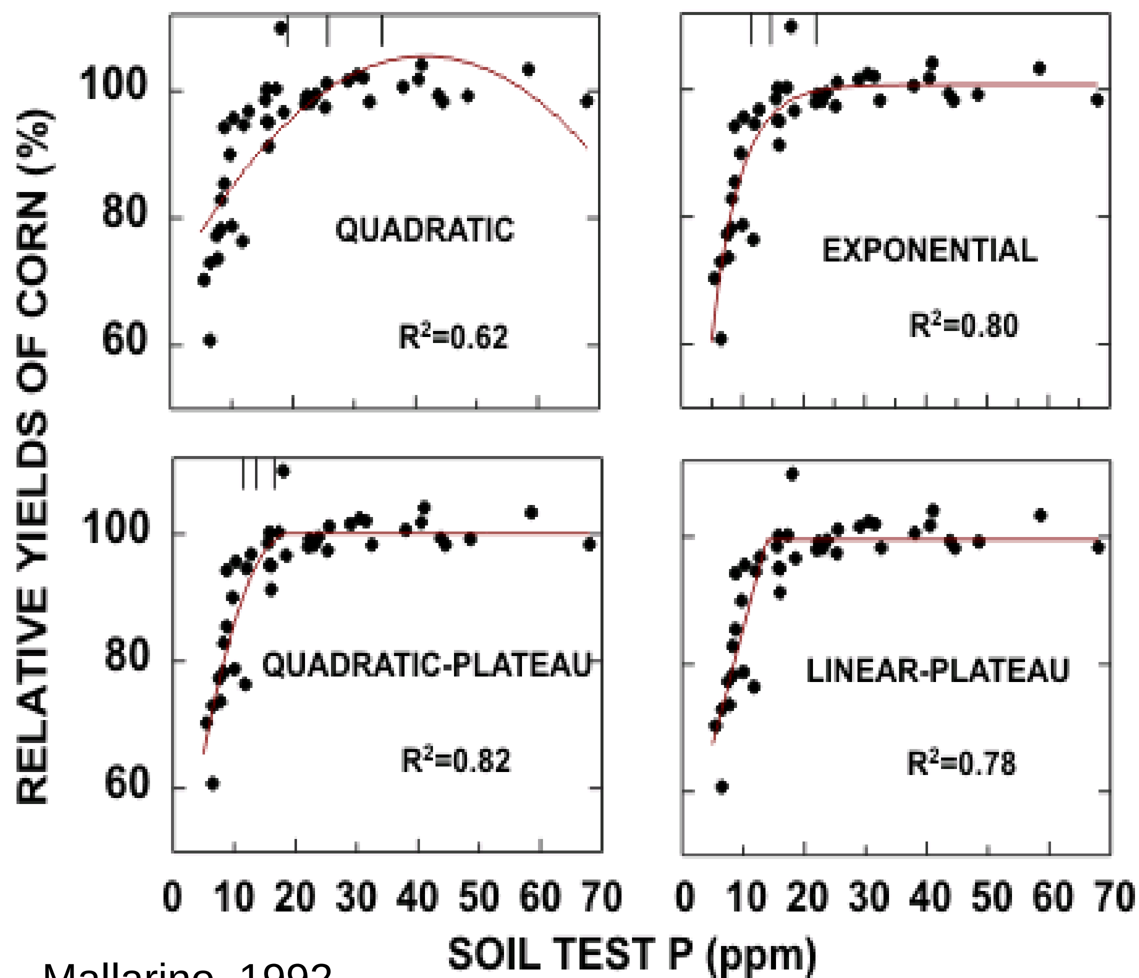
Soil Test Field Calibration

- Tests correlation with crop response
  - Find the critical concentration range that separates values responsive and non-responsive at some probability level
- Tests calibration
  - For the deficient range, find the amount of nutrient needed for different levels to maximize yield or economic response
- Prevailing P and K removal help determine fertilizer rates to maintain optimum levels

Determining Critical Soil-Test Ranges

Math models:

No single best model, some fit data better than others, some subjective judgment involved to establish interpretations



Mallarino, 1992

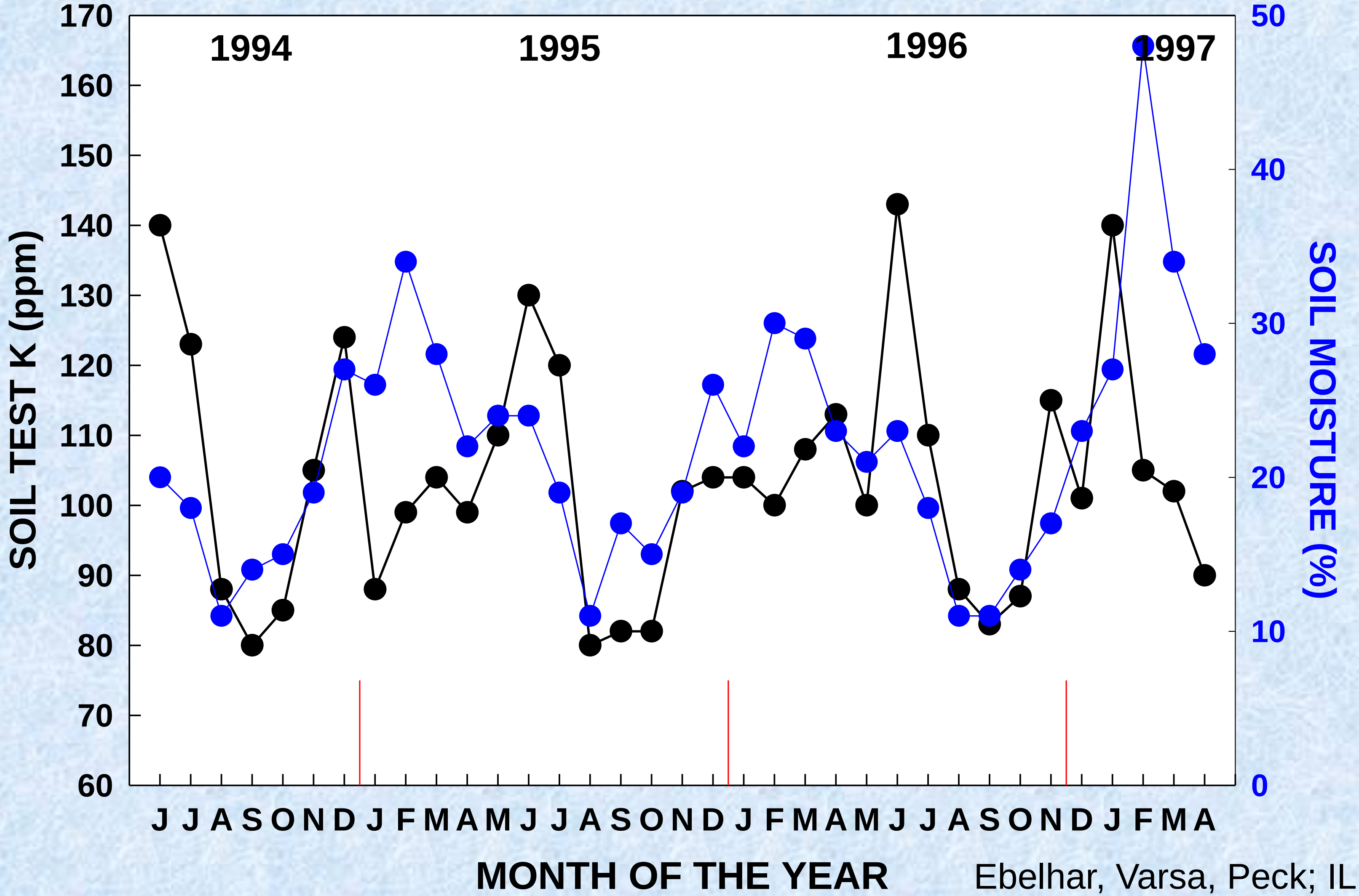
Consider Sampling Time Effects

- Soil or plant tests correlation/calibration and use in production agriculture often need to define a specific sampling time
  - No major issues for soil P
  - Late-spring nitrate test: corn 6 to 12" tall
  - Soil K: Greatly affected by drought and amount of rainfall shortly after harvest
  - pH: Greatly affected by drought (often values are lower)

Soil-Test K Temporal Variation

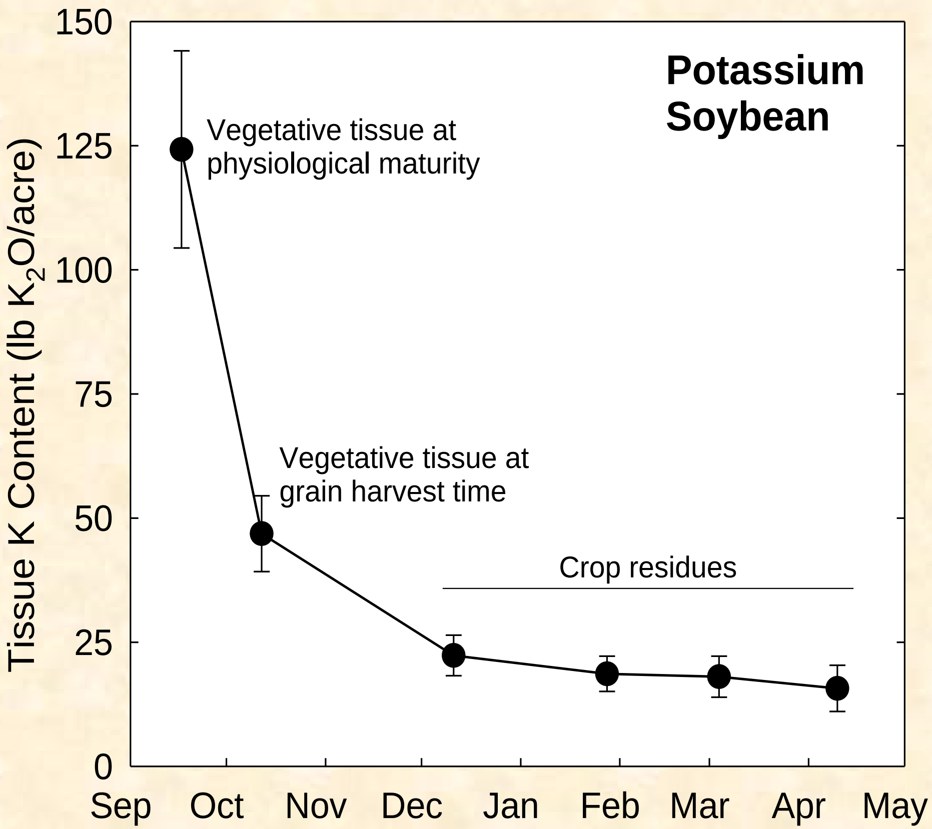
- Timing of recycling from standing crops and residues interacting with amount and distribution of rainfall
- Equilibrium between exchangeable and nonexchangeable K in the soil
  - Growing crops reduce K exchangeable pool
  - Dry soil limits resupply from the K nonexchangeable pool
- Soil-test K is more stable in the spring, but still more is variable than soil-test P

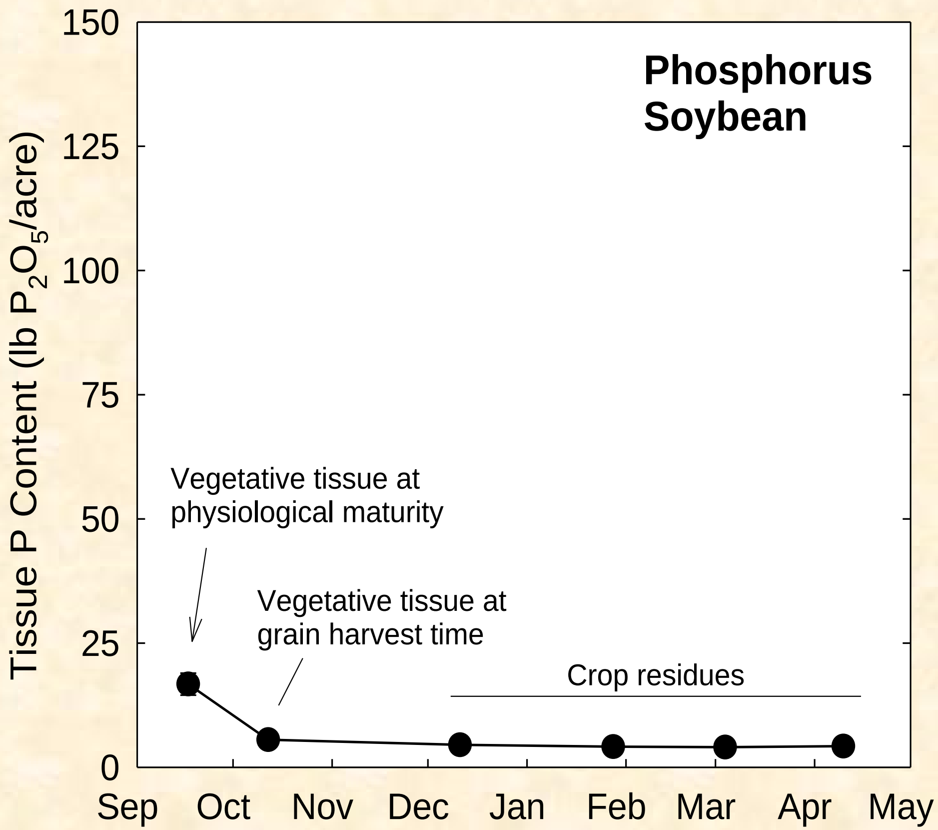
Consider Sampling Time Effects



Ebelhar, Varsa, Peck; IL

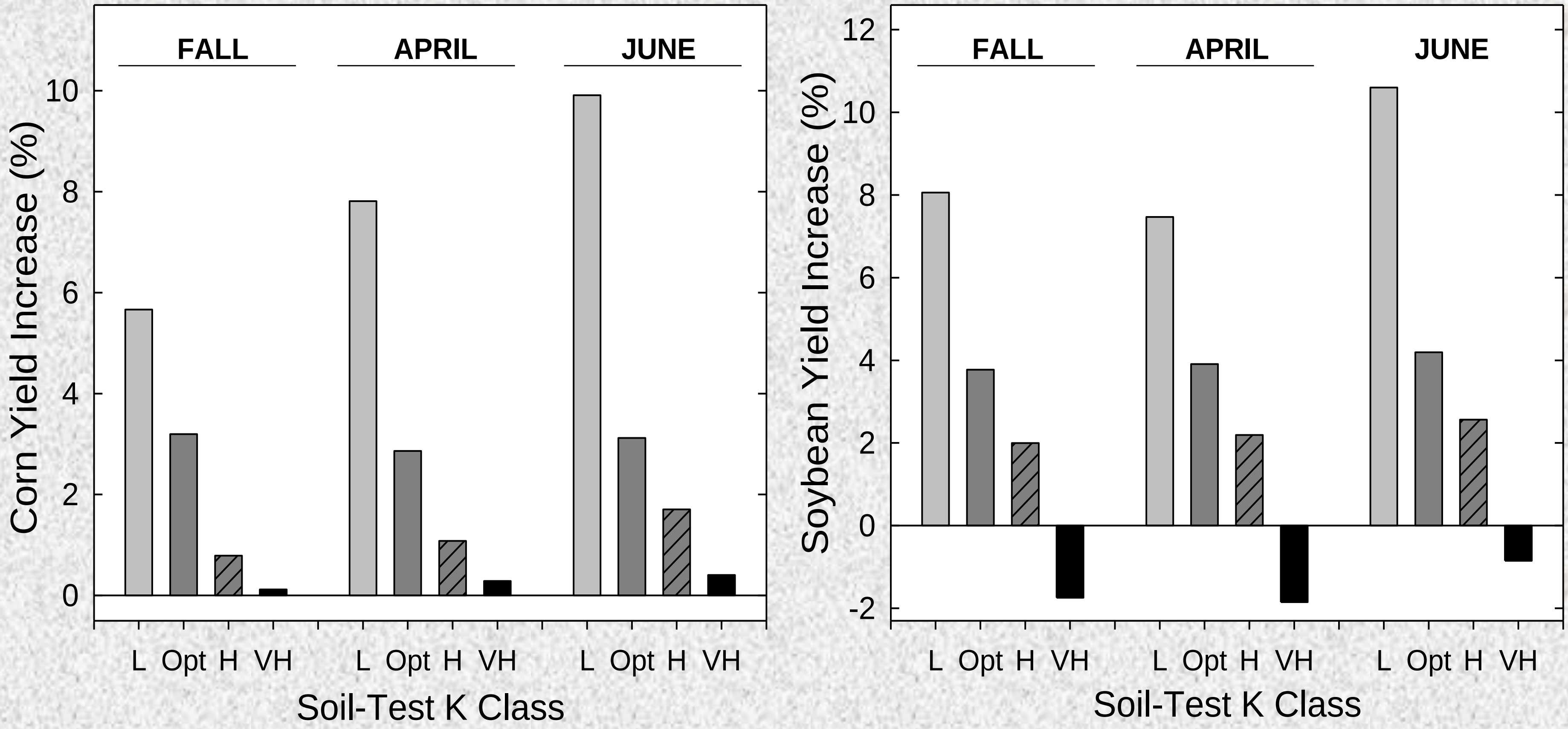
P and K Recycling to Soil





Oltmans and Mallarino, 2011
Data for 11 site-years

What Sampling Time is Better?

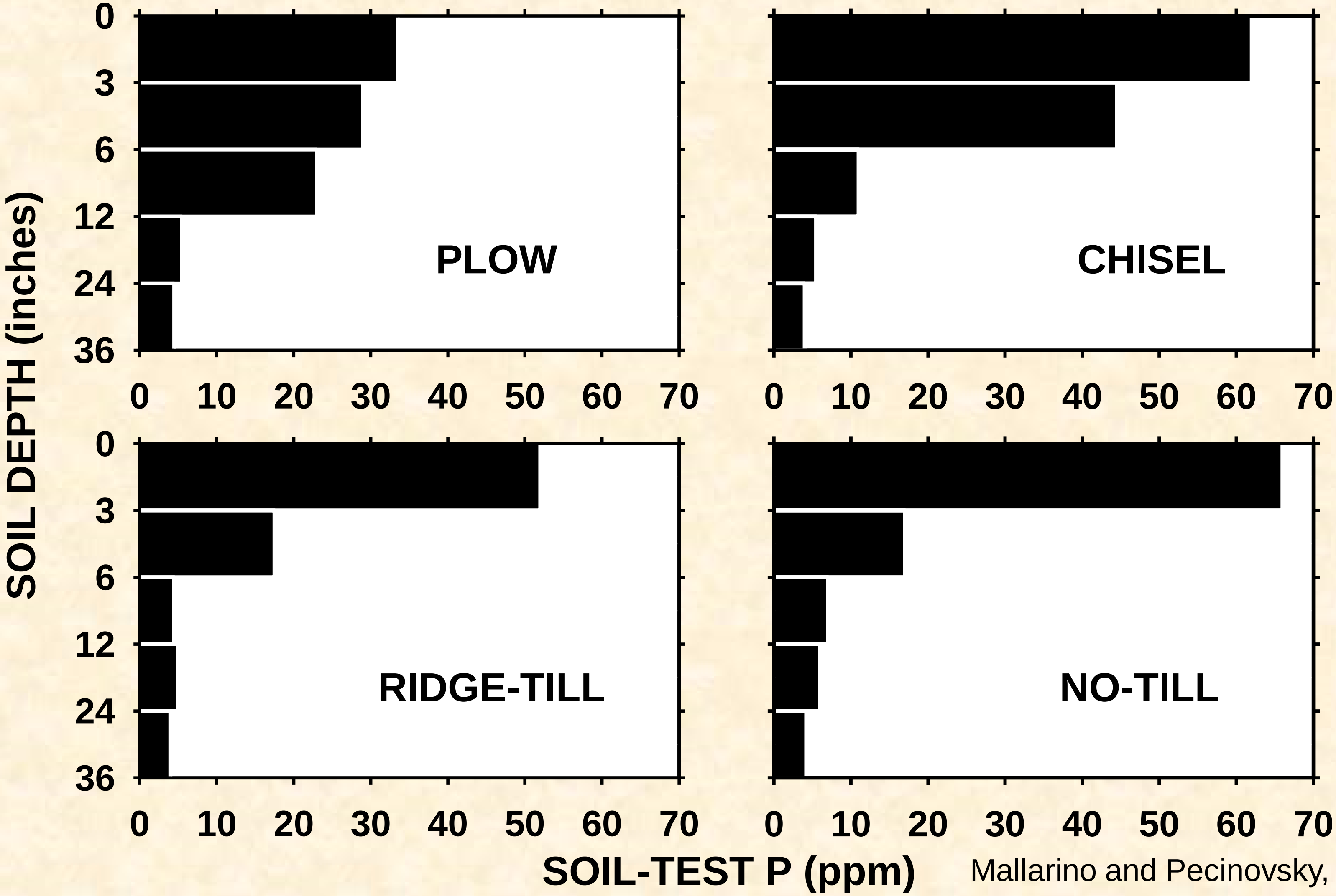


Clover and Mallarino, 2008

Soil pH Temporal Variation

- Ca, Mg, and K sulfates and chlorides accumulate during prolonged drought
- Cations displace H^+ from clay and OM exchange sites, which lowers the pH
  - May reduce pH by 0.1 to 0.4 units
  - No much change in strongly acidic or calcareous soils (pH <5.5 or >7.5)
  - Larger effects with drier climate; pH measured in $CaCl_2$ may be more stable
- Buffer pH (lime requirement) isn't affected

Nutrient Stratification, Example for P



Mallarino and Pecinovsky, ISU

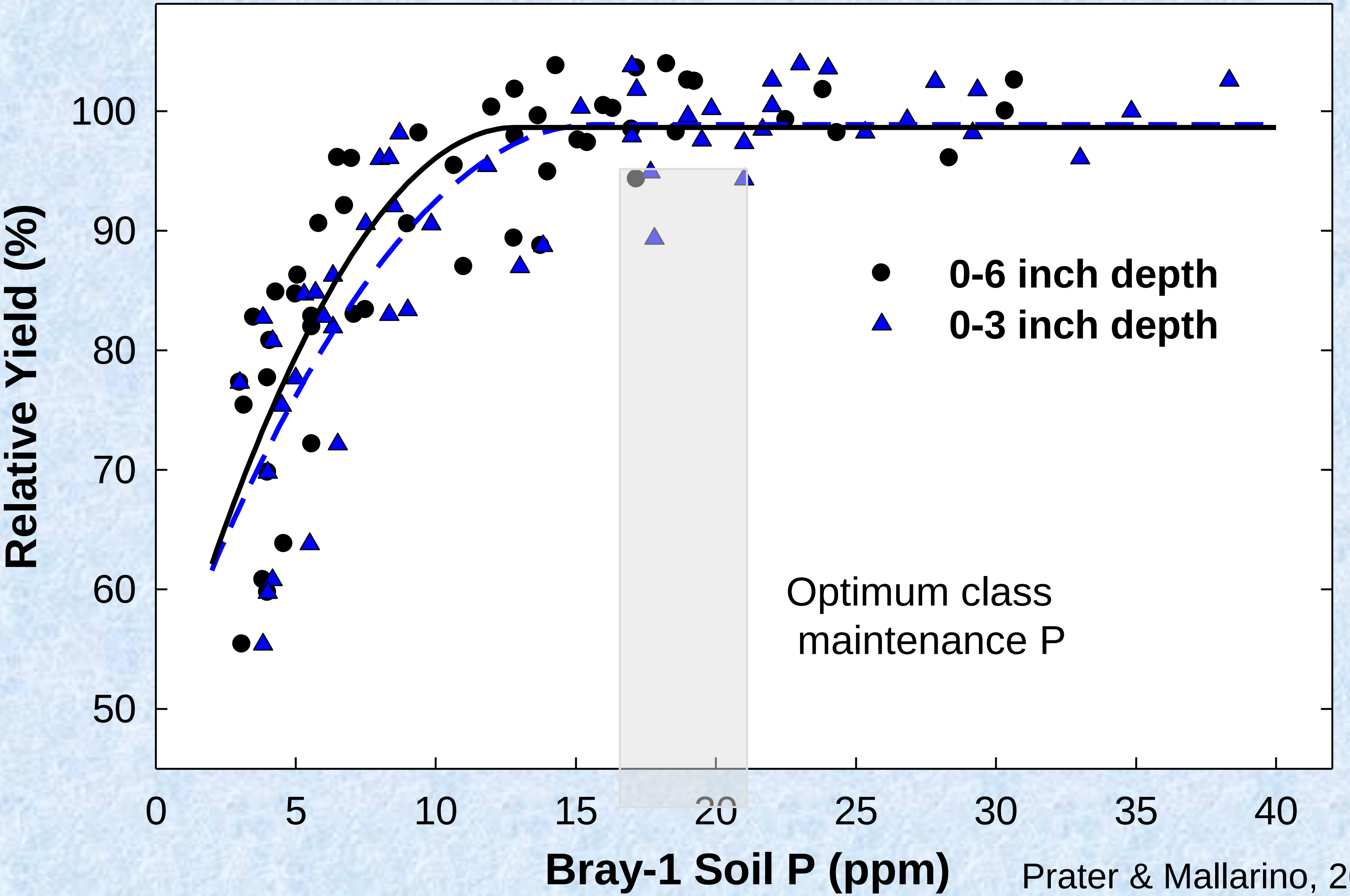
What's the Best Sampling Depth?

- Tests for P, K, micros: Depth best to measure sufficiency and predict response, NOT depths with higher or lower levels
- Lime requirement is different: The depth and volume in which pH can be changed
- Nitrate test: Mostly and index in humid regions that needs to be calibrated, in dry regions the amount in the profile can be accounted for recommendations

Standardize Soil Sampling Depth

- The sampling depth used for a test calibration and its use should match
- Suggested soil sampling depths in Iowa
  - 6 inches for P, K, and Zn: Best correlations and more practical
  - 2-3 inches for lime in no-till or pasture: because that's what liming can change
  - 1 foot for the late spring nitrate test: mostly an index, deeper sampling isn’t more useful in most soils, not practical

Field Soil-Test P Correlations for No-Till



Prater & Mallarino, 2007

The Sufficiency Level Concept

- Each nutrient has levels of sufficiency and deficiency
  - A level below which crops will respond to fertilization, a range at which there is no response, and possibly a level above which yield is decreased
- Requires frequent soil testing
- The need for a nutrient may be affected by levels of others, but sufficiency levels are not related in a fixed ratio

Build-up and Maintenance Concept

- Build-up soil test up to a certain level and then maintain; several interpretations
- A strict interpretation: Know the nutrient amount needed to increase soil-test to a specific level for various soils and crops, maintain values with unlikely response
- Reduces the likelihood of lower than optimal fertilization rates but often results in higher than needed fertilization rates

Nutrient Balance Does Not Work

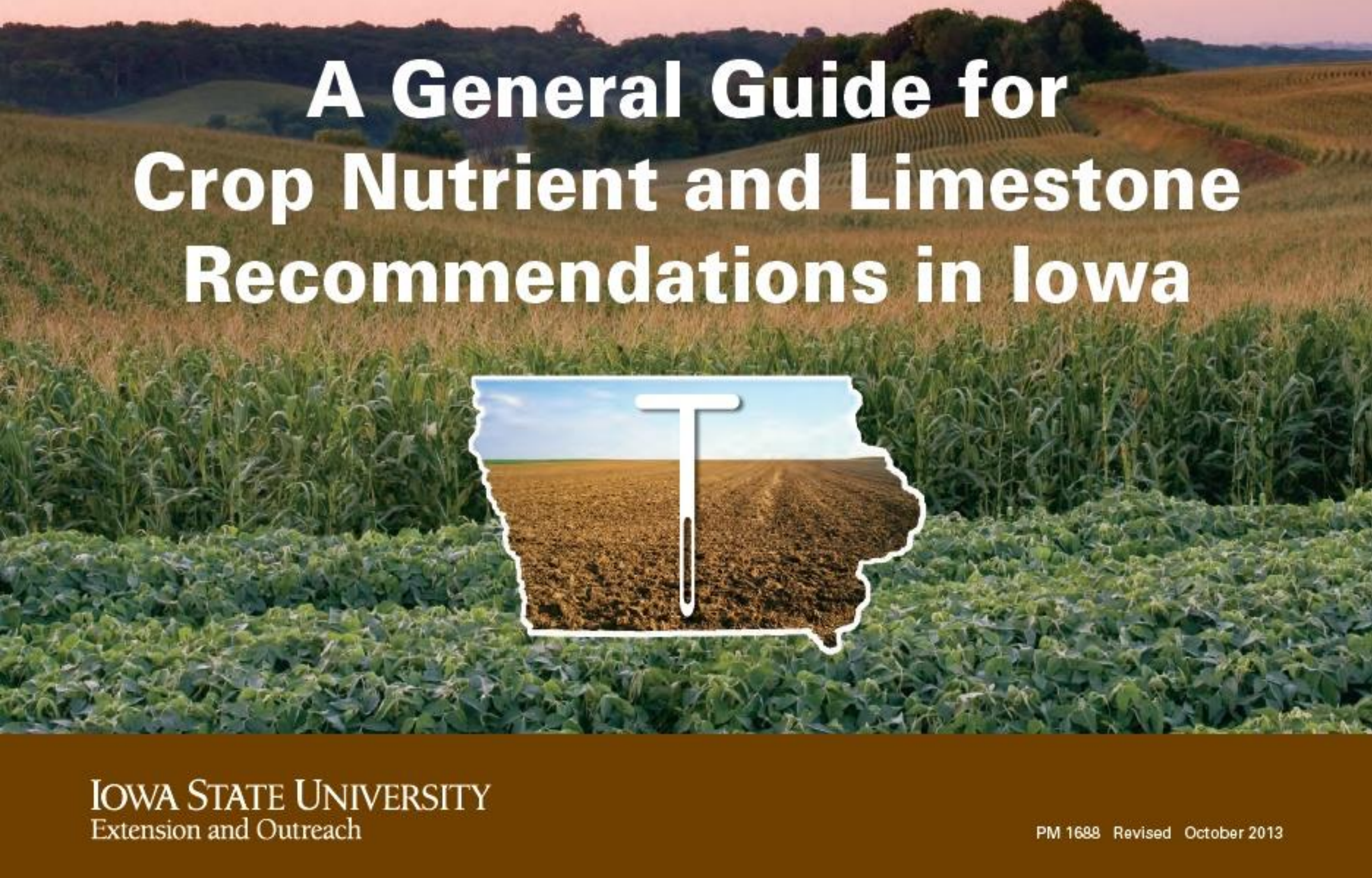
- Although "balance" and cation ratios concepts seems to make sense they don't work in most conditions:
  - The Nebraska studies by Olson in the 1980's, McLean research in Ohio, recent Iowa research with K
- Reason: Nutrient ratios for maximum yield are very wide and vary greatly
- Balance-based recommendations grossly overestimate fertilizer needs

Predominant Concept for P and K

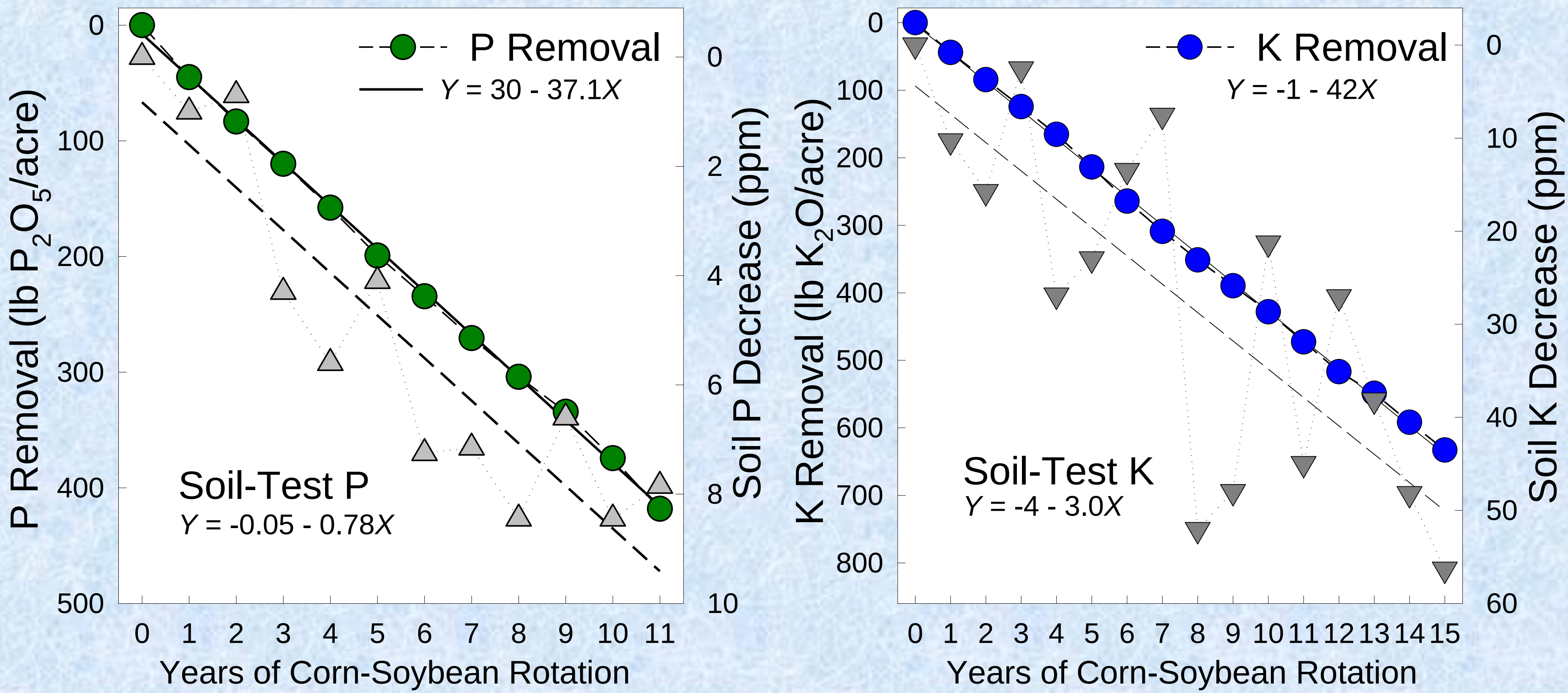
- A compromise between strict sufficiency level and build-up & maintenance approaches
- Fertilization rates for low-testing soils are based on crop response data, and there is gradual buildup over time
- Maintenance of long-term economically optimum levels, based on nutrient removal with harvested products

http://store.extension.iastate.edu/

http://www.agronext.iastate.edu/soilfertility/



Maintenance of Desirable Soil-Test Values



Villavicencio and Mallarino, 2011

Adjust for Prevailing Yield Level!

Calculations From PM 1688

Yield Level Effect for the Optimum Category					
	Yield Level, bu/acre				
Corn	180	200	220	240	260
Soybean	55	65	75	85	95
	Rotation 2-Year P or K Rate				
P_2O_5/acre	97	111	124	138	152
K_2O/acre	106	122	138	155	171

P and K Removal for Maintenance

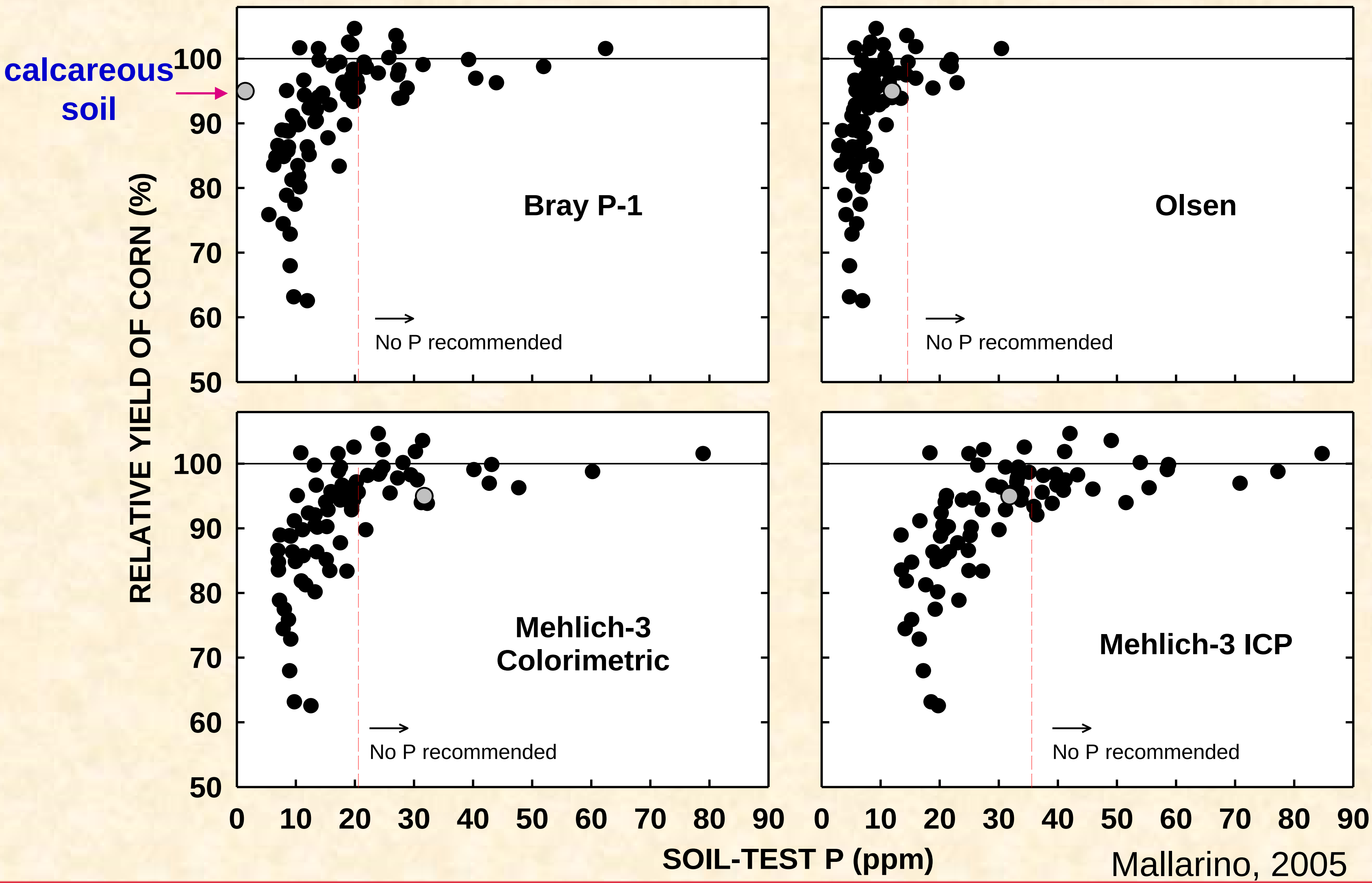
From PM 1688

Crop	Moisture Basis	Yield	P_2O_5 Rate	K_2O Rate
Corn	bu, 15%	180	58	40
Corn silage	bu grain equiv., 15%	180	80	200
Corn silage	ton, 65%	22	80	200
Soybean	bu, 13%	55	40	66
Oats	bu, 13%	80	25	15
Wheat	bu, 12%	55	30	15
Sunflower	100 lb, 10%	2,000	15	15
Alfalfa, alfalfa-grass	ton, 15%	5	65	215
Clover-Trefoil-grass	ton, 15%	3	35	100
Trefoil-grass	ton, 15%	3	35	100
Warm-Tall grasses	ton, 15%	3	35	100

Interpretation Classes

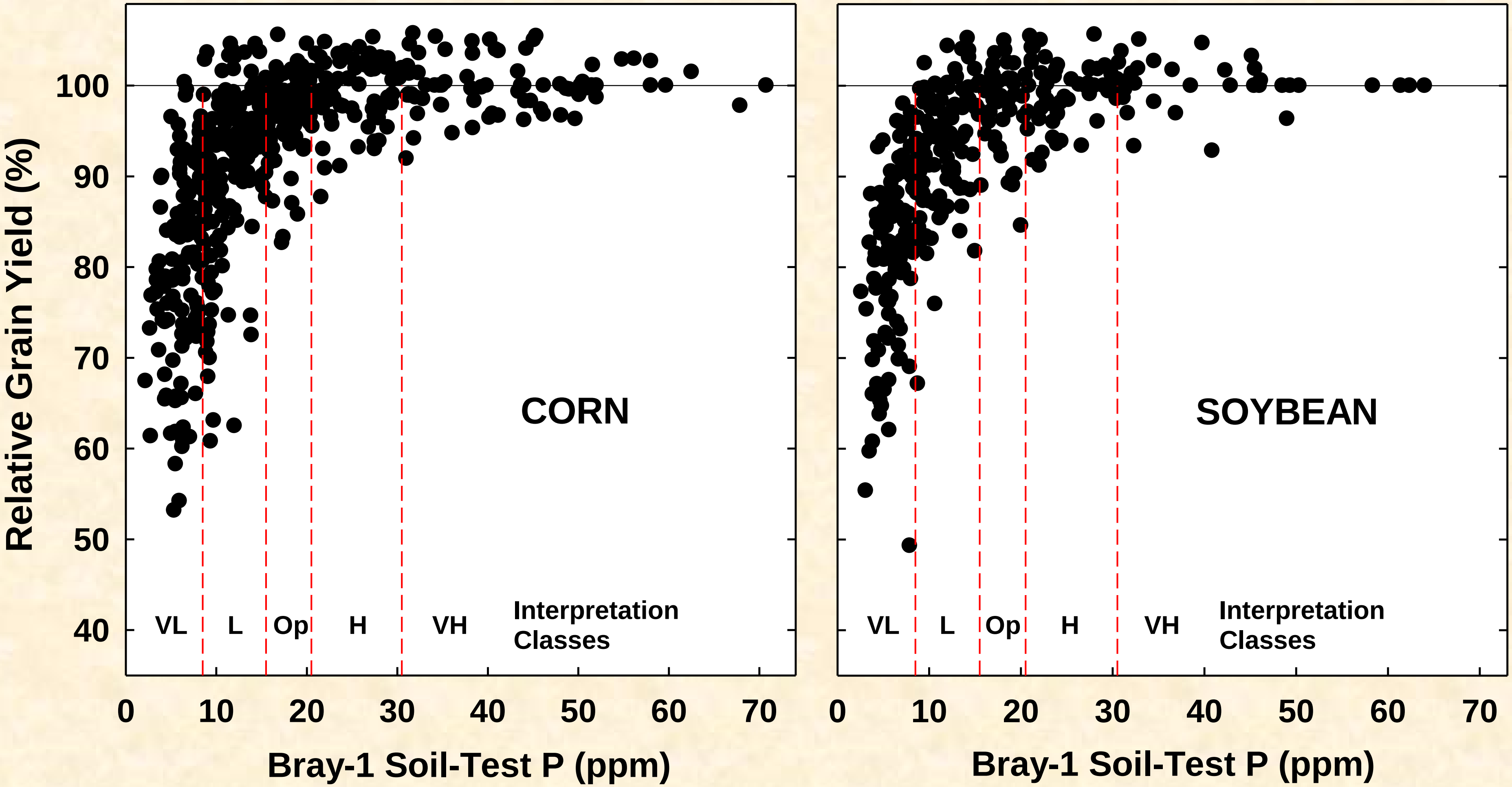
- Different tests for one nutrient provide different results (“ppm” values)
- Experimental data usually do not support use of continuous equations
- Use of interpretation classes is useful
  Probability of response in Iowa
    - Very Low, about 80%
    - Low, about 65%
    - Optimum, less than 25%
    - High, less than 5%

Soil P Methods Correlation



Mallarino, 2005

Soil P Correlation, Interpretation Classes



Mallarino, 2013

Soil-Test P Interpretations

Dry or Moist Sample Handling	Soil Test P Categories				
	Very Low	Low	Optimum	High	Very High
	ppm				
Bray-1 or Mehlich-3	0-8	9-15	16-20	21-30	31+
Mehlich-3 ICP	0-15	16-25	26-36	36-45	46+
Olsen	0-5	6-9	10-13	14-18	19+

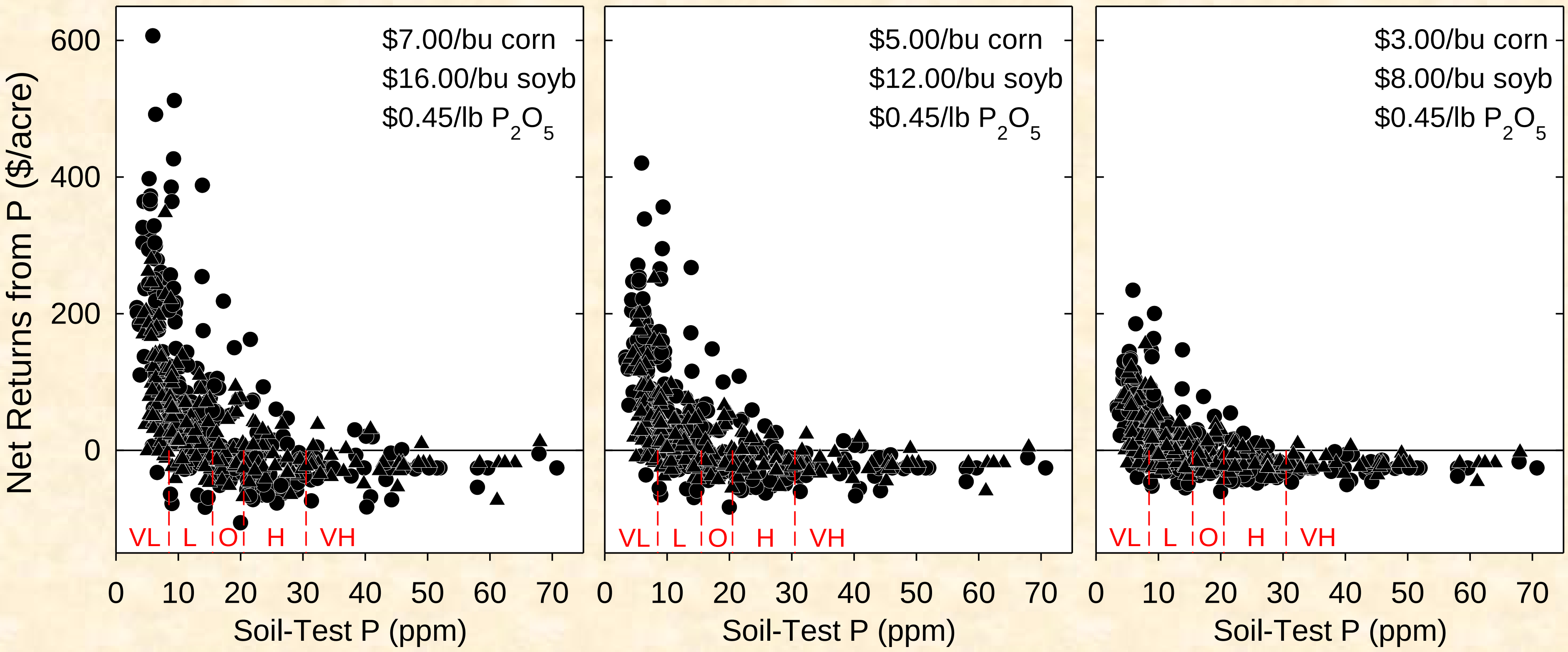
Crop	Fertilizer Recommendations*				
	P_2O_5/acre				
Corn	100	75	58	0	0
Soybean	80	60	40	0	0
Corn-Soybean	160	115	98	(50)	0

* For Optimum assumes 180 bu corn and 55 bu soybean

Slow build up (Very Low, Low) — Maintain soil P adjusting for yield (Optimum) — No need or doesn't pay (High, Very High)

From PM 1688

Soil-Test P and Economic Benefits



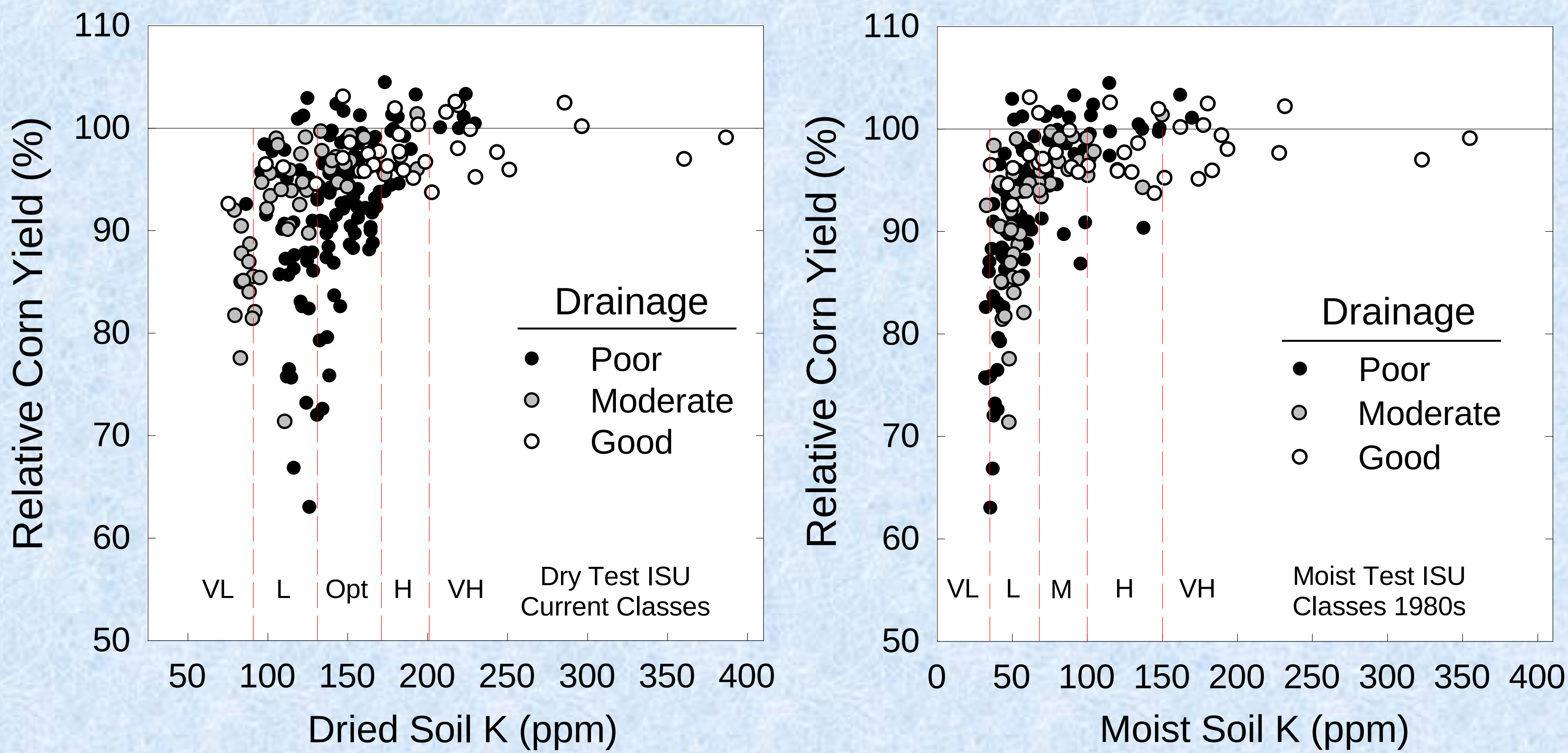
Iowa recommended rates in extension publication PM 1688 for Very Low and Low categories, and removal-based rates for the Optimum or higher categories assuming 180 bu/acre for corn and 55 bu/acre for soybean

Mallarino, ISU, 2015

Greater Uncertainty for K than for P

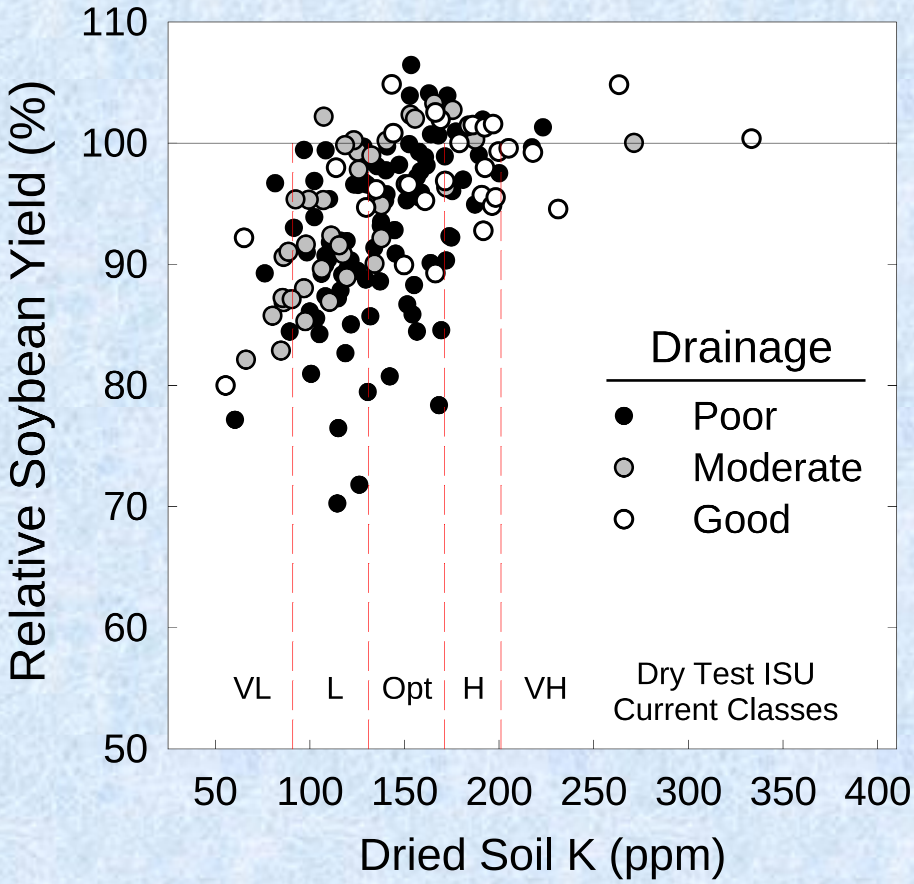
- Historically more variable relationships between yield response and soil test K
  - CEC and Ca-Mg-K ratio do not fully explain the variation across soils and years
- Large effects of
  - Field soil moisture/rainfall recent history
  - Drying of soil samples in the lab
  - Seasonal moisture/aeration differences
- Spring sampling or the moist test reduces uncertainty but doesn’t eliminate it

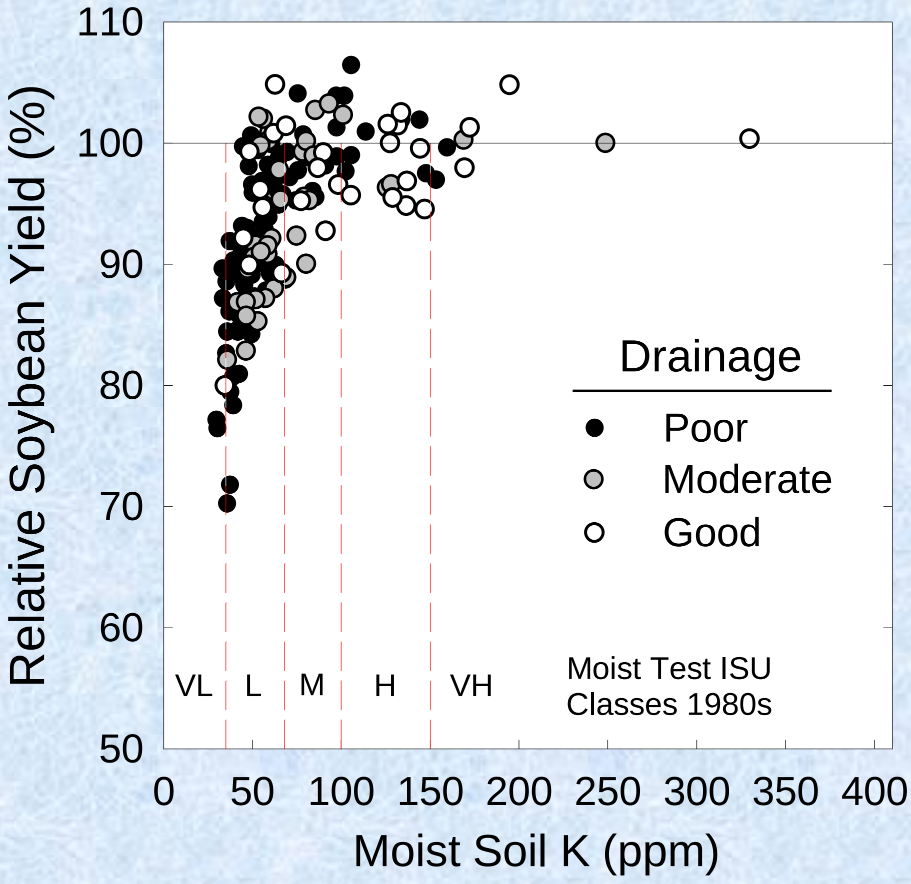
Corn: Dry and Moist K Field Correlation



Mallarino et al., 2012 (data 2001 - 2006)

Soybean: Dry & Moist K Field Correlation





Mallarino et al., 2012 (data 2001 - 2006)

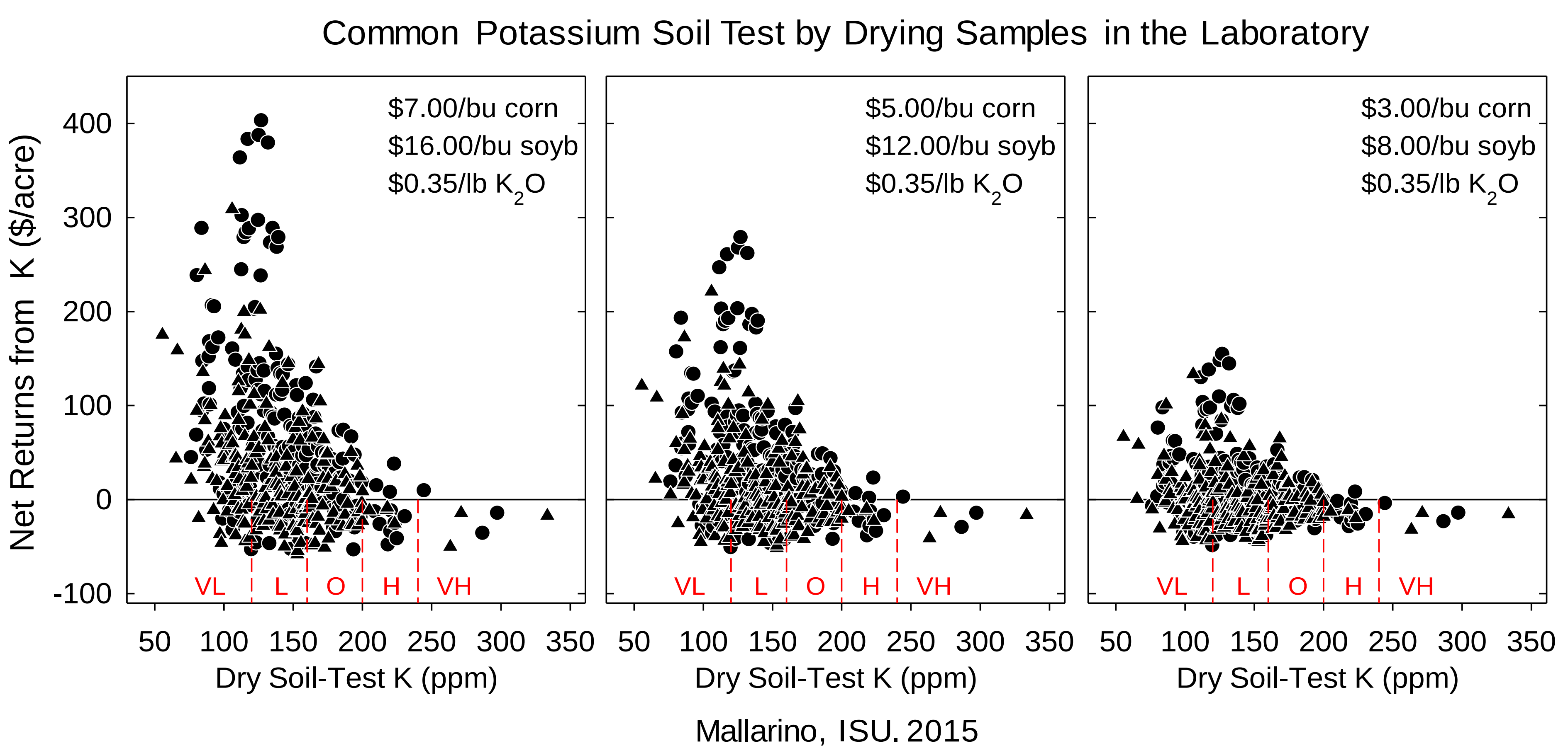
Updated K Interpretations in 2013

From PM 1688	Soil Test K Categories Ammonium Acetate or Mehlich-3				
Sample Handling	Very Low	Low	Optimum	High	Very High
	---------- ppm ----------				
Dry samples	0-120	121-160	161-200	201-240	241+
Moist or Slurry	0-50	51-85	86-120	121-155	156+
Crop	**Fertilizer Recommendations***				
	---------- K_2O/acre ----------				
Corn	130	90	40	0	0
Soybean	120	90	66	0	0
Corn-Soybean	220	156	106	(55)	0

* For Optimum assumes 180 bu corn and 55 bu soybean

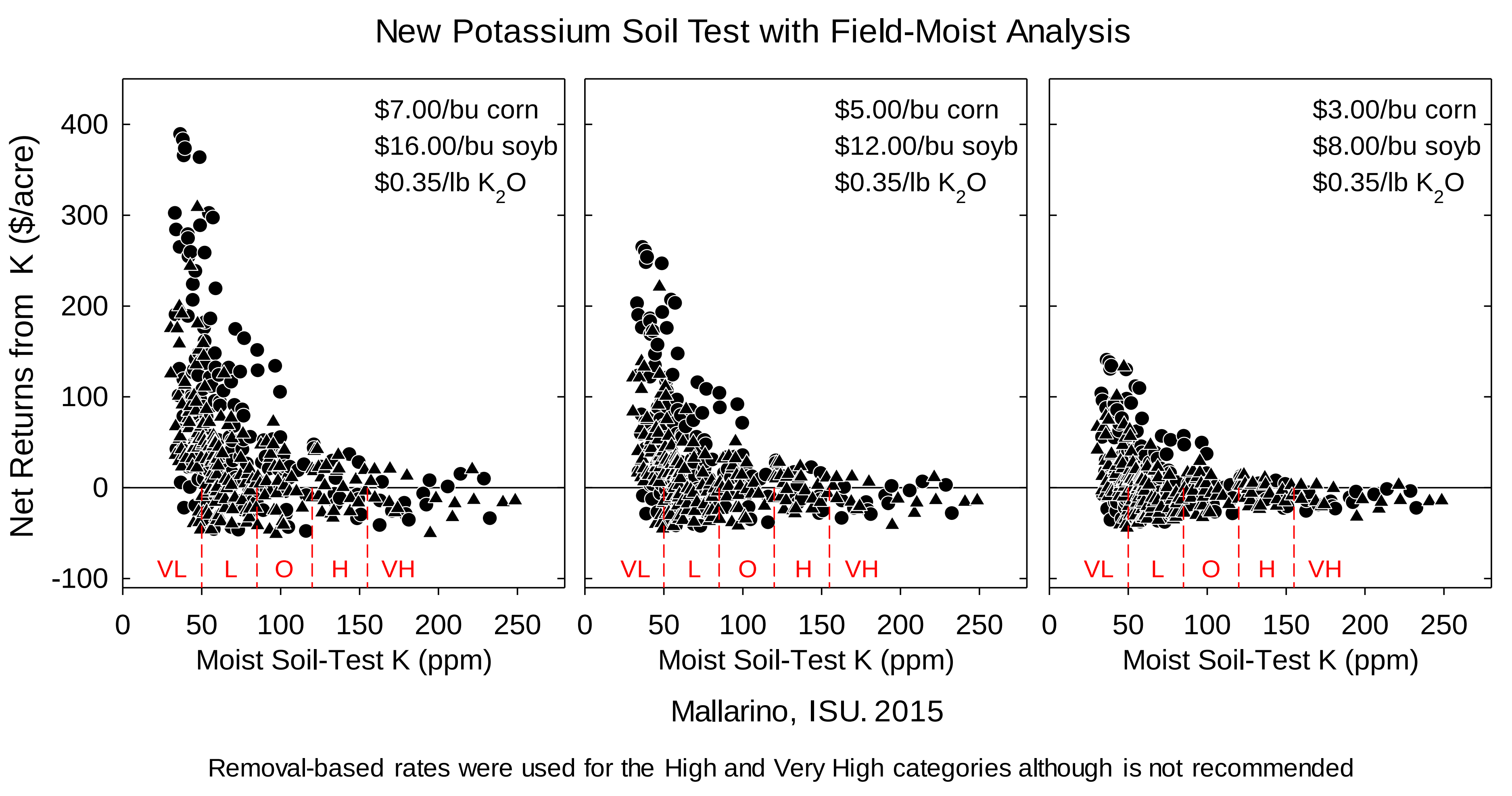
Slow build up (Very Low, Low) — Maintain soil K adjusting for yield (Optimum) — No need or doesn't pay (High, Very High)

Dry K Test, Prices, and Benefits

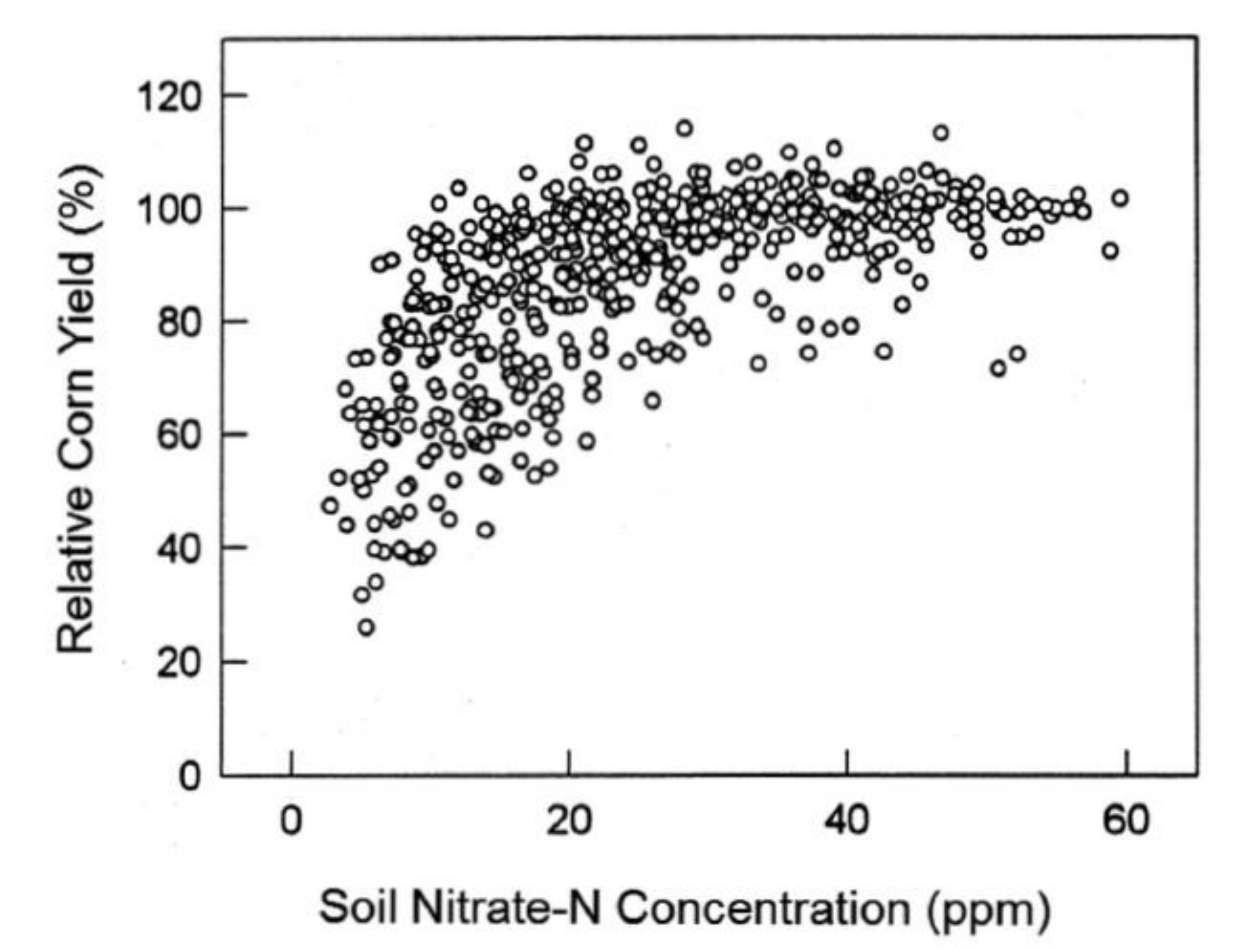


Removal-based rates were used for the High and Very High categories although is not recommended

Moist K Test, Prices, and Benefits



Correlating the Late Spring Nitrate Test



Publication CROP 3140

- Corn 6-12 inches tall
- 1-foot soil samples

Usefulness of Soil Testing

- A very useful but not perfect tool
- Should be aware of potential errors and interpret results with care, many expect too much accuracy and precision from soil testing
- Always consider
  - Potential factors affecting results
  - Trend lines for previous test results and removal (yield levels)
  - Economics and environmental issues

Soil Fertility Web Site
http://www.agronext.iastate.edu/soilfertility/

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