THE POWER TO MAKE THINGS GROW

Soil Testing Then and Now - So What has Changed?

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Soil testing – Why would they ask me?

Papers and talks on Soil Testing

Type	Number
Research and proceedings	55
International lectures	10
Extension talks	200+

Sample of Soil Testing papers in proceedings

- 1987 - Soil Testing-Perception, Expectations, Reality, Practical Implications
- 1992 - Sources of Variation in Soil Testing
- 1996 - Depth of sampling for soil testing – Revisited
- 2001 - Conventional Soil Testing and Site Specific Management
- 2002 - Soil Testing – The Other Side of the Story
- 2002 - Predicting Macronutrient Levels and requirement from Crop Growth Characteristics and Past History – Virtual Soil Testing
- **2003 - Soil Testing – the Art of the Science**
- 2004 - Soil Testing Philosophy, or How to make Fertilizer Recommendations
- **2005 - The Science of Soil Testing**
- **2006 - Soil Testing Philosophy and Fertilizer Economics**

Has the Soil Testing Process Changed?

- Hell, No!

Nothing had changed in 2003

- ✓ For 85% of the farmers: Guessing
- ✓ For 15% of the farmers: Following the 4 steps

Why Farmers in Western Canada Use or Don't Use Soil Sampling as Part of Their Nutrient Management Planning*

2015 Olds College study:

- 78% of farms had soil sampling done some time in the past
- 22% had never used soil sampling;

- 29% of farms use soil sampling every year
- 23% every two to three years
- 3% every five years, and
- 45% only occasionally;

* http://research.ipni.net/page/RNAP-6570

They've always been Four Steps

…and still are!

- Sampling
- Extraction and Chemical Analysis
- Correlation and Calibration
- Fertilizer Recommendation

So what is different?

- **Interpretation and delivery has changed**
- **Why?**
  - **Changing management practices**
  - **Dramatic drop in fertility research in the last two decades**
  - **Increasing demands for soil testing database adaptation to current practices**

So what is different?

- **So, the Labs have to come up with answers needed today or give no answers altogether, so… here comes the Art of the Science … or does it?**

So what is different about Soil Sampling?

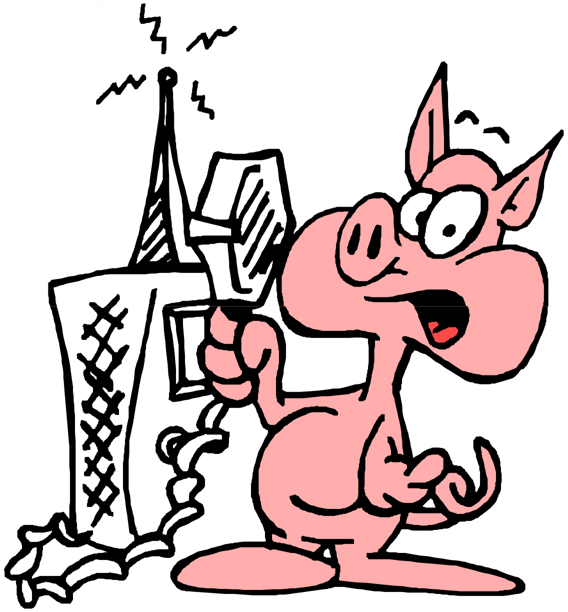
Field Representation – What does it mean?

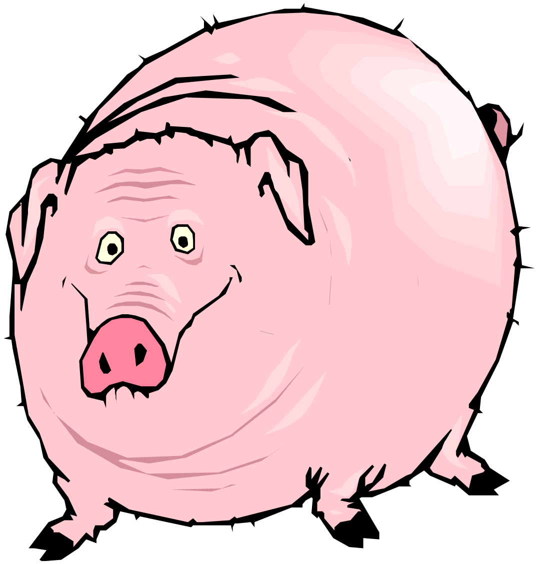
- In the sixties/seventies it was an “average” of the field
  - Topography = Fertility
- What does “representative” mean today?

Tips from Les Henry's Desk
The Analyzer May/June 1992

Applied P_2O_5	"Available" P, lb/acre			
	Bradwell		Elstow	
	Row	Inter row	Row	Inter row
0	13	10	7	8
40	27	12	14	9
80	61	17	28	12

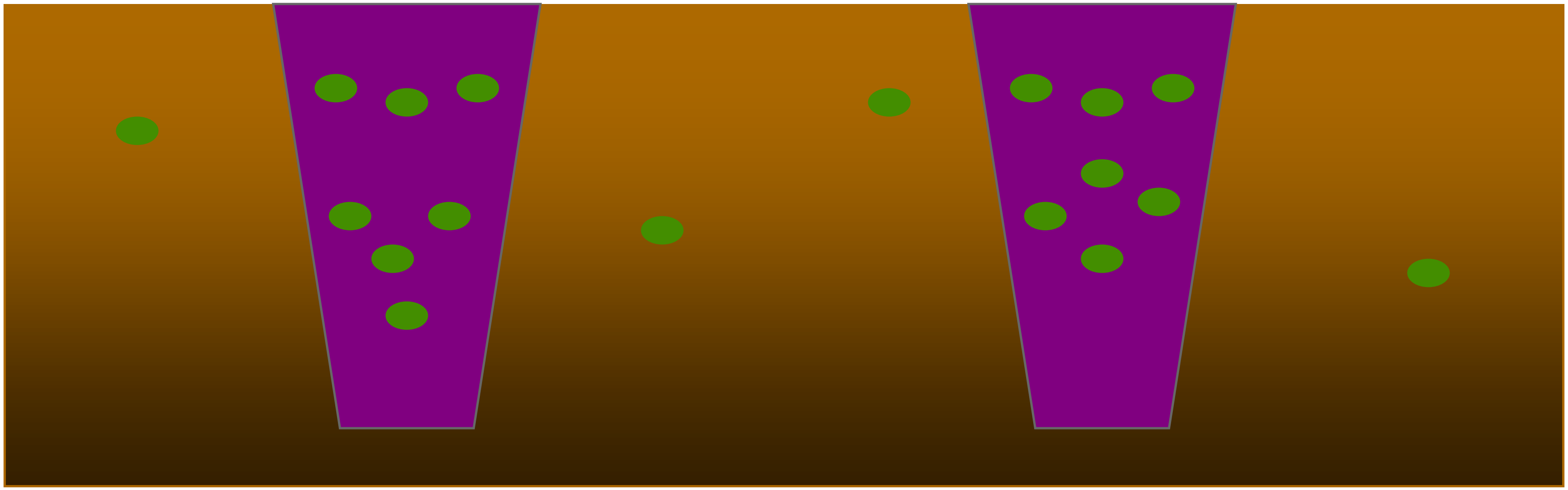
What is the "average" ration for these two pigs?





What is the "average" fertilizer recommendation?

=N



Soil Population

- **Suppose one uses a 1” probe to sample a one-acre site**
  - **6,278,400 inches**
- **Approximation for margin of error of populations**
  - **SQR(X) ≅ σ, (σ/X)*100 = CV**
  - **SQR(1,051)/1,051 ≅ 3% (19/20)**

So What Is the Error With:

- **16 samples:**
  - **SQR(16)/16 ≅ 25% (19/20)**
- **20 samples:**
  - **SQR(20)/20 ≅ 22.4% (19/20)**
- **30 samples:**
  - **SQR(32)/32 ≅ 17.8% (19/20)**
- **4 samples:**
  - **SQR(4)/4 ≅ 50% (19/20)**

Has this changed? **NO**

So What Could the Maximum Error Due to Sampling Be?

Parameter	Activity	Value	Maximum Error
Soil test N	20 Samples 0-12”	54 lb/acre	± 22.4%
Soil test N	Analysis	54 lb/acre÷8 = 13.5 ppm ±1.5 ppm	± 11.1%
Soil test N	Sampling and Analysis	54 lb/acre	± 33.5%
Soil test N	Resulting Recommendation	100 lb/acre	65-135 lb/acre

So What Could the Maximum Error Due to Sampling Be?

Parameter	Activity	Value	Maximum Error
Soil test N	20 Samples 0-12”	24 lb/acre	± 22.4%
Soil test N	Analysis	24 lb/acre÷4 = 6 ppm ±1.5 ppm	± 25%
Soil test N	Sampling and Analysis	27 lb/acre	± 47.4%
Soil test N	Resulting Recommendation	100 lb/acre	55-145 lb/acre

So what is different about Extraction and Chemical Analysis?

Extraction and Chemical Analysis?

- **Nothing!**
- **The misconception has always been that soil test levels represent “plant available” nutrients (CAST 2000).**
- **Different extractants extract different amounts, which have no meaning until they go through step 3.**

Extraction and chemical analysis

- **Different Labs means:**
  - **Different methodology**
  - **Different interpretation**

All Soil Testing Laboratories Should Have the Same Objectives

- High analytical standards – Participate in a Testing program
- Solve soil fertility problems that may be limiting yields
- Timely sample turnaround
- Environmental protection

Different Methodology - Which one is the best?

- **Two criteria**
  - **Compatibility of chemistry or methodology**
  - **CALIBRATION WITH LOCAL FIELD RESEARCH DATA**

Compatibility of chemistry or methodology

- Chemicals or technique must be suitable for the soils of the area.
- Example:
  - Use of a weak acid for calcareous soils. The acid will react with the lime and extraction will be in water!

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So what is different about Correlation and Calibration?

Correlation and Calibration?

This is the most abused step in the soil testing process

Nutrient Inventory

- **A Nutrient is available providing it is accessible to plant roots**
- **Soil testing is searching for nutrient forms that are "potentially" available to plant roots.**

How is this done?

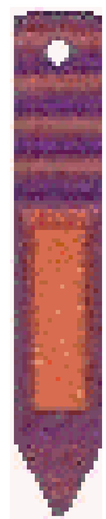
- **By determining readily available nutrients and obtaining a "measure" of potentially available nutrients. Therefore:**

Soil Tests are ONLY INDICES

CALIBRATION WITH LOCAL FIELD RESEARCH DATA

Remember no matter what one uses, the test is done ahead of the growing season! Therefore, ALL methods, whether chemicals, membranes, resin or even plants grown in pots, SIMULATE PLANT ROOTS and HAVE NO VALUE UNLESS THEY ARE CORRELATED WITH CROP YIELDS.

or

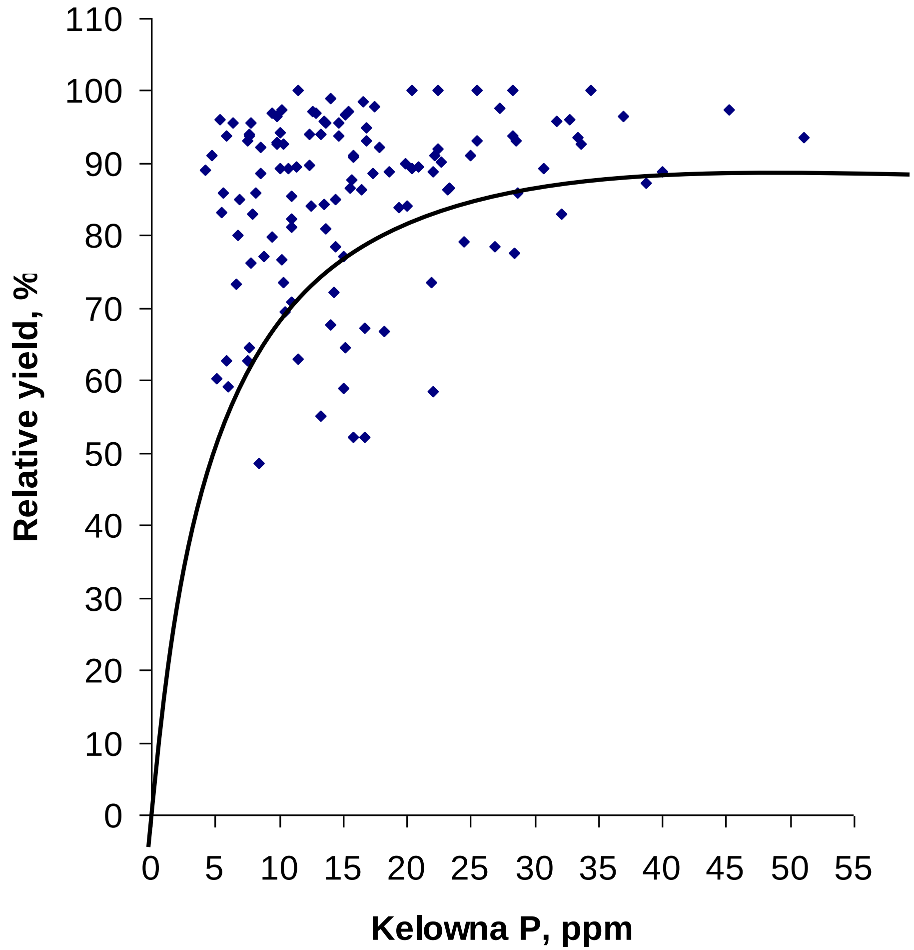


or

?

Example of P Soil Test Calibration Data

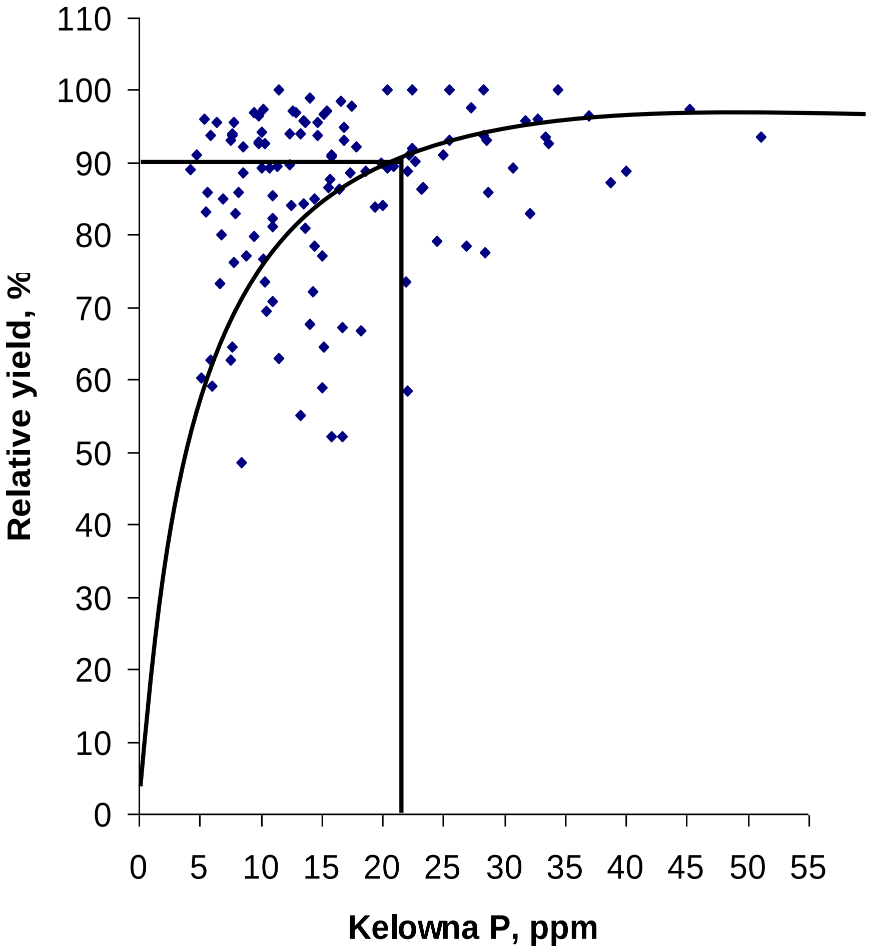
- Calibration curve indicates which soil test levels tend to limit yields
- Data based on P responses observed across several sites and years



McKenzie et al., 1995

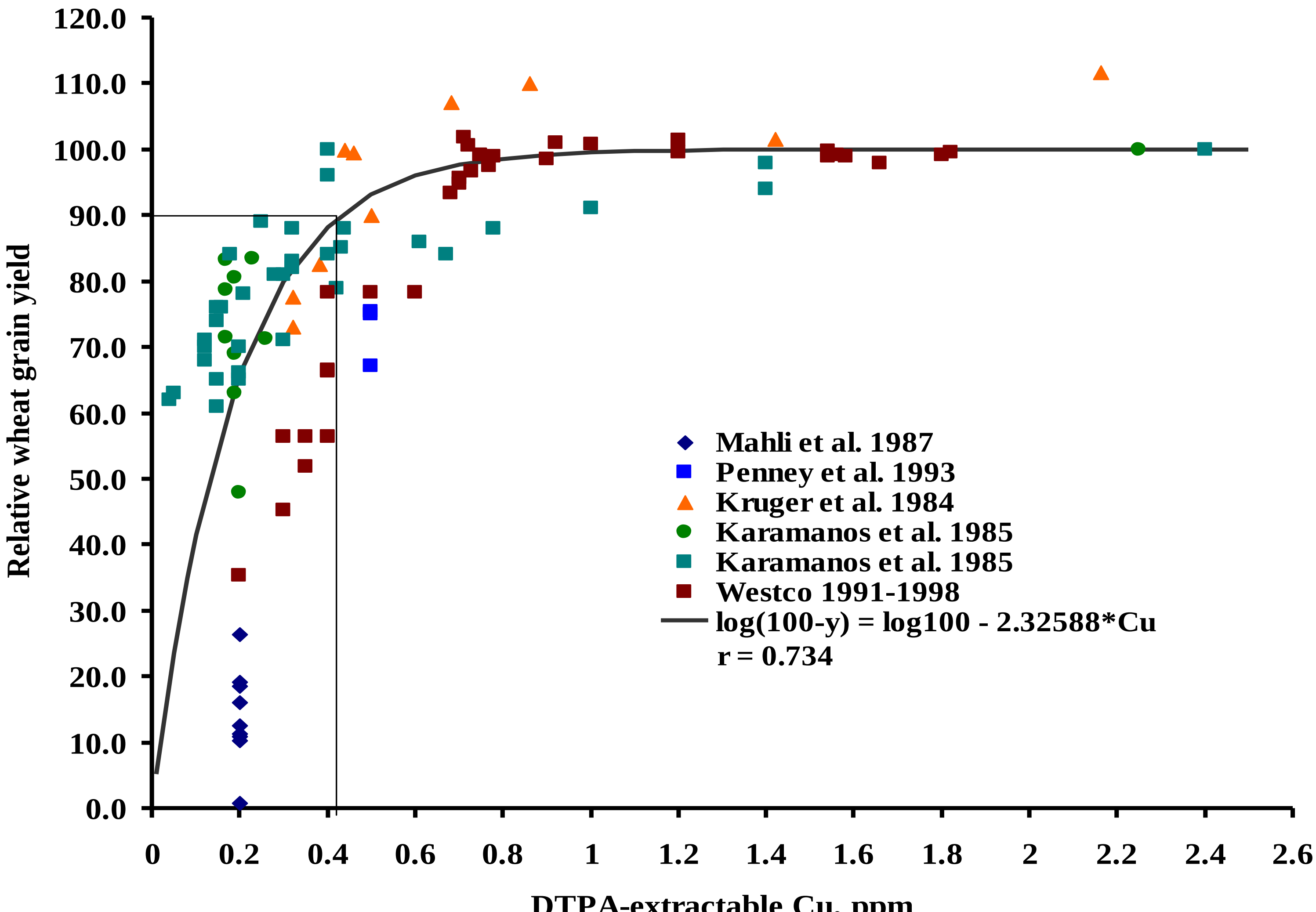
Sufficiency Soil Test P Level for Canola

- The results of this calibration data set from Alberta show a critical level (sufficiency) of 20 to 25 ppm (40 to 50 lb/A) P
- This is the level of soil test P above which minimal response to applied P can be expected.



McKenzie et al., 1995

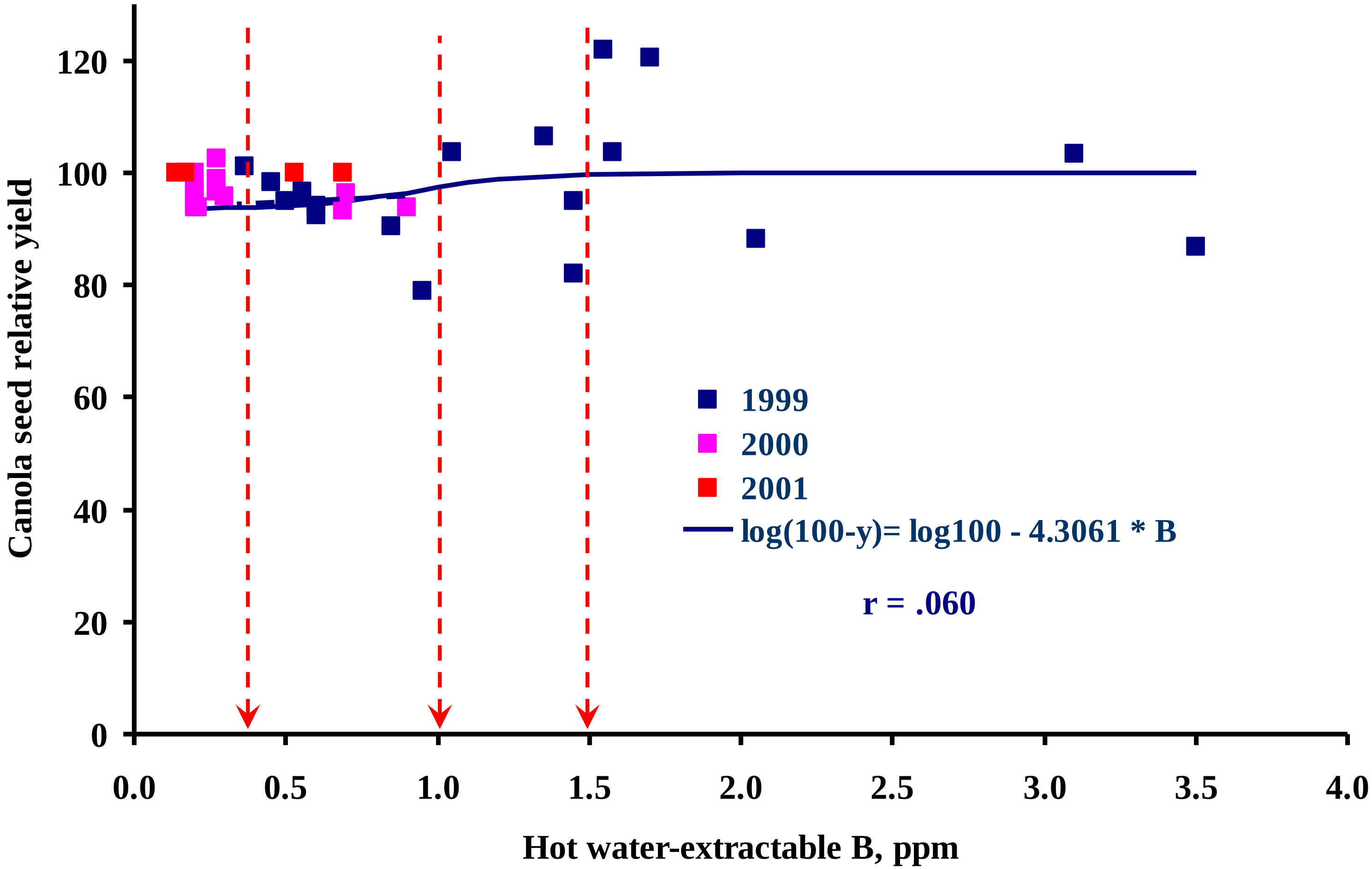
Interpretation of Soil Tests



R.E. Karamanos, T.B. Goh and J.T. Harapiak, 2003, Canadian Journal of Soil Science 83, 213-221

Interpretation of Soil Tests

w. Canada 40 sites; yield 18-63 bu/ac

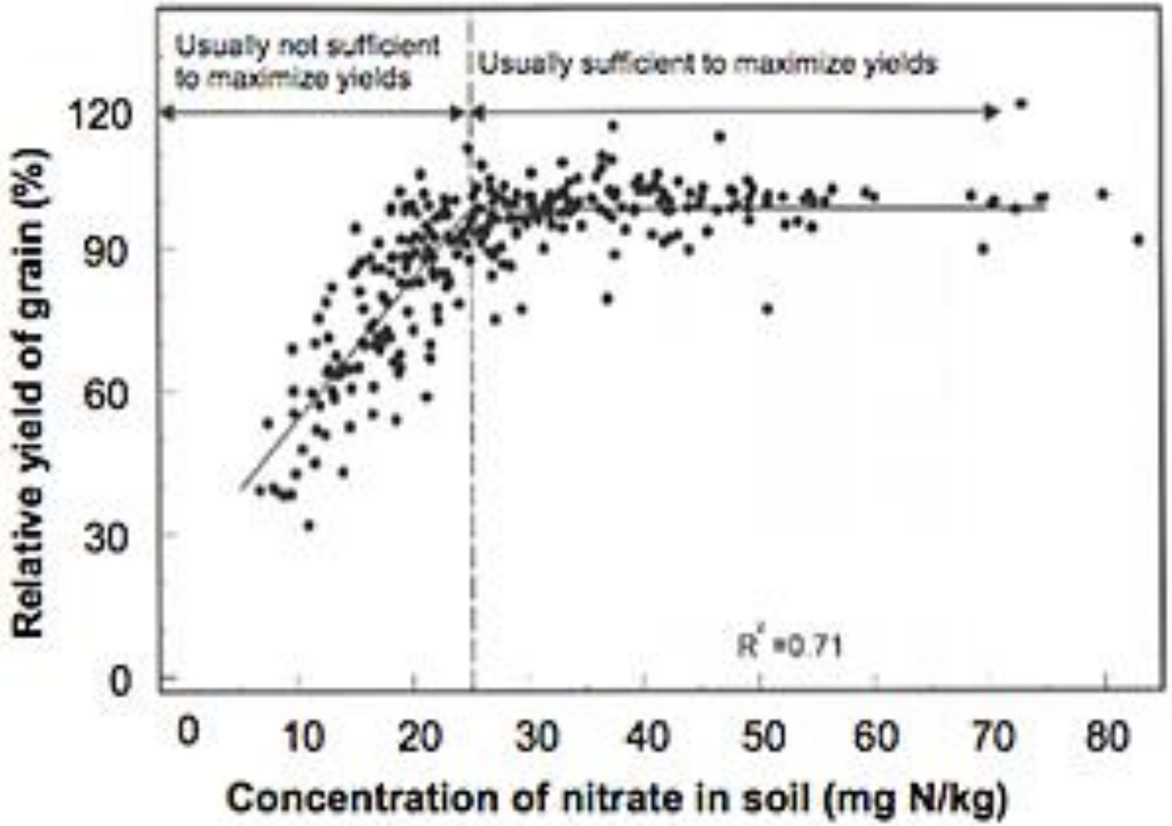


R.E. Karamanos, T.B. Goh and T.A. Stonehouse, 2003, Canadian Journal of Plant Science 83, 249-259

Principle for Recommendations

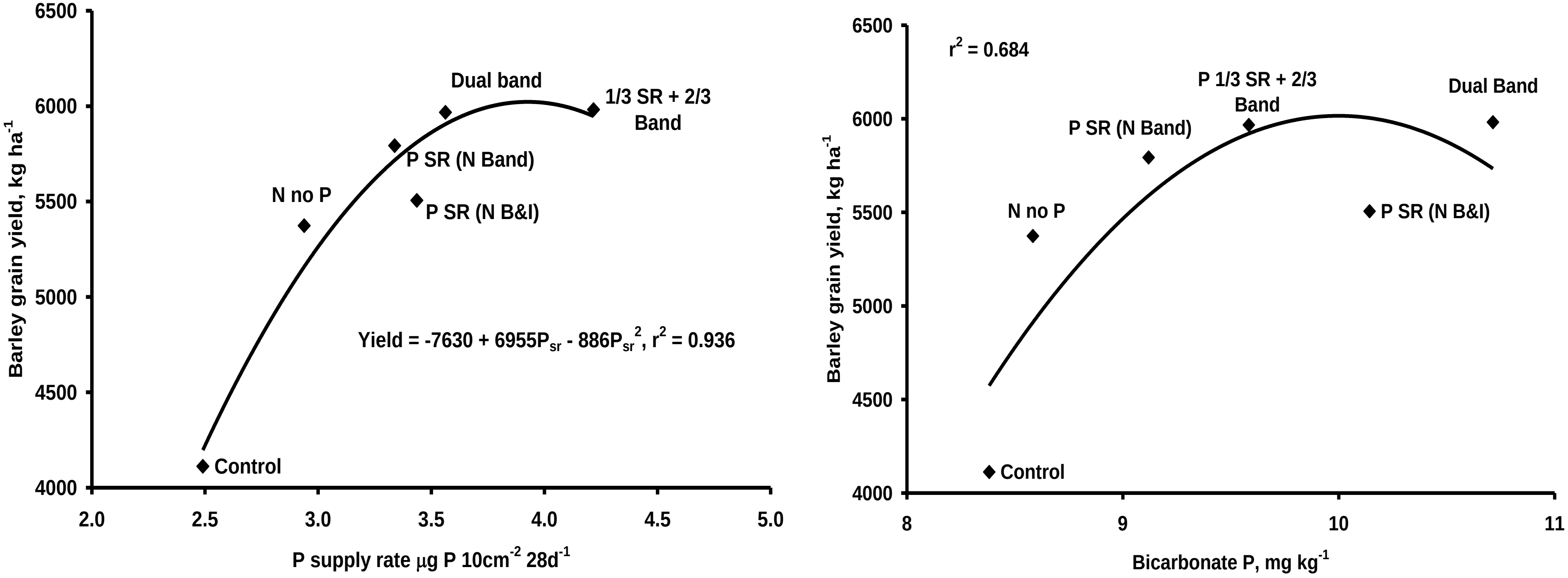
http://solum.ag/no-wait-nitrate/

[redacted]



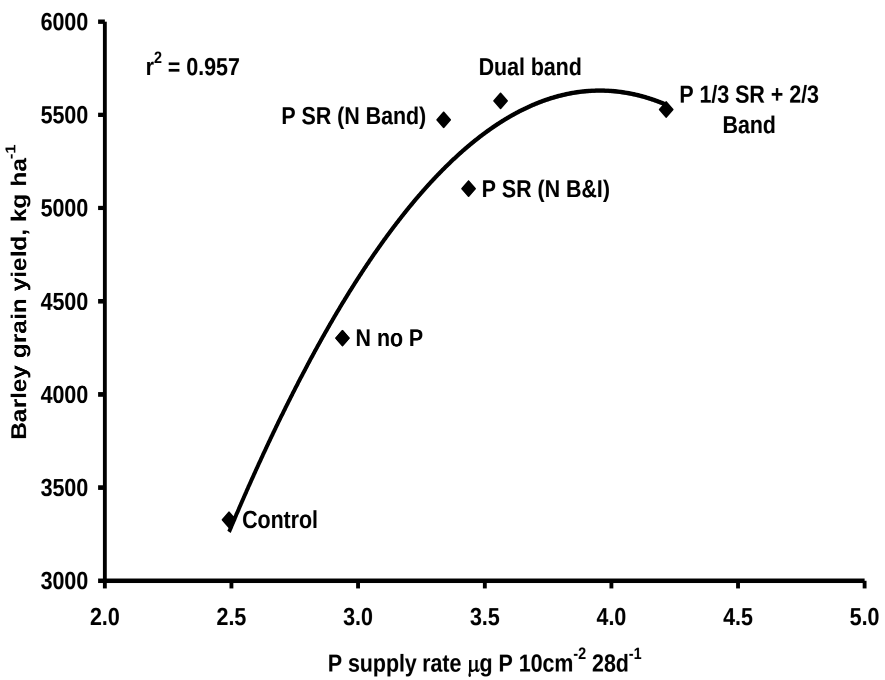
Simply weigh a sample, estimate its moisture and the machine does the rest-laboratory accurate results in 3 minutes or less

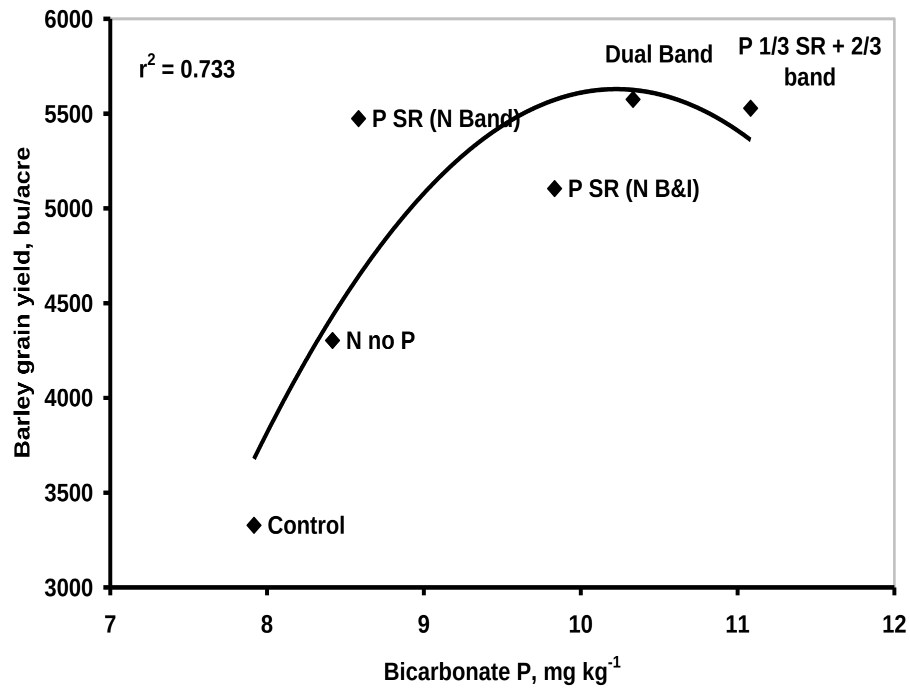
Correlation between average barley grain yields obtained over 23 years and supply rates (left half) or bicarbonate-extractable P levels (right half)



Karamanos and Kruger, 2009. Comm. Soil Sci. Plant Anal. 40, 538-554

Correlation between 2004 barley grain yields obtained and supply rates (left half) or bicarbonate-extractable P levels (right half)





Karamanos and Kruger, 2009. Comm. Soil Sci. Plant Anal. 40, 538-554

Correlation and Calibration?

- **Adoption of criteria from other regions can introduce many unnecessary fertilizer practices at the expense of the producers (never mind controversy and confusion).**
- **Ultimately the market place prevails.**
- **But… is this what science is all about?**

Soil tests that have been calibrated in field studies for western Canadian soils

- N Water (bicarbonate, Kelowna modifications)
- P Olsen (bicarbonate), Kelowna modifications, Miller Axhley
- K NH_4OAC (ammonium acetate), Olsen, Kelowna modifications
- S 0.01M $CaCl_2$
- Cu, Zn DTPA
- B Hot water extractable (useless)

Soil tests that have NOT been calibrated in field studies for western Canadian soils

- P Bray (weak and strong), Mehlich extractants
- K based on %K saturation, K/Ca
- Cu, Zn HCl extraction
- Mn All extractants
- B Sorbitol
- Cl Cl electrode, chromatography, $AgNO_3$, water mercury (II) thiocyanate
- Ca All extractants

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So what is different about Fertilizer Recommendations?

Fertilizer Recommendations?

- This is the most misunderstood step in the soil testing process

Fertilizer Recommendations?

There is no right or wrong recommendation as long as the soil testing process has been adhered to and the farmer understand the "philosophy" of the recommendation

Fertilizer Recommendations?

This step encompasses the “Art of the Science” in the soil testing process

Fertilizer Recommendations?

Without proper research it becomes:

- **The Science of Deduction**
- **The Science of Perception**
- **The Science of Fear**

- **Who is doing the necessary research for all recent innovations?**

Soil Testing Is …

- An Abstract of a long and often difficult to understand scientific research.
- Abstract = A summary or statement of contents of a book etc.

Soil Testing Is an Abstract

- Quality of abstract will depend on:
  - Quality of scientific research.
  - Understanding of the research.
  - Ability to summarize the research.
  - Summarizing what research.
- Soil testing is an art based on scientific information.

Who are the "artists"?

- Provincial sub-councils GONE!
- Laboratory agronomists GONE!
- Extension specialists GONE!
- Consultants

- Knowing the "artist" is extremely important!

- Where there are Artists there are also con Artists

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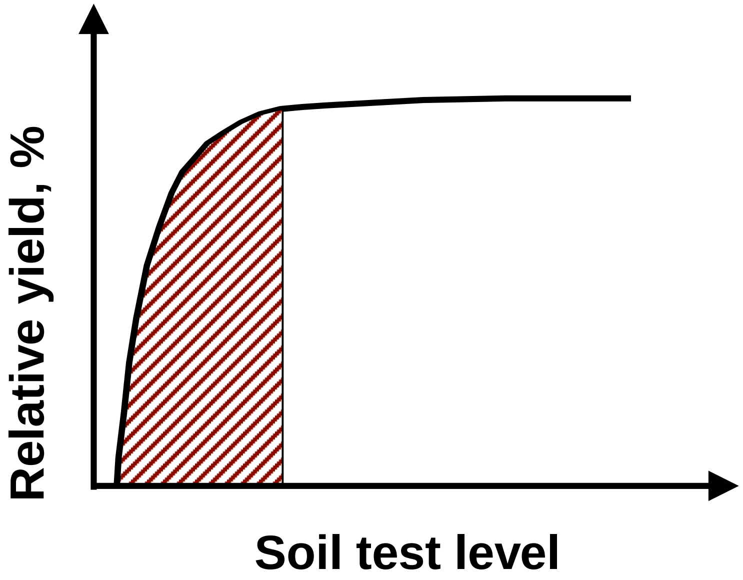
Principle for Recommendations

- Sufficiency
- Built and Maintenance
- Base Cation Saturation Ratio
- Other

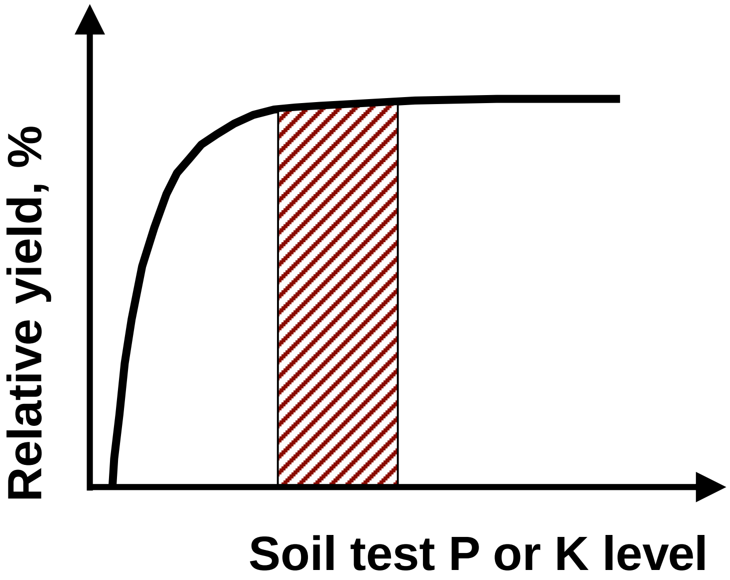
Sufficiency Approach to Fertilization

- Apply nutrient to maximize net returns to fertilization in the year of application
  - **Strategy: fertilize only when there is a good chance that a profitable yield response will be realized**
  - Soil test levels kept in lower, responsive ranges



Build and Maintenance Approach

- Remove P or K as a yield-limiting variable
  - **Strategy: apply extra P or K (more than expected crop removal) to build soil tests to levels that are not yield-limiting**
  - Soil test levels kept in higher, non-responsive ranges



Build and Maintenance Criteria

- **Add P and K at a rate equal to crop removal + to build the soil levels.**
  - **50 bu/A wheat @ 0.5 lb P_2O_5/bu = 25 lbs**
- **To build soil P by 1 lb/A you need 12-28 lb P_2O_5/A.**
- **To build soil K by 1 lb/A you need 8-16 lb K_2O/A.**

Sufficiency vs. BCSR

- the main objective when using the sufficiency level concept is to fertilize according to the plant's needs
- the BCSR aims to fertilize according to the soil's needs

The BCSR Concept

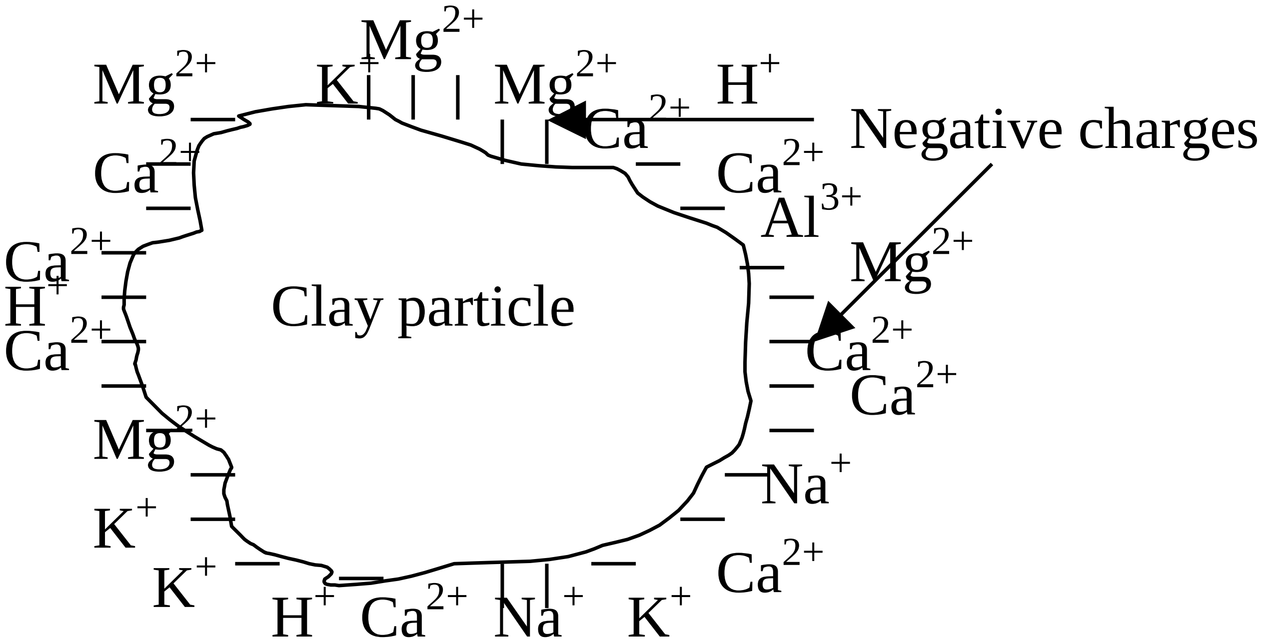
- Bear et al. (1945) tentatively stated that their evidence indicated that, “for the ideal soil,… 65% of the exchange complex should be occupied by Ca, 10% by Mg, 5% by K, and 20% by H.”
- So, an “ideal” soil suggests a Ca/Mg ratio of 6.5:1, a Ca/K ratio of 13:1, a Ca/H ratio of 3.25:1, and a Mg/K ratio of 2:1 (all ratios are presented on a charge [equivalent] basis).
- **It is unclear, however, how these values for the ideal soil were established**.

Base Cation Saturation Ratio (BCSR)

- The BCSR approach promotes the concept that maximum yield is only achieved by creating an ideal ratio of soil calcium, magnesium and potassium.
- The BCSR approach does not apply to nitrogen, phosphorus, sulphur and micronutrients.
- Percent saturation of cations selected as being "ideal". Work originally conducted on alfalfa.
- Ca 65%, Mg 10%, K 5%, H 20% - Ca:K > 13:1
- It was developed for low to moderate CEC soils, highly weathered soils of low pH that require major adjustments in fertility – **not western Canada**.

Base Saturation

- The term base saturation is used to characterize how completely occupied are the adsorbing (surface held) sites of soil mineral and organic particles with basic cations. The basic cations commonly found in the soil are calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) and acidic cations are aluminum (Al) and hydrogen (H).



Base Saturation

- So, base saturation describes how completely the soil particle surface is filled with the basic cations (Ca, Mg, K, Na). When all the soil particle exchange sites are occupied with bases we have 100% saturation. This happens when the soil pH is above 5.5.
- However at lower pH values, some H and Al find their way onto the surface of the soil mineral and organic particles and that drops the base saturation to less than 100.

Base Saturation

- So, base saturation is:

$$\%BS = \frac{Ca+Mg+Na+K}{Ca+Mg+Na+K+H+Al} \times 100$$

Base saturation has been used as a tool to make decisions on whether a soil should be limed or not, along with a number of other tools. It is not a soil testing index and does not necessarily imply nutrient fertility of a soil.

The BCSR Concept

- The early concern of researchers was with the luxury consumption of K by alfalfa - that is, if K is present in very high levels, alfalfa will continue to take up much more K than it needs, and, to a certain extent, it does so at the expense of Ca and Mg.
- When looking with the hindsight provided by more than a half century of soil research after the work of Bear and Albrecht, **the experiments carried out in New Jersey and Missouri were neither well designed nor well interpreted by today's standards**.

The BCSR Concept

- In 1959 Graham stated that "the balance soil scientists recommend… is 75% Ca, 10% Mg and from 2.5 to 5% K." In addition, he also suggested that the range could be from 65 to 85% for Ca, 6 to 12% for Mg, and 2 to 5% for K.
- **Again it is unclear, however, how these "new" values for the ideal soil were established**.
- Many of the original experiments were flawed and results often confounded by a decrease in acidity or other ions, e.g., Ba toxicity.
- **Benefits were from change in pH NOT cation ratios!**

The BCSR Concept

- First cracks in the concept appeared with the research by Giddens and Toth (1951), who carried out an experiment with four soils that were saturated at seven Ca/Mg/K ratios (with one being “ideal”), and compared plant growth between treatments.
- **They concluded that provided Ca was the dominant cation, no specific cation ratio produced the best yield.**

The BCSR Concept

- In addition to the lack of modern research indicating that it actually helps to use the BCSR system to make recommendations, and the problems that can arise when it (in contrast to the sufficiency system) is used, its use perpetuates a basic misunderstanding of what CEC and base saturation are all about.
- Than there is another issue: **The system is based on a faulty understanding of CEC and soil acids, as well as a misuse of the greatly misunderstood term percent base saturation.**

The BCSR Concept

- Once soils are much above pH 5.5 (and almost all agricultural soils are above this pH, making them moderately acid to neutral to alkaline), the entire CEC is occupied by Ca, Mg, and K (as well as some Na and ammonium). There are essentially no truly exchangeable acids (hydrogen or aluminum) in these soils. This means that the actual CEC of the soils in this normal pH range is just the sum of the exchangeable bases. **The CEC is therefore 100% saturated with bases when the pH is over 5.5 because there are no exchangeable acids.**

The BCSR Concept

- Even when the ratios of the nutrients are within the recommended crop guidelines, there may be such a low CEC (such as in a sandy soil that is very low in organic matter) that the amounts present are insufficient for crops.
- If the soil has a CEC of only 2 meq/100 g of soil, for example, it can have a "perfect" balance of Ca (70%), Mg (12.5%), and K (3.5%) but contain only 560 pounds Ca, 60 pounds of Mg, and 53 pounds of K per acre to a depth of 6 inches.
- Thus, while these elements are in a supposedly good ratio to one another, there isn't enough of any of them.
- **The main problem with this soil is a low CEC**; the remedy is to add a lot of organic matter over a period of years, and, if the pH is low, it should be limed.

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The BCSR Concept

- The opposite situation also needs attention. When there is a high CEC and satisfactory pH for the crops being grown, even though there is plenty of a particular nutrient, the cation ratio system may call for adding more.
- This can be a problem with soils that are naturally moderately high in magnesium, because the recommendations may call for high amounts of calcium and potassium to be added when none are really needed—wasting the farmer’s time and money.

The BCSR Concept

- The cation ratio system can be used to reduce the chance of nutrient deficiencies, if interpreted with care and common sense—not ignoring the total amounts present and paying attention to the implications of a soil's pH. Using this system, however, **will usually mean applying more nutrients than suggested by the sufficiency system—with a low probability of actually getting a higher yield or better crop quality.**

"Available" (extractable) Ca and K in 1220 western Canadian soils (lb/ac)*

	Calcium	Potassium
All		
Minimum	3500	220
Maximum	30600	1620
Mean	8812 ± 5262	359 ± 240
Non-calcareous		
Mean	6399 ± 2103	317 ± 57
Calcareous		
Mean	13200 ± 6469	435 ± 396

*courtesy EnviroTest (now ALS) Labs

Example from Manitoba CanoLAB

The BCSR Concept

Ca:Mg ratio	Ca	Mg	Yield
	---- % -----		ton/acre
Theresa silt loam:			
2.28	34	35	3.31
3.4	45	22	3.31
4.06	46	19	3.4
4.76	49	17	3.4
5.25	52	16	3.5
8.44	62	12	3.22
Plainfield loamy sand			
2.64	32	20	4.14
2.92	35	20	4.28
3.48	38	18	4.35
4.81	43	15	4.12
7.58	65	13	4.3
8.13	68	15	4.35

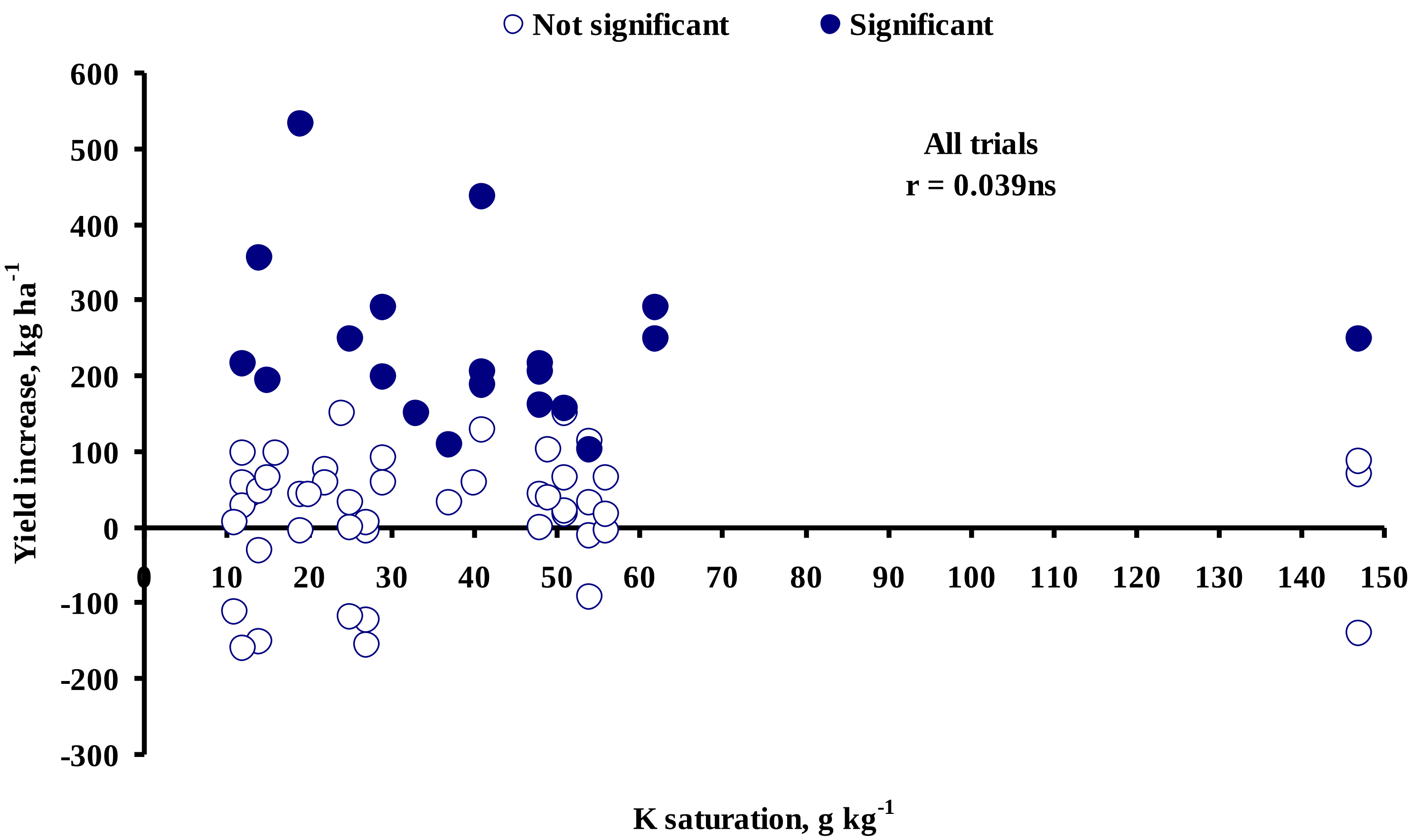
Simpson et al. 1979. Comm. Soil Sci. plant Anal. 10:153-162

McLean et al. 1983. Agron. J. 75: 635-639.

The main conclusions were:

- Sufficiency concept still worked the best.
- The results strongly suggest that for maximum crop yields, emphasis should be placed on providing sufficient, but non-excessive levels of each basic cation rather than attempting to attain a favorable BCSR **which evidently does not exist**.

Response of barley to K application on high K soils*



*adapted from Karamanos et al. 2003

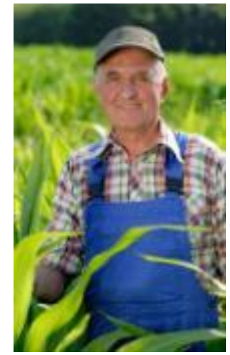
Nutrient ratios

- **Quote (Soil Testing and Plant Analysis):**
  - **"It is surprising that the cation saturation concept has received the credibility accorded to it in consideration of other early and recent literature accounts on the issue"**
  - **"They (a number of researchers) emphasized the need for assuring sufficient levels of each cation rather than attempting adjustment to an ideal cation saturation ratio that does not exist"**

Imbalance between K and Mg in grass tissue can lead to grass tetany in cattle

Production Models

- These models use factors that cannot be measured or predicted.
- The strength or weakness of such models, therefore, resides with their ability to accurately predict the factors involved in the process.



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