Lessons from a Soil Fertility Laboratory

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Abstract

A growth chamber experiment was established to demonstrate several basic principles of soil fertility to undergraduate students. Barley and field pea were grown in pots to demonstrate the effects of erosion and crop rotation on the yield potential and nitrogen response for two soils from the Brown soil zone. The results demonstrated differences in the ability of different crops to access nutrients, the effect of landscape position on nutrient availability and fertilizer response, and the ability of soil analytical tools like PRS to reveal differences in soil nutrient supplying power.

Background

A growth chamber pot experiment was conducted with Haverhill Chernozemic soils collected in early September, 1999 from two fields located near Tugaske, SK. A Rego Brown Chernozemic soil was sampled from an upland area that had grown canola the season prior to sampling. The field had experienced severe wind erosion in the past and had little or no history of fertilizer application. This soil was able to produce an average yield of only 12 bu/ac of canola in 1999. The nearby Eluviated Brown Chernozemic soil was sampled from the foot slope position of a field seeded to a variety of crops grown in rotation with regular application of fertilizer. The wheat yield from this soil during the crop year prior to sampling was 45 bu/ac. Obviously, the yield potential of the Eluviated Brown soil was significantly greater than the Rego Brown soil. The characteristics for the two bulk soil samples are summarized in Table 1.

Soil Characteristics

The Rego Brown soil had a much higher pH, a slightly heavier texture, and a lower organic matter content compared to the Eluviated Brown soil. According to conventional soil chemical extraction, both soils had similar levels of available nitrogen (N). The Rego Brown soil had an extractable P concentration that was one-third that of the Eluviated Brown soil, a slightly lower extractable K concentration than the Eluviated Brown soil, but an extractable S concentration that was 50% higher than the Eluviated Brown soil.

Although the trends in relative nutrient availability between the soils as predicted by the extractable nutrient concentration and the PRS™ resin membrane probe supply rate tended to agree, there were differences in the magnitude of the predicted nutrient supply. The PRS probe indicated much lower N and K supply power, similar P supply power, and higher S supply power for the Rego Brown soil. The discrepancy between the chemical based soil extractant and the PRS™ probe may lead a grower to apply different rates of N-P-K-S. In order to maximize economic return, it is important to compare how the two measures of nutrient availability compare with crop plant growth.

Table 1: Chemical properties of the selected soils for growth chamber trial

	Texture	**pH**	**E. C. (mS/cm)**	**NO_3-N (lb/ac)**	**Ext. P[2] (lb/ac)**	**Ext. K[2] (lb/ac)**	**SO_4-S (lb/ac)**	**OM (%)**
Rego Brown	CL	7.9	1.3	12	22	468	44	1.8
Eluviated Brown	L	6.6	0.9	14	60	600	32	3.5
	PRS™ Nutrient		**Supply Rates**		**(lbs/ac/24 hr)[1]**			
	N supply Rate		**P supply Rate**		**K supply Rate**		**S supply Rate**	
Rego Brown	0.5		7.1		71		39	
Eluviated Brown	3.4		7.8		348		13	

[1]Nutrient supply rate data measured using the PRS™ probe and derived from PRS™ Nutrient Forecaster™

[2] Qian, P., Schoenau, J.J., and Karamanos, R.E. 1994. Simultaneous extraction of available phosphorus and potassium with a new soil test : a modification of Kelowna extraction. Comm. Soil Sci. Plant Anal. 25:627-635.

Plant Responses

The soils were appraised for their ability to produce barley and field pea biomass in the growth chamber. The purpose of the experiment was to demonstrate the impact of landscape position, and past management on soil fertility, especially N supplying power, and the response of soils to added N fertilizer.

Ammonium nitrate was dissolved in water and the two soils were amended with four rates of nitrogen (0, 50, 100, and 200 mg N/kg). The individual pots were randomly arranged in an environmentally controlled growth chamber. Ten seeds of barley or field peas were planted into each microcosm (experimental unit). Following emergence of the plants, each pot was thinned to three plants for the duration of the experiment. The plants were harvested after about 4 weeks of growth. The dry matter yield produced in each pot was determined by cutting the plants at soil level and drying the samples at 60°C. Plant tissue nutrient content of N and S were determined by combusting the ground plant tissue in a Leco CNS Analyzer. Plant tissue P was determined by H_2S0_4 – H_20_2 digest. The nutrient uptake of each treatment was determined by multiplying the dry matter yield by the nutrient content of the plant tissue.

The dry matter yield and nutrient content of the barley and field pea samples are provided in Tables 2 and 3 respectively. While both soils responded to added N fertilizer, the maximum yield attainable by adding N fertilizer was much greater in the Eluviated Brown soil for both barley and pea. Higher yields attainable in the Eluviated Brown soil with added N reflect higher supply of other nutrients in this soil. Limitations of nutrients other than N were holding back yield response to N in the Rego Brown soil. This demonstrates the importance of considering more than soil N when attempting to optimize responses to added fertilizer.

Table 2: Barley dry matter yield and tissue nutrient content for growth chamber experiment

Barley	N added (mg N/kg soil)	Dry Matter Yield (g/pot)	Plant N (% N)	Plant P (% P)	Plant K (% K)	Plant S (%S)
Rego Brown	0	0.10	2.03	0.15	4.1	0.37
	50	0.35	2.29	0.10	4.3	0.37
	100	0.55	2.87	0.08	5.8	0.33
	200	0.60	4.09	0.10	6.2	0.34
Treatments	LSD (0.05)	0.16	1.02	NA	NA	0.10
Eluviated Brown	0	0.32	2.52	0.78	5.1	0.62
	50	1.02	2.14	0.34	4.7	0.35
	100	1.40	2.44	0.27	4.7	0.36
	200	1.52	3.83	0.22	4.6	0.38
Treatments	LSD (0.05)	0.30	0.28	NA	NA	0.08
Soils	LSD (0.05)	0.24	0.75	NA	NA	0.10

The barley grown on the Eluviated Brown soil showed a decrease in N concentration in the plant tissue with the initial increment of N applied because the cereal responded to the added N with greatly enhanced growth and illustrates the classic "dilution effect" often seen with cereals. As the rate of applied N continued to increase, the plant uptake of N eventually "caught up" to the increase in growth (growth response to N rate slowed) and the tissue levels of N then began to increase. The tissue levels of P, K and S tended to decrease with the added N due to growth dilution for both crops. Concentrations of P, K and S were lower on the Rego than the Eluviated soil at equivalent N rates with the exception of K in barley.

Table 3: Pea dry matter yield and tissue nutrient content for growth chamber experiment

Field pea	N added (mg N/kg soil)	Dry Matter Yield (g/pot)	Plant N (% N)	Plant P (% P)	Plant K (% K)	Plant S (%S)
Rego Brown	0	1.14	2.50	0.15	2.3	0.35
	50	1.51	3.00	0.14	2.5	0.33
	100	1.39	3.01	0.13	2.3	0.30
	200	1.45	3.20	0.13	2.4	0.27
Treatments	LSD (0.05)	0.48	0.49	NA	NA	0.04
Eluviated Brown	0	1.43	3.91	0.38	4.0	0.54
	50	2.19	3.59	0.35	3.8	0.49
	100	2.28	4.08	0.35	4.1	0.51
	200	2.65	3.98	0.30	4.2	0.41
Treatments	LSD (0.05)	0.49	0.81	NA	NA	0.07
Soils	LSD (0.05)	0.48	0.67	NA	NA	0.06

The effects of added N in the two soils demonstrated to the students an important principle of plant nutrition: balanced nutrition. When another nutrient is limiting growth other than the one that is being added, growth response to the added nutrient (in this case, N) and maximum attainable yield is reduced. The field pea shows less response to added N than barley because it can fix its own N. The lower yield in the Rego soil suggests greater growth limitation of another nutrient other than N.

This raises in the mind what other nutrients might be limiting the response to added N, resulting in lower yields in the Rego soil. From a casual evaluation of the nutrient concentrations in the soil and plant, one might first conclude that P was actually the only deficient nutrient in the Rego Brown soil. Its uptake was only about 10% of uptake observed with the Eluviated Brown soil (Table 4). More attentive evaluation of the soil and plant data shows that K could also be deficient. Lower plant K concentrations at equivalent rates of added N (or no N) suggest that K is also a limitation or poised to become one, once

Table 4: Barley dry matter yield and nutrient uptake for growth chamber trial

Barley	N added (mg N/kg soil)	Dry Matter Yield (g/pot)	N uptake (mg/pot)	P uptake (mg/pot)	K uptake (mg/pot)	S uptake (mg/pot)
Rego Brown	0	0.10	2.1	0.2	4.1	0.4
	50	0.35	8.5	0.4	15.0	1.3
	100	0.55	16.7	0.4	31.7	1.9
	200	0.60	24.3	0.6	37.4	2.0
Treatments	LSD (.05)	0.16	8.9	NA	NA	1.1
Eluviated Brown	0	0.32	8.1	2.4	16.3	2.0
	50	1.02	22.0	3.5	47.4	3.6
	100	1.40	34.3	3.8	65.5	5.1
	200	1.52	57.6	3.3	70.2	5.7
Treatments	LSD (.05)	0.30	31.3	NA	NA	1.8
Soils	LSD (.05)	0.24	27.0	NA	NA	1.5

P deficiency is addressed. One recalls that the PRS^{TM} probe soil analysis showed that P supply between these two soils was slightly lower in the Rego Brown soil, but that K supply was much lower in the Rego Brown soil. Yield of both barley and field pea was much

Table 5: Field pea dry matter yield and nutrient uptake for growth chamber trial.

Field pea	N added (mg N/kg	Dry Matter Yield (g/pot)	N uptake (mg/pot)	P uptake (mg/pot)	K uptake (mg/pot)	S uptake (mg/pot)
Rego Brown	0	1.14	29.1	1.7	26.6	3.9
	50	1.51	44.9	2.1	37.9	4.8
	100	1.39	41.9	1.8	32.4	4.2
	200	1.45	47.5	1.9	34.4	3.9
Treatments	LSD (.05	0.48	18.2	NA	NA	1.3
Eluviated Brown	0	1.43	56.1	5.4	57.5	7.7
	50	2.19	78.5	7.6	82.3	10.8
	100	2.28	92.5	7.9	93.0	11.5
	200	2.65	105.3	7.9	111.3	10.8
Treatments	LSD (.05	0.49	21.8	NA	NA	2.5
Soils	LSD (.05	0.48	20.1	NA	NA	2.0

higher on the Eluviated Brown soil, which indicates that the overall fertility status of Eluviated Brown soil is much better than that of the Rego Brown soil. This demonstrates why responses to added N fertilizer alone are often greater in lower slopes than on knolls; better moisture and availability of other nutrients.

The experiment also shows one of the weaknesses of using plant tissue concentration alone for identifying the limiting nutrient. Plant tissue levels of the deficient nutrient may be higher when grown in a soil critically deficient in other nutrients as compared to the plant tissue levels observed when grown in a marginally deficient soil. This effect, known as the Piper-Steenbjerg effect, occurs as a stress response in the plant tissue. Barley is more sensitive to potassium deficiency than field pea. The potassium levels in the barley tissue, however, were high enough to be considered adequate by usual standards, but deficiency of N and P were greatly reducing biomass yields contributing to elevated concentrations of other nutrients in the plant tissue. Plant S concentrations were similar between soils, and extractable sulphate and PRS supply rates were also high and similar among soils. This suggests that S is not a primary limiting nutrient and cannot explain the difference in response to N.

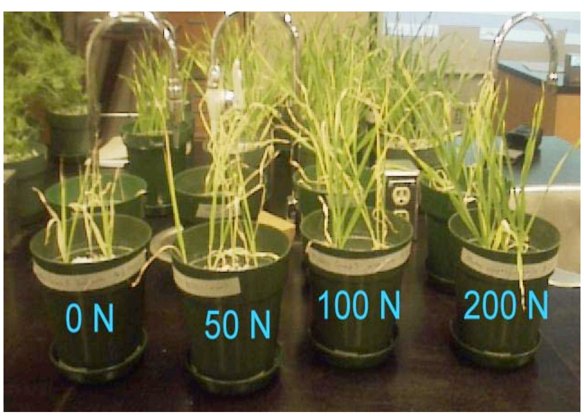

Figure 1: Barley plants grown on Rego Brown soil (knoll slope position) with four rates of added N.

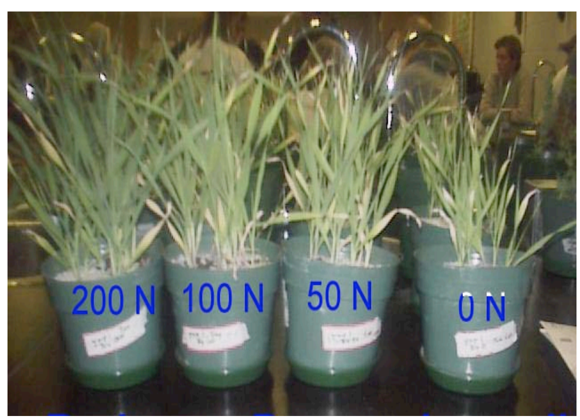

Figure 2: Barley plants grown on Eluviated Brown soil (lower slope position) with four rates of applied N.

Conclusion:

This laboratory experiment was effective in demonstrating to students the concept of Leibig's Law of the minimum, the need for balanced fertility to maximize yield, and the need for multiple evidence of soil analysis and tissue analysis to conclusively identify limitations in soil nutrient availability.

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