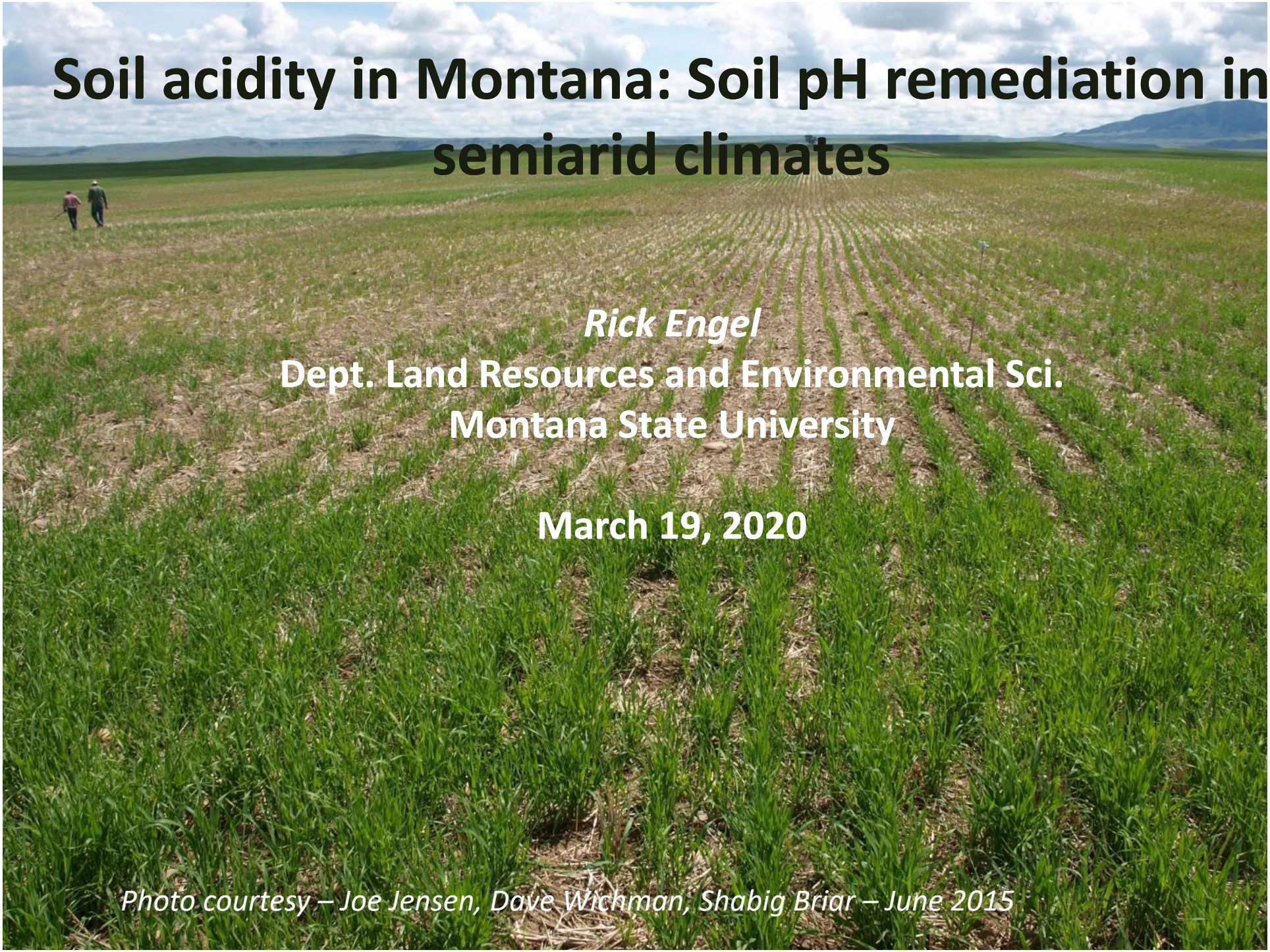
Soil acidity in Montana: Soil pH remediation in semiarid climates



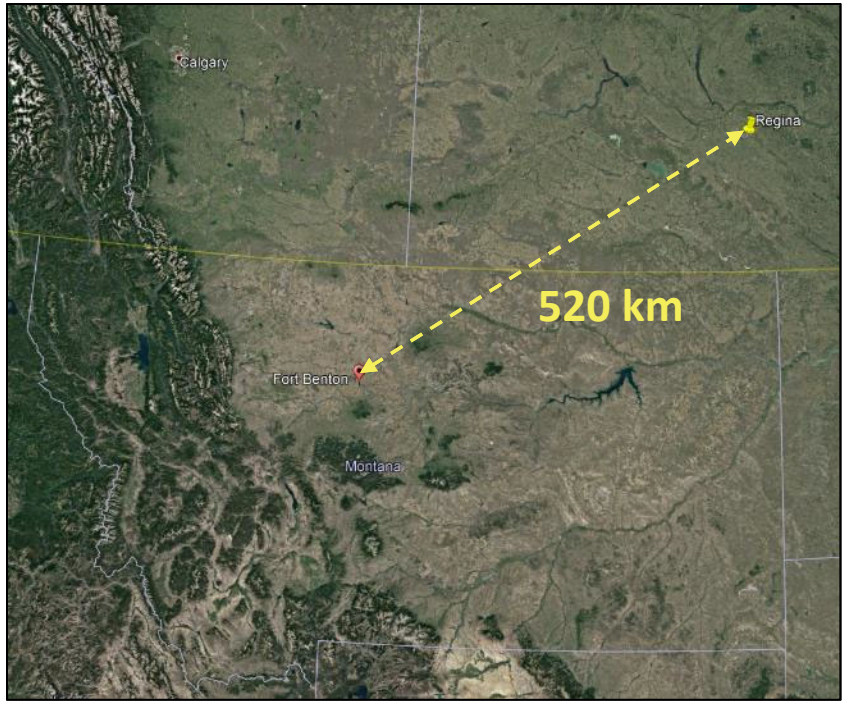
Rick Engel
Dept. Land Resources and Environmental Sci.
Montana State University

March 19, 2020

Photo courtesy – Joe Jensen, Dave Wichman, Shabig Briar – June 2015

Background – Montana

- rainfall in 13-16” range vs. Regina 15.4” (390 mm)
- historical acidity or low pH was not an issue; however soil pH are falling
- Fort Benton (north central Montana) - in 2012 farmers started finding problems related to stands/production of cereal grains
  - number of factors were considered
  - acidic soil (pH 4.3 to 4.4) & elevated extrac. aluminum (169 ppm)
  - plants with Al toxicity symptoms (what does this look like?)



Al toxicity in crops

- Tops – stunted growth, yellowing or purple leaves (P deficiency?)
- Roots: witch's broom roots, thickened, twisted, club ends, stubby, no fine branching

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Safflower - necrotic tissue and J-shaped effect

Barley field - Highwood Bench

Lentil - pot experiment (without $CaCO_3$)

Lentil - pot experiment (with $CaCO_3$)

Soil pH and Al toxicity – why this happens ?

Two issues (all minerals will have a lot of Al)

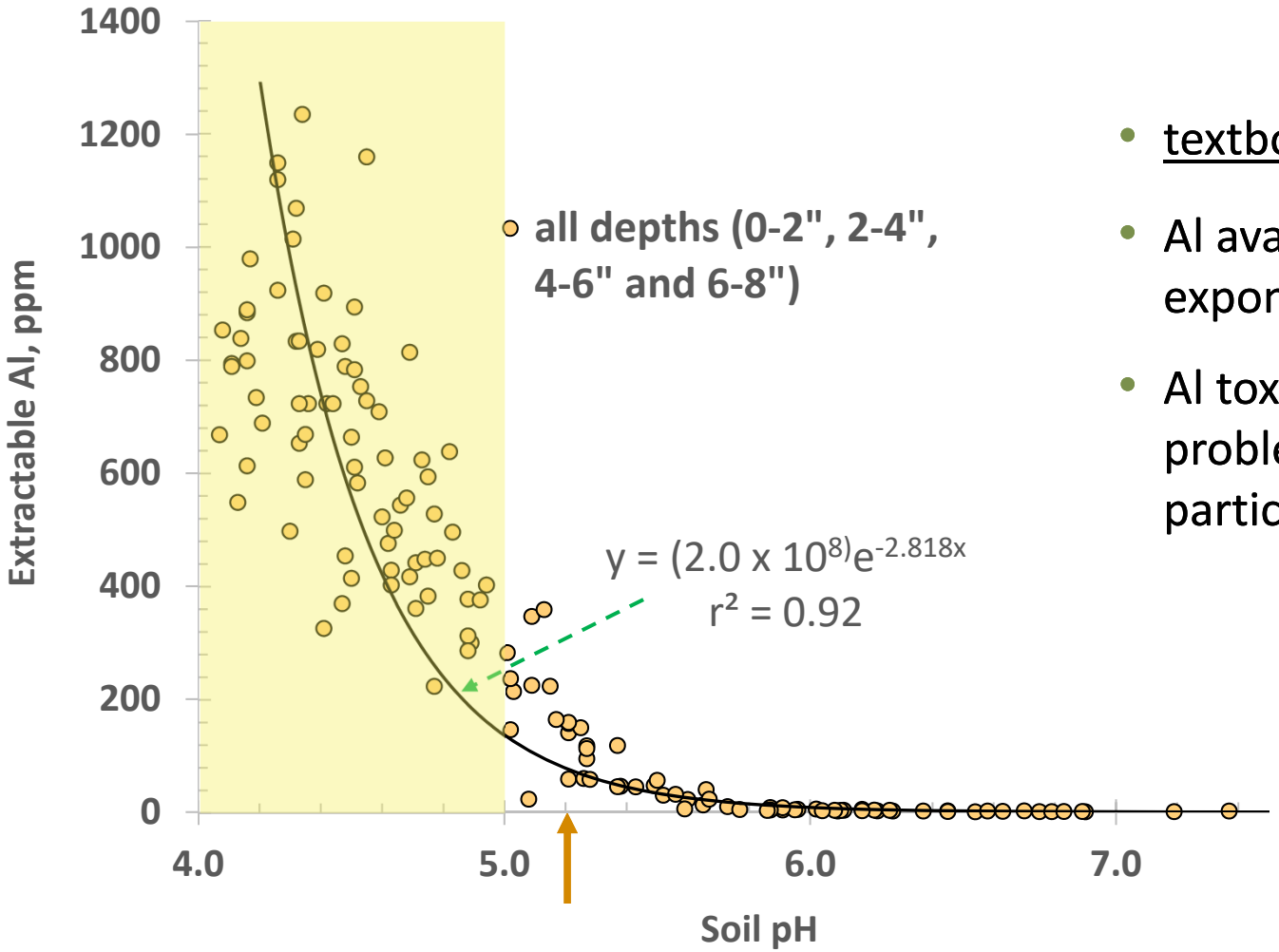
- <u>solubility</u> of Al increases as pH falls with more Al dissolving from solid-phases, e.g. Al-silicate clay minerals and Al hydroxides)

- <u>Al ions</u> - exist in soil solution as different ion species -

Al^{+3}, $Al(OH)^{+2}$, $Al(OH)_2^{+1}$, $Al(OH)_3$

most toxic species? and it is found in > abundance in acidic solutions, i.e. pH < 5

Al_{ext} vs. soil pH relations in minerals soils



Summary

- textbook relationship
- Al availability increases exponentially below pH 5.2
- Al toxicity becomes problematic at pH < 5, particularly pH < 4.5

Fertilizer N and soil acidity – textbook

Factors Affecting Soil Acidity

Increasing soil acidity in crop production systems is caused by (1) use of commercial fertilizers, especially NH_4^+ sources that produce H^+ during nitrification; (2) crop removal of cations in exchange for H^+; (3) leaching of cations being replaced first by H^+ and subsequently by Al^{3+}; and (4) decomposition of organic residues.

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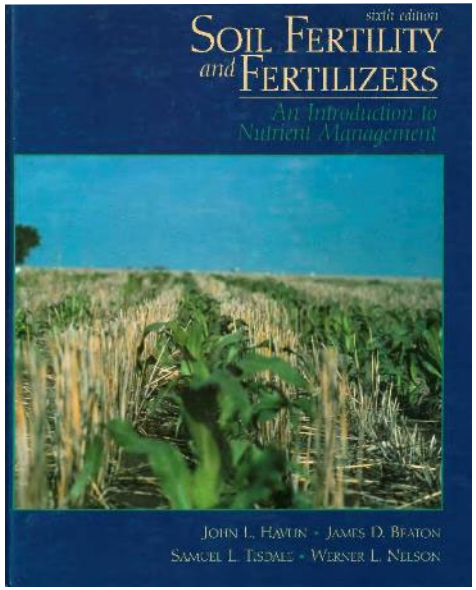
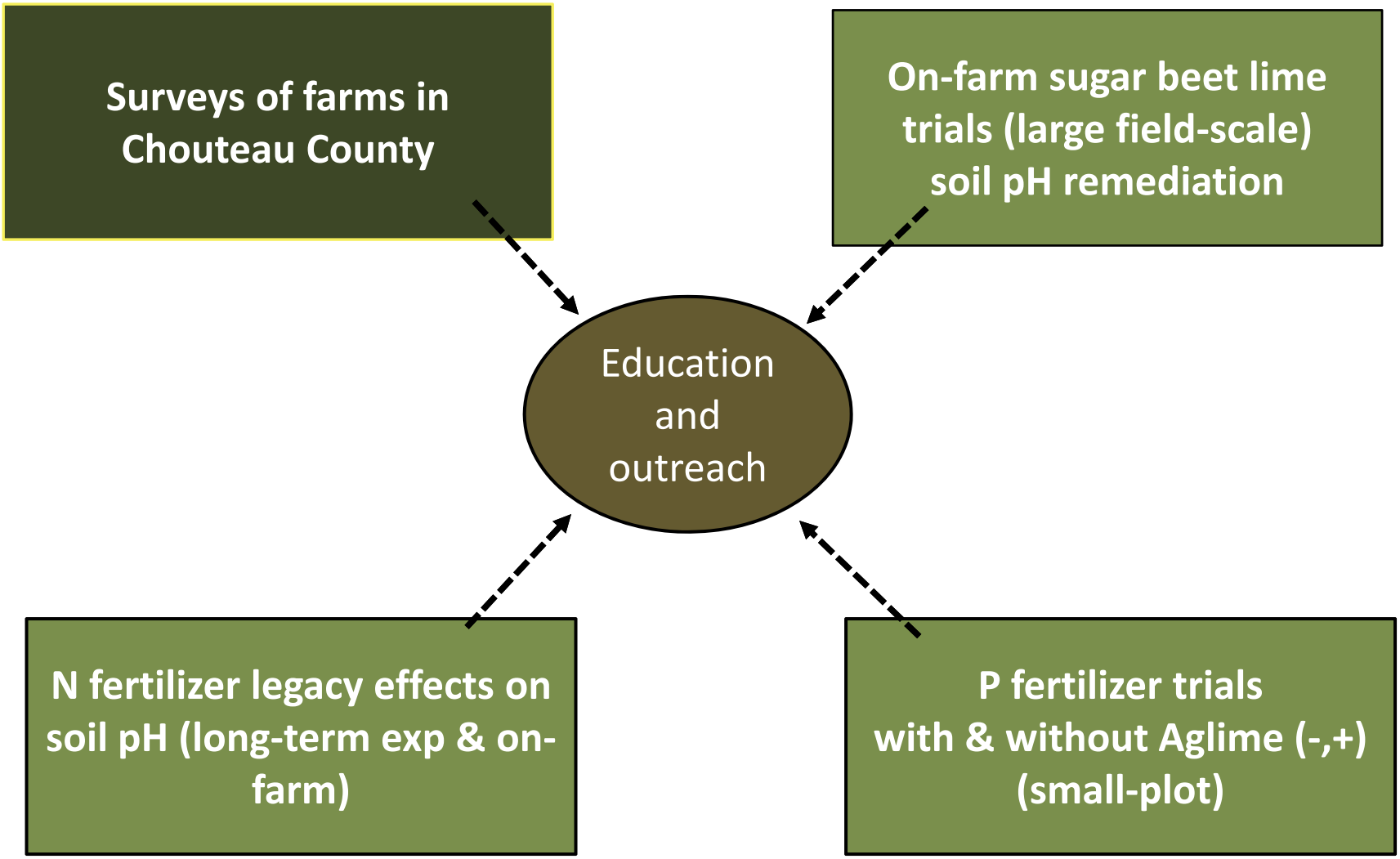


6th ed. 1999

Project activities

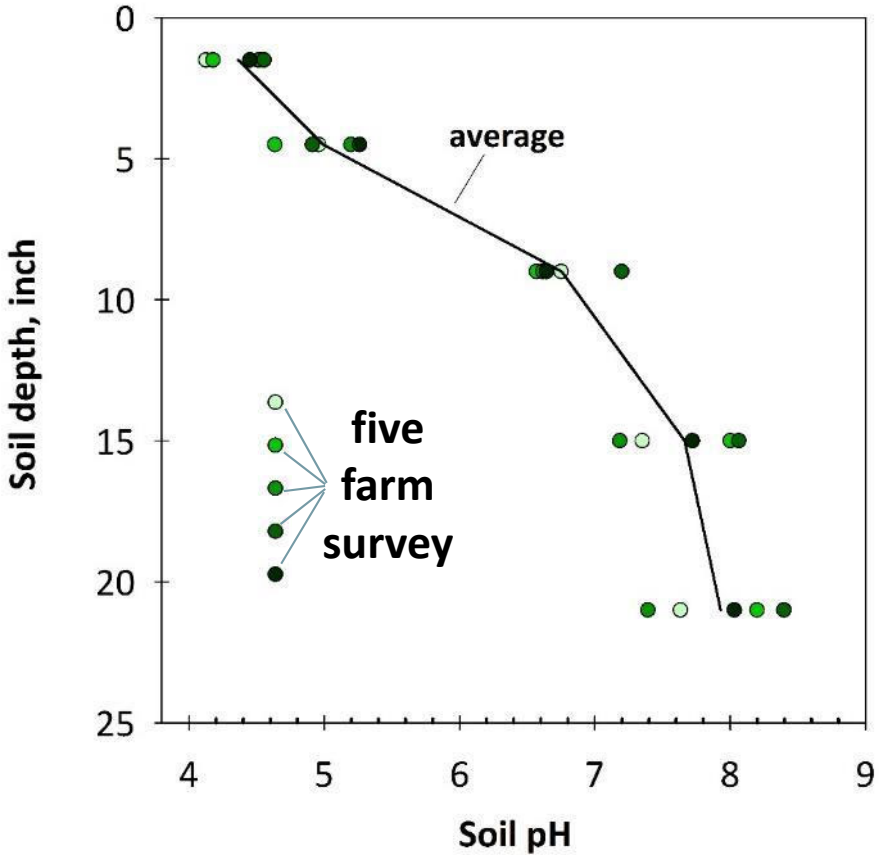


Background - Chouteau County

Regina ☆

- focus of soil acidity concerns
- localized areas of higher rain relative to much eastern Montana
- annual cropping more common & fertilizer N inputs ⬆
- saline seep control
- localized areas with sandy soils

Soil pH stratification and no-till

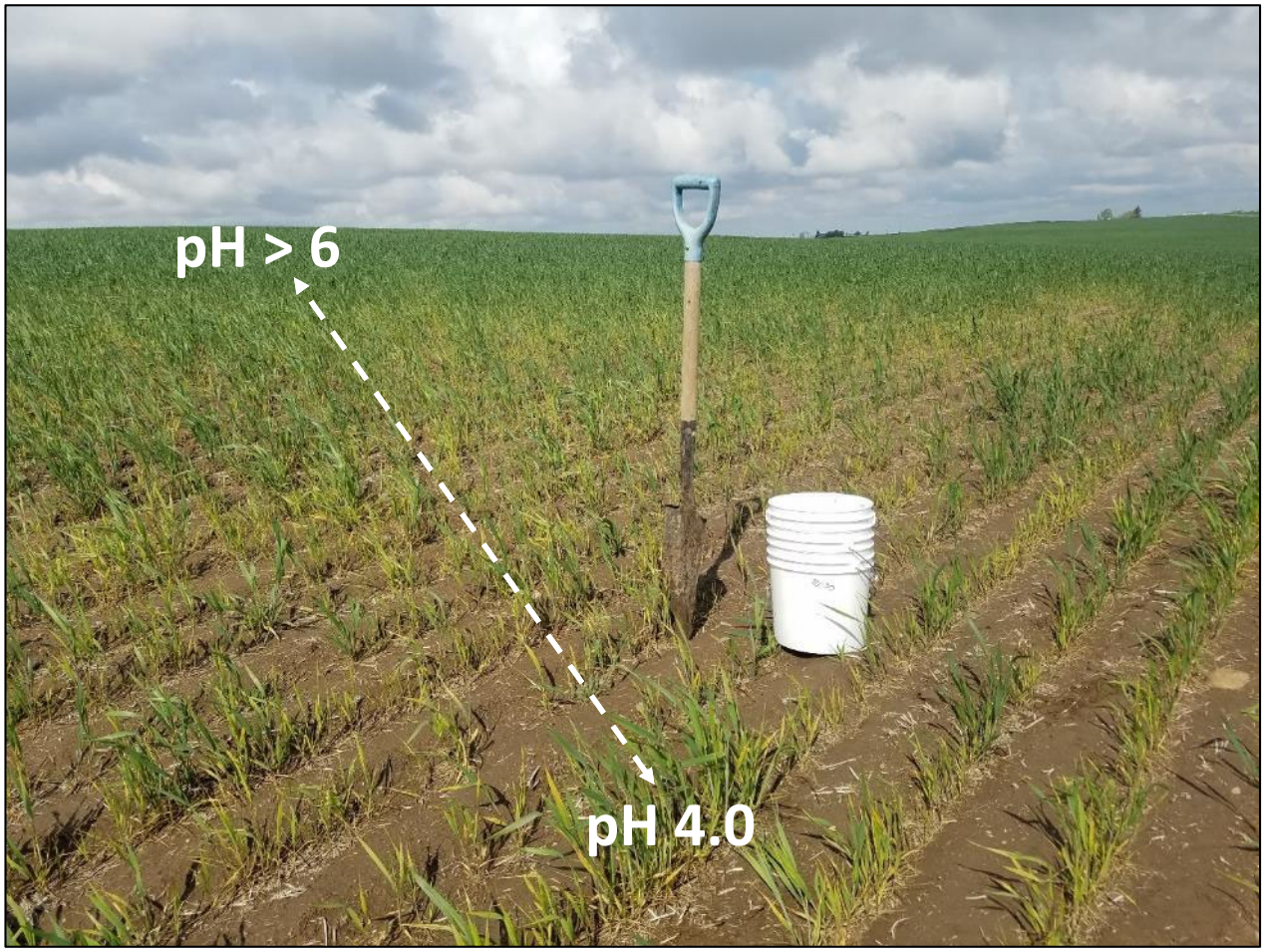


Summary

- **lowest pH likely to be found in shallowest depth because…**
  1. **N applied near surface & no-till**
  2. **subsoils have a lot of natural lime (Ca, Mg, Na carbonates)**

direct seeding has contributed

Chouteau Co acidity survey – field variances



"the world is a patchy place"

Summary

- "spatial variance in soil pH can be very large within fields & over short distances
- often lowest pH found in low lying areas, and/or foot slope position

Chouteau Co acidity survey – field variances

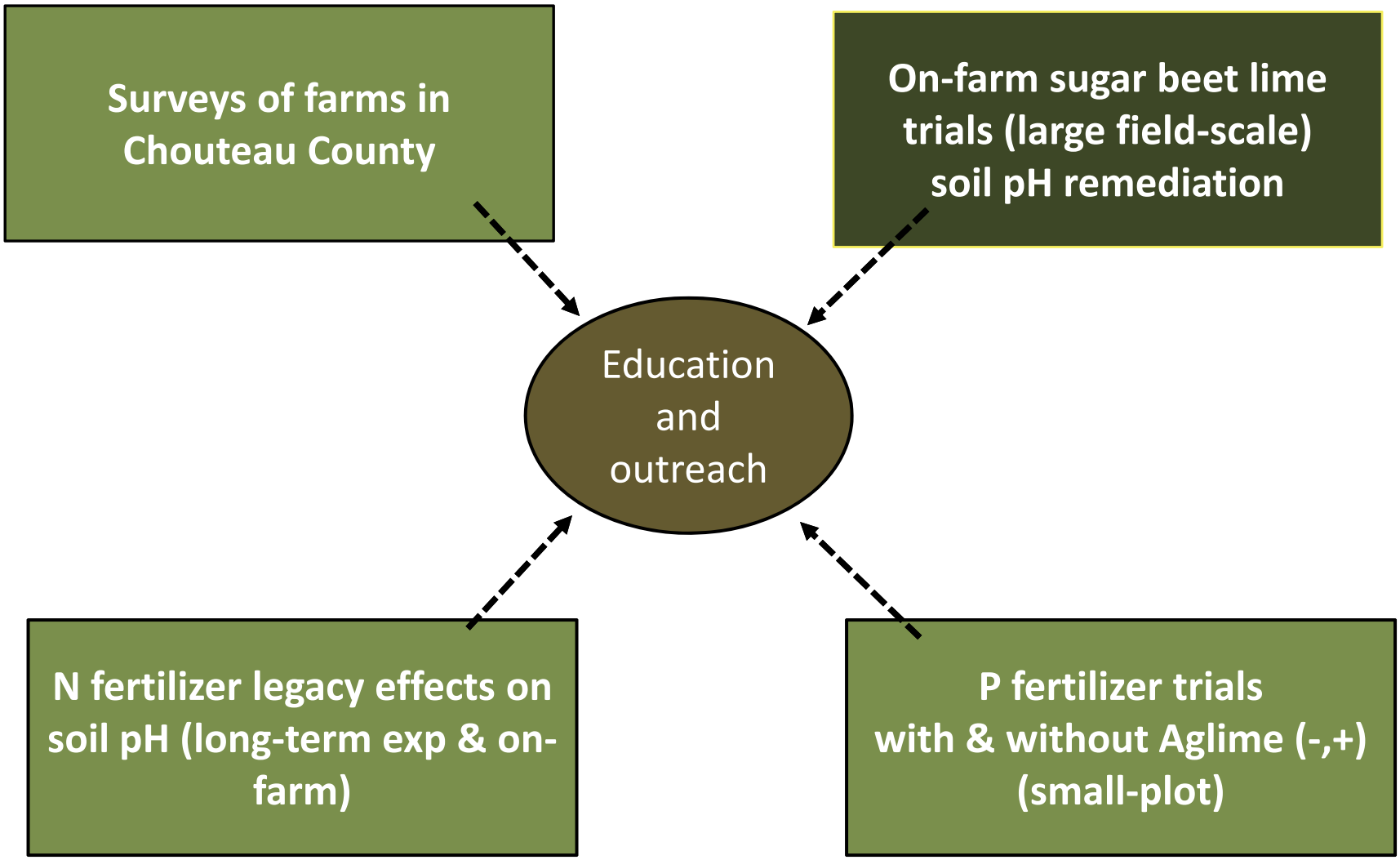
Summary

- spatial variance in soil pH can be very large within fields & over short distances
- typically lowest pH found in low lying areas, and/or foot slope position

Implications to soil sampling

- composite soil sampling may not tell the whole story
  - ✓ there may be low pH areas within a field even if composite pH result suggests no problem
  - ✓ mixing one part soil pH 8 + one part soil pH 4 may not equal pH 6 (what ? 1 + 1 ≠ 2)
- sampling depth matters
  - ✓ pH 0-2” or 0-3” will likely be < pH 0-6”, particularly for no-till
- small differences in soil pH can make a big difference @ pH < 5

Project activities



What is sugar beet lime (spent lime)?

- byproduct of raw juice purification process.

- chemical characteristics
  - ✓ contains a lot of water (e.g. 30%)
  - ✓ organic matter (beet impurities)
  - ✓ $CaCO_3$ (75-80% of dry wgt) or 55% $CaCO_3$ (wet wgt)

- free ($0.00), is being used by by farmers in Chouteau Co.

Western Sugar Co. – Billings, MT

Sugar beet lime – Western Sugar Co.

35$ per ton to ship to Chouteau County field sites

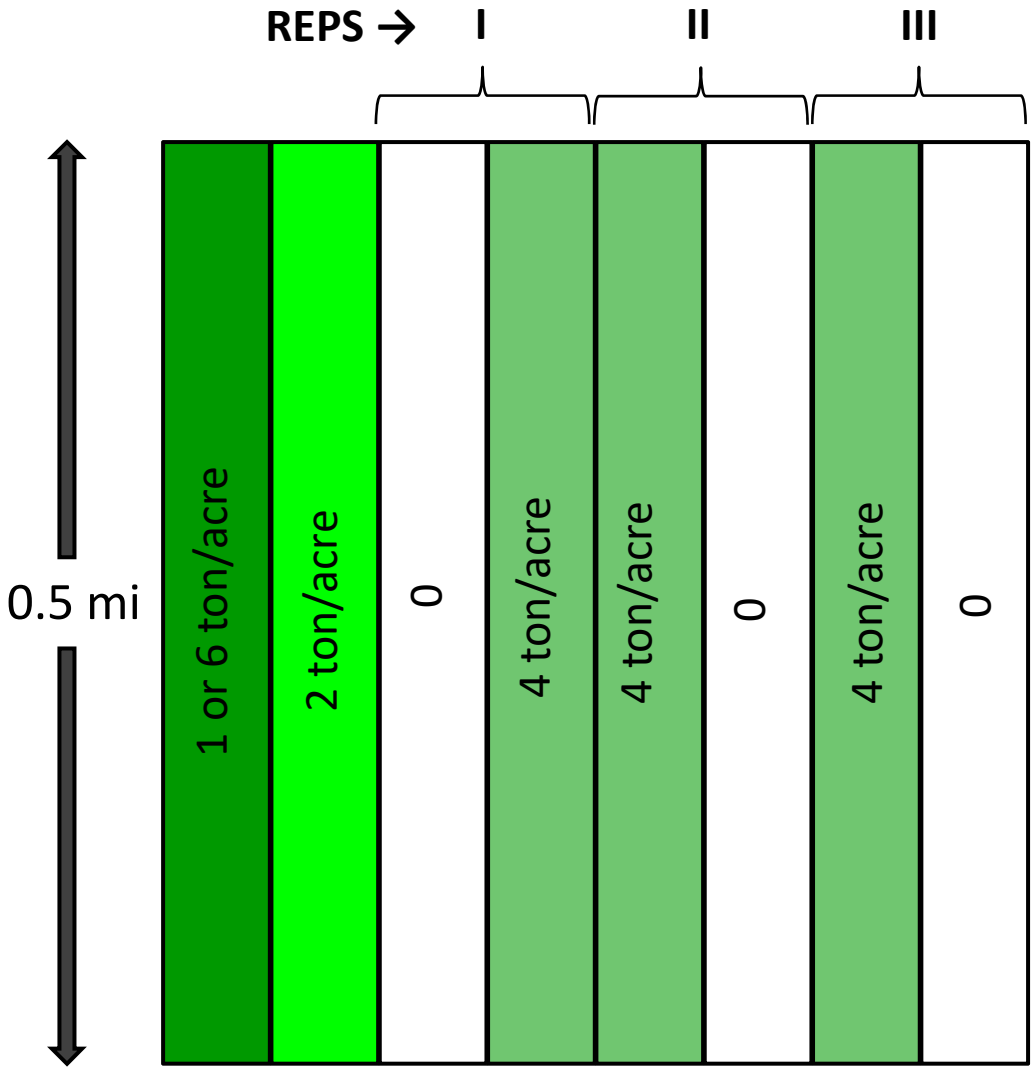
Sugar beet lime – Western Sugar Co.

Stolzfus wet lime applicator

Sugar beet lime – Western Sugar Co.

Stolzfus wet lime applicator

On-farm sugar beet lime strip trials

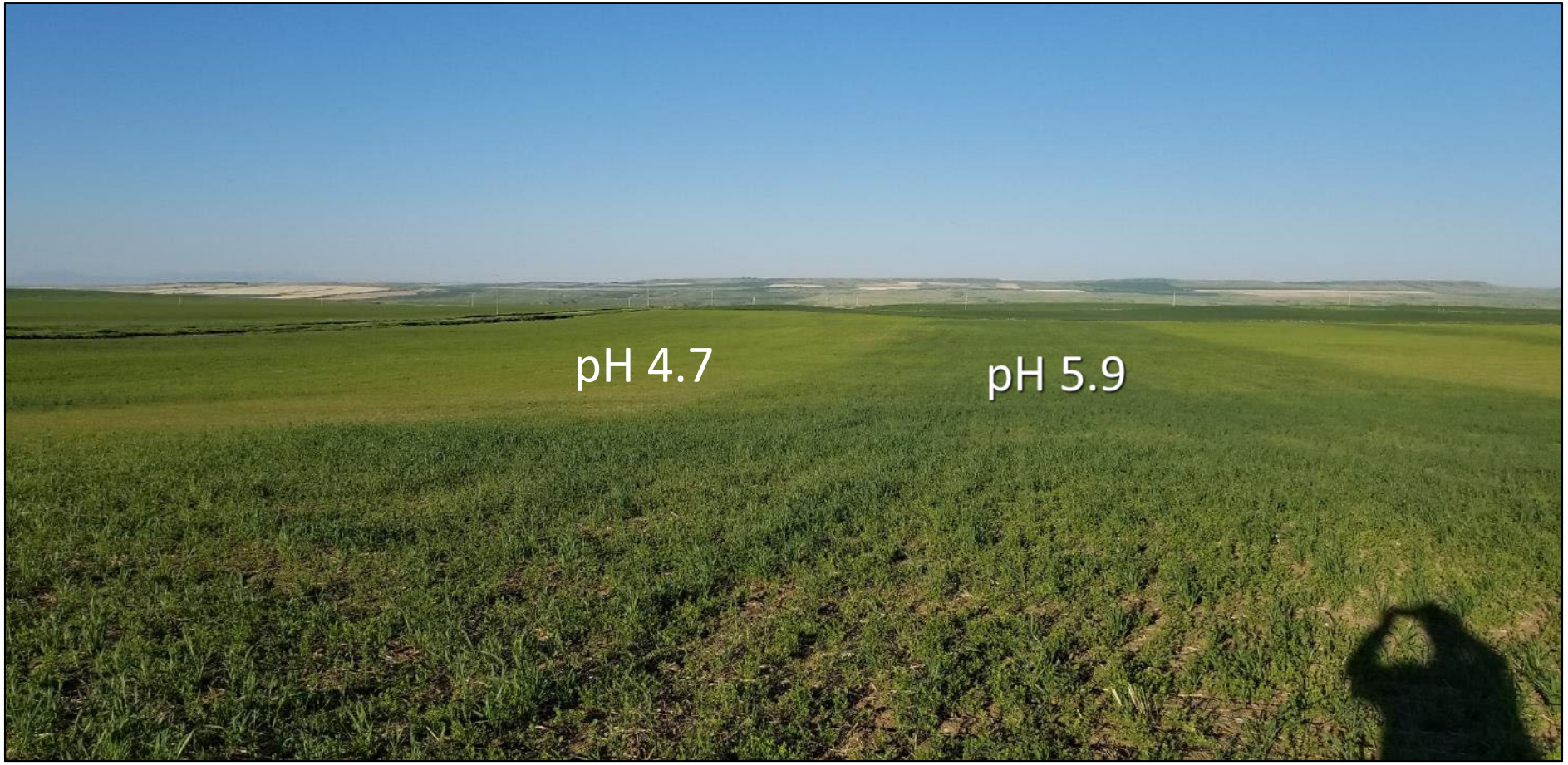


Lime app rates (each strip is 60’ wide)

Summary

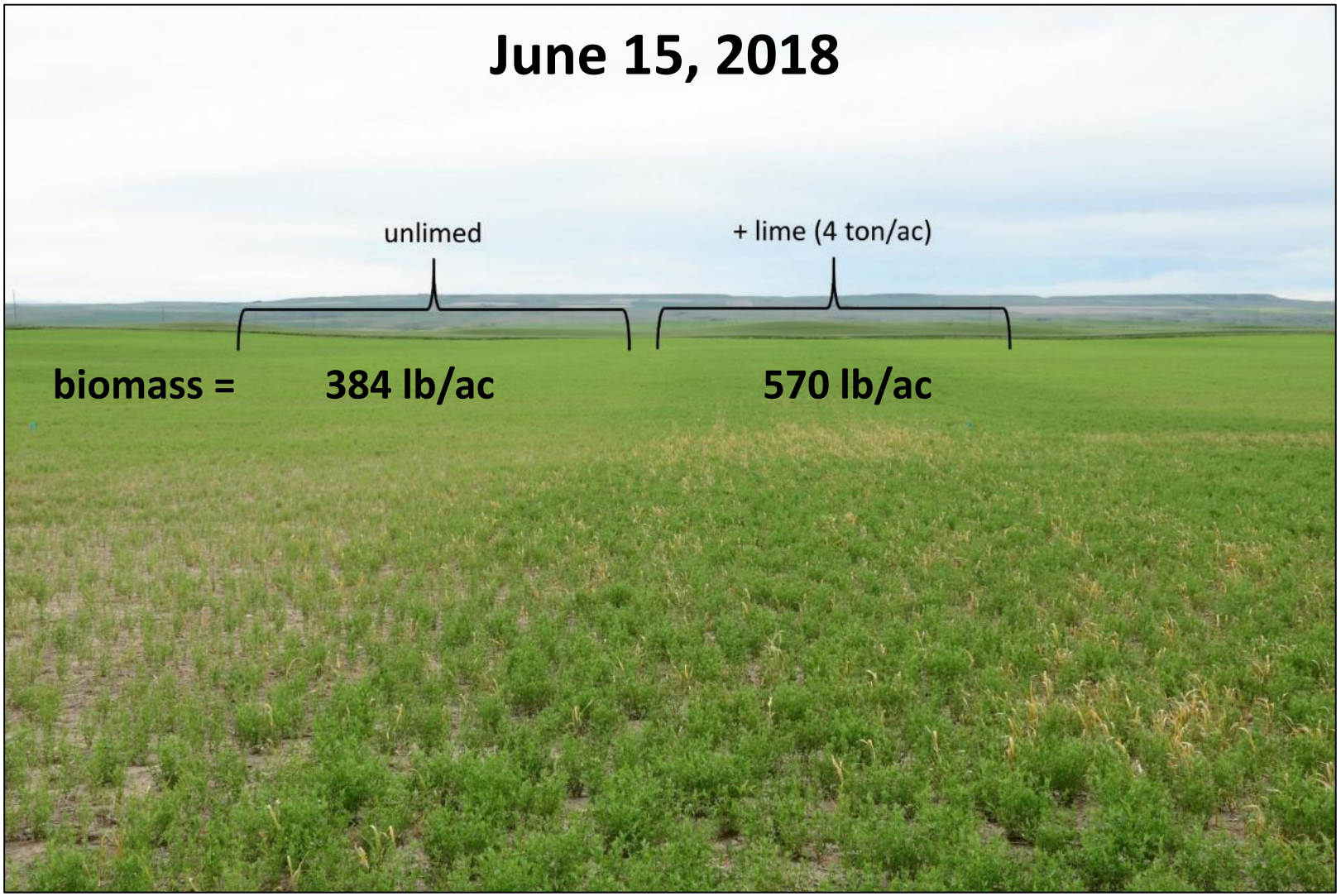
- trials at three farms (Big Sandy, Fort Benton, N. Geraldine)
- grower cooperation with application of beet lime
- incorporation with tillage at two farms, one farm without

Fort Benton SB lime trial - lentils

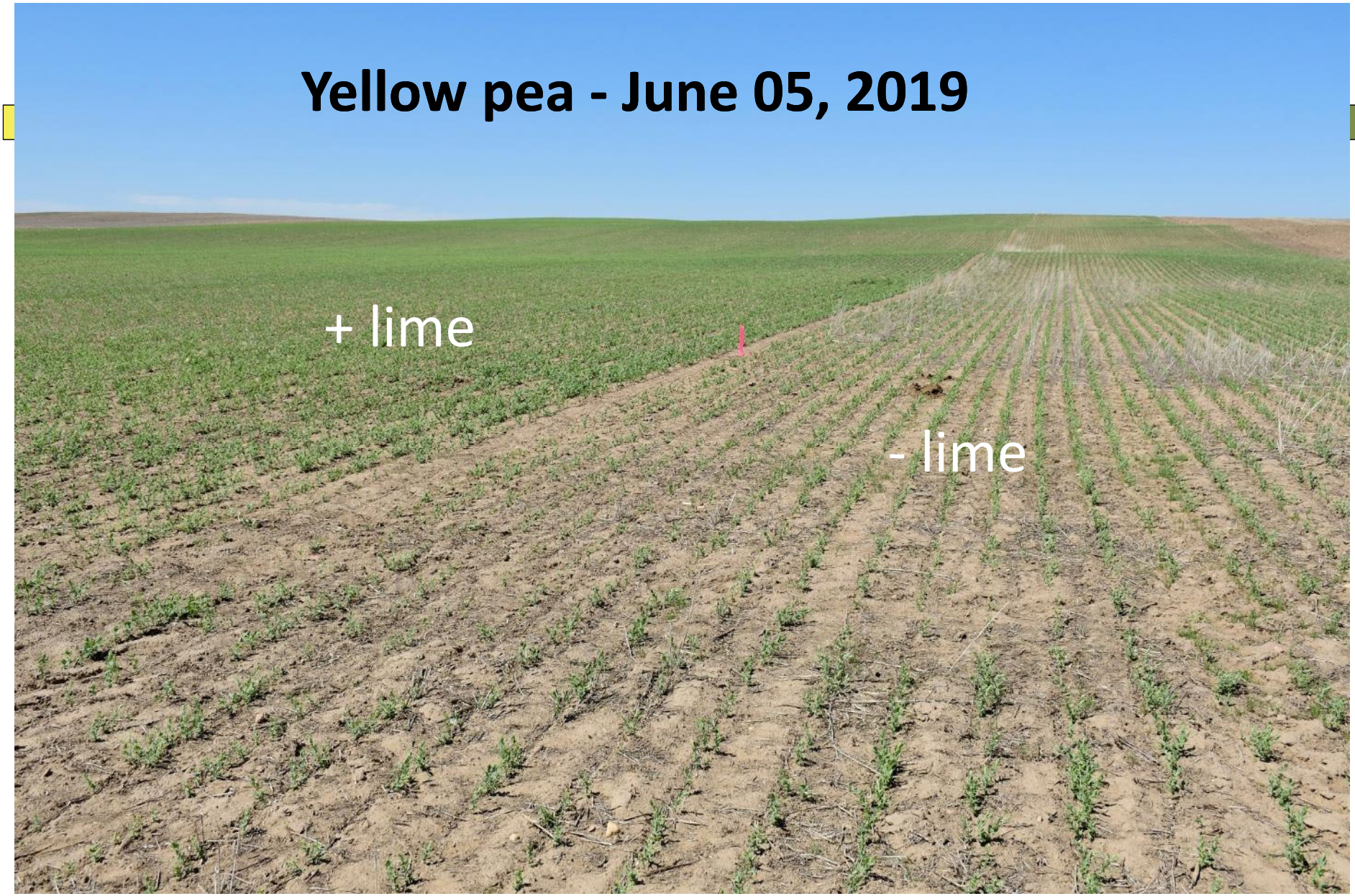


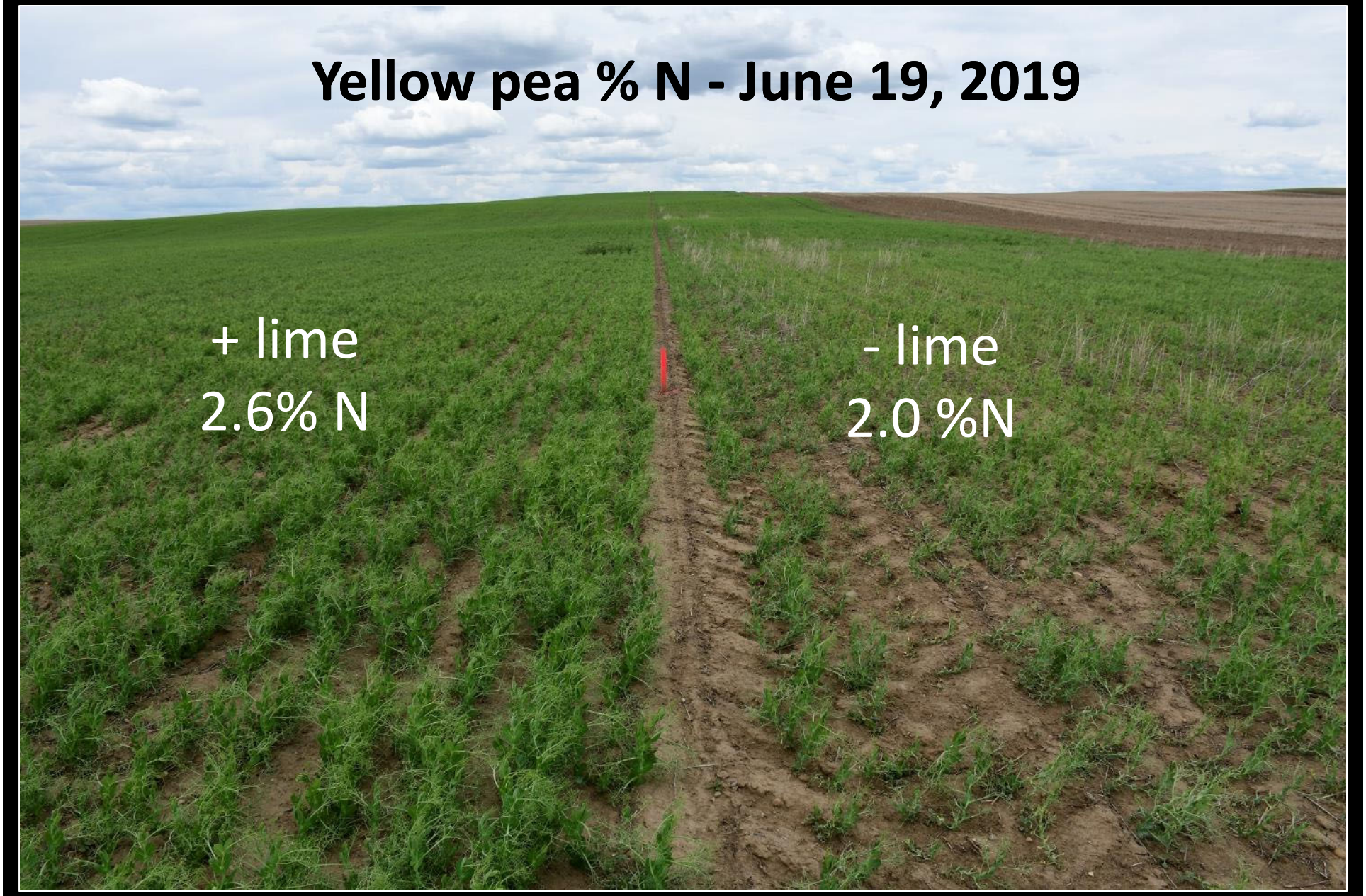
May 29, 2018 photo with +lime and -lime strips

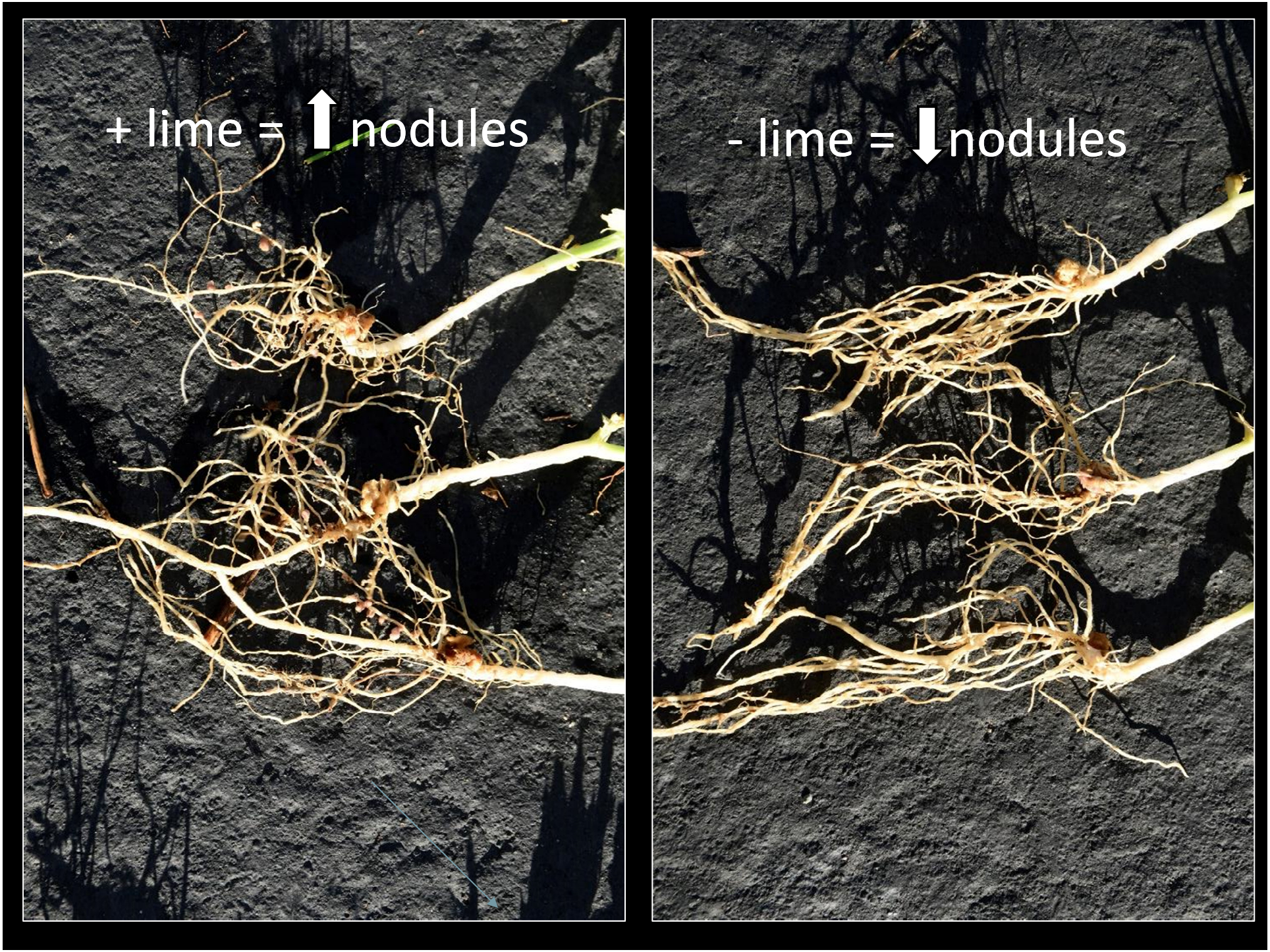
SB lime strip trials at Fort Benton - lentils



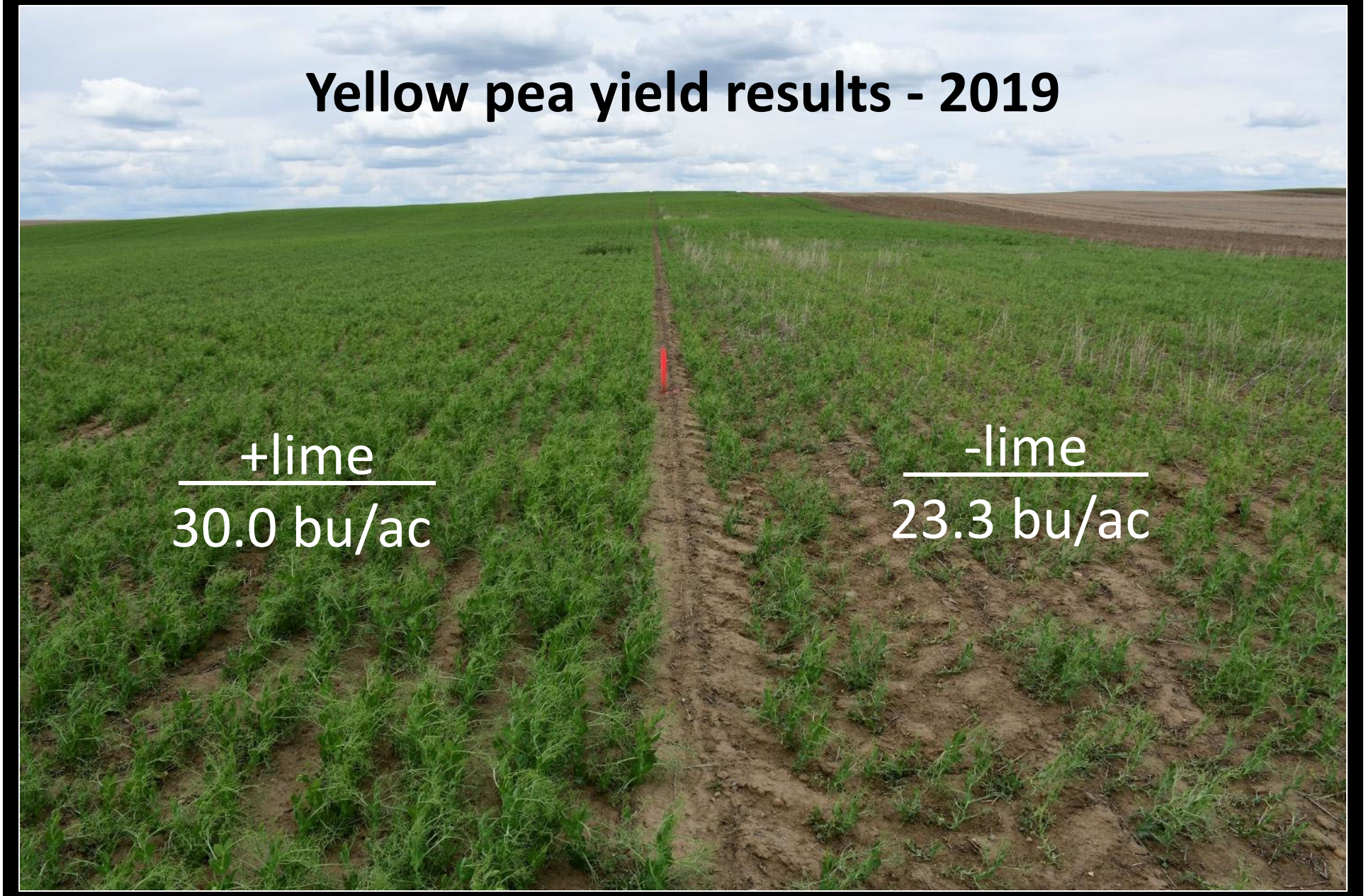
Yellow pea - June 05, 2019



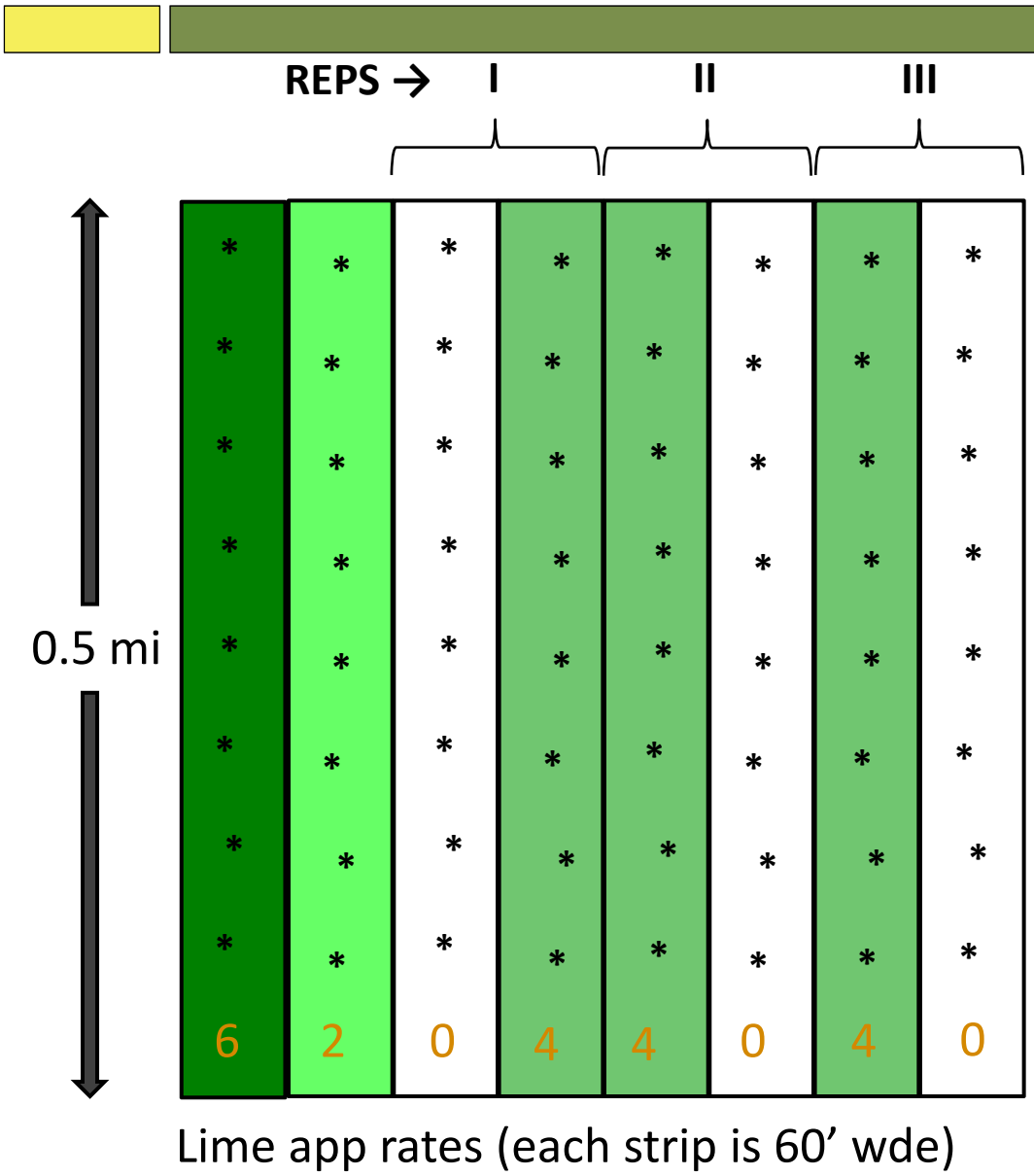

Yellow pea % N - June 19, 2019
+ lime
2.6% N
- lime
2.0 %N


+ lime = ⬆ nodules
- lime = ⬇ nodules

Yellow pea yield results - 2019



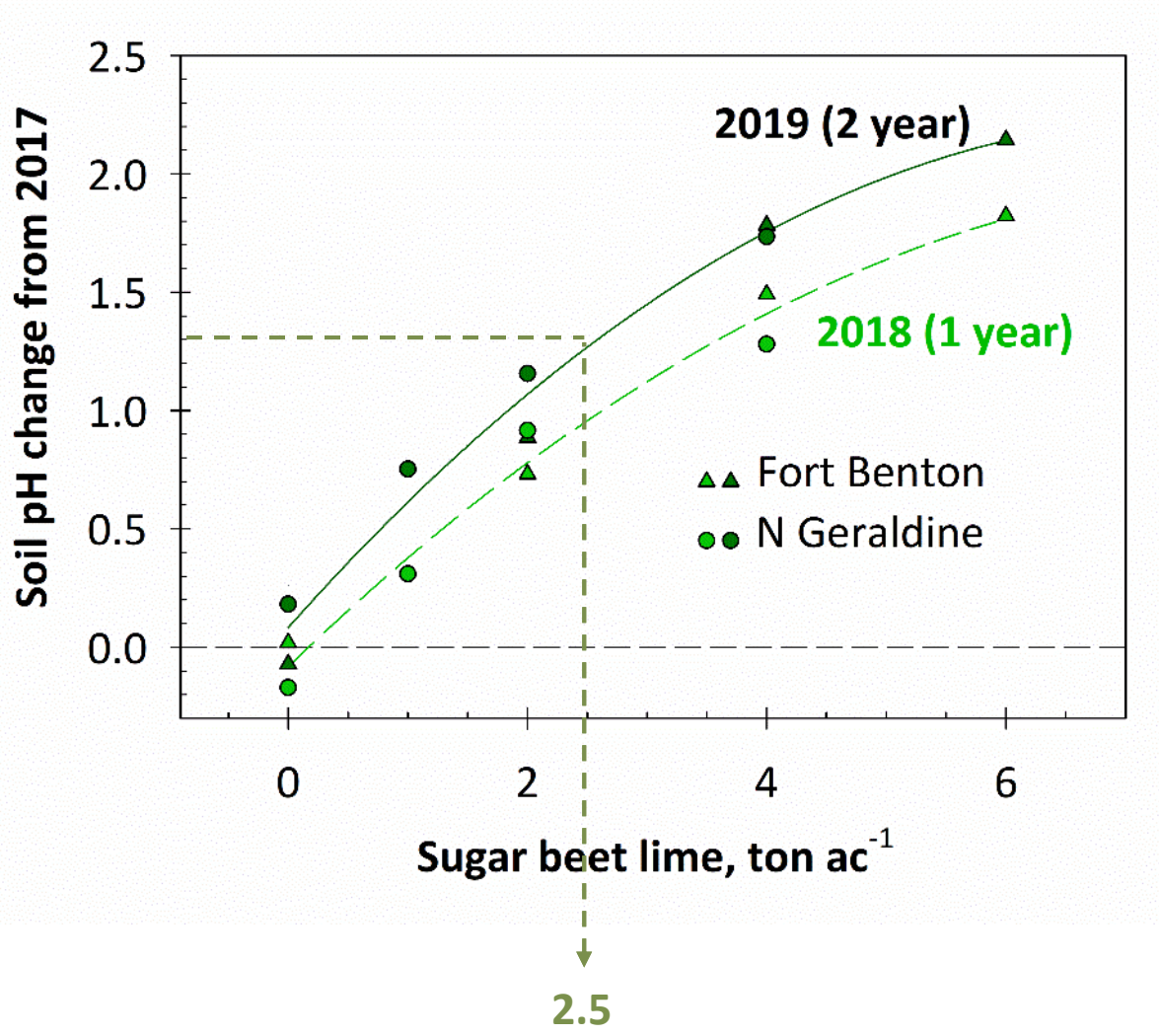
On-farm sugar beet lime strip trials - soil pH results



Soil sampling approach

- GPS referenced points*
- collected before (fall 2017 & after lime application (fall 2018 & 2019)
- composite soil cores (0-2”, 2-4”, 4-6” and 6-8”)

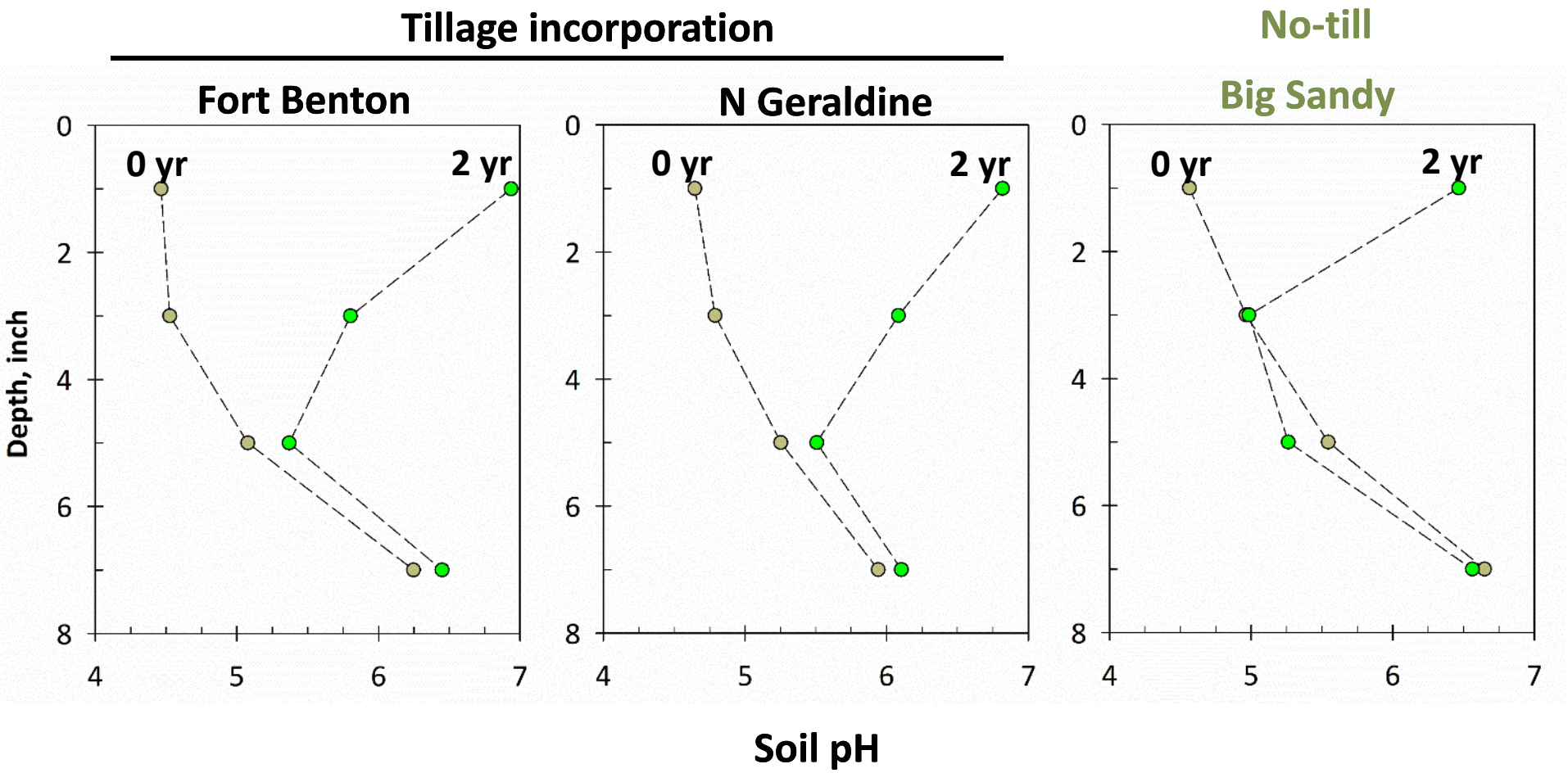
Sugar beet lime effect on Δ soil pH (1 yr, 2 yr)



Summary points

- two locations
  $pH_{initial}$ = FB 4.6, NG 4.8
- pH remediation yr 1 & 2
- SBL@ 2.5 ton/ac were required to change pH 1.3 units (pH target 6) or 1.4 ton $CaCO_3$e/ac
- seed-placed lime at 200-300 lb/a/yr will likely not correct

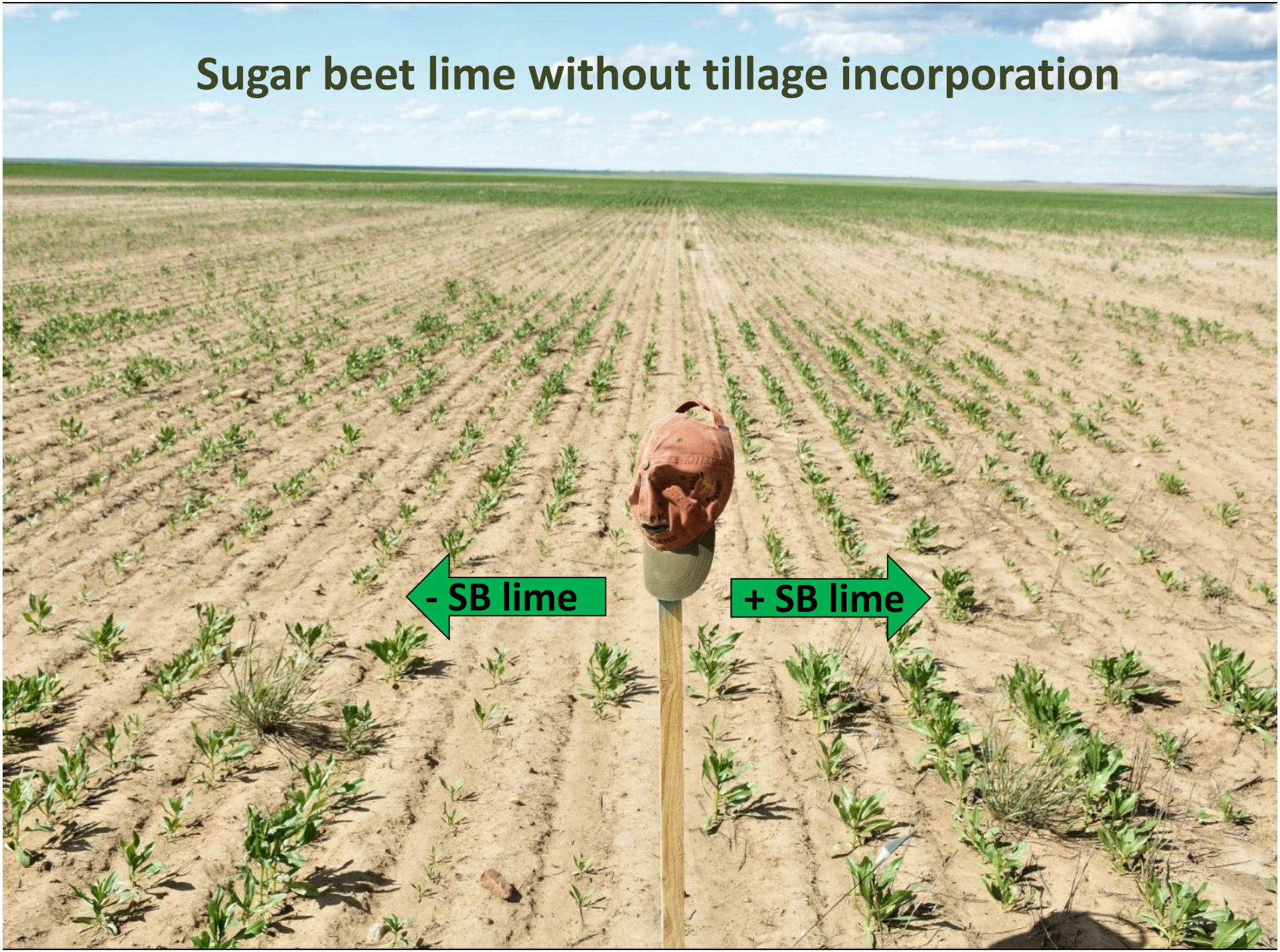
Soil pH profile 2 yr after liming with & w/o tillage



- SBL 4 tons /ac = 2.2 tons $CaCO_3$e/ac
- lime does not wash/leach into soil profile – w/o tillage pH remediation will be confined to surface

Safflower field with Al toxicity – July 20, 2018

Sugar beet lime without tillage incorporation



Does a single tillage event affect SOC?

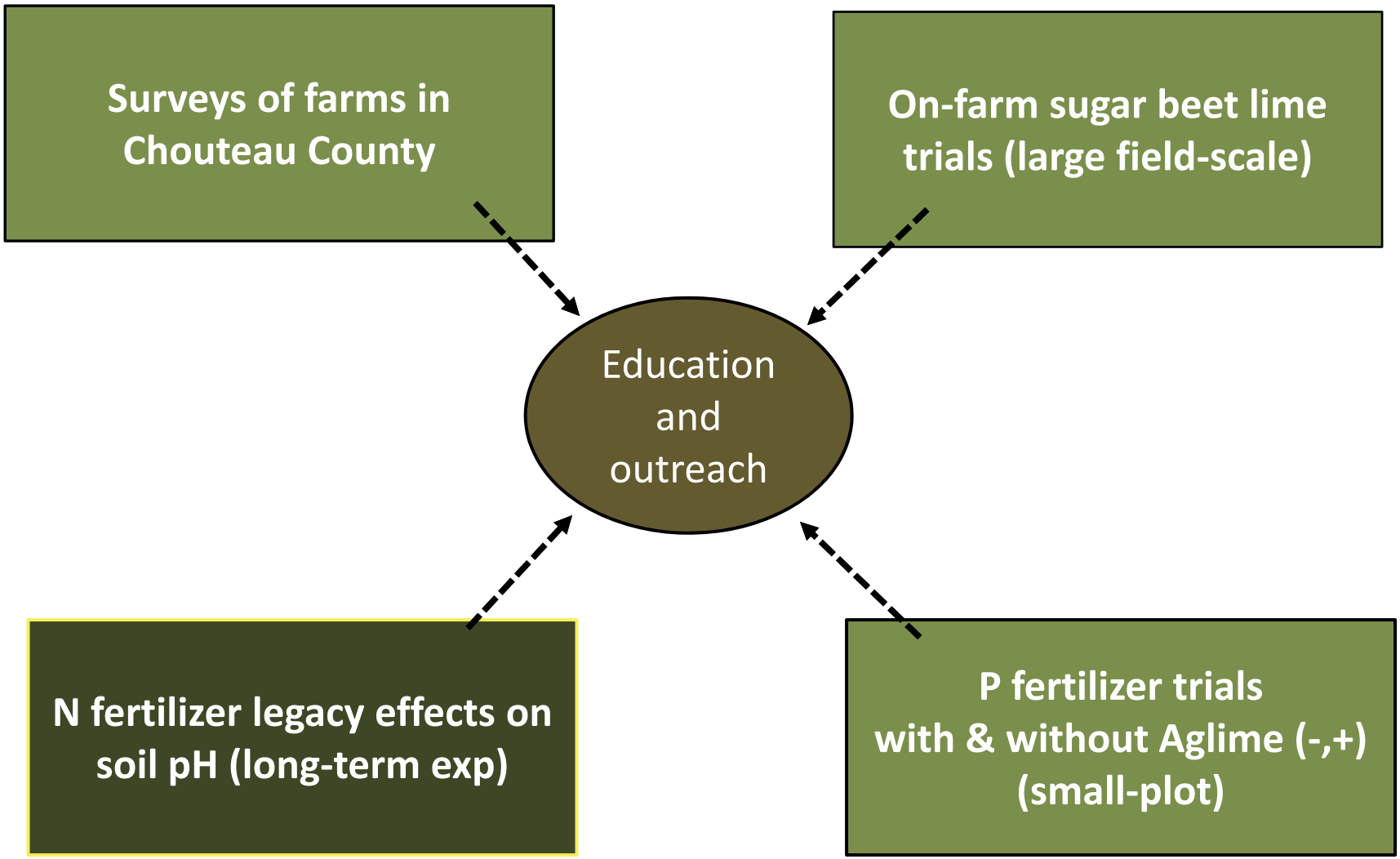
		before	after
	Depth	**2017**	**2018**
		---------- % ---------	
Fort Benton	0-2"	2.26 ⟺	2.26
	2-4"	1.41	1.68
	4-6"	1.15	1.17
	6-8"	1.14	1.10

	Depth	**2017**	**2018**
		---------- % ---------	
Geraldine	0-2"	1.37	1.38
	2-4"	0.95	1.03
	4-6"	0.83	0.81
	6-8"	0.79	0.76

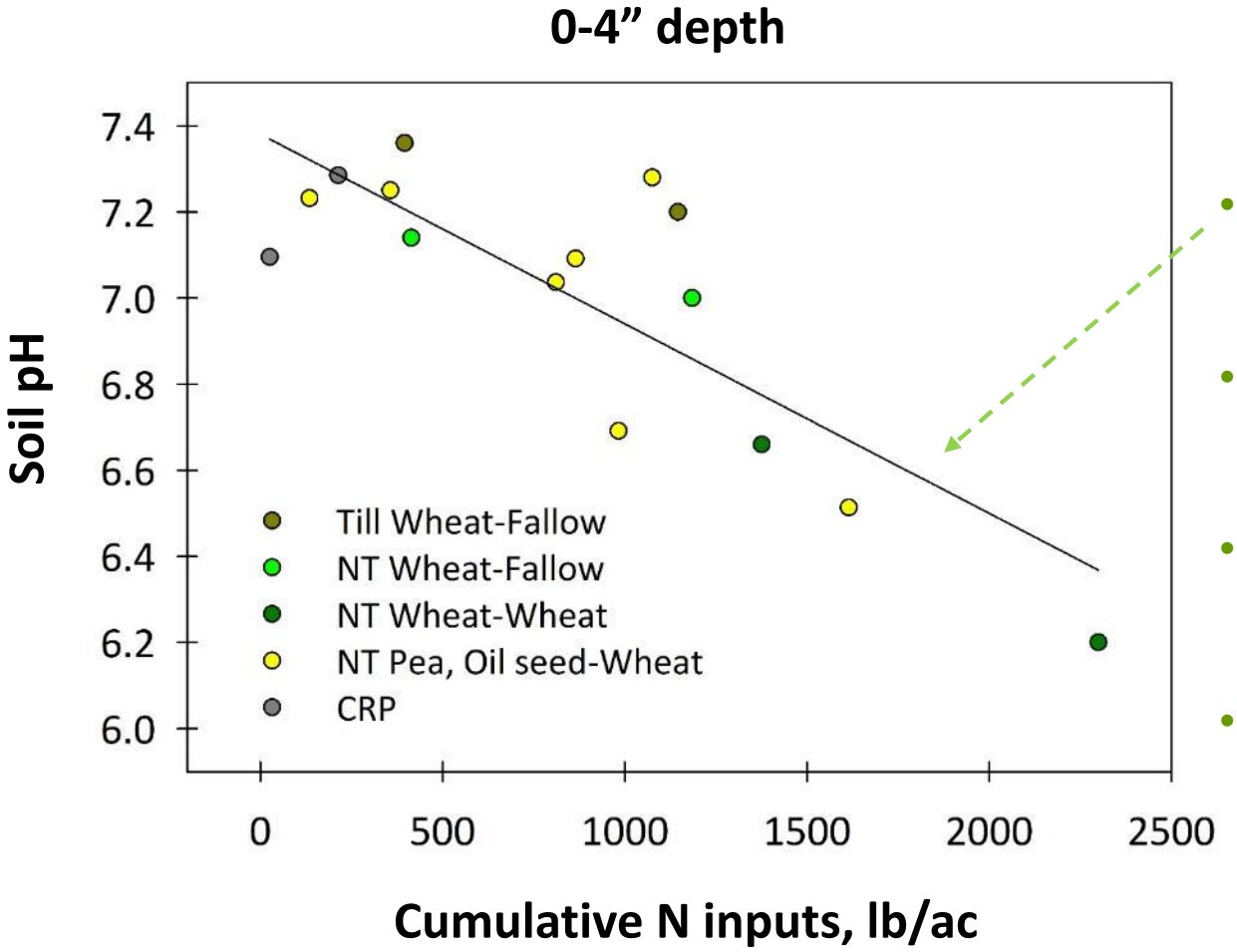
Summary

- a single tillage event (beavertail spike + harrow) did not destroy SOC at Fort Benton and at Geraldine
- consistent with long-term studies in Wyoming and Saskatchewan, and a review article from Nebraska (Blanco-Canqui, 2020)

Project activities



Fertilizer - N legacy effects at GGRS (14-yr)



Summary points

- slope of line says 100 lb N ac^{-1} drops pH 0.044 units
- acidification takes a long-time and a lot of cumulative N
- e.g. 100 lb N/ac N input x 23-yr ⇨ 1 pH unit drop
- relevant to economics of lime remediation – lime app should be viewed as capital investment

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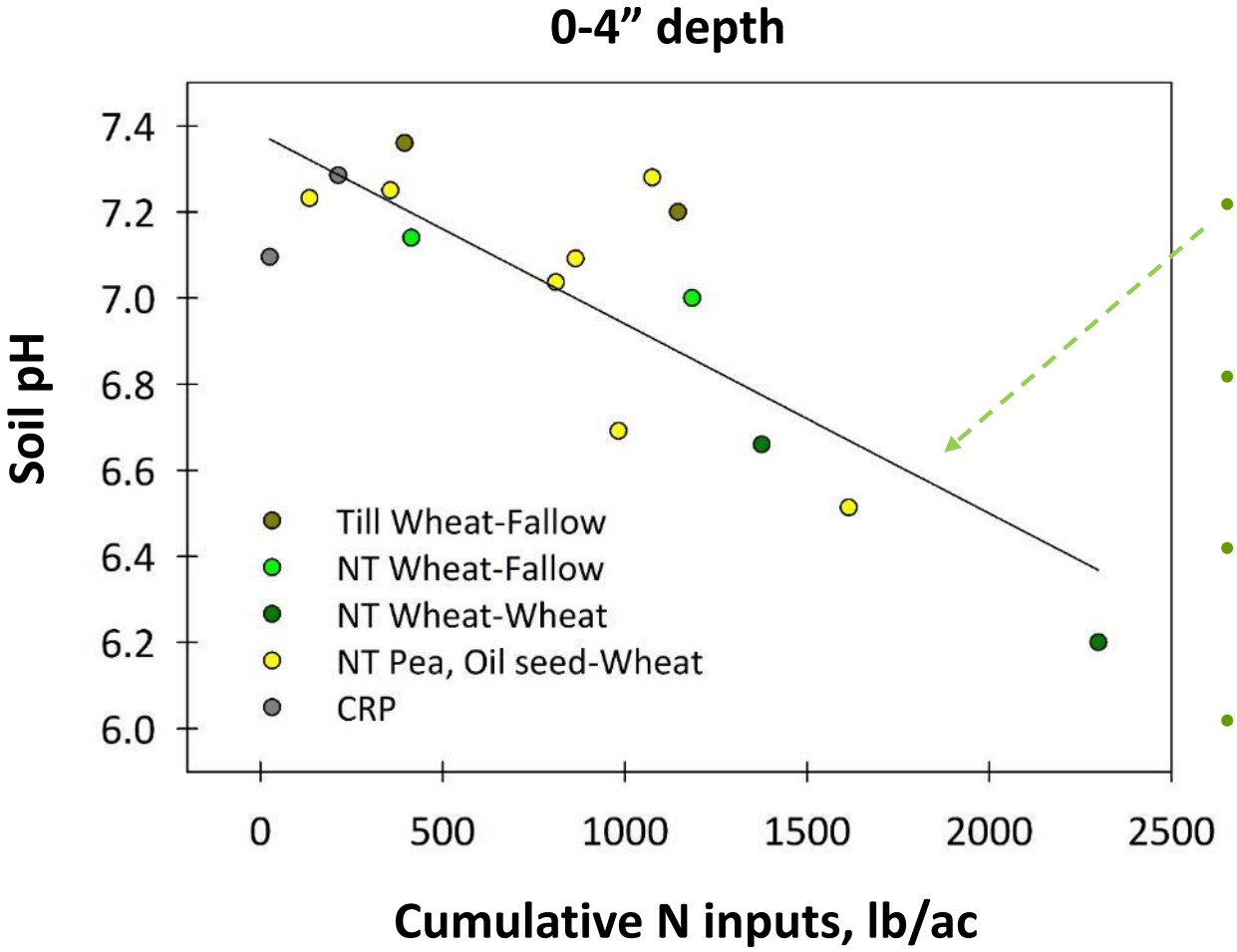

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Longevity of liming in Western Canada

R.A. Date et al. (eds.), Plant Soil Interactions at Low pH, 703–710, 1995.
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Longevity of liming in western Canada: Soil pH, crop yield and economics*

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Key words: acid soils, crop yield, economics, liming, longevity, soil pH

Abstract

In western Canada, approximately 2.0 million ha of cultivated soils are acid (pH < 6.0), but liming of these acid soils is seldom practised because of its high cost. Liming increases yield of the most important crops (wheat, barley, canola and legumes), but long-term economic returns have not been measured until this report. Field experiments were initiated in 1965 at Chedderville, Alberta (0, 2.2, 4.4, 6.6, 8.8 and 11.0 t lime ha^{-1}), in 1970 at Tomahawk, Alberta (0, 4.9 t lime ha^{-1}) and in 1963 at Scott, Saskatchewan (0, 6.1 and 9.1 t lime ha^{-1}). The original soil pH without lime was 5.4, 5.0 and 4.9 at Chedderville, Tomahawk and Scott, respectively. The test crops were alfalfa, barley and wheat. Single application of lime maintained increased soil pH and crop yield for 16 to 27 years. Crop yield increases from single applications of lime were similar with the years. Economic value of increased crop yield from lime was substantial at all sites. Because of this long-lasting effect, the cost of applying lime to an acid soil should not be considered a normal production cost, but rather a capital investment amortised over a long period.

Introduction

In Alberta and northern British Columbia, there are some 1.9 million ha of cultivated acid soils with estimated soil pH ≤6.0 (Penney et al., 1977). Minor areas are found in Saskatchewan and Manitoba. Acid soils are less suitable for crops than neutral or slightly alkaline soils and can reduce the yield of certain crops such as alfalfa at pH <6.0 and barley at pH <5.5 because of toxicity or nutritional problems (Elliott et al., 1973; Hoyt et al., 1974; Rice et al., 1977). Large crop yield responses from liming in Alberta have been shown on acid soils with barley, canola, grasses and legumes (Elliott et al., 1973; Penney et al., 1977). Soluble Al and Mn together with soil pH have been established as practical soil tests for soil acidity (Hoyt and Nyborg, 1987).

Despite intensive research on cropping of acid soils in Alberta, little of the 1.9 million ha area has been limed, nor have acidity-tolerant cultivars been developed. In the Prairie Provinces of Canada there is only one crop per year and yields are limited by lack of rain (350 to 500 mm precipitation annually). As well, the cost of lime is high and most acid soils are heavy-textured, requiring high rates of application. The needed frequency of re-liming is an open question. Hoyt and Hennig (1982) found that on three soils, in the Place River Region, yield increases from liming were sustained over an 8-year period even though soil pH declined.

Our objective was to find the long-term benefit to yield from a single liming and to compute its long-term economics.

Materials and methods

Experimental description

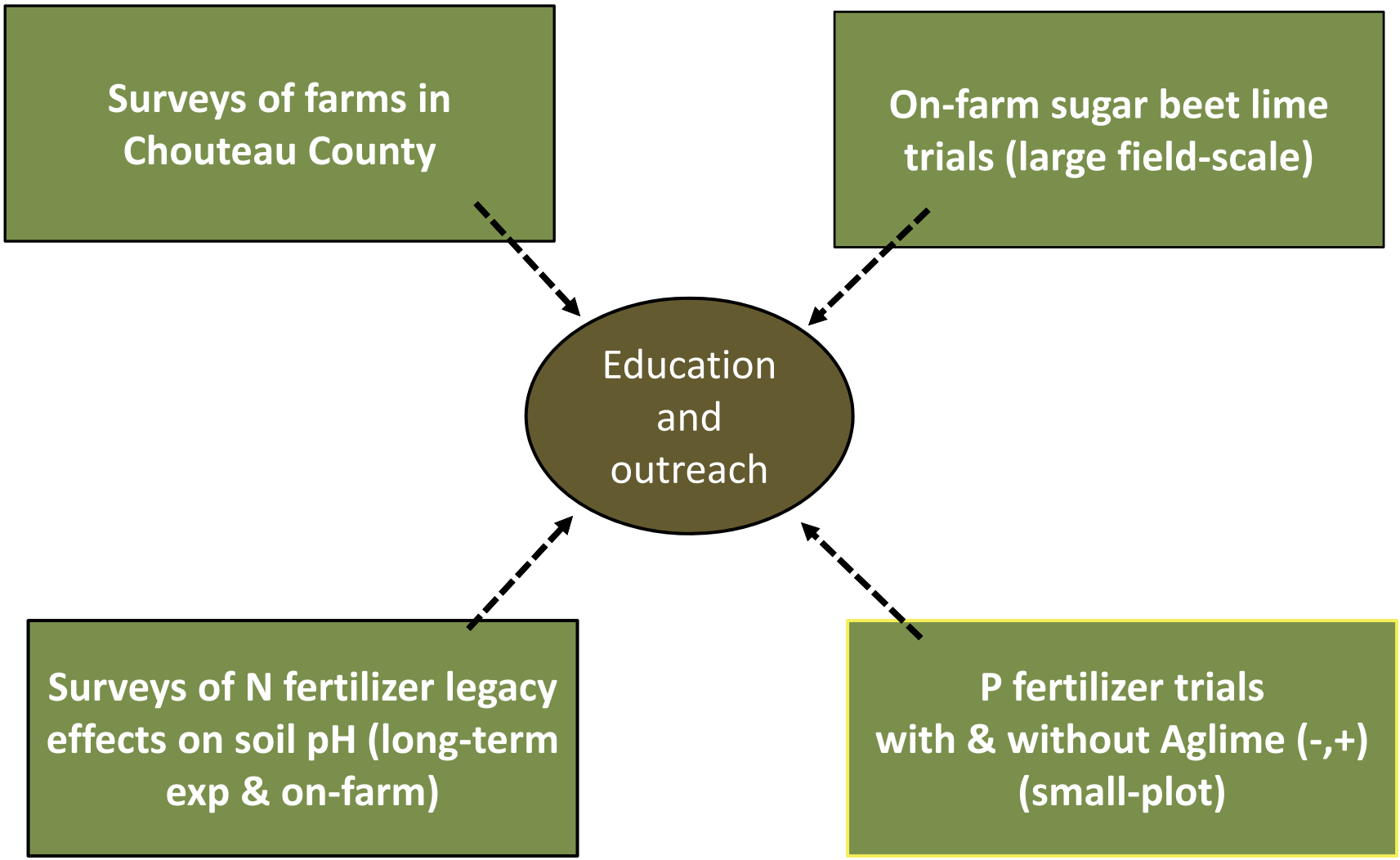
Three field experiments were conducted in Alberta (Chedderville and Tomahawk) and Saskatchewan

* Contribution no. 795.

"Single application of lime maintained increased soil pH and crop yield for 16 to 27 years. Crop yield increases from single applications of lime were similar with the years. Economic value of increased crop yield from lime was substantial at all sites. Because of this long-lasting effect, the cost of applying lime to an acid soil should not be considered a normal production cost, but rather a capital investment amortised over a long period."

NE Montana – Daniels County

Project activities



Why interested in seed-placed P? OK studies

Control (pH 4.9)

2-ton Aglime/ac (pH 5.6)

Summary

- large growth and yield benefits from seed-placed P in winter wheat observed at field sites with acidic soil – pictures courtesy Lollato et al., 2013

Why interested in seed-placed P? OK studies

Control (pH 4.9)

50 lb TSP (0-45-0)/ac

Summary

- large growth and yield benefits from seed-placed P in winter wheat observed at field sites with acidic soil – pictures courtesy Lollato et al., 2013

Aglime applic had a big effect on durum growth

Highwood Bench study, 2018

+ Aglime
soil pH 6.1

+	90	60	30	15	0
-	90	60	30	15	0

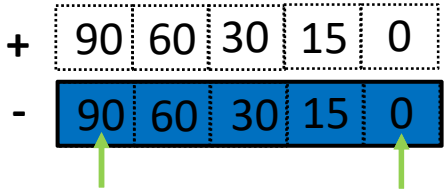
- Aglime
soil pH 4.4

Seed-placed P can mitigate Al toxicity

Durum trials (cv. Alzada) – Highwood Bench

0 P (tissue P = 0.17%)

90 P_2O_5 (tissue P = 0.37%)



Soil P test was very high (Olsen P - 50 ppm) !

Seed-placed P can mitigate Al toxicity

Durum trials (cv. Alzada) – Highwood Bench

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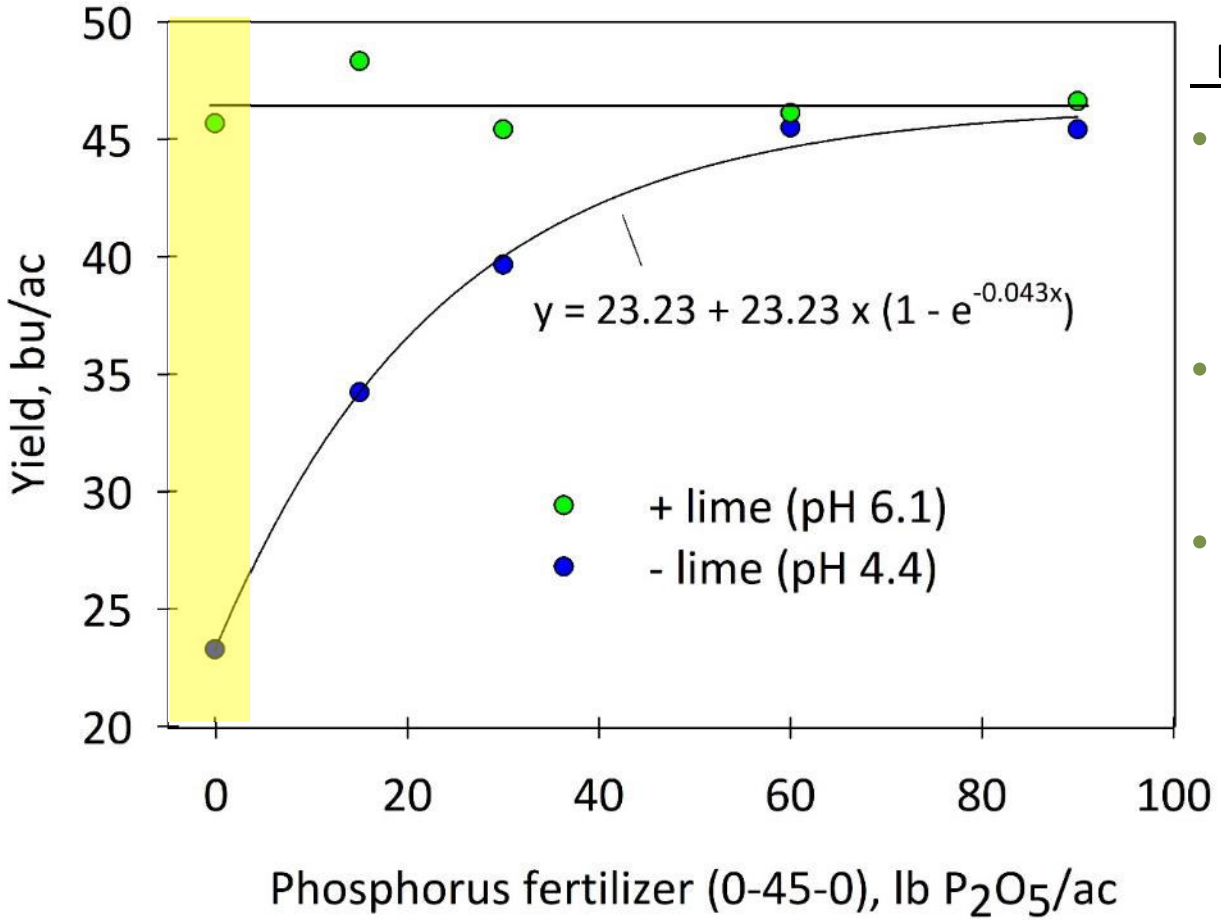

Durum trials (cv. Alzada) - 2018

- soil acidity effect = 50% yield loss relative to Aglime (5 ton/ac) = + control
- + P fertilizer = + Aglime yield & 22 bu ac^{-1} response **!**
- Conclusion: + P fertilizer is short-term solution, not remediation, results are consistent with Kansas study

Summary – take home messages

- cropland surface soils are becoming more acidic in Montana & N fertilizer inputs are a big reason
- Al toxicity can happen if soil pH < 5 & likely if pH < 4.5; in the field “the world is a patchy place”
- pulse crops (particularly lentils) appear to be very sensitive, N fixation/nodule – response to lime app observed in pulses
- management options exist to cope/adapt to this problem (seed-placed P, Al tolerant genotypes) over short-term, but liming (= capital investment) is required to *remediate acidity* (long-term)