Potassium for corn: Soil test K and yield inconsistences

John S. Breker
Soil Scientist, AGVISE Laboratories

2018 AGVISE Soil Fertility Seminars
January 9-11, 2018

AGVISE LABORATORIES

johnb@agvise.com
@jsbreker

Potassium deficiency in corn

Deficiency symptoms

- Chlorosis, necrosis of outer leaf margin

Mobile nutrient in plant

- Expressed in lower leaves

AGVISE LABORATORIES

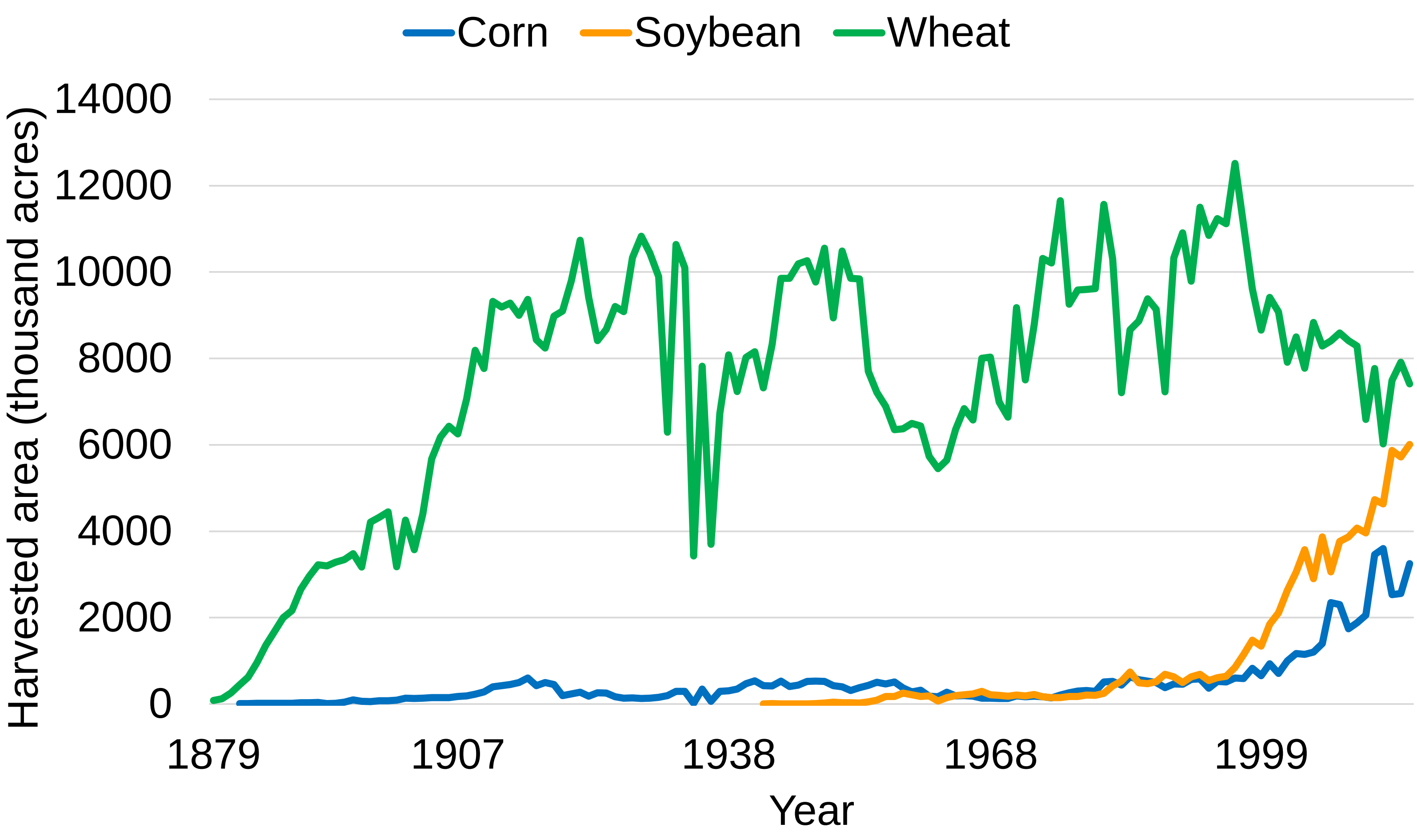
Potassium deficiency in corn

Near Lisbon, ND (Aug. 2016)
Soil K: 47 ppm

<u>Plot 106</u>
0 K_2O/ac
174 bu/ac

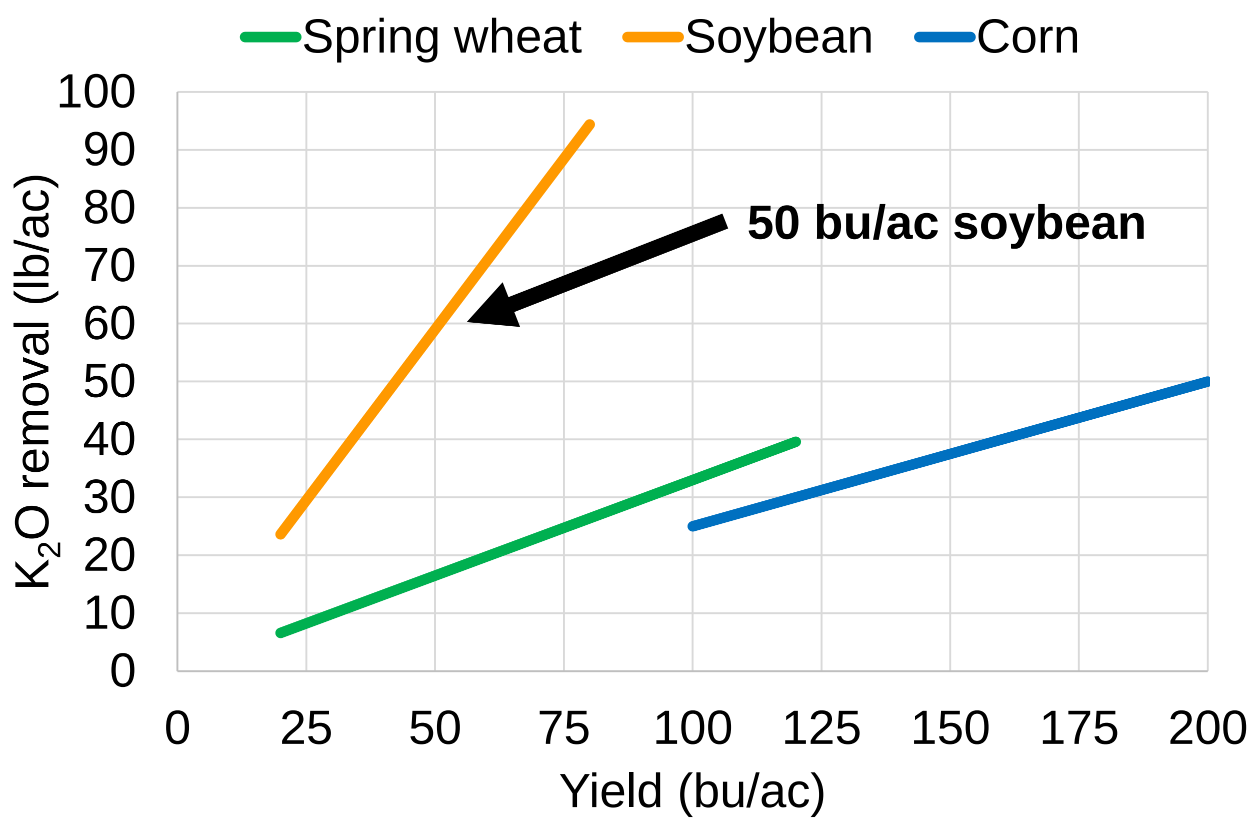
<u>Plot 107</u>
150 K_2O/ac
226 bu/ac

Acreage changes in North Dakota



USDA-NASS. 2017. Quick stats database. https://quickstats.nass.usda.gov/ (accessed 3 Mar. 2017).

Typical grain K removal for principal crops at various yields



Change to corn/soybean production removing K at twice the rate

IPNI. 2014. IPNI estimates of nutrient uptake and removal. Intl. Plant Nutr. Inst., Norcross, GA. http://www.ipni.net/article/IPNI-3296 (accessed 6 Mar. 2017).

Revisiting potassium in North Dakota

- Increase in corn/soybean acreage
  - Higher yields, higher K export
- More soil tests below soil K critical level
  - 1980: 3% of samples (Nelson, 1980)
  - 2010: 17% of samples (Fixen et al., 2010)
  - 2015: 16% of samples (IPNI, 2016)
- Potash price spike

  ~$150/ton (1980-early 2000s)

  $853/ton (2008)
- General lack of soil K research (high native K fertility)

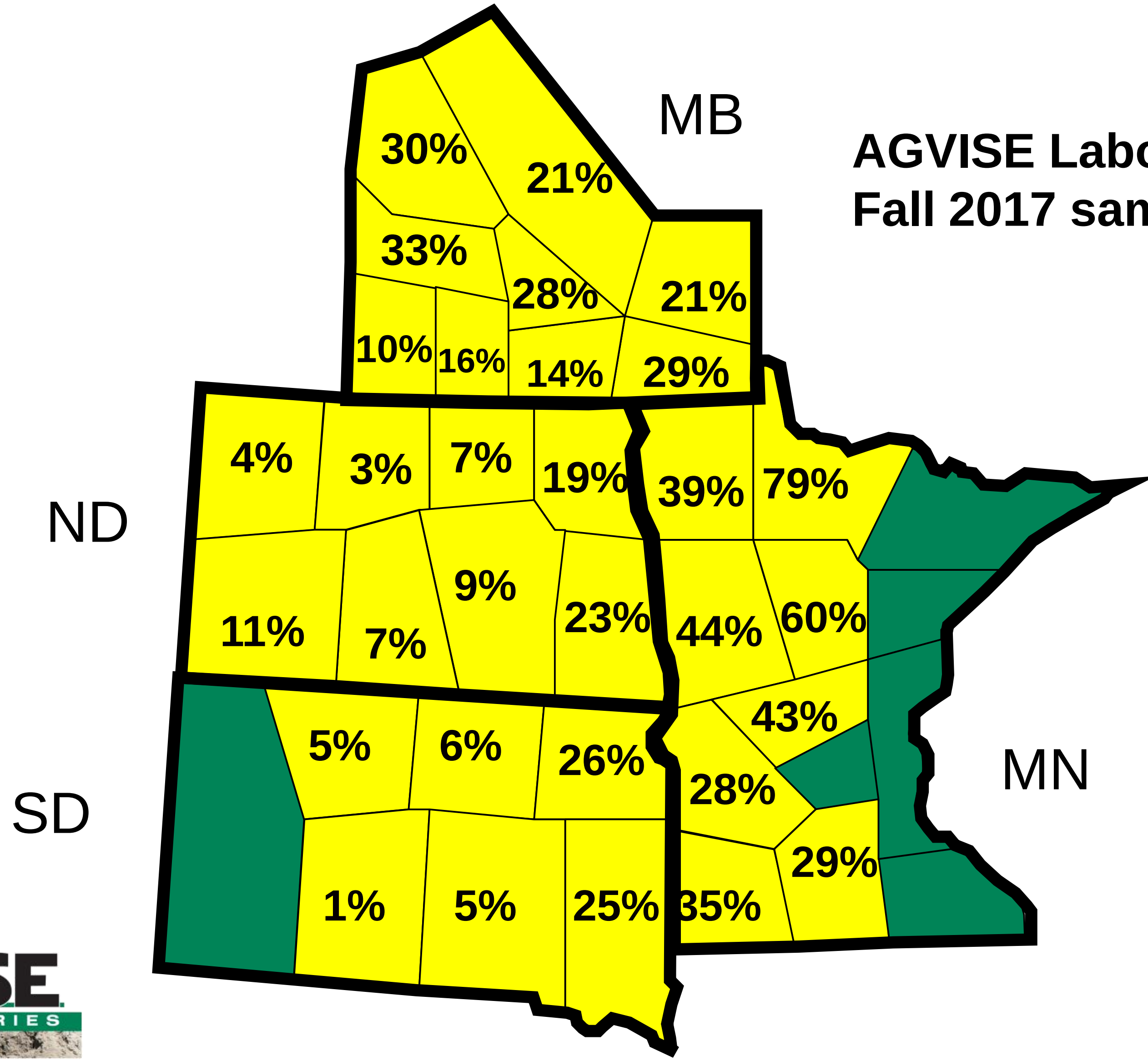
Fixen, P.E., T.W. Bruulsema, T.L. Jensen, R. Mikkelsen, T.S. Murrell, S.B. Phillips, Q. Rund, and W.M. Stewart. 2010. The fertility of North American soils, 2010. Better Crops 94(4): 6–8.

IPNI. 2016. Soil test levels in North America, 2015. Intl. Plant Nutr. Inst., Norcross, GA. http://soiltest.ipni.net/ (accessed 22 Feb. 2017).

Nelson, W.L. 1980. Soil test summaries and their interpretation. Better Crops 63(4): 6–10.

Soil samples with less than 150 ppm K

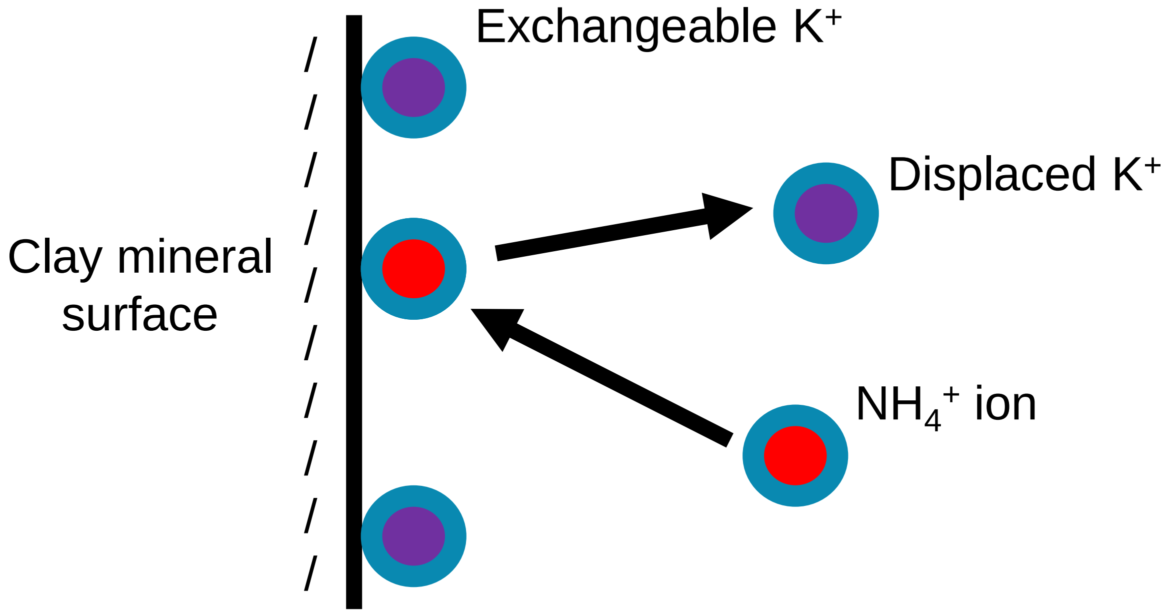
AGVISE Laboratories
Fall 2017 samples (0-6")



Soil testing for potassium

Standard method in North Central region:

1.0 M NH_4OAC (pH 7) extraction on dry soil



Scrutiny of soil testing method

Standard method:

1.0 M NH_4OAC (pH 7) extraction on dry soil

- Effect of sample drying on extractable K
- Inconsistent yield responses to K fertilization
- Plant availability of nonexchangeable K
- Seasonal soil test K variation

AGVISE LABORATORIES

Objectives

1. **Evaluate corn yield response to K fertilization**
   - Broadcast potash (KCl, 0-0-60)
   - Six rates: 0 to 150 lb K_2O acre^{-1}
2. **Identify adequate soil K test method**
   - Determine STK critical level (STK_{CL})
3. **Assess seasonal soil K variation**

Potassium deficiencies exist in NoDak!

Yield response prediction by soil test class

Frequency of yield response prediction by dry soil K test					
	Soil K test class (mg kg^{-1})				
	VL	**L**	**M**	**H**	**VH**
	0-40	**41-80**	**81-120**	**121-160**	**161+**
Number of sites in soil test class	0	3	6	5	5
Number of sites with significant yield response	---	2	2	2	1
Probability of yield response	---	67%	33%	40%	20%

- Six of 14 sites below 160 mg kg^{-1} DK had significant yield increases
- Drier years of 2015 and 2016 had more inconsistences
- Two of six responsive sites had significant yield decreases at 150 lb K_2O $acre^{-1}$

AGVISE LABORATORIES

Breker, J.S. 2017. Recalibration of soil potassium test for corn in North Dakota. M.S. thesis. North Dakota State Univ., Fargo, ND.

Soil test methods evaluated

Exchangeable K

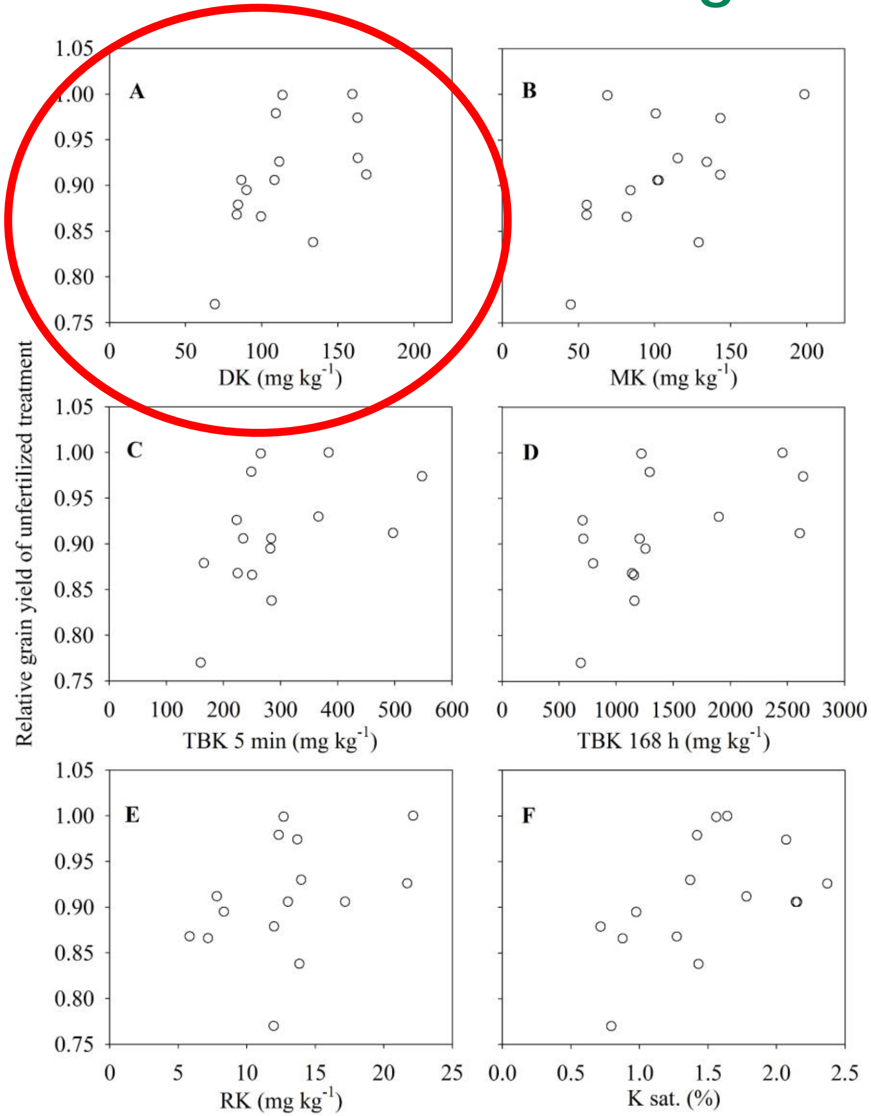
- Ammonium acetate
  - Air-dried soil
  - Field-moist soil
  - Interpretation using sufficiency and BCSR approaches

Exchangeable K AND nonexchangeable K

- Ion-exchange resin capsule (UNIBEST Inc.)
  - 168-hour incubation
- Sodium tetraphenylboron (Cox et al., 1999)
  - 5-min, most reactive nonexchangeable K
  - 168-hour, total nonexchangeable K

Cox, A.E., B.C. Joern, S.M. Brouder, and D. Gao. 1999. Plant-available potassium assessment with a modified sodium tetraphenylboron method. Soil Sci. Soc. Am. J. 63(4):902–911.

Soil test K and corn grain yield response



Standard method (NH_4OAc on air-dry soil) had best correlation with yield response

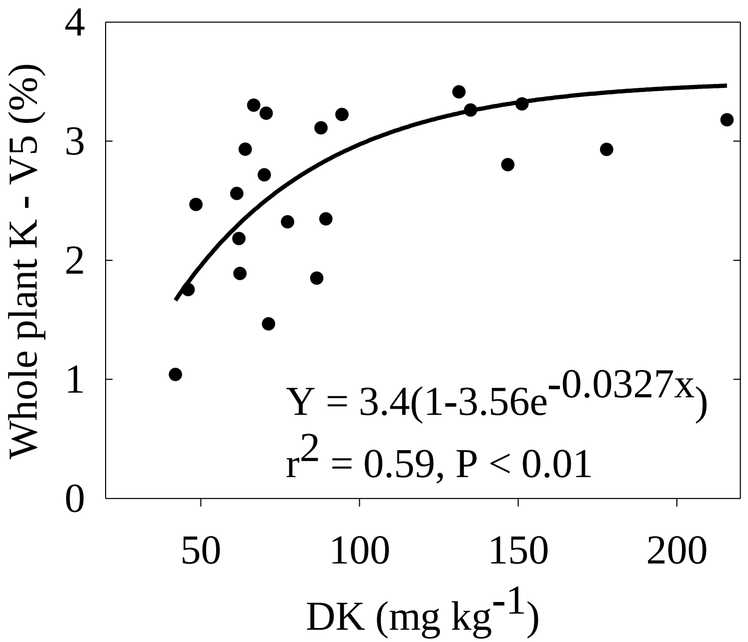
Linear-plateau model of relative corn yield and plant-available K methods			
Method†	**STK at plateau**	**r^2**	**P>F**
Air-dry K	93	0.49	0.02
Field-moist K	61	0.47	0.02
TBK 5 min	333	0.33	0.09
TBK 168 h	2028	0.30	0.12
Resin K	NA	0.16	0.14
K sat. (%)	1.56	0.42	0.04

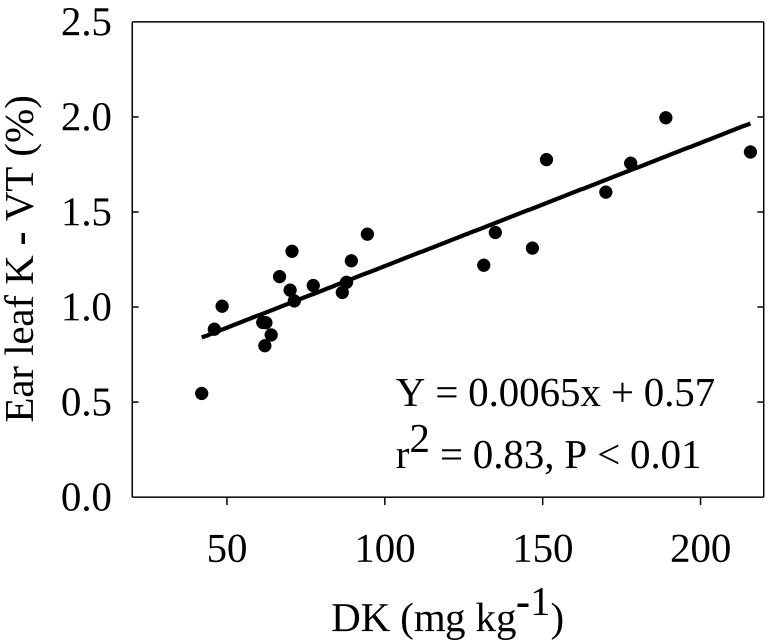
† DK and MK are 1 M NH4OAC extractable K on air-dry and field-moist soil, respectively; TBK is tetraphenylboron extractable K; RK is resin extractable K; K. sat is K saturation.

AGVISE LABORATORIES

Breker, J.S. 2017. Recalibration of soil potassium test for corn in North Dakota. M.S. thesis. North Dakota State Univ., Fargo, ND.

Soil test K and plant tissue K



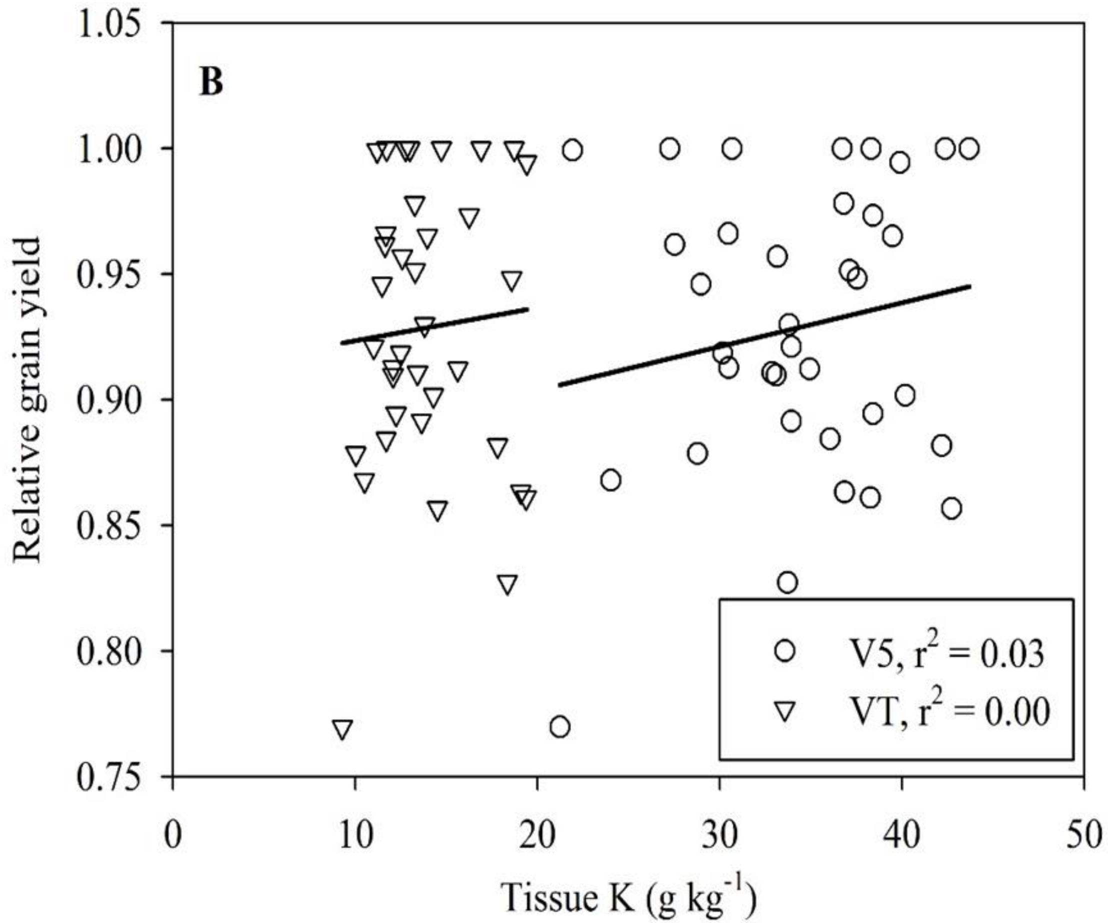


Soil test K had strong correlations with plant tissue K
at growth stages V5 and VT

AGVISE LABORATORIES

Breker, J.S. 2017. Recalibration of soil potassium test for corn in North Dakota. M.S. thesis. North Dakota State Univ., Fargo, ND.

Unfortunately, plant tissue K did not relate well with grain yield response…



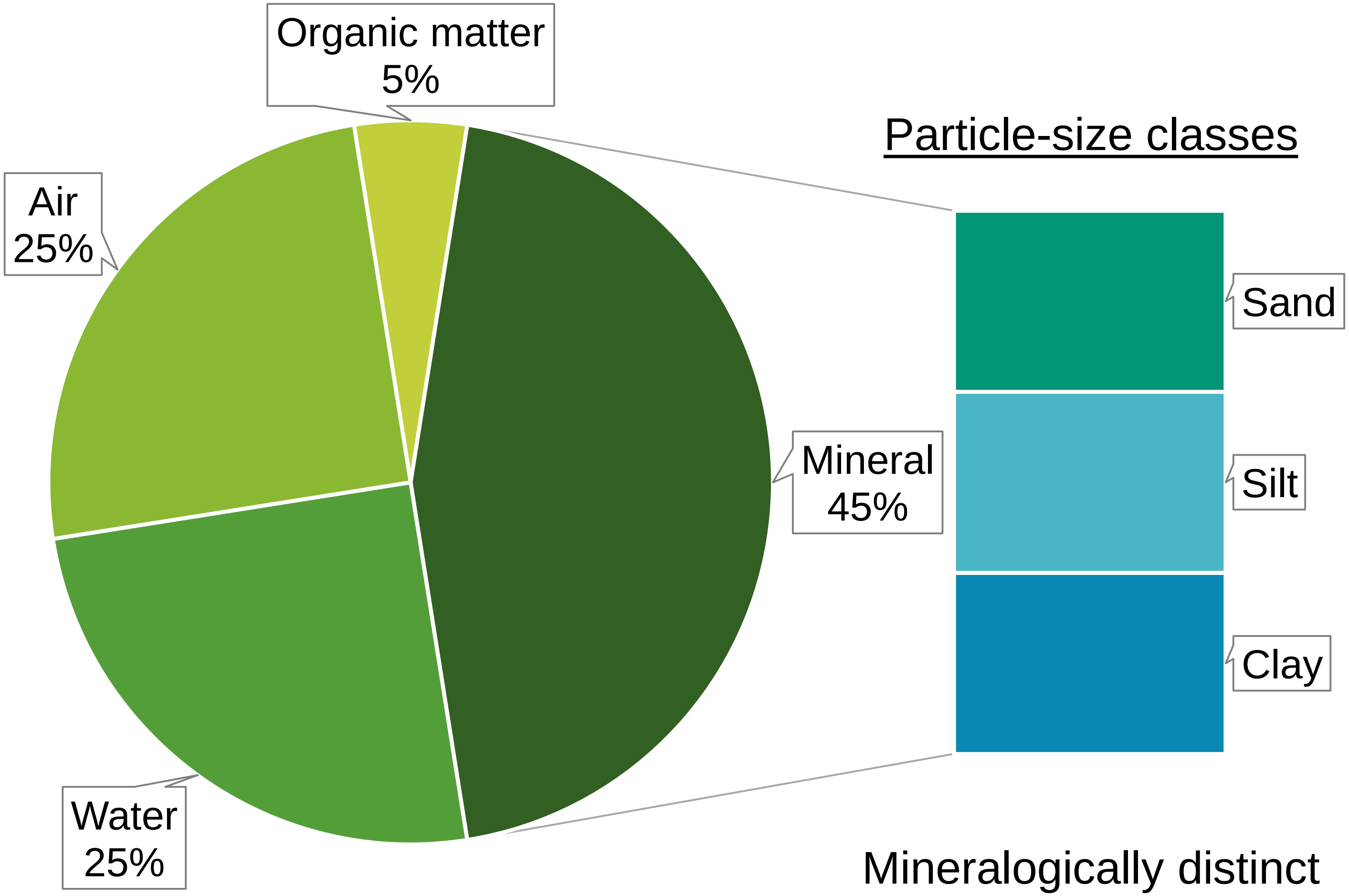
Breker, J.S. 2017. Recalibration of soil potassium test for corn in North Dakota. M.S. thesis. North Dakota State Univ., Fargo, ND.

Bury our heads or look deeper?

Soil mineralogy and potassium: SOIL 101 refresher

This sleep aid has not been approved by the U.S. Food and Drug Administration (FDA).

Quick review: Soil components

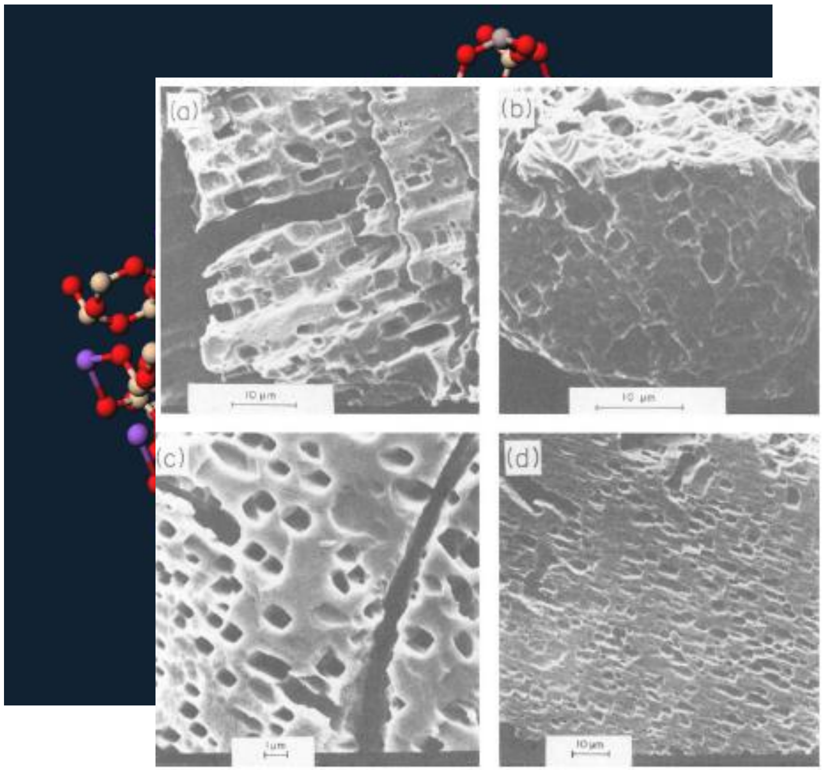


Mineralogically distinct

Primary K minerals

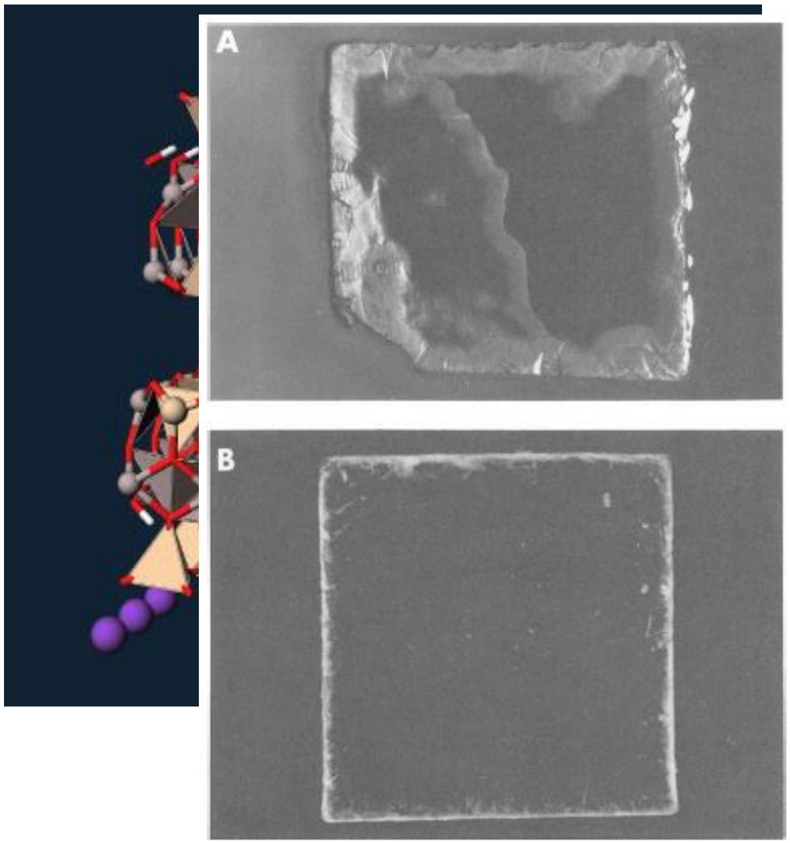
<u>K-feldspar</u>

Si-O framework



<u>Mica</u>

Al-Si-O sheets



Barak, P, and E.A. Nater. 1997-2017. The Virtual Museum of Minerals and Molecules. Online resource. http://virtual-museum.soils.wisc.edu
Fanning, D.S., V.Z. Keramidas, and M.A. El-Desoky. 1989. Micas. In: Dixon, J.B. and S.B. Weed, editors, Minerals in Soil Environments. SSSA Book Ser. 1. 2nd ed. SSSA, Madison, WI. p. 551–634.
Huang, P.M. 1989. Feldspars, olivines, pyroxenes, and amphiboles. In: Dixon, J.B. and S.B. Weed, editors, Minerals in Soil Environments. SSSA Book Ser. 1. 2nd ed. SSSA, Madison, WI. p. 975–1050.

Smectite and Vermiculite
(swelling/expanding)

2:1 clay layers

- Two tetrahedral Si-O layer
- One octahedral Al-O layer

Expansible interlayer

- Hydrated interlayer cations
- Hydrated = water around cation, bigger cation size

Expansible interlayer space

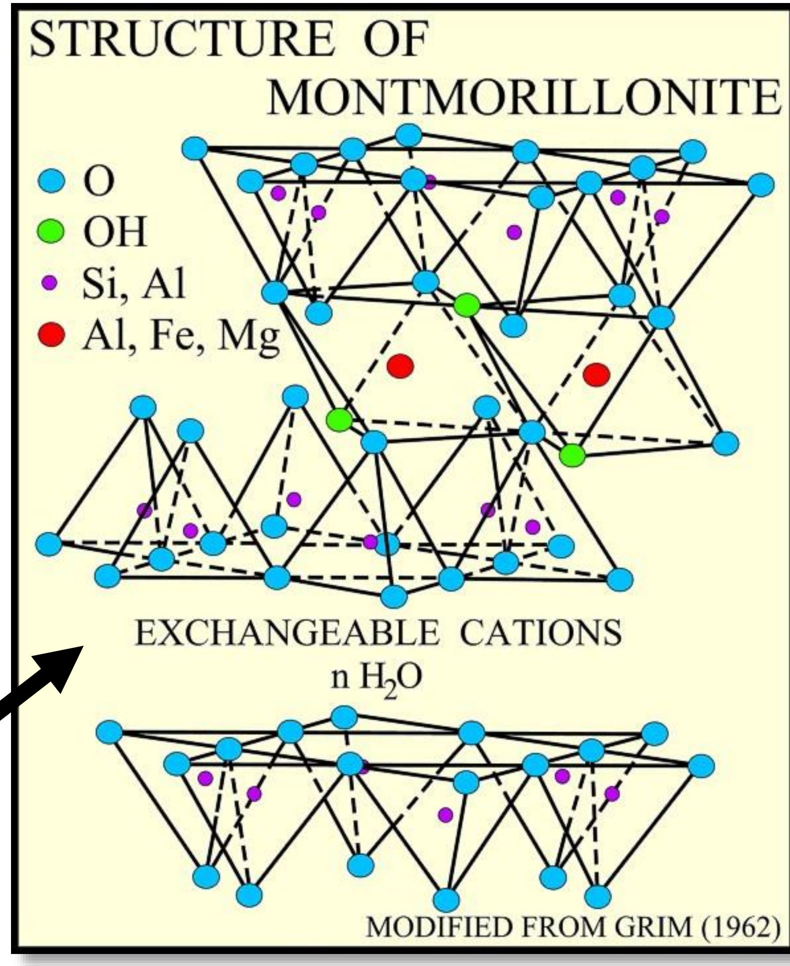


Image from https://pubs.usgs.gov/of/2001/of01-041/htmldocs/clays/smc.htm (verified 27 Oct. 2017)

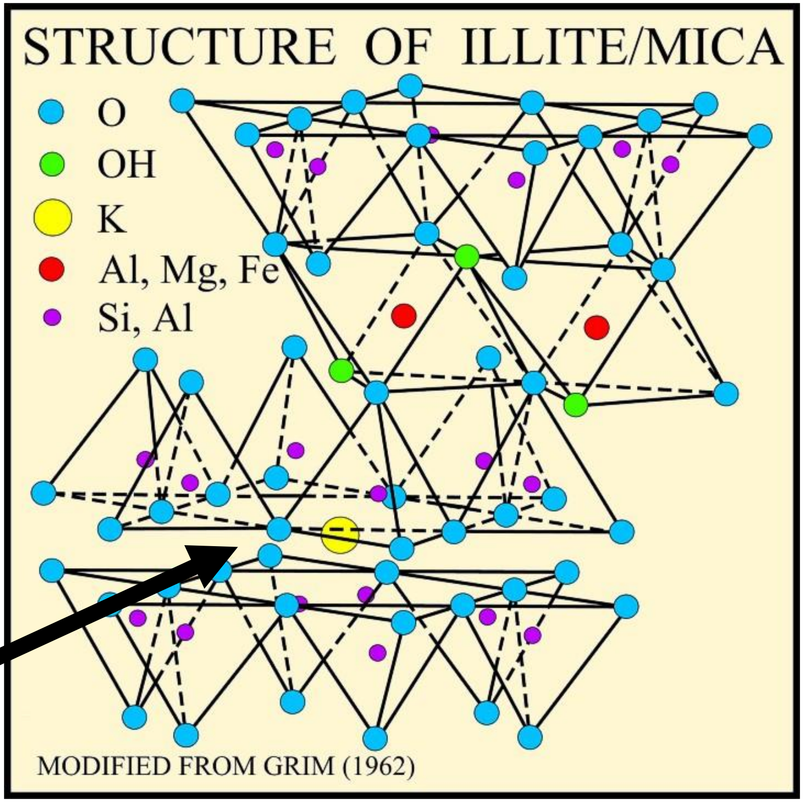
Illite
(non-expanding)

2:1 clay layers

Higher layer charge than vermiculite or smectite

Interlayer collapsed

- **Dehydrated interlayer cations**



Collapsed interlayer
Fixed K

Image from https://pubs.usgs.gov/of/2001/of01-041/htmldocs/clays/illite.htm (verified 27 Oct. 2017)

Clay layer charge

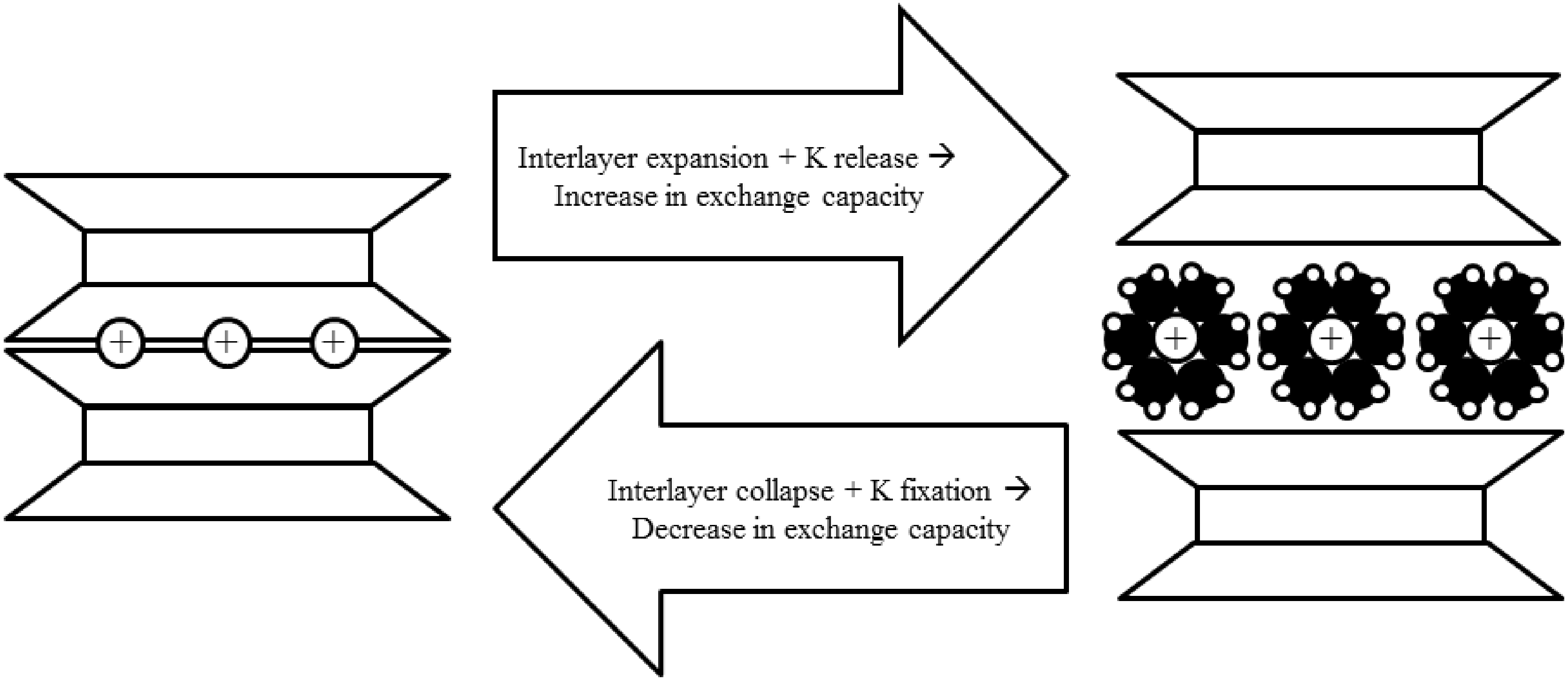
- Positive cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) balance negative clay layer charge
- Low layer charge → more expansion

	Smectite		**Vermiculite**	**Illite/mica**
Layer charge (charge/half unit cell)	-0.2 to -0.6		-0.6 to -0.9	-0.75 to -1.0
Expansibility	High		Moderate	None

Gray area between smectite and vermiculite.
Transitional minerals, some refer to high-charge smectites (beidellite).

Ransom, M.D., A. Florence, M. Thompson, and R. Southard. 2017. How do mineralogy and soil chemistry impact how closely potassium soil test changes are related to mass balance? In: Murrell, T.S. and R.L. Mikkelsen, editors, Frontiers of Potassium Science Conference. Rome, Italy. 25-27 Jan. 2017. Intl. Plant Nutr. Inst., Peachtree Corners, GA. p. O189-O196.

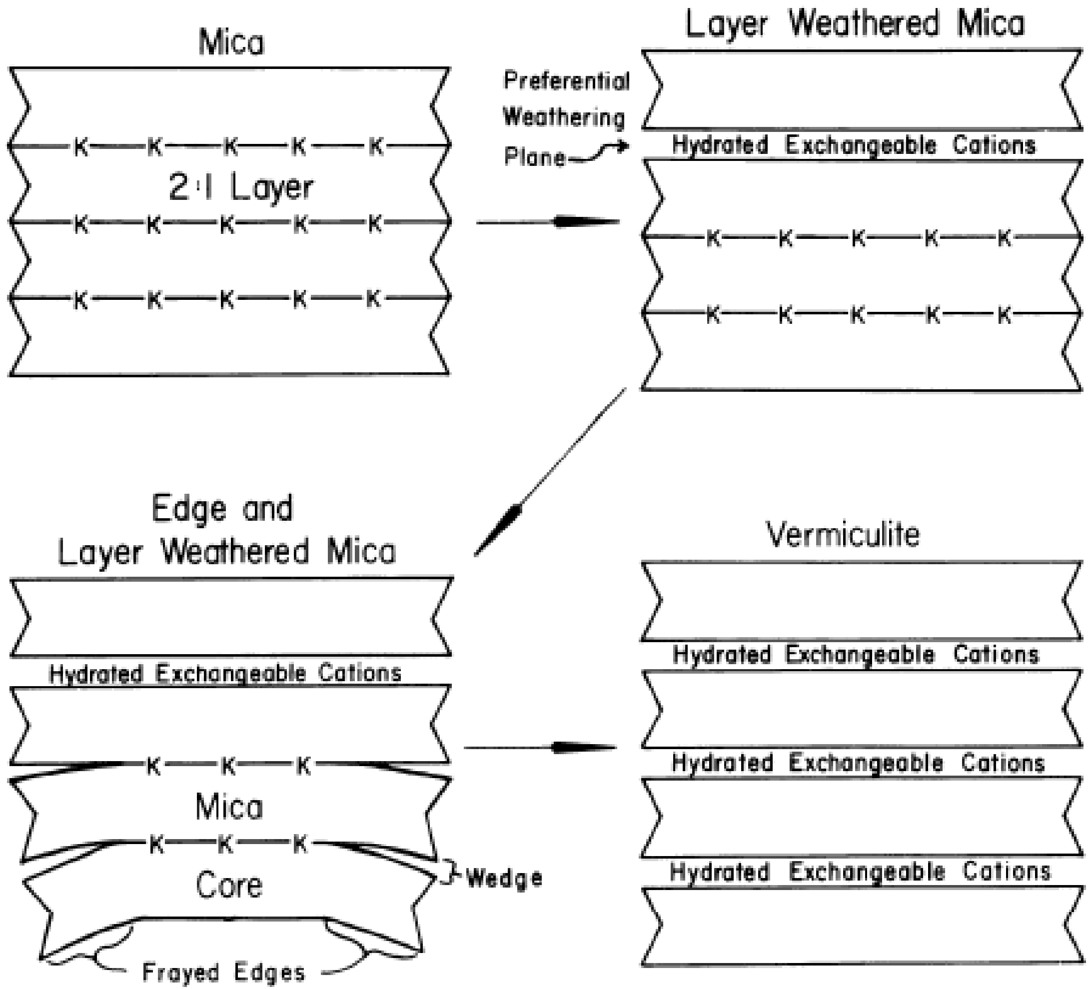
K fixation: conceptual model



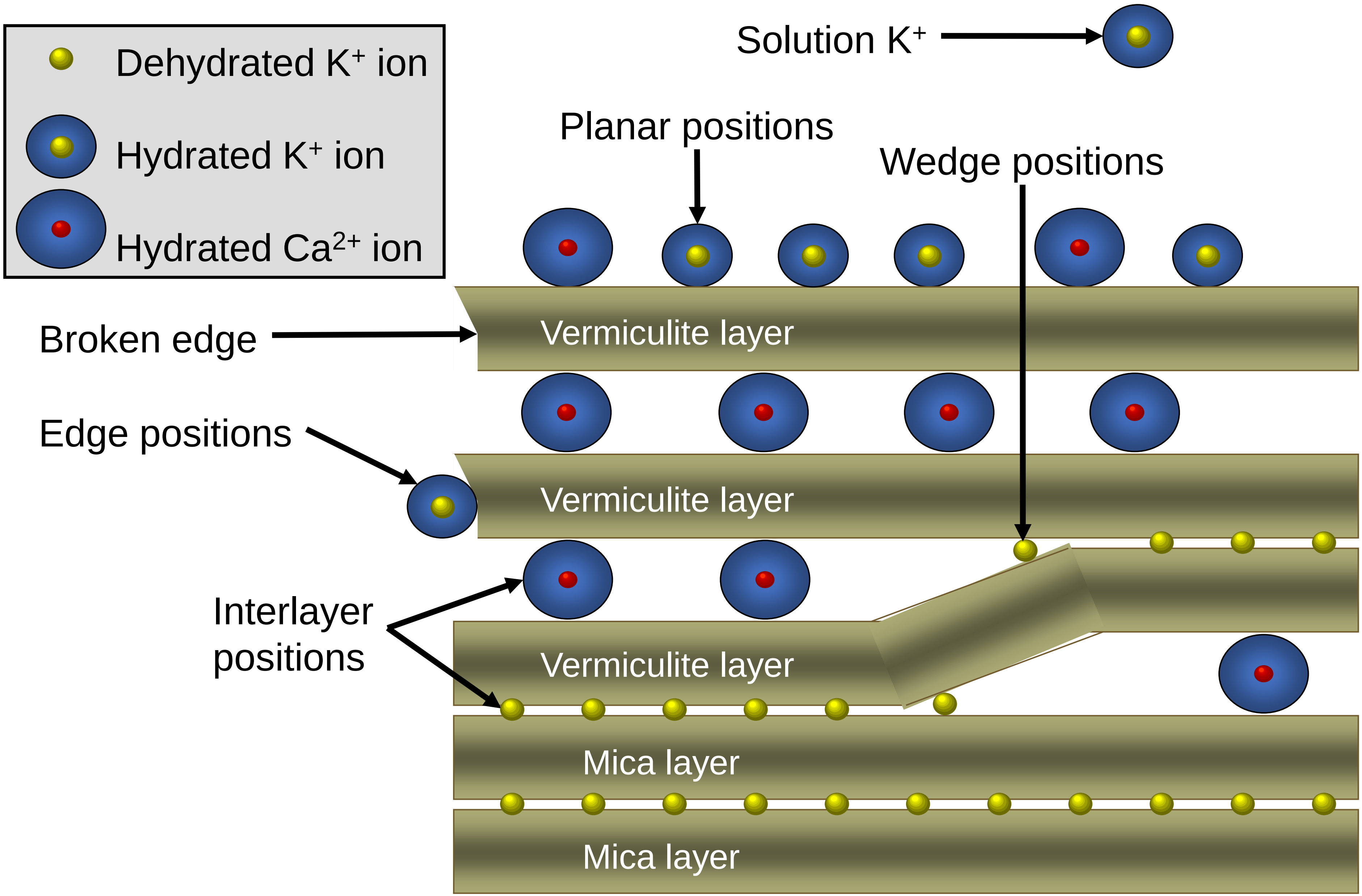
$$\text{K fixation} = \text{interlayer K} + (F_{contraction} > F_{expansion})$$

Ransom, M.D., A. Florence, M. Thompson, and R. Southard. 2017. How do mineralogy and soil chemistry impact how closely potassium soil test changes are related to mass balance? In: Murrell, T.S. and R.L. Mikkelsen, editors, Frontiers of Potassium Science Conference. Rome, Italy. 25-27 Jan. 2017. Intl. Plant Nutr. Inst., Peachtree Corners, GA. p. O189-O196.

Mica weathers to other clays: existing as mixed-layer intergrades



Fanning, D.S., V.Z. Keramidas, and M.A. El-Desoky. 1989. Micas. In: Dixon, J.B. and S.B. Weed, editors, Minerals in Soil Environments. SSSA Book Ser. 1. 2nd ed. SSSA, Madison, WI. p. 551–634.



Murrell, T.S. 2014. The potassium sandwich: Is it nutritional? In: Lee, J.T., editor, AGVISE Laboratories Soil Fertility Seminars. Granite Falls, MN; Watertown, SD; and Grand Forks, ND. 7-9 Jan. 2014. AGVISE Laboratories, Northwood, ND.

Rich, C.I. 1968. Mineralogy of soil potassium. In: Kilmer, V.J., S.E. Younts, and N.C. Brady, editors, The Role of Potassium in Agriculture. ASA, CSSA, and SSSA, Madison, WI. p. 79–108.

Potassium availability

How does K^+ get to the root?

Soil K cycle: from mineral to root

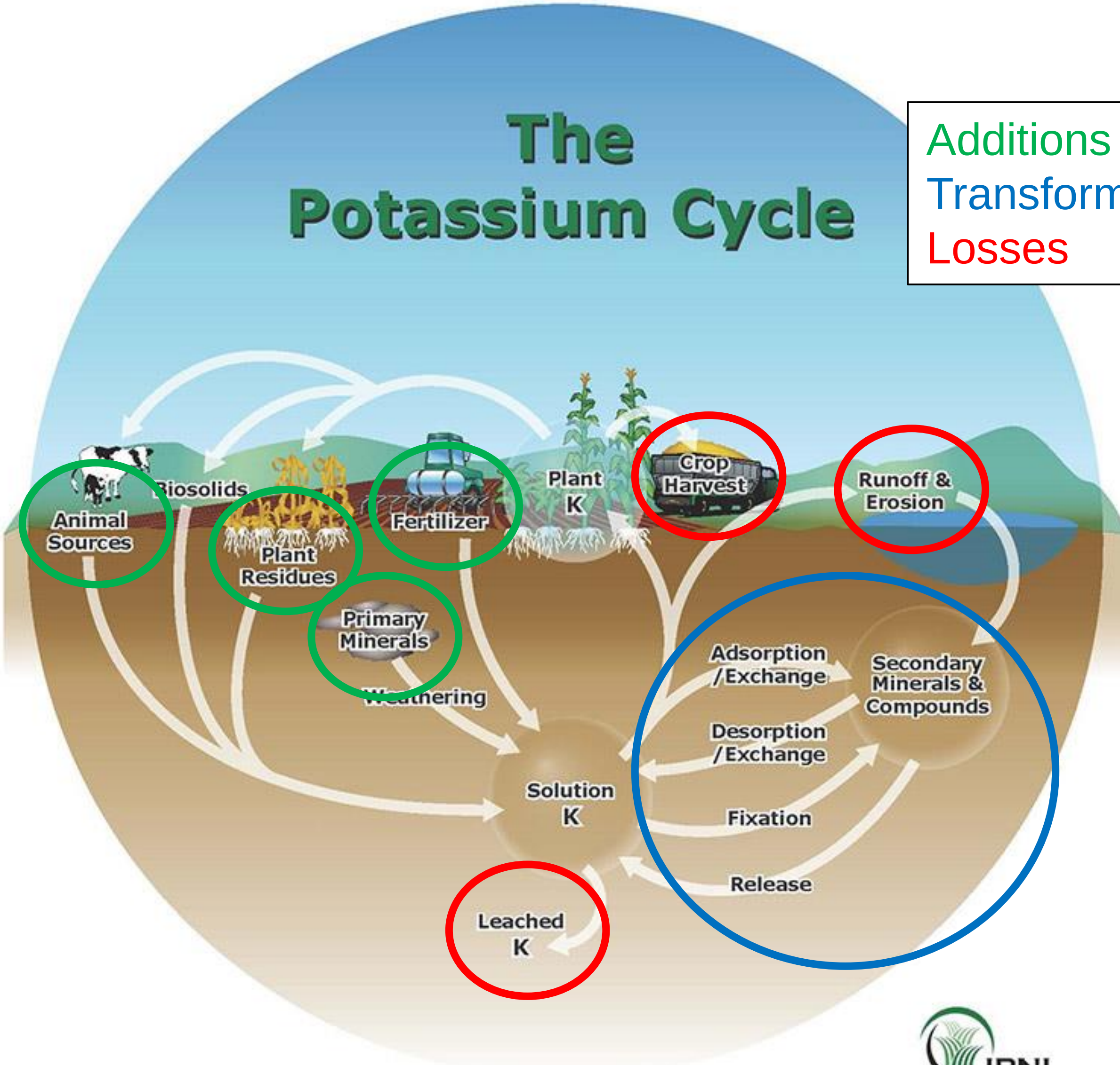
Plant roots only take up K^+ from soil solution

Whatever the K source:

- fertilizer
- manure/residue
- mineral

K^+ must enter soil solution

Soil K reactions are dynamic



Additions
Transformations
Losses

AGVISE LABORATORIES

IPNI International Plant Nutrition Institute

Factors affecting soil K availability

Static

- Soil texture
  - CEC
  - Soil water content
- Soil organic matter
- Mineralogy
  - K-feldspar
  - Smectite, illite, etc.

Dynamic

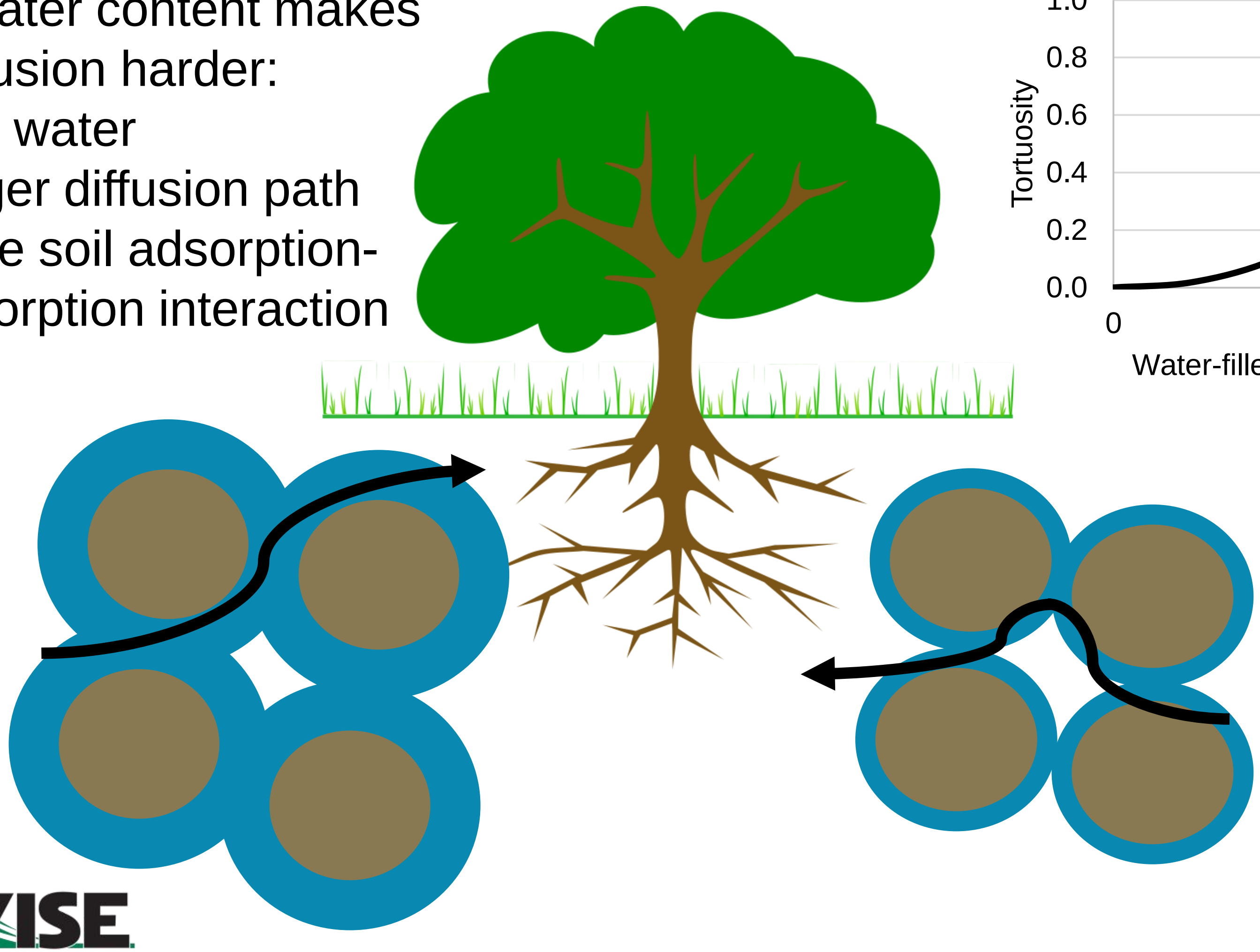
- Soil water content
  - K diffusion
  - K fixation/release
- Addition/removal
  - Fertilizer K
  - Crop K uptake
  - Crop residue K return

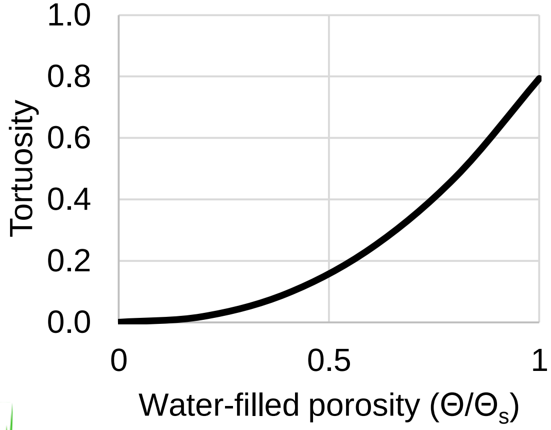
AGVISE LABORATORIES

K^+ diffuses to plant roots through water films

Low water content makes K^+ diffusion harder:

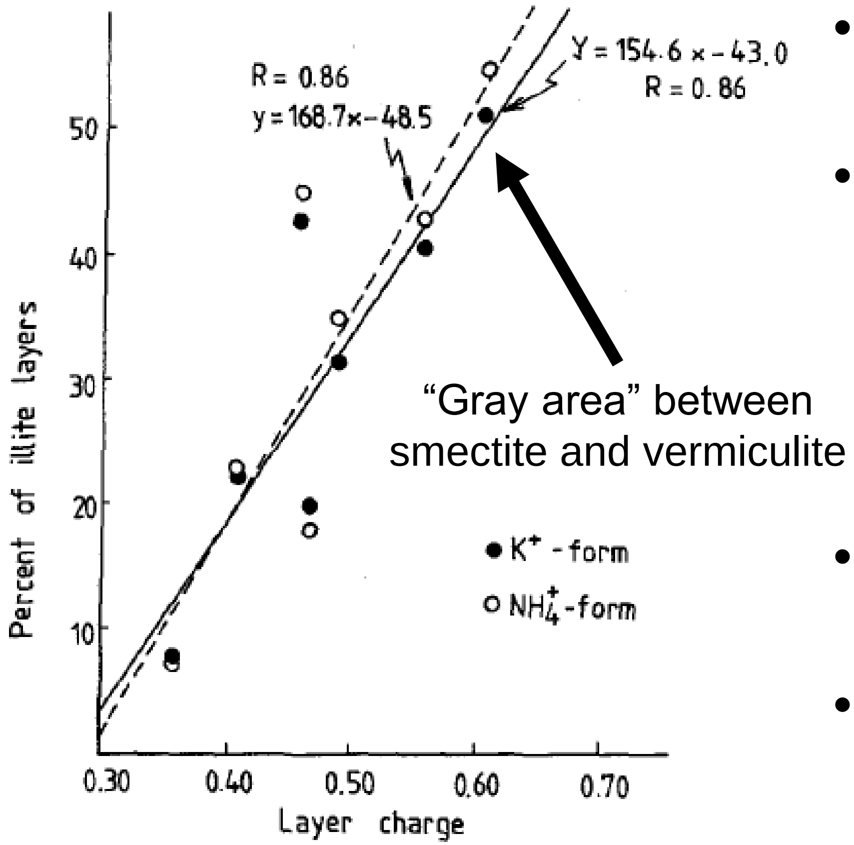
- less water
- longer diffusion path
- more soil adsorption-desorption interaction





Millington, R.J., and J.P. Quirk. 1961. Permeability of porous solids. Trans. Faraday Soc. 57:1200–1207.
Zeng, Q., and P.H. Brown. 2000. Soil potassium mobility and uptake by corn under differential soil moisture regimes. Plant Soil 221(2):121–134.

Wetting/drying cycles promote K fixation



- Wet/dry cycles can convert smectite to illite
- Redistribution of interlayer cations, allowing layer collapse

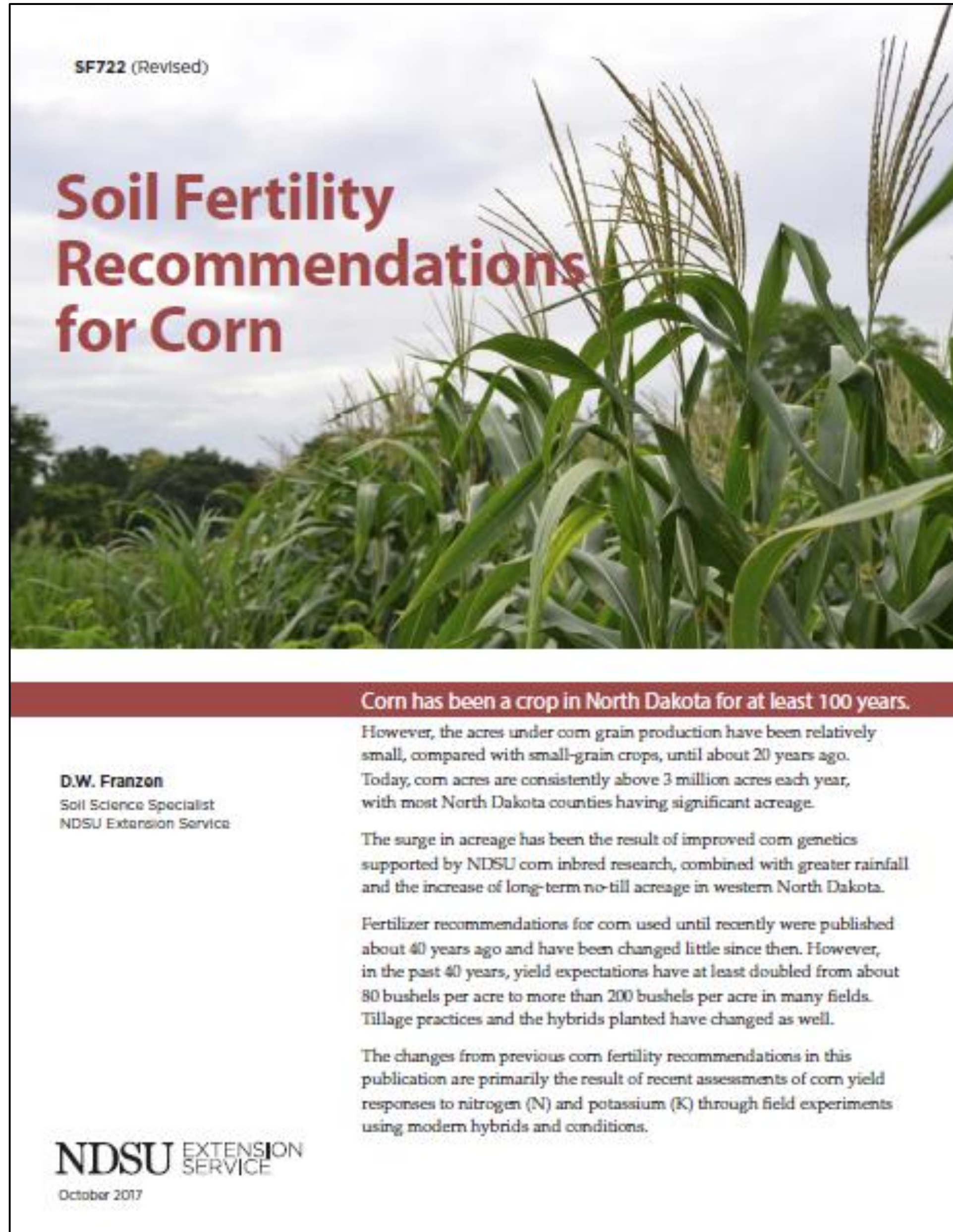
- Greater for high layer-charge smectite (beidellite)
- Beidellite identified in Red River Valley

Badraoui, M., P.R. Bloom, and R.H. Rust. 1987. Occurrence of high-charge beidellite in a Vertic Haplaquoll of northwestern Minnesota. Soil Sci. Soc. Am. J. 51(14): 813–818.
Sucha, V., and V. Siranova. 1991. Ammonium and potassium fixation in smectite by wetting and drying. Clays and Clay Miner. 39(5): 556–559.
Zeng, Q., and P.H. Brown. 2000. Soil potassium mobility and uptake by corn under differential soil moisture regimes. Plant Soil 221(2):121–134.

New from NDSU October 2017

<u>Resulting from</u>

- Recalibration of potassium soil test for corn in North Dakota (2014-2016)
- Soil mineralogical survey of North Dakota (2014-2017)



SF722 (Revised)

Soil Fertility Recommendations for Corn

Corn has been a crop in North Dakota for at least 100 years.

However, the acres under corn grain production have been relatively small, compared with small-grain crops, until about 20 years ago. Today, corn acres are consistently above 3 million acres each year, with most North Dakota counties having significant acreage.

The surge in acreage has been the result of improved corn genetics supported by NDSU corn inbred research, combined with greater rainfall and the increase of long-term no-till acreage in western North Dakota.

Fertilizer recommendations for corn used until recently were published about 40 years ago and have been changed little since then. However, in the past 40 years, yield expectations have at least doubled from about 80 bushels per acre to more than 200 bushels per acre in many fields. Tillage practices and the hybrids planted have changed as well.

The changes from previous corn fertility recommendations in this publication are primarily the result of recent assessments of corn yield responses to nitrogen (N) and potassium (K) through field experiments using modern hybrids and conditions.

D.W. Franzen
Soil Science Specialist
NDSU Extension Service

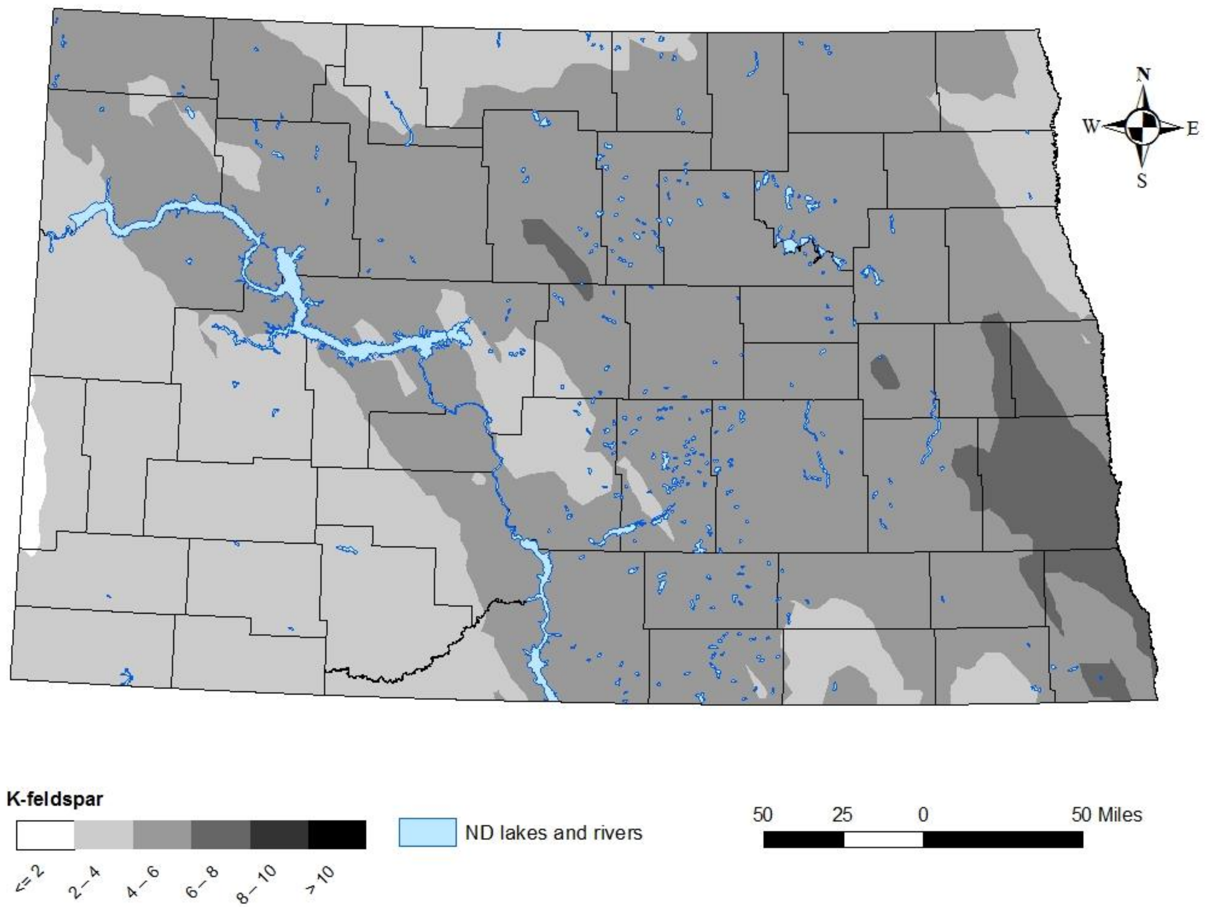
NDSU EXTENSION SERVICE

October 2017

AGVISE LABORATORIES

Franzen, D.W. 2017. Soil fertility recommendations for corn. NDSU Ext. Circ. SF-722 (revised). North Dakota State Univ., Fargo, ND.

K-feldspar content of total soil minerals in North Dakota

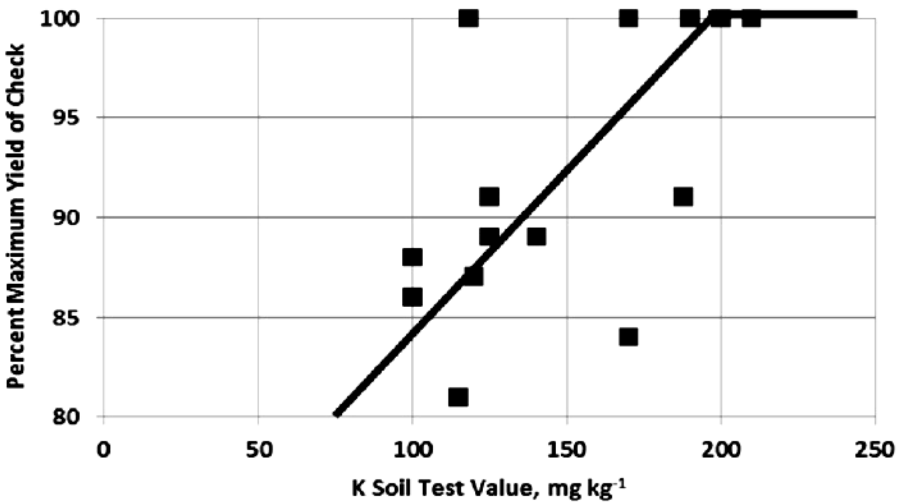


D.W. Franzen, North Dakota State Univ. (personal communication, 2017)

Smectite/illite groups require different soil test K critical levels

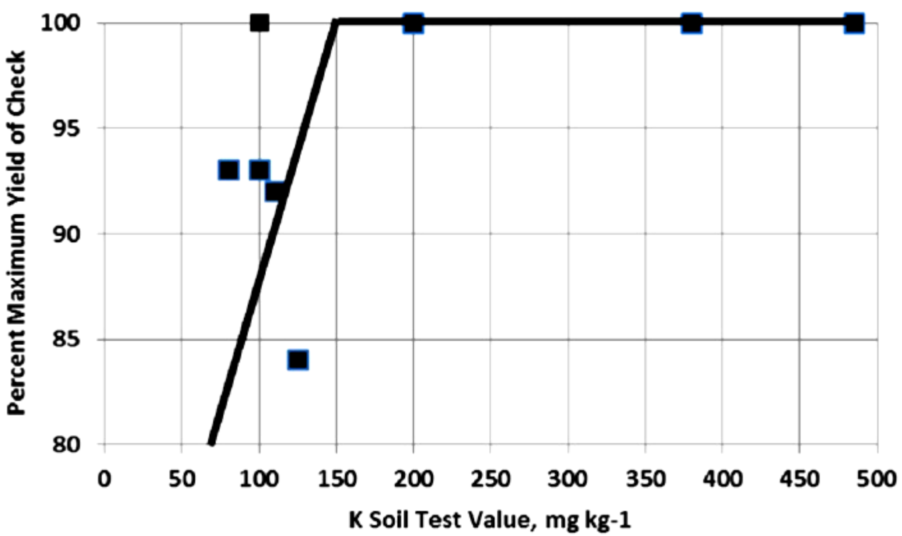
High smectite/illite

- STK_{CL} = 200 ppm, when dry



Low smectite/illite

- STK_{CL} = 150 ppm

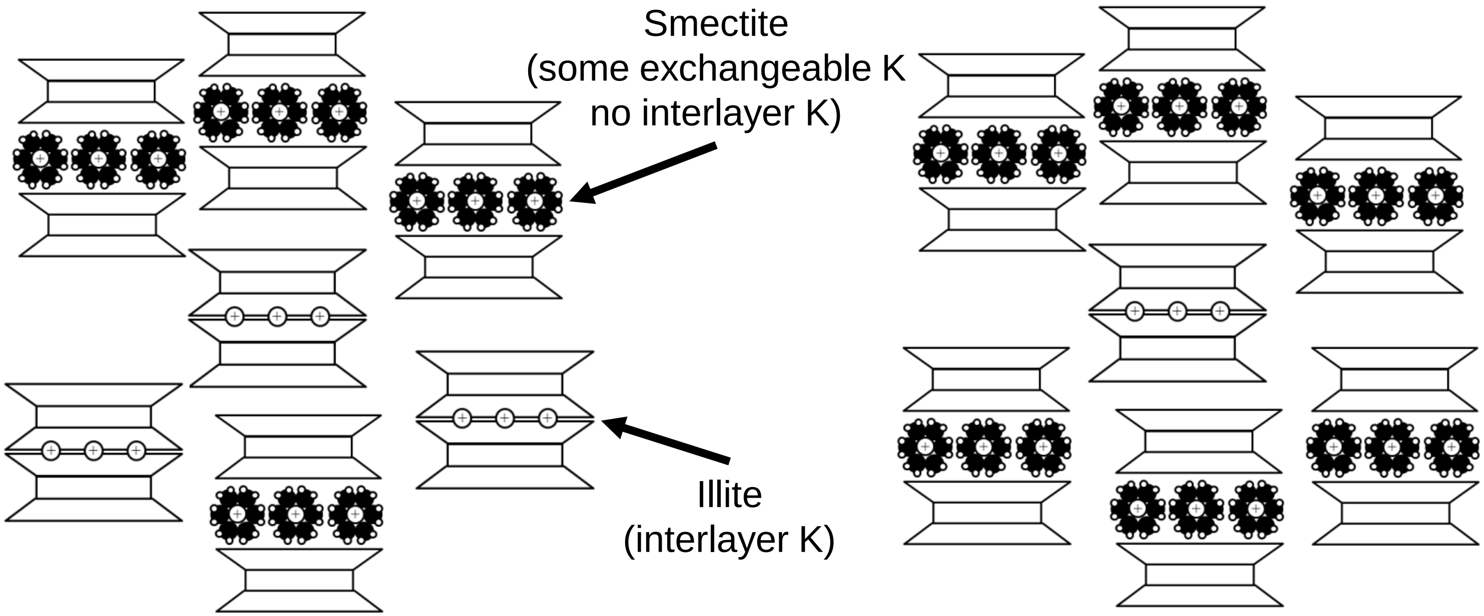


AGVISE LABORATORIES

D.W. Franzen, North Dakota State Univ. (personal communication, 2017)

Two clay types, two STK critical levels

Low smectite/illite (ratio < 3.5) **High smectite/illite (ratio > 3.5)**

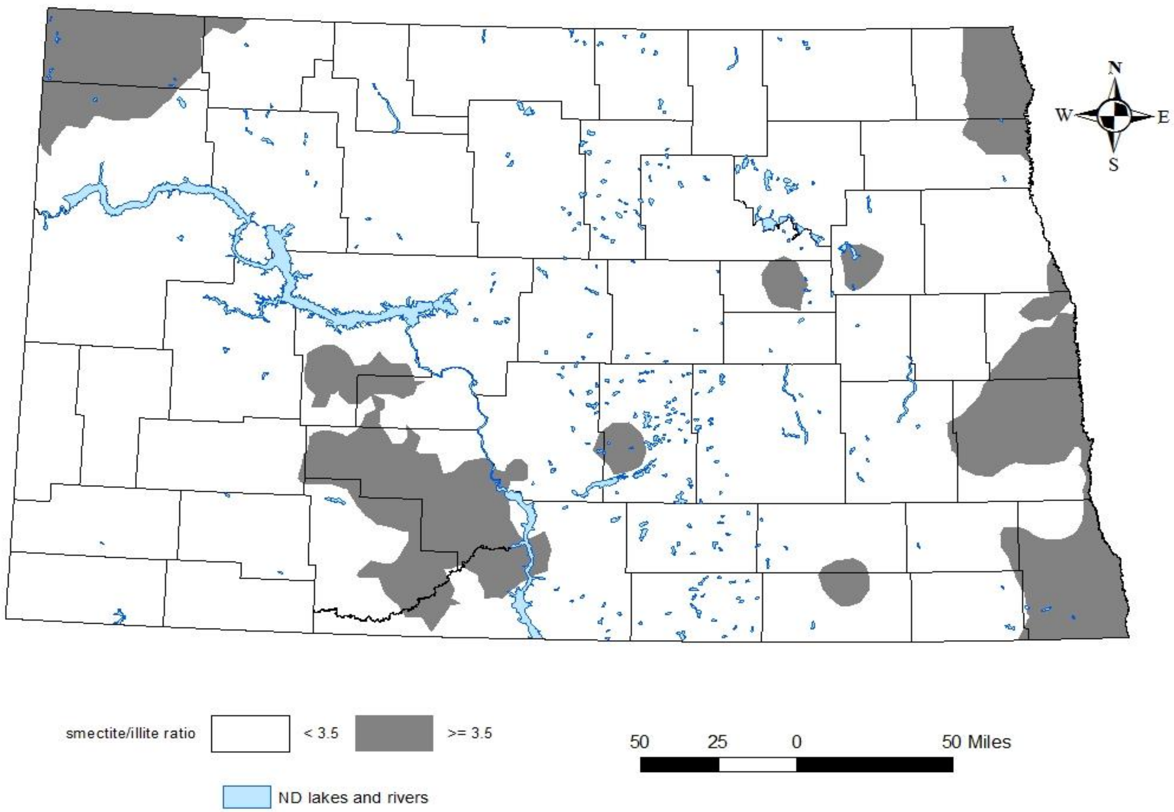


More illite, more interlayer K Lower potential for layer collapse when dry STK_{CL} = 150 ppm	Less illite, less interlayer K Greater potential for layer collapse when dry STK_{CL} = 200 ppm

AGVISE LABORATORIES

Ransom, M.D., A. Florence, M. Thompson, and R. Southard. 2017. How do mineralogy and soil chemistry impact how closely potassium soil test changes are related to mass balance? In: Murrell, T.S. and R.L. Mikkelsen, editors, Frontiers of Potassium Science Conference. Rome, Italy. 25-27 Jan. 2017. Intl. Plant Nutr. Inst., Peachtree Corners, GA. p. O189-O196.

Smectite/illite ratio of clay fraction of soils in North Dakota



Soils with smectite/illite ratio > 3.5 (gray area), STK_{CL} = 200 ppm

D.W. Franzen, North Dakota State Univ. (personal communication, 2017)

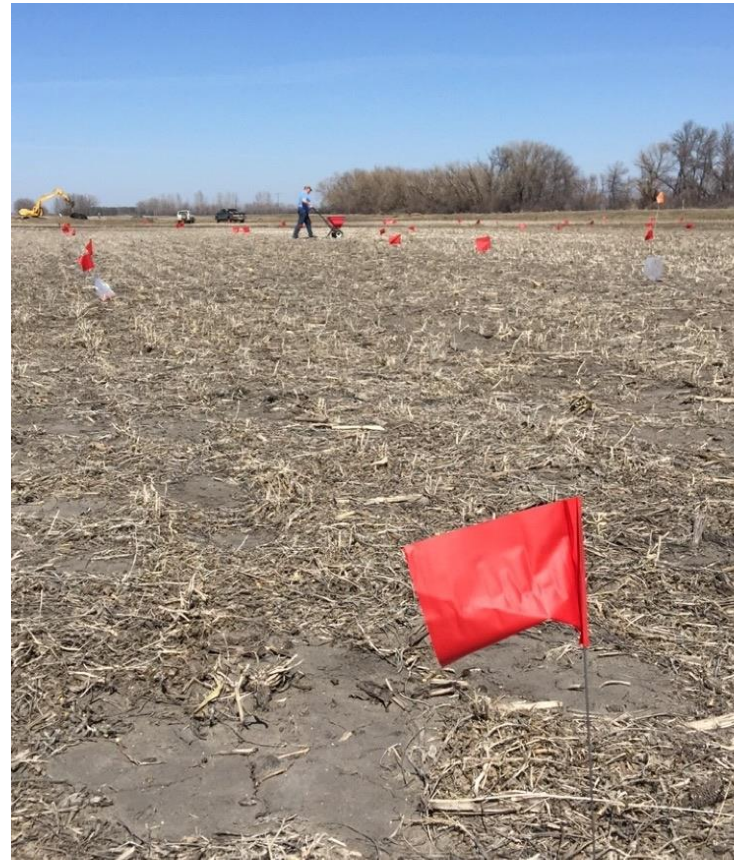
Potassium rate limits (broadcast)

Low rate: 60 lb K_2O acre^{-1}

- Minimum amount of fertilizer K material (100 lb potash acre^{-1}) needed for adequate distribution to enough plants
- Banded K lower rates?

High rate: 120 lb K_2O acre^{-1}

- Corn yield reduction often occurring at 150 lb K_2O acre^{-1}
- Cause still under investigation



AGVISE LABORATORIES

D.W. Franzen, North Dakota State Univ. (personal communication, 2017)

Why not minimum broadcast rate for phosphorus then?

- Plant requirement for K much greater than P

Corn yield (bushel $acre^{-1}$)	Plant P_2O_5 uptake (lb $acre^{-1}$)	Plant K_2O uptake (lb $acre^{-1}$)
200	102	270

- Root interception per granule (lower P analysis)

Fertilizer	Nutrient mass per granule (mg)	Granules per acre (assume 20 lb $acre^{-1}$ rate)
Potash, 60% K_2O	14.4	628,000
MAP, 52% P_2O_5	11.6	782,000

AGVISE LABORATORIES

Fertilizer calculations based on PCS product information
www.potashcorp.com/media/POT_SS_FER_GRA285.pdf
www.potashcorp.com/media/POT_SS_FER_MAP.pdf

Conclusions

No loose ends here. Okay, maybe a few.

How will AGVISE handle this?

- Ongoing discussion this winter
- We serve multi-state and -province region
  - Soil mineralogical data is sparse in most areas

- For now, North Dakota clients encouraged to consult NDSU clay survey to determine STK_{CL} for their local area

Which STK_{CL} do you consider?

STK_{CL} = 200 ppm

High smectite/illite (ratio>3.5)

- Higher risk of dry conditions
- STK variability in composite samples

STK_{CL} = 150 ppm

Low smectite/illite (ratio<3.5)

- STK_{CL} of 150 ppm still valid for many soils
- Avoid unnecessary K

Between 150 – 200 ppm?

Risk management (how close can you be?)

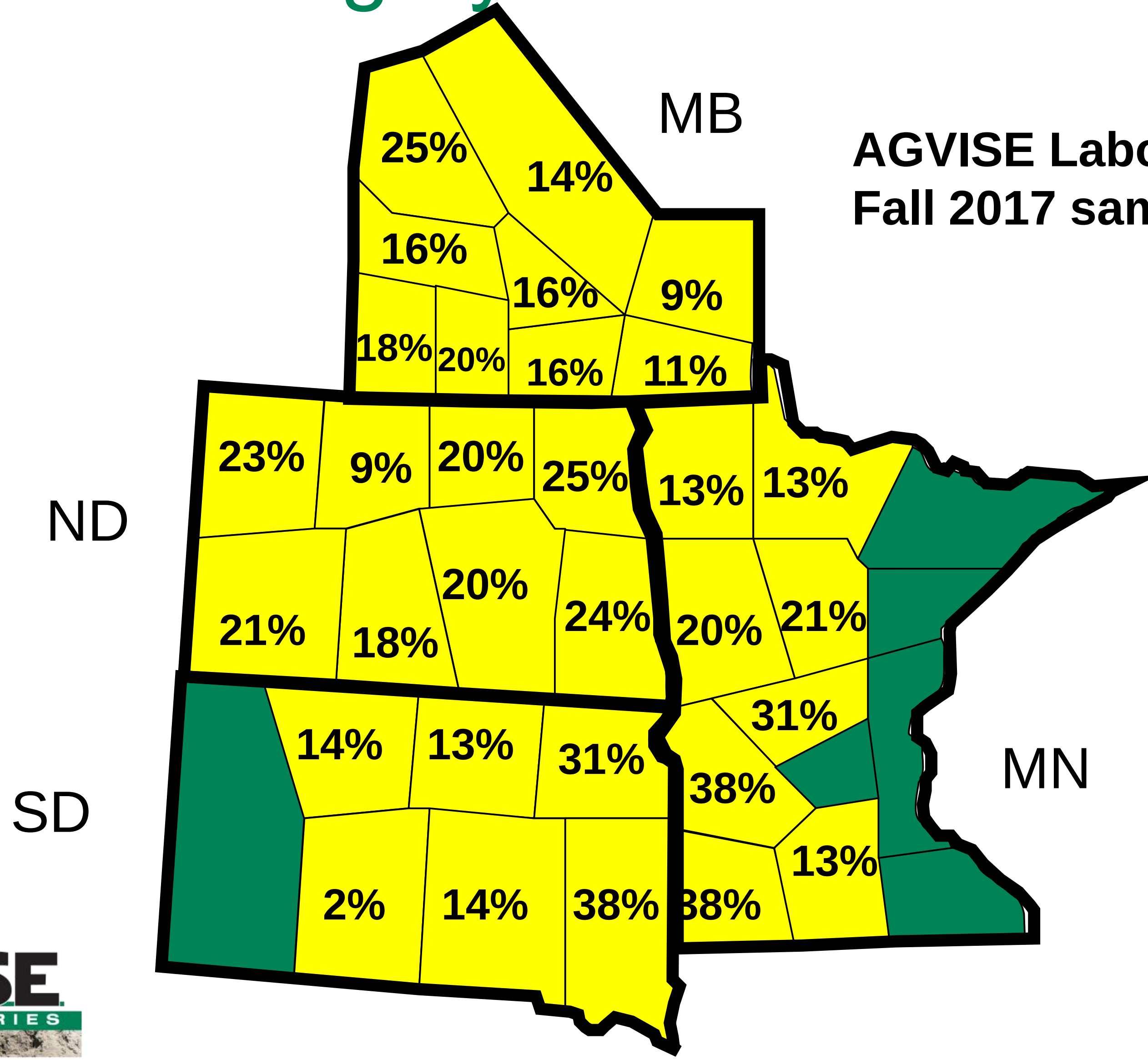
–or–

Strip trials, you can do this!

AGVISE LABORATORIES

Soil samples in the 150-200 ppm K critical level “gray area”

AGVISE Laboratories
Fall 2017 samples (0-6”)



Going forward

- Crop response to potassium is difficult to predict
  - Soil test K only gets us so far

- Mineralogy addresses some inconsistencies
  - High smectite/illite soils require higher initial STK, when dry
  - Yet, not clear for lower STK soils with high K-feldspar or illite content that provide ample plant available K

- Soil water content for growing season is not predictable
  - Crop response will be greater in dry years
  - Computer models? Limited usefulness if model predicts deficiency too late for K application and correction

AGVISE LABORATORIES

Thank you for your attention

Acknowledgements

North Dakota Corn Council

Dr. David W. Franzen

NDSU Extension Soil Specialist

Manbir Rakkar

Honggang Bu (mobile app developer)

Dr. Lakesh Sharma

Eric Schultz

Austin Kraklau

Conner Swanson

Makenzie Ries

Kevin Horsager

Dr. Shiny Mathews

Dr. Thomas DeSutter

Dr. Amitava Chatterjee

AGVISE LABORATORIES

Questions?

johnb@agvise.com
@jsbreker