Soil mineralogy: A missing link in potassium fertility

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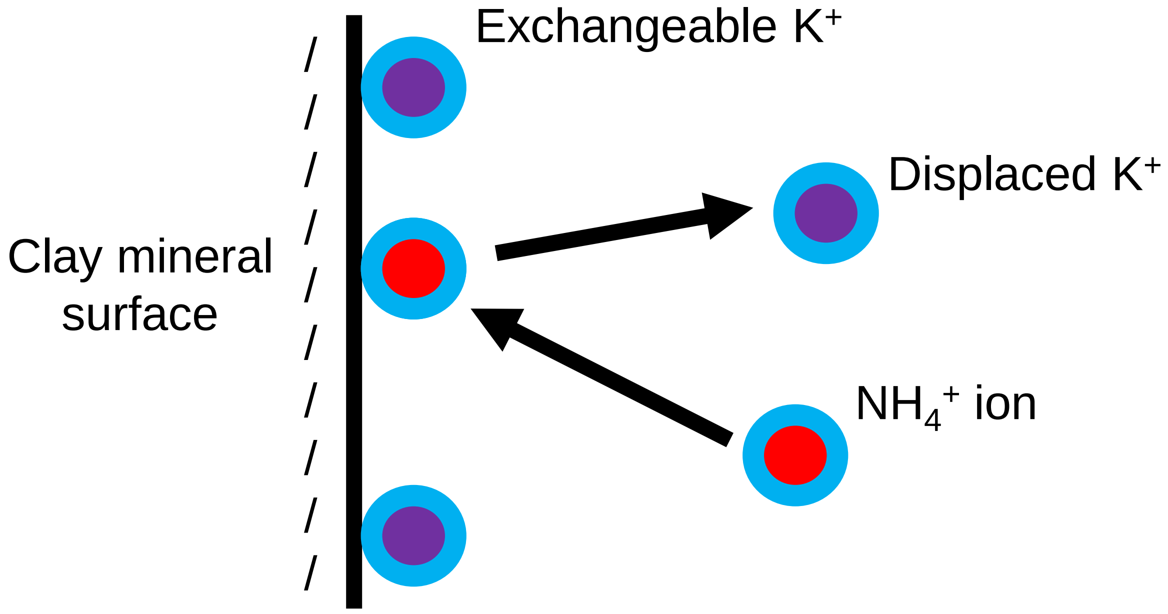
Soil testing for potassium

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

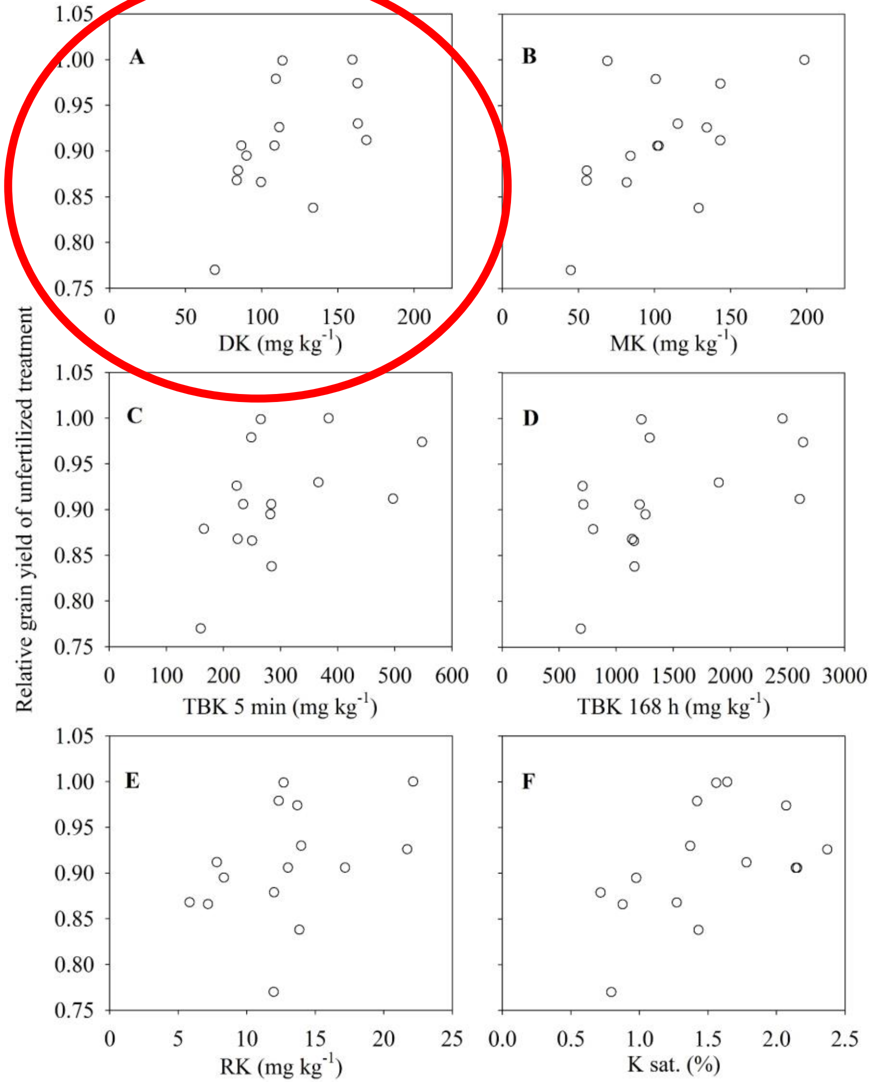
Predicted corn grain yield response based on soil test K

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} STK had significant yield increases

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 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.

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

A time before the K crusade…

Undergraduate student at American Society of Agronomy 2014 meetings in Long Beach, CA

Dr. Donald Sparks, Univ. of Delaware

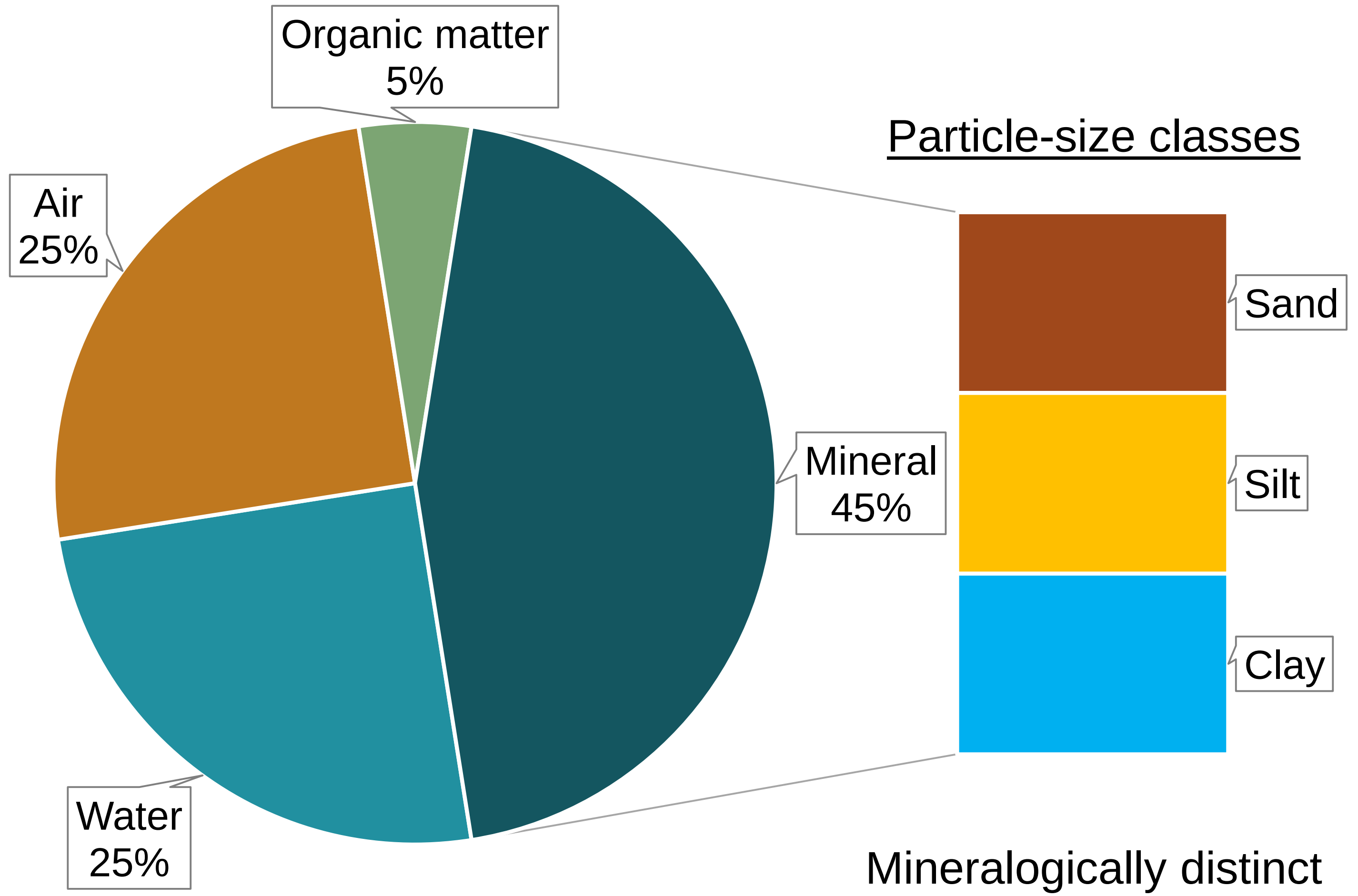
"Historical perspective on the chemistry and mineralogy of soil potassium"

I should have taken better notes…

Soil mineralogy and potassium: SOIL 101 refresher

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

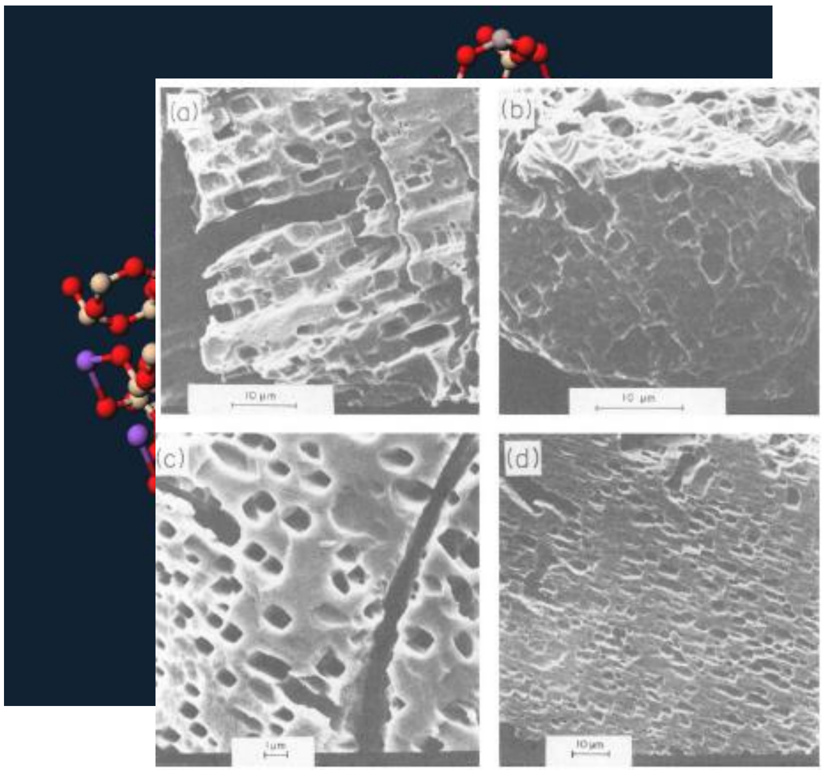
Quick review: Soil components



Primary K minerals

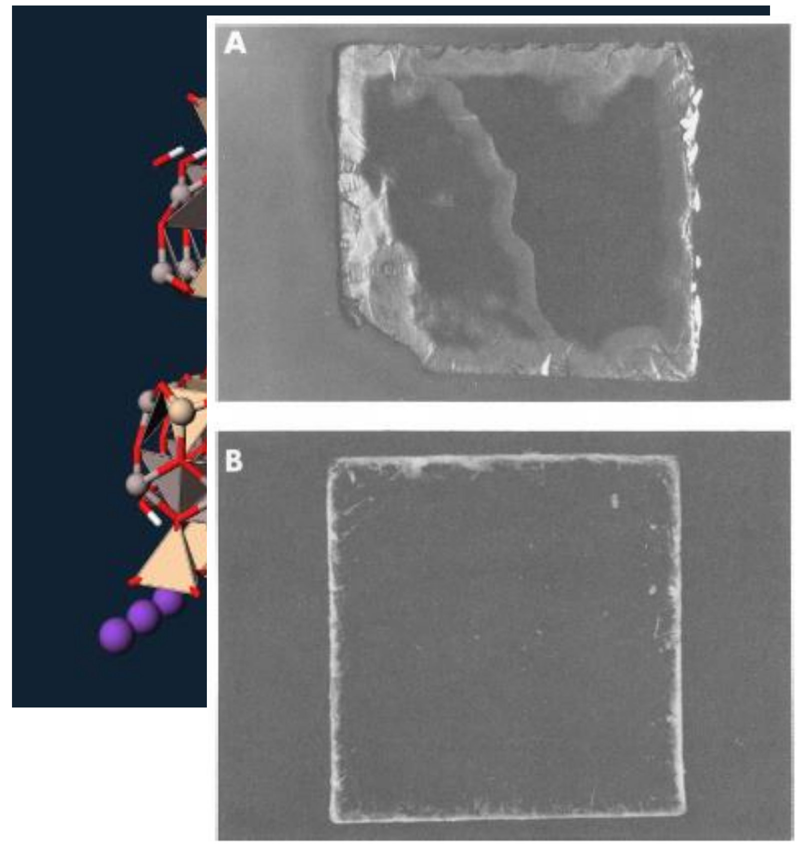
<u>K-feldspar</u>

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

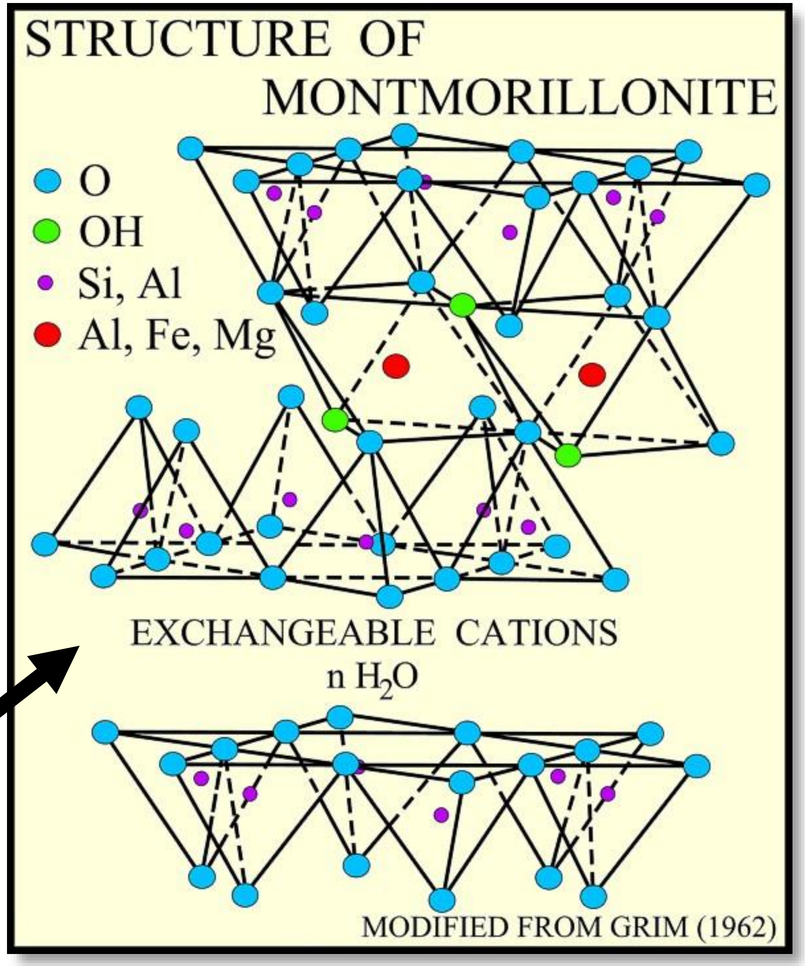


Image from https://pubs.usgs.gov/of/2001/of01-041/htmldocs/clays/smc.htm (verified 27 Oct. 2017)

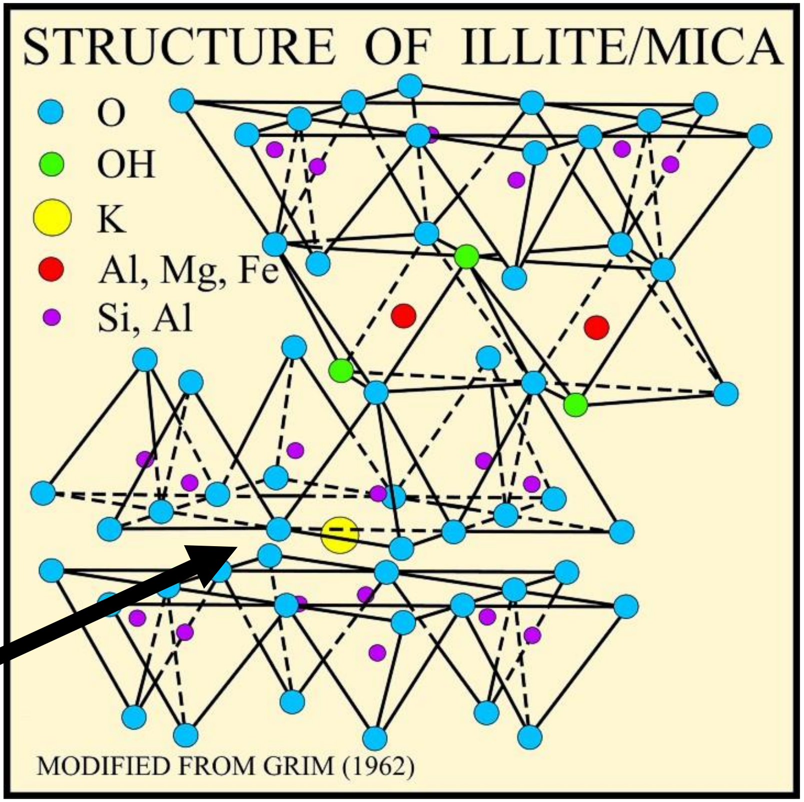
Illite
(non-expanding)

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

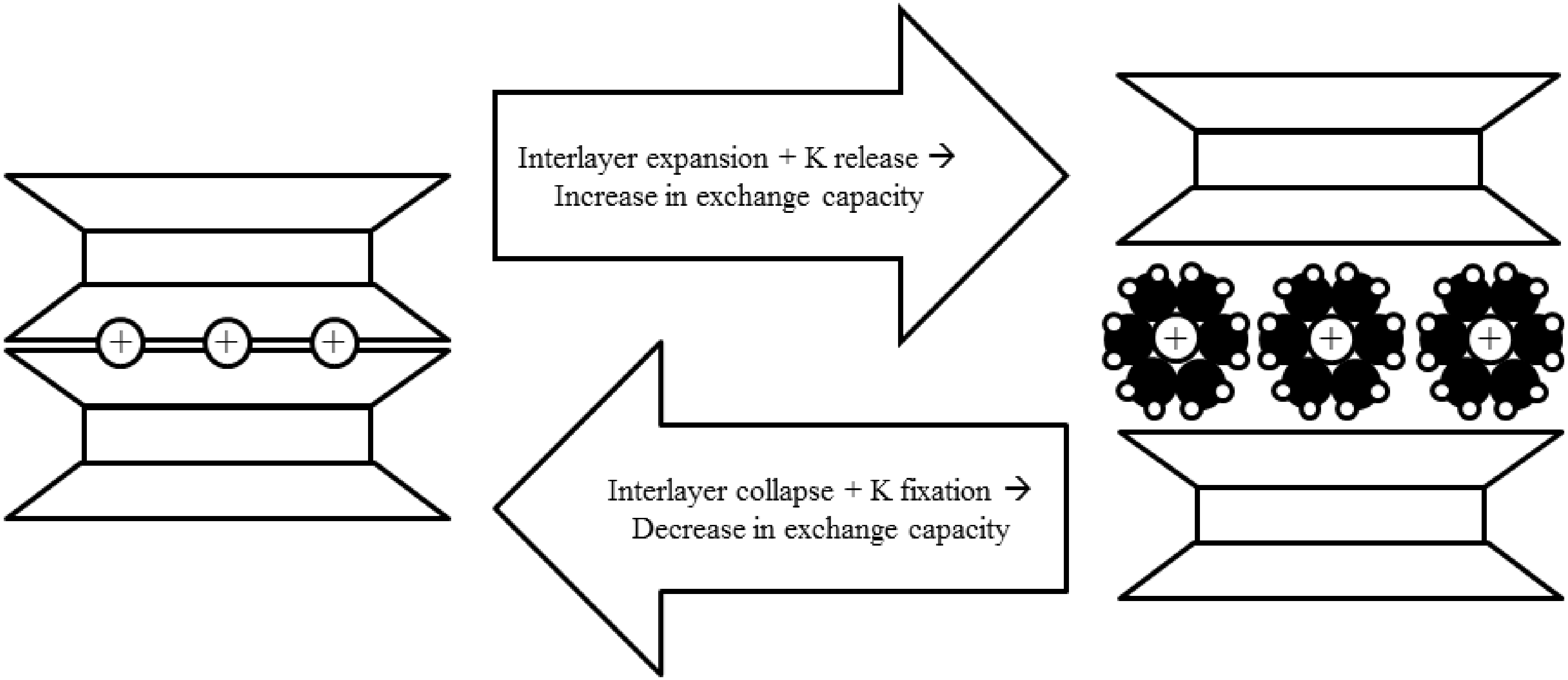
- Positive cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) balance negative clay layer charge
- Low layer charge → more expansion

	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.

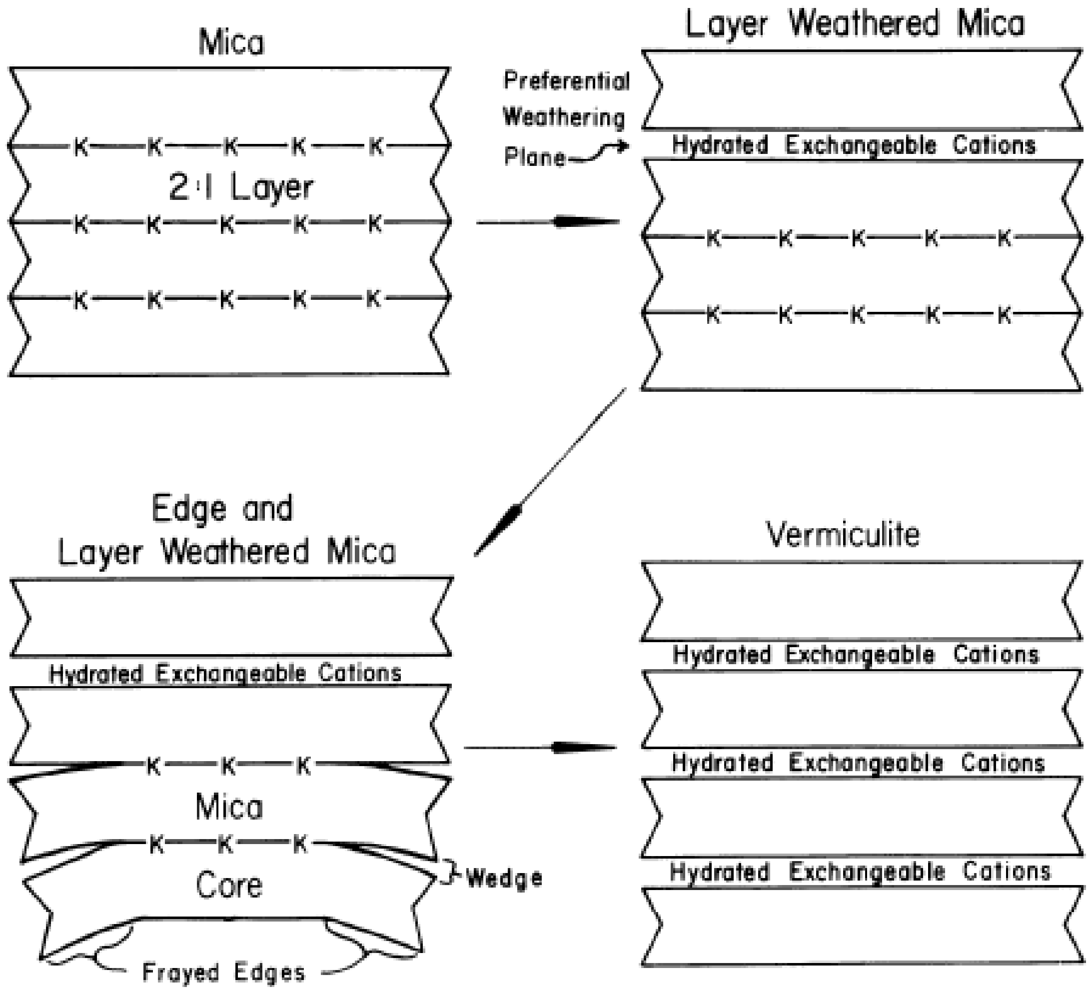
K fixation: conceptual model



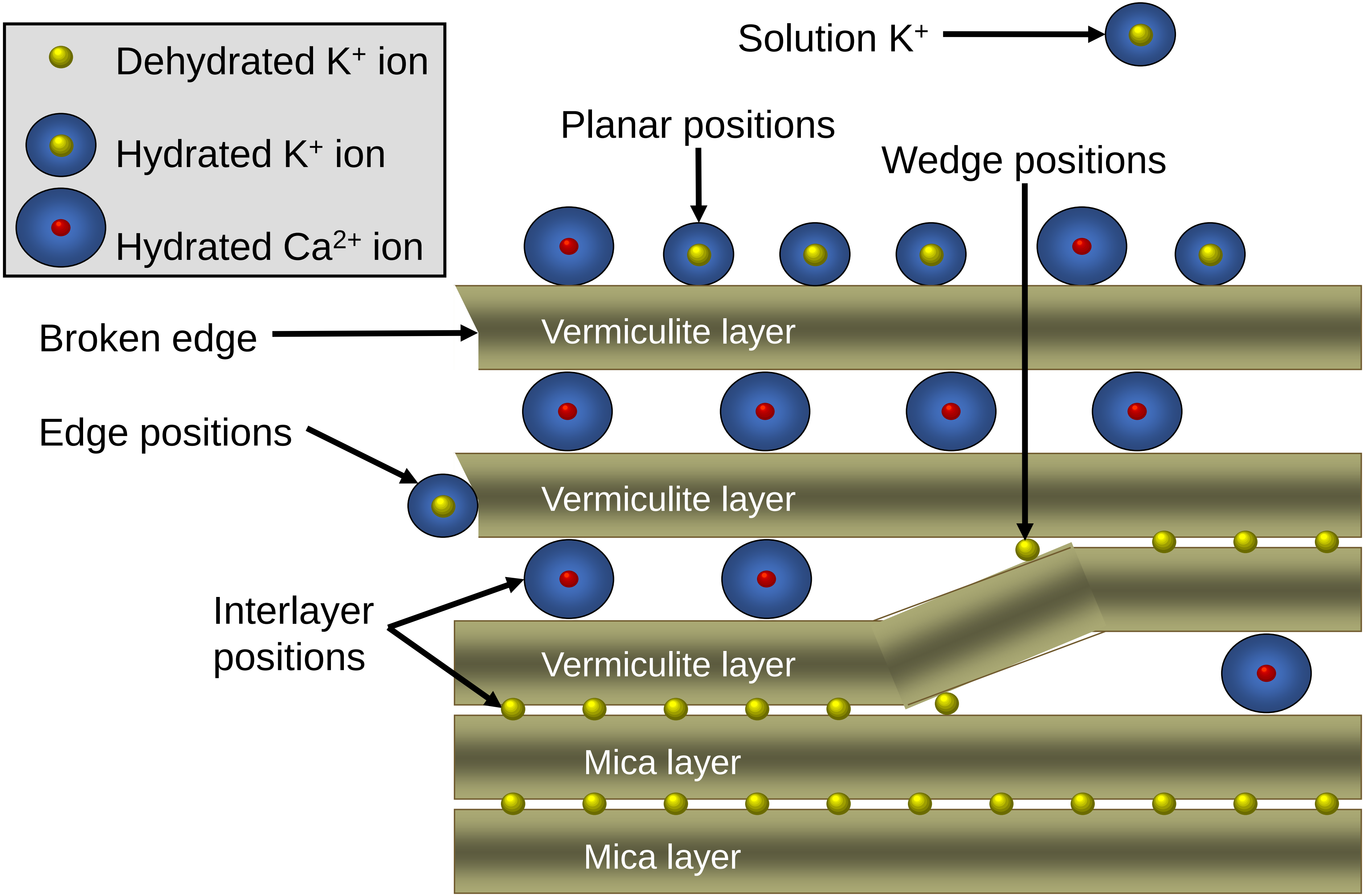
$$K\ fixation = interlayer\ K + (F_{contraction} > F_{expansion})$$

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

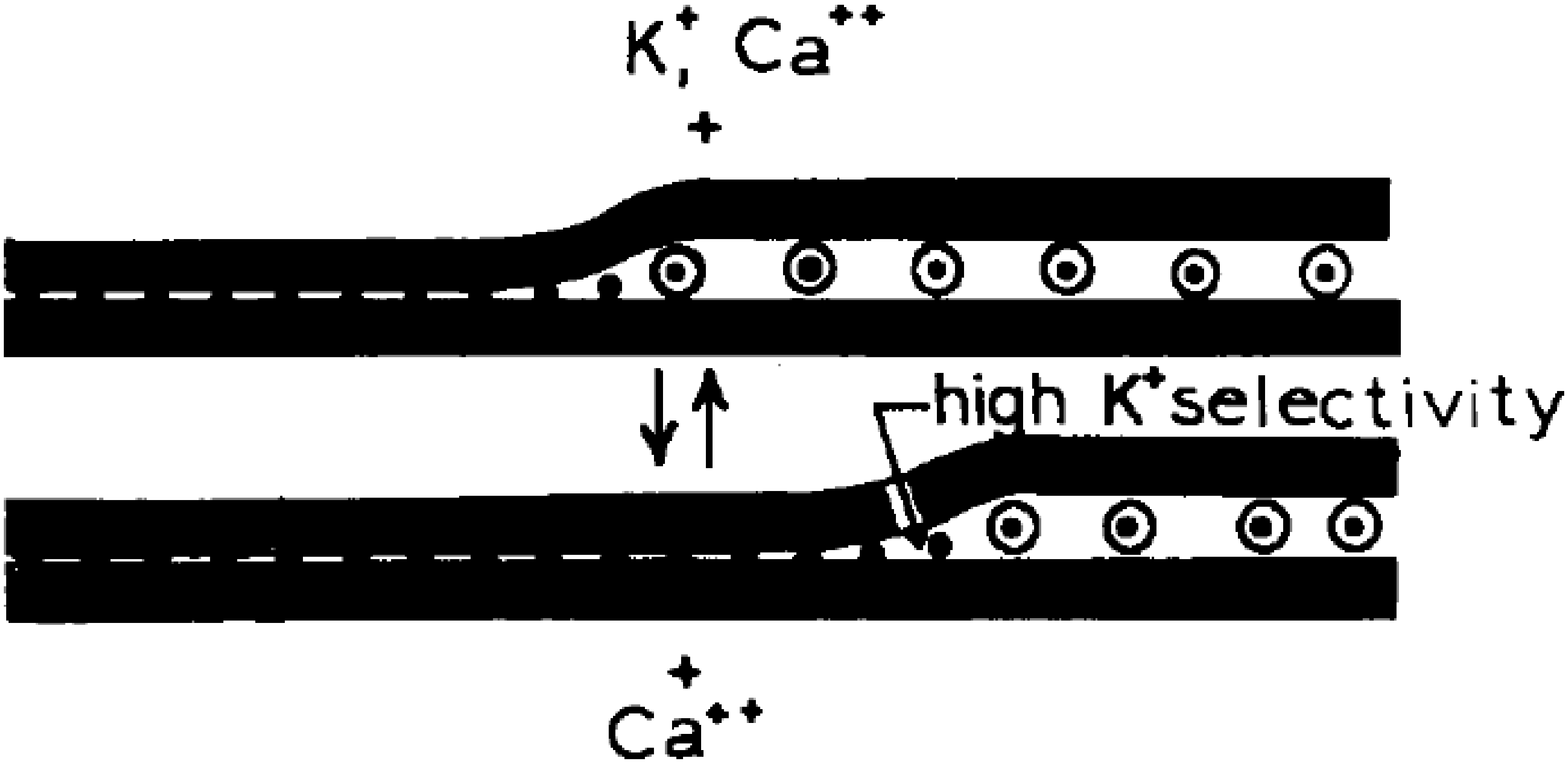


Fanning, D.S., V.Z. Keramidas, and M.A. El-Desoky. 1989. Micas. In: Dixon, J.B. and S.B. Weed, editors, Minerals in Soil Environments. SSSA Book Ser. 1. 2nd ed. SSSA, Madison, WI. p. 551–634.



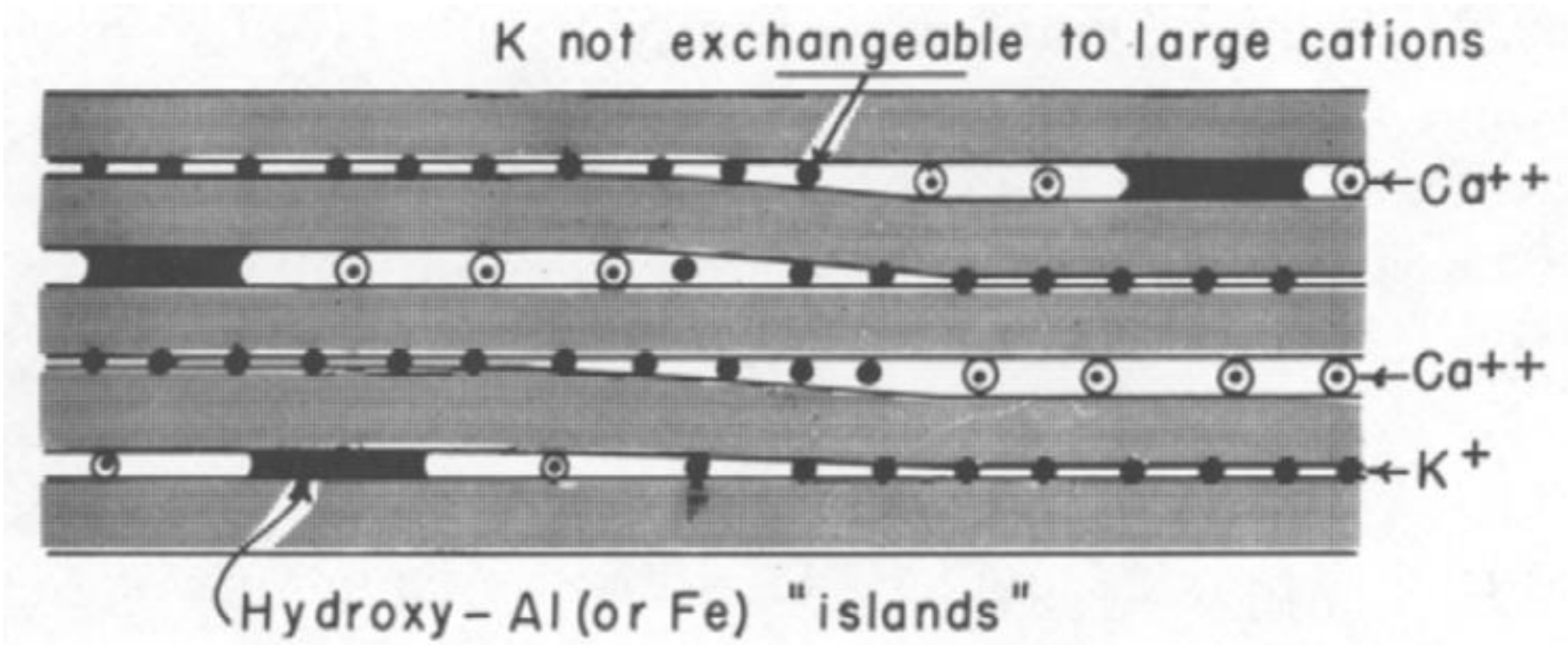
Murrell, T.S. 2014. The potassium sandwich: Is it nutritional? In: Lee, J.T., editor, AGVISE Laboratories Soil Fertility Seminars. Granite Falls, MN; Watertown, SD; and Grand Forks, ND. 7-9 Jan. 2014. AGVISE Laboratories, Northwood, ND.
Rich, C.I. 1968. Mineralogy of soil potassium. In: Kilmer, V.J., S.E. Younts, and N.C. Brady, editors, The Role of Potassium in Agriculture. ASA, CSSA, and SSSA, Madison, WI. p. 79–108.

The K fixation zipper



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.

Oxide “islands” can prop open layers



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?

How can K^+ be released from minerals?

Soil K cycle: from mineral to root

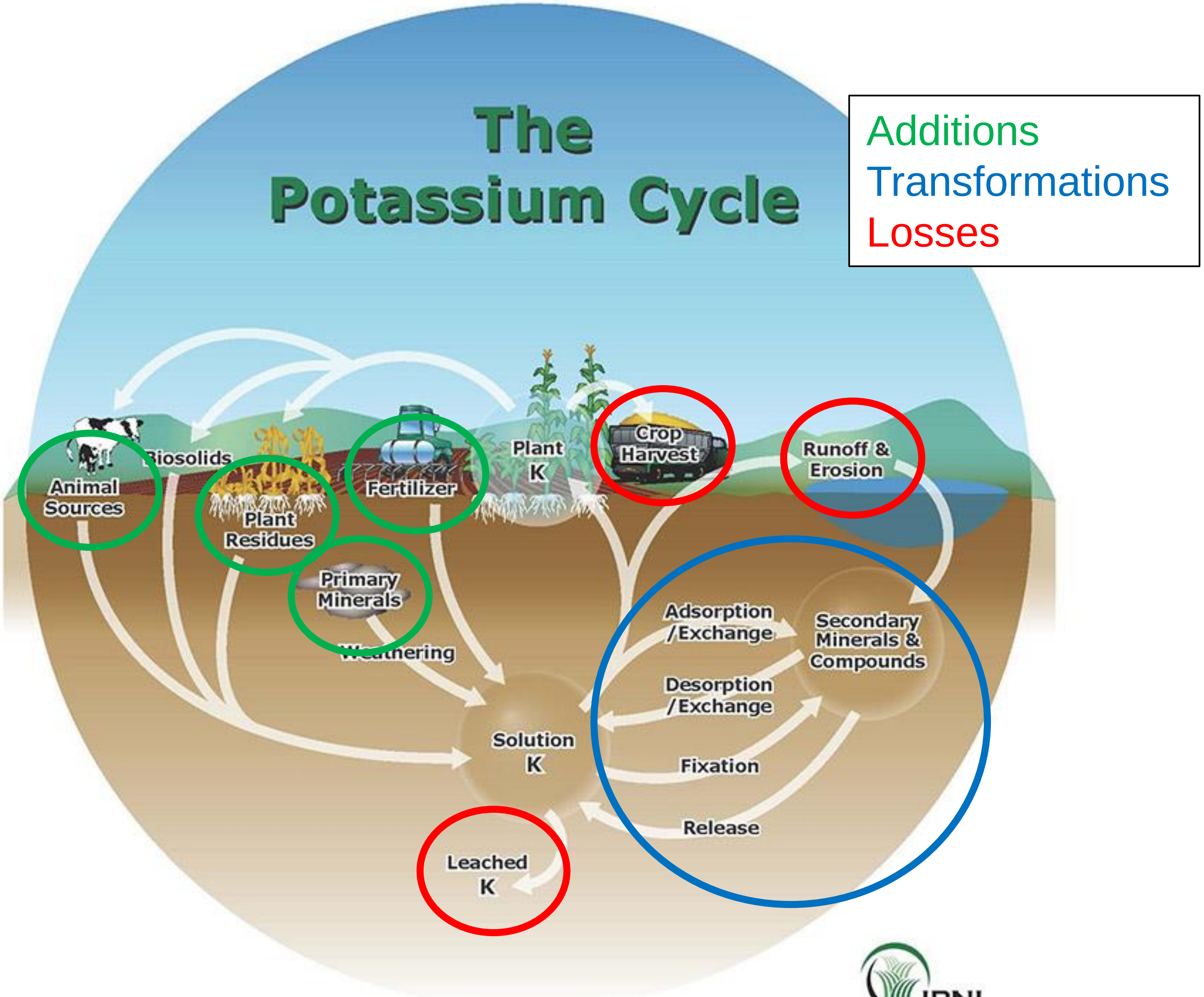
Plant roots only take up K^+ from soil solution

Whatever the K source:

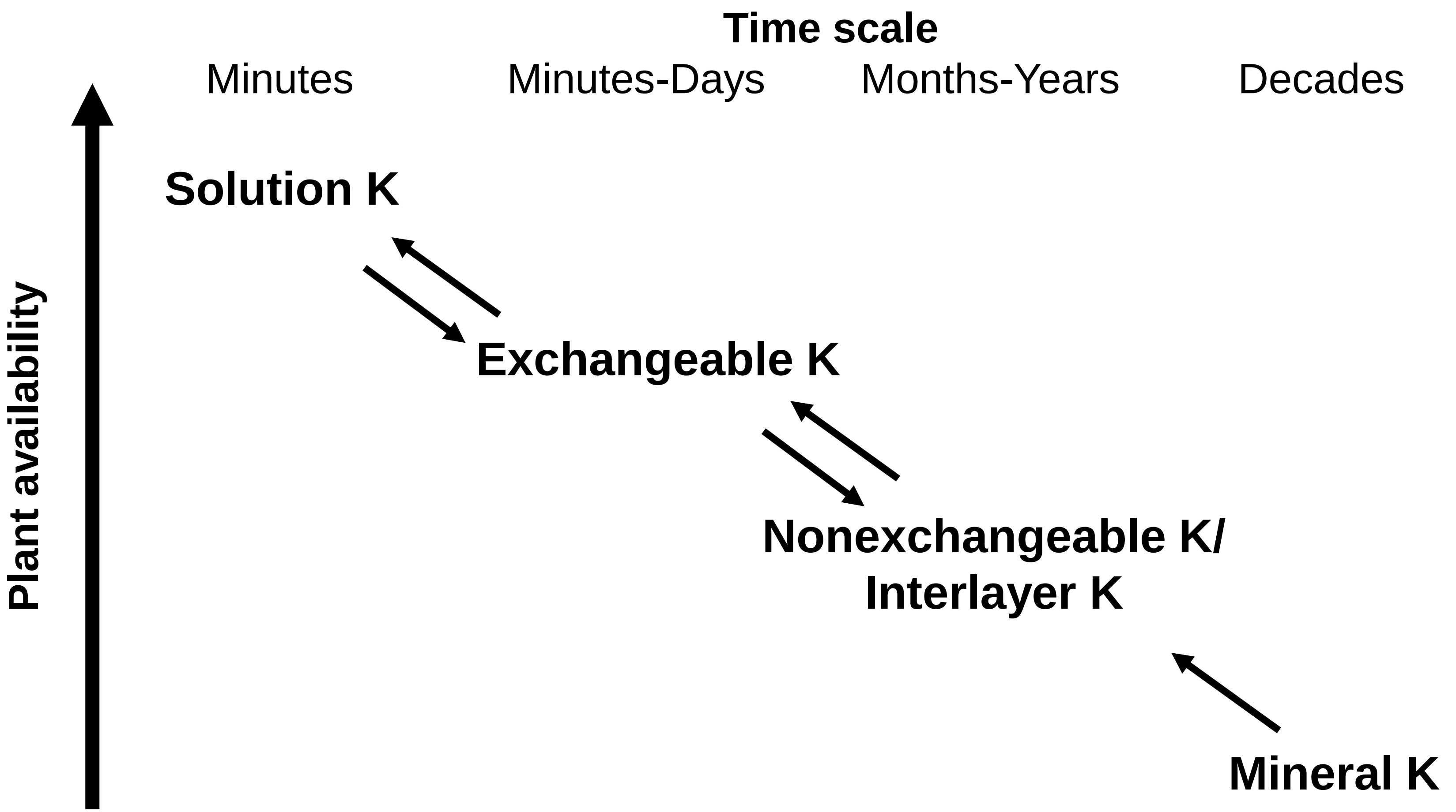
- fertilizer
- manure/residue
- mineral

K^+ must enter soil solution

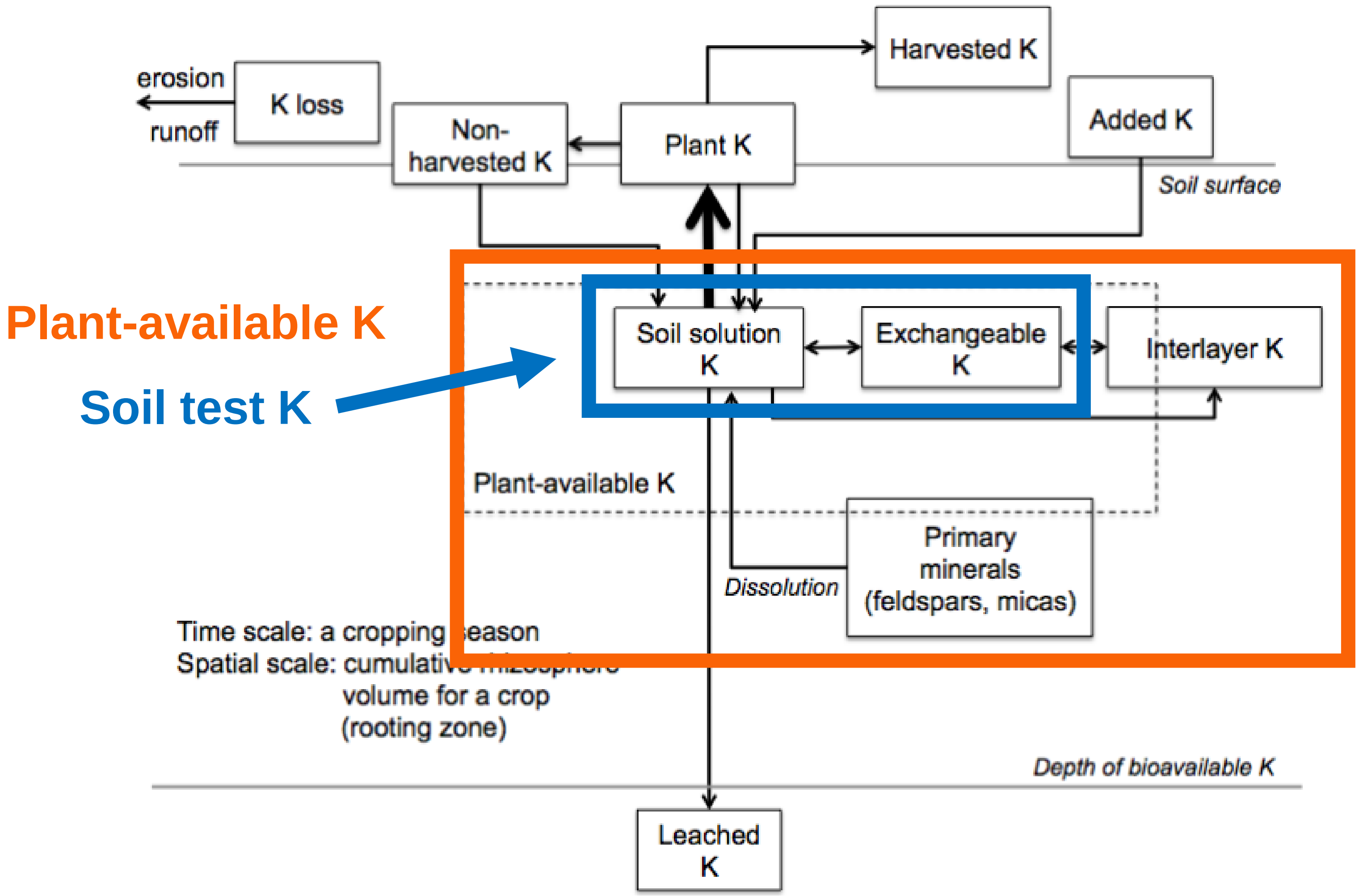
Soil K reactions are dynamic



Classical thought on K availability

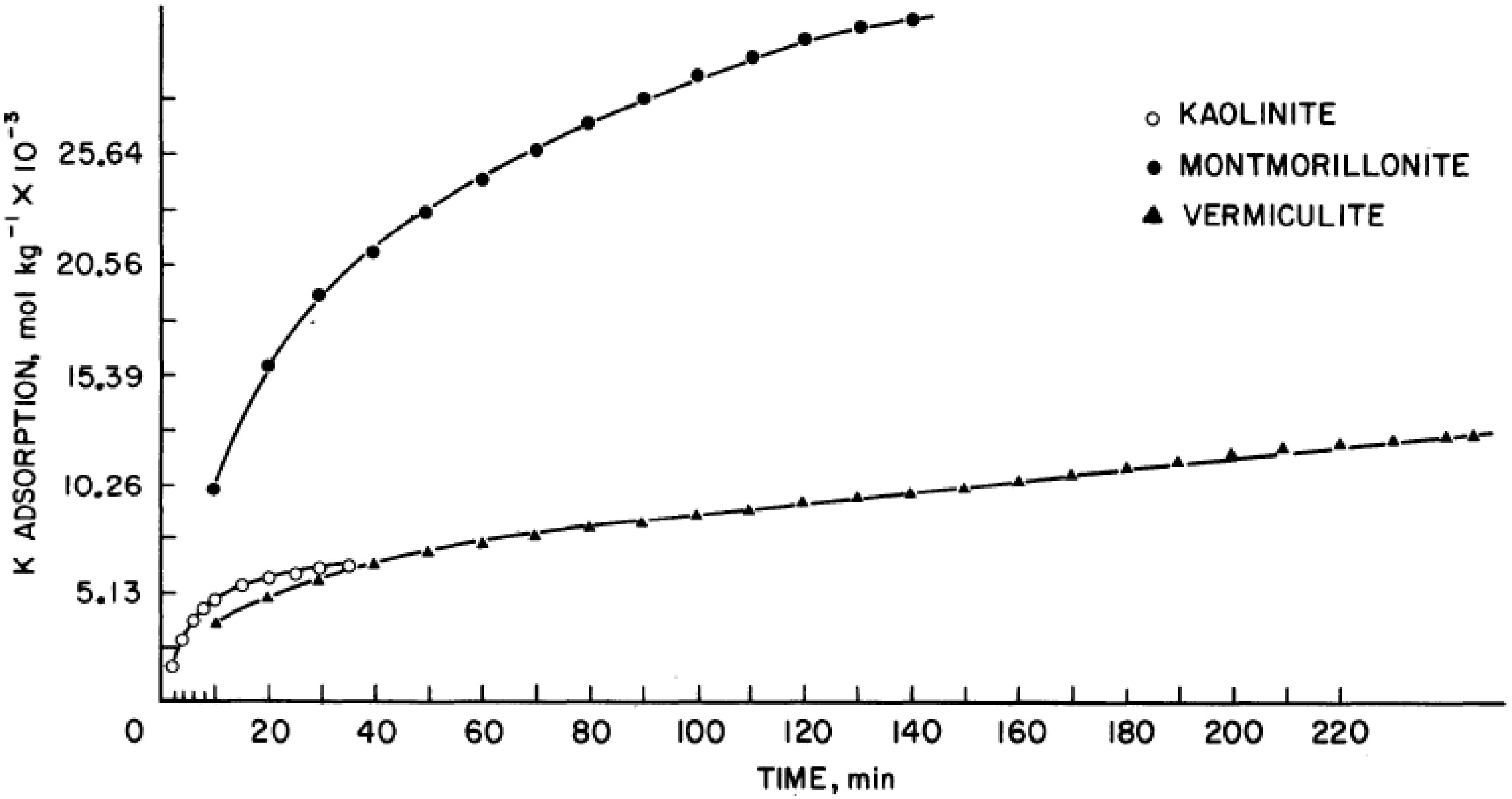


Plant K uptake induces K release



IPNI. 2015. Summary report. In: Frontiers in Potassium Science: Developing a Roadmap to Advance the Science of Potassium Soil Fertility Evaluation. 26-30 Jan. 2015. Kona, HI. Intl. Plant Nutr. Inst., Peachtree Corners, GA. p. 1–9.

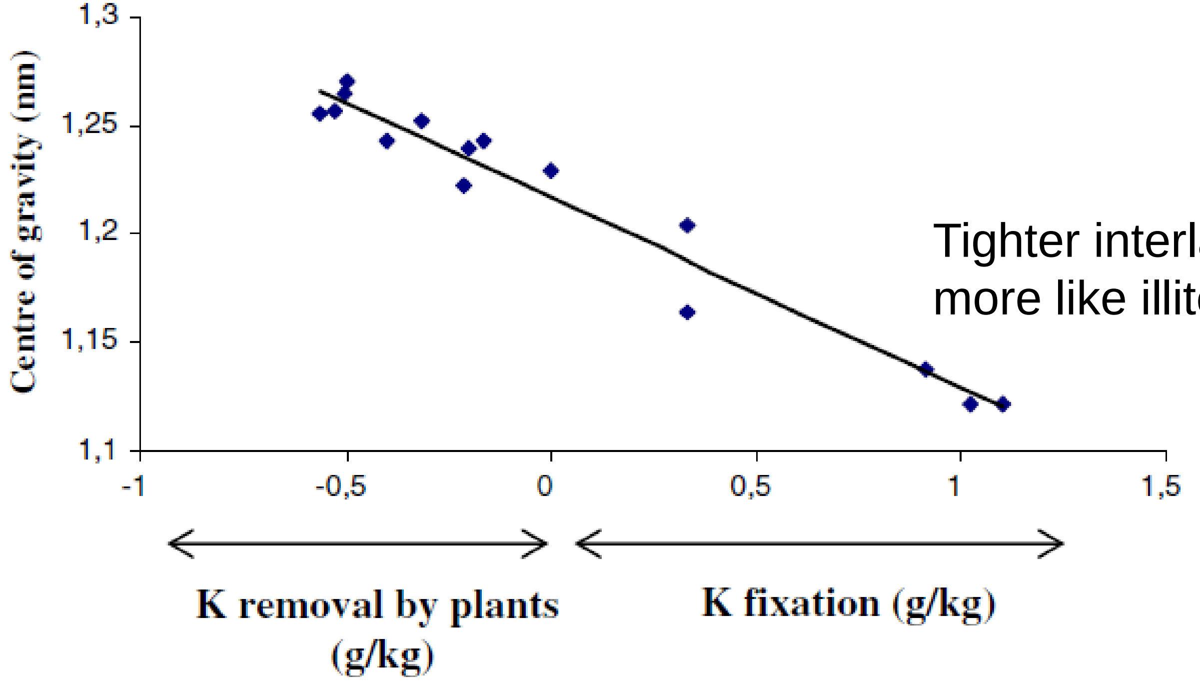
Potassium exchange kinetics are often called “slow” yet occur over few hours



Sparks, D.L., and P.M. Jardine. 1984. Comparison of kinetic equations to describe K-Ca exchange in pure and in mixed systems. Soil Sci. 138:115–122.

Plant K uptake opens illite layers, acting as a K reservoir

Wider interlayer space,
more like smectite



Tighter interlayer space,
more like illite

Barré, P., B. Velde, N. Catel, and L. Abbadie. 2007. Soil-plant potassium transfer: Impact of plant activity on clay minerals as seen from X-ray diffraction. Plant Soil 292(1–2):137–146.

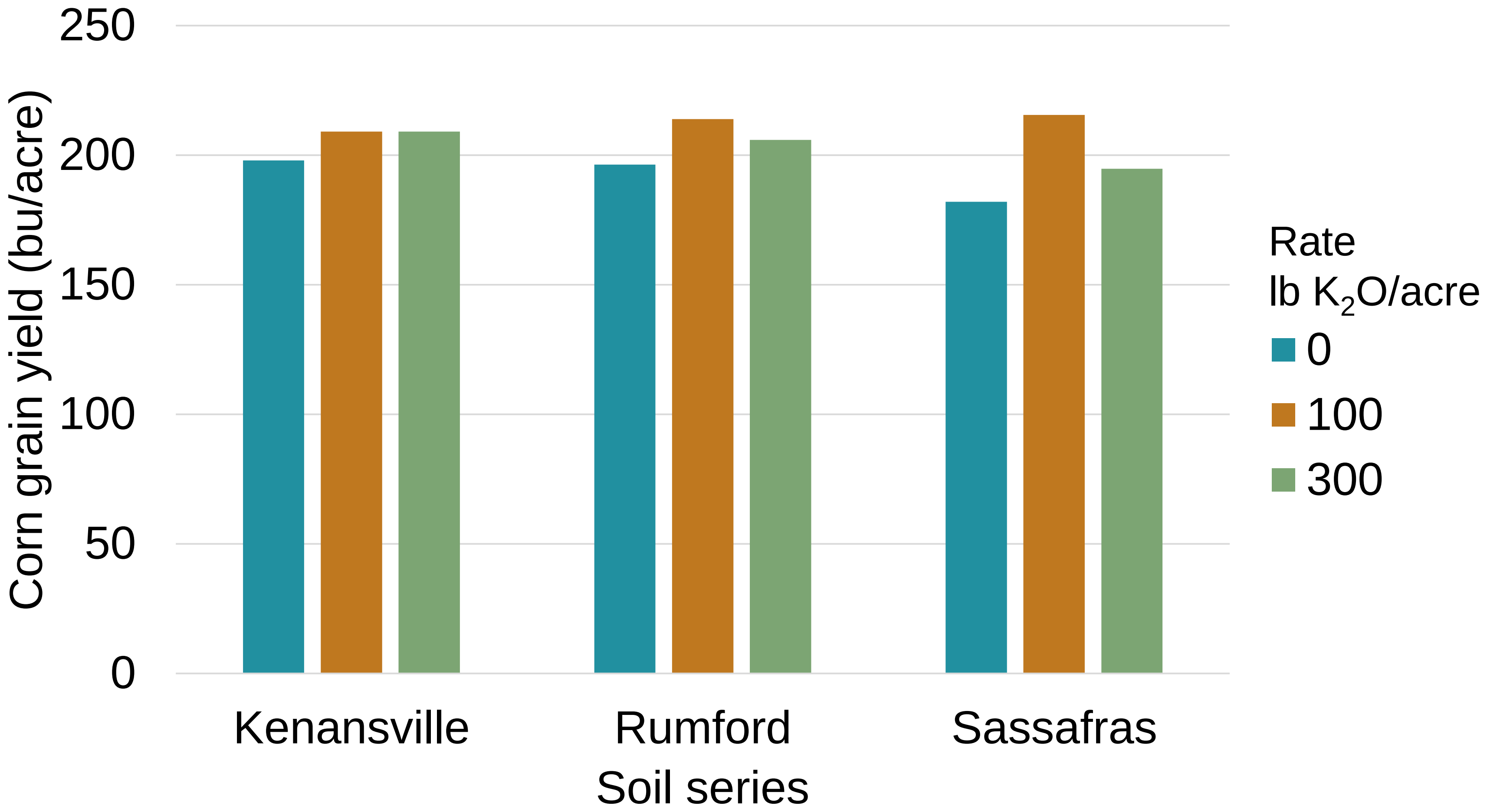
K-feldspars contribute available K

- Atlantic Coastal Plain soils in Delaware: No yield responses even though soil test K was low
- Sand fraction contained large amounts of mineral K as K-feldspar

Soil series	K_{exch}	$K_{nonexch}$	$K_{mineral}$	K-feldspar
	ppm	ppm	ppm	%
Kenansville loamy sand	98	164	13661	10
Rumford loamy sand	129	191	8453	7
Sassafas fine loamy sand	137	218	16985	16

Sadusky, M.C., D.L. Sparks, M.R. Noll, and G.J. Hendricks. 1987. Kinetics and mechanisms of potassium release from sandy Middle Atlantic Coastal Plain soils. Soil Sci. Soc. Am. J. 51(6):1460–1465.

Delaware: No significant yield response on loamy sands with low STK



Parker, D.R., G.J. Hendricks, and D.L. Sparks. 1989. Potassium in Atlantic Coastal Plain Soils: II. Crop Responses and Changes in Soil Potassium Under Intensive Management. Soil Sci. Soc. Am. J. 53(2):397–401.

Nonexchangeable K release can be faster than we thought

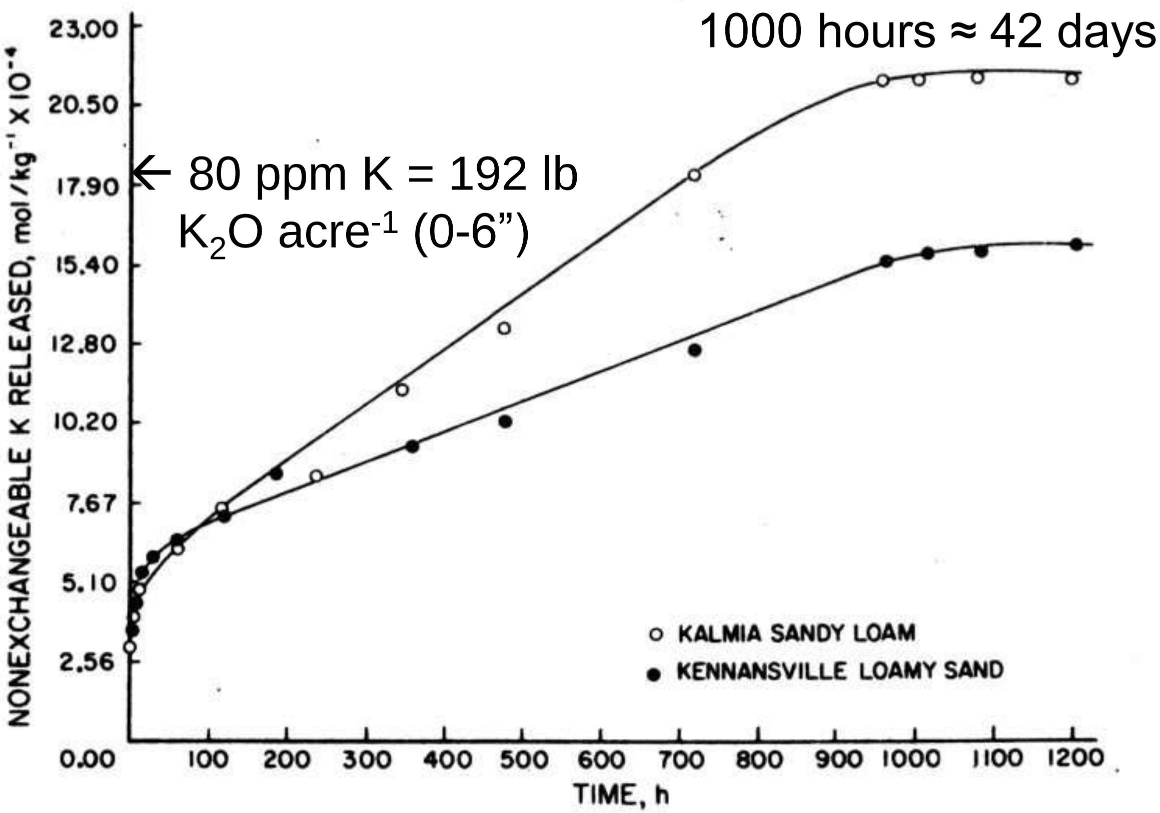
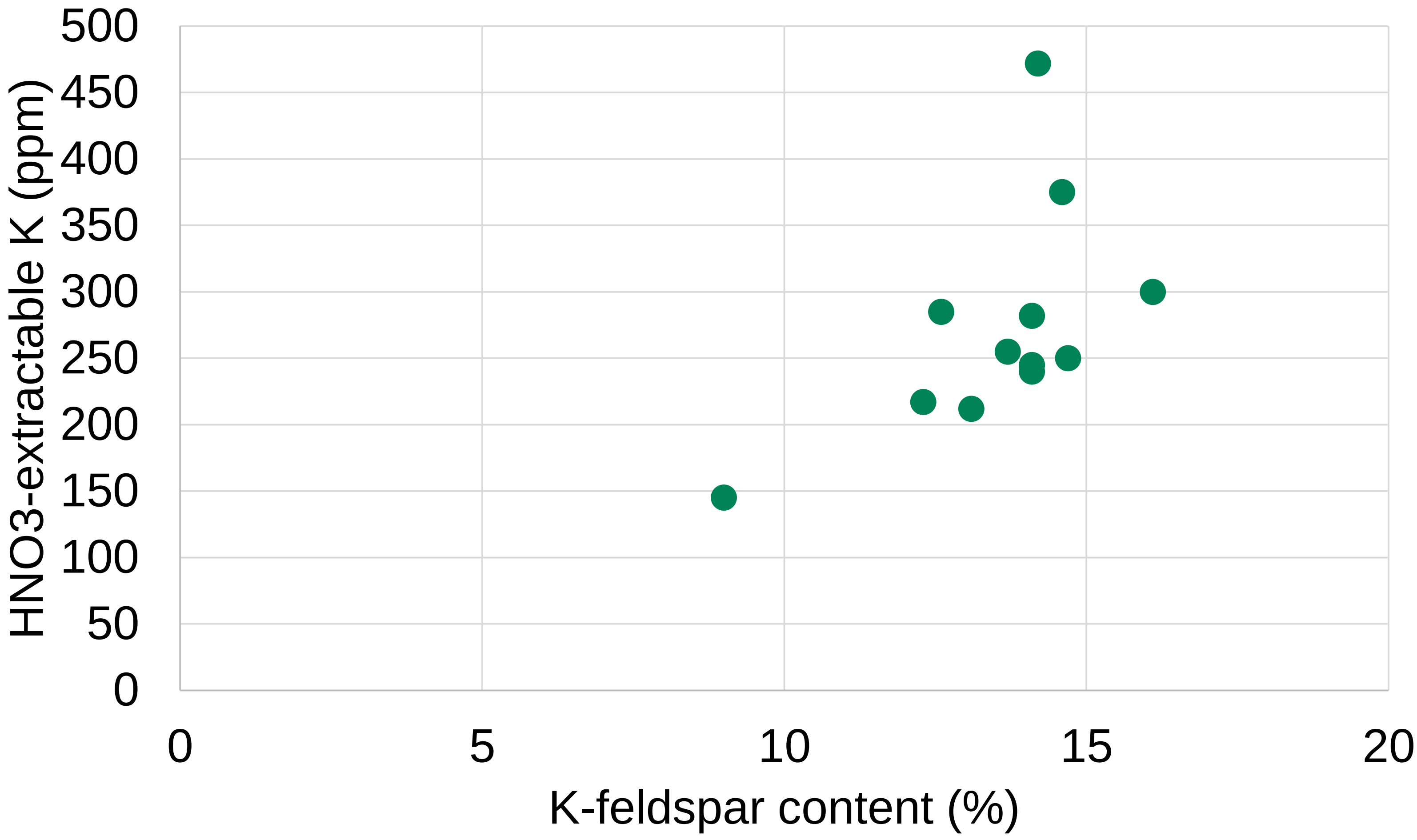


Fig. 1—Amount of nonexchangeable K released vs. time in the 0.45- to 0.60-m depth of Kalmia and Kennansville soils.

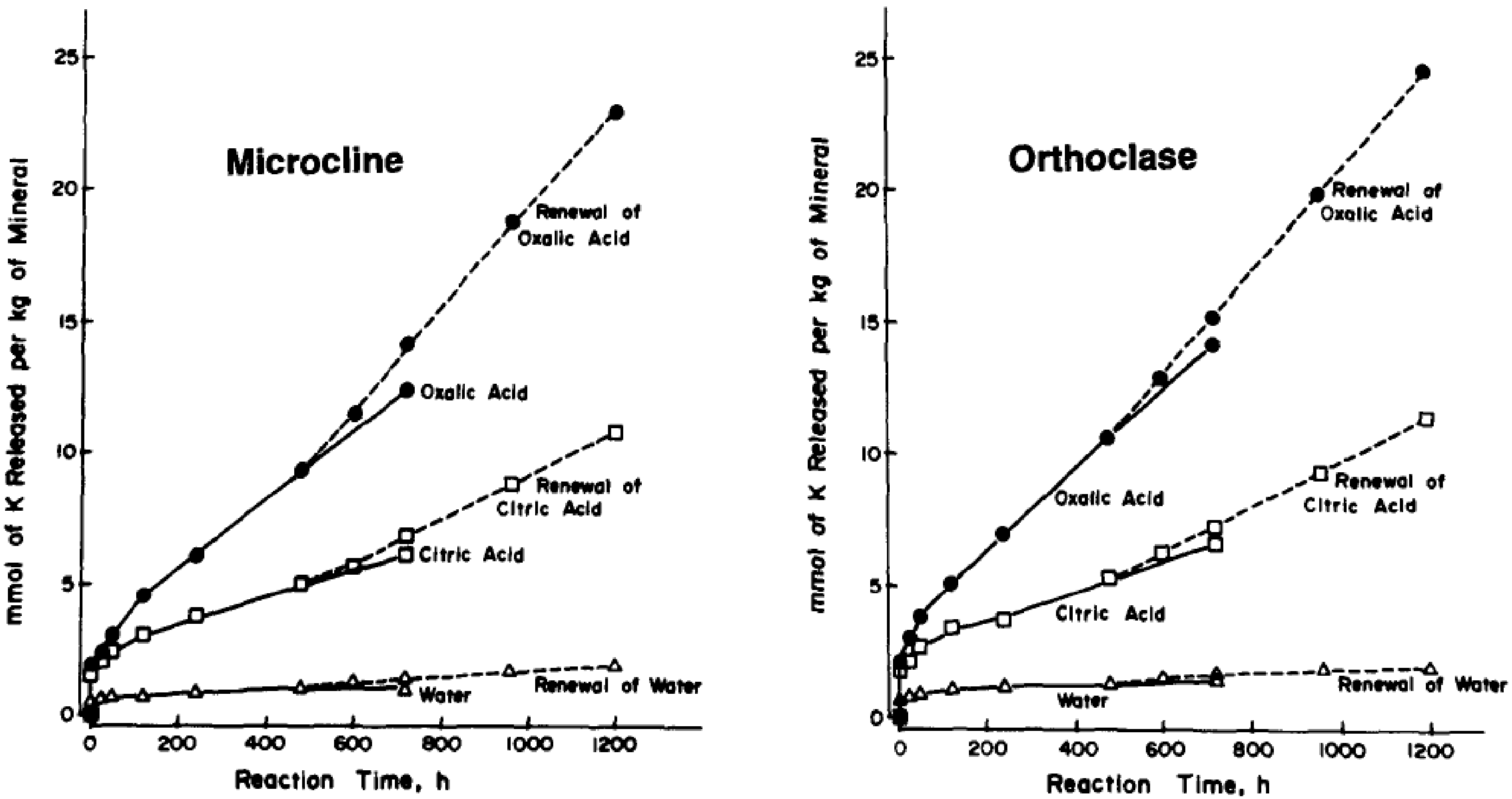
Martin, H.W., and D.L. Sparks. 1983. Kinetics of nonexchangeable potassium release from two Coastal Plain soils. Soil Sci. Soc. Am. J. 47(5):883–887.

Don’t forget about K-feldspar in the silt fraction



Phillipe, M.M., and J.L. White. 1952. Acid-soluble potassium and microline content of the silt fraction of 12 Indiana soils. Soil Sci. Soc. Am. Proc. 16(4):371.

Organic acids in rhizosphere promote K-feldspar dissolution



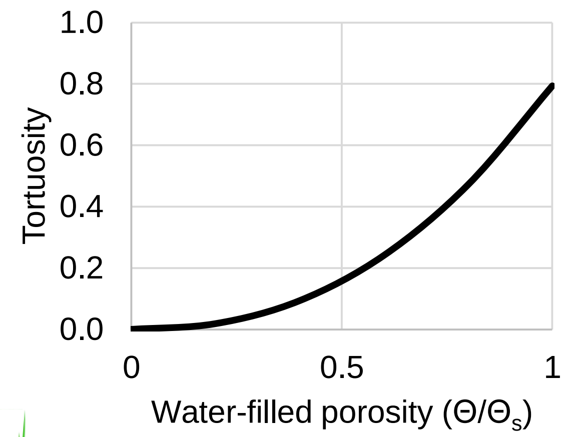
1000 hours ≈ 6 weeks

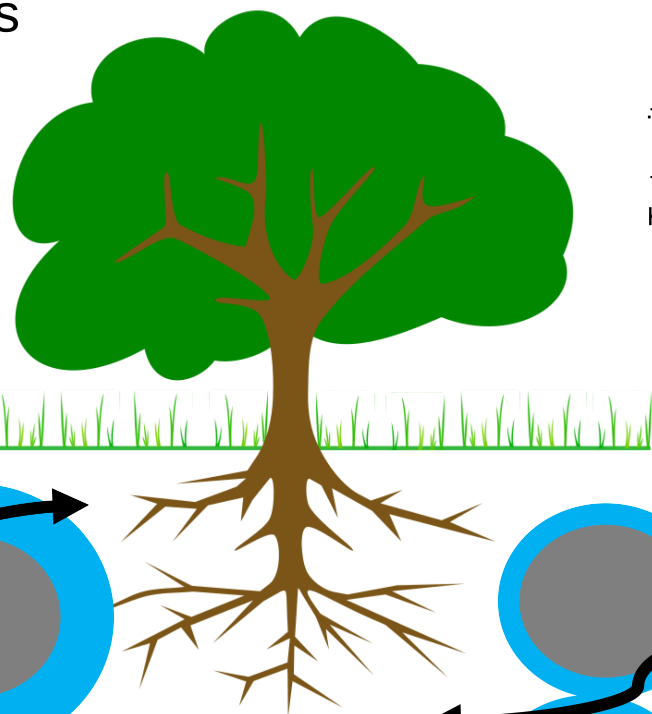
Song, S.K., and P.M. Huang. 1988. Dynamics of potassium release from potassium-bearing minerals as influenced by oxalic and citric acids. Soil Sci. Soc. Am. J. 52(2):383–390.

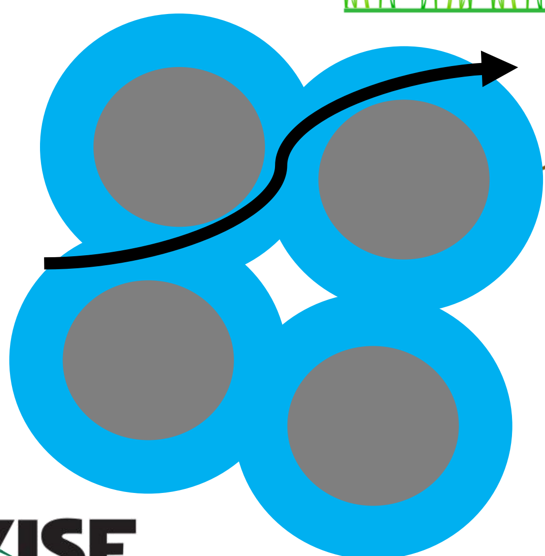
K^+ diffuses to plant roots through water films

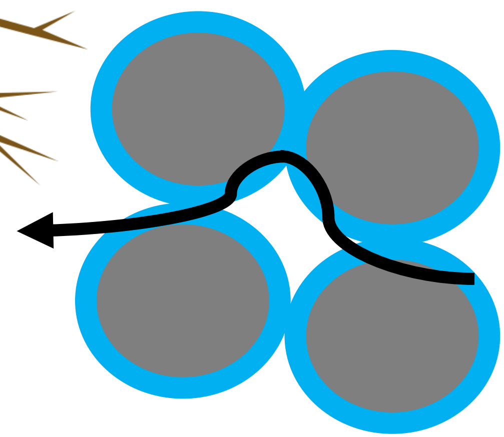
Low water content makes K^+ diffusion harder:

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



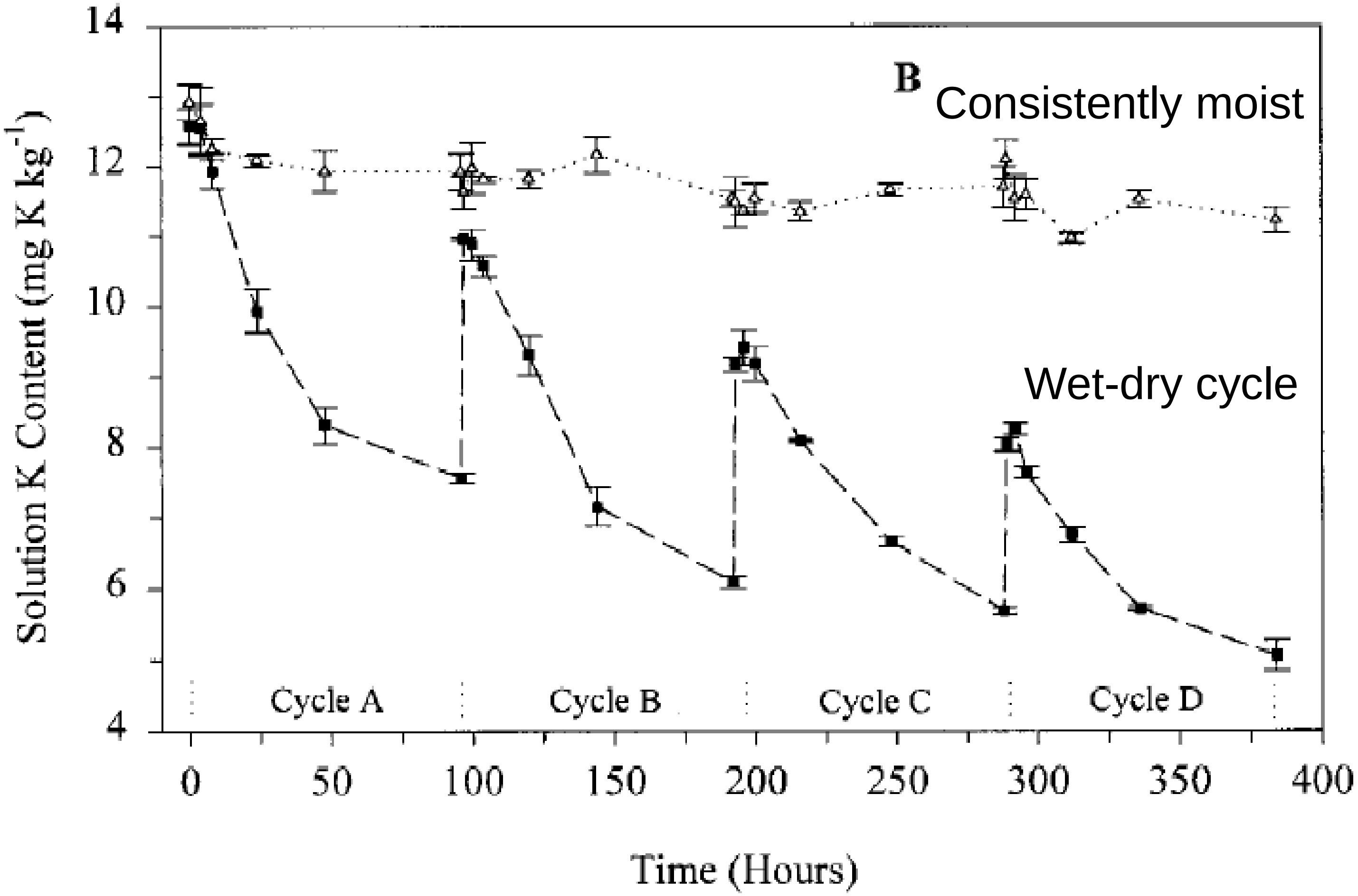






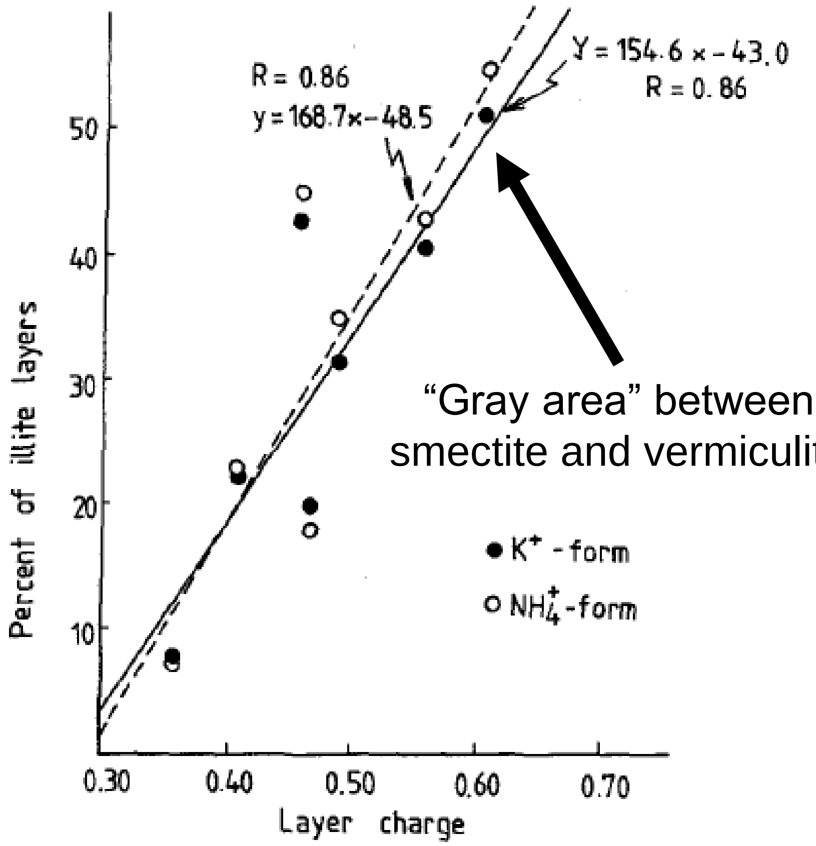
Millington, R.J., and J.P. Quirk. 1961. Permeability of porous solids. Trans. Faraday Soc. 57:1200–1207.

Wet/dry cycles reduce K availability



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.

Wet/dry cycles promote K fixation



"Gray area" between smectite and vermiculite

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

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

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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.

Conclusions

No loose ends here. Okay, maybe a few.

Conclusions

- Mineral K can be released during the growing season
  - Mica, illite
  - K-feldspar
- Dry soil conditions reduce K availability
  - Slower diffusion to plant root
  - Smectites may “suck up” K

Questions?

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