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1

Soil Sampling and Phosphorus in Calcareous Soils

Paul Stukenholtz

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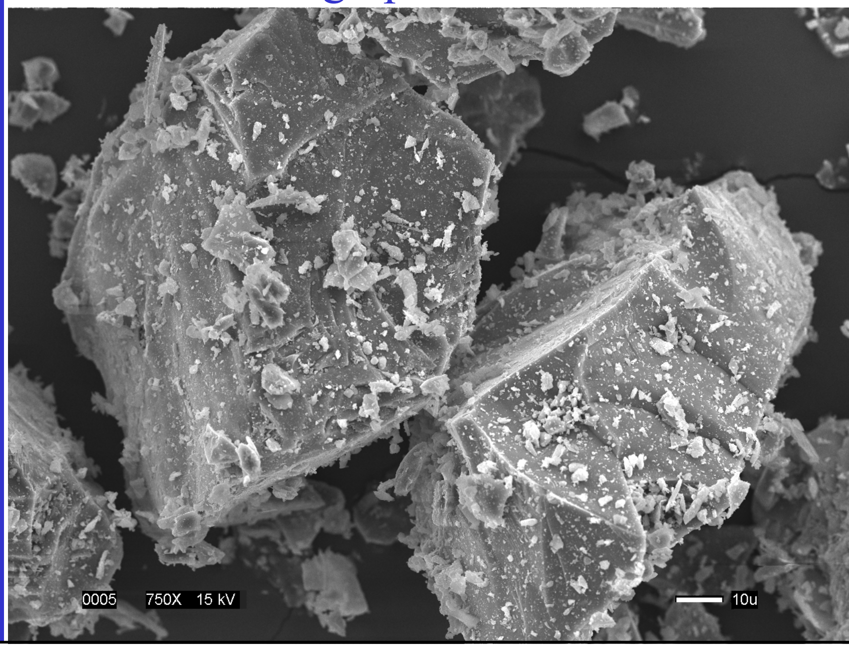
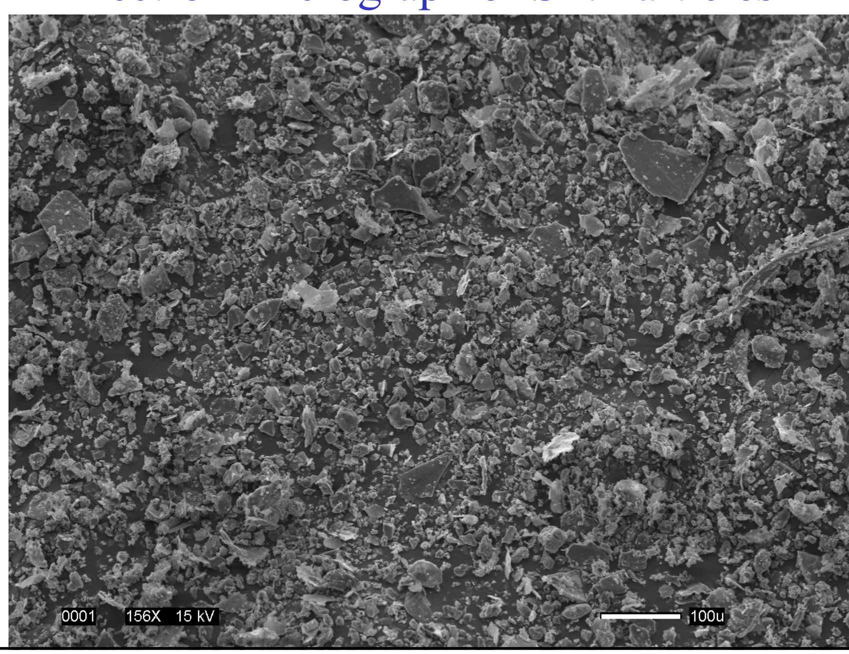
2

Electron Micrograph of Sand Particles



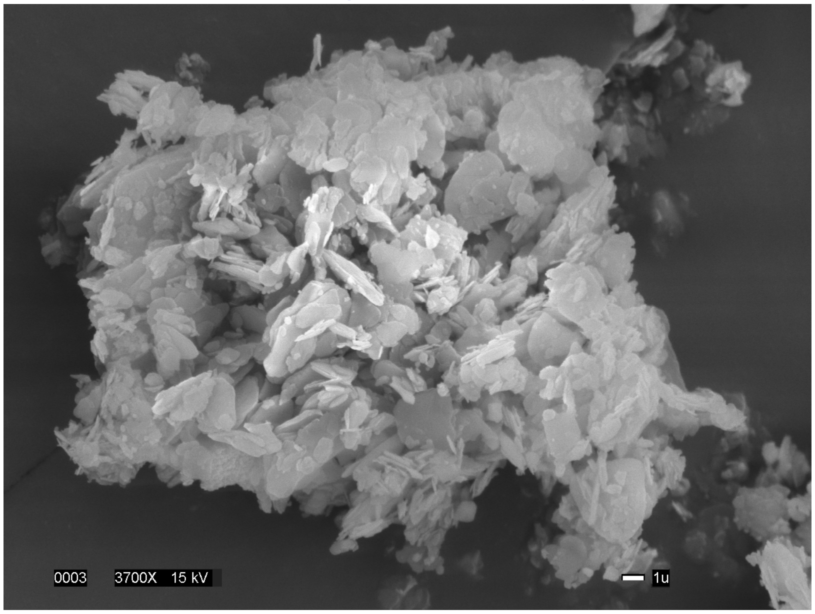
3

Electron Micrograph of Silt Particles



4

Electron Micrograph of Clay Particle



5

6

Phosphorus - P

- Used for energy storage and transport
- Very important for root growth
- Very important for disease resistance
- Tied-up by excess lime in the soil
- Often <u>never</u> shows deficiency symptoms
  - even when severely stunting growth

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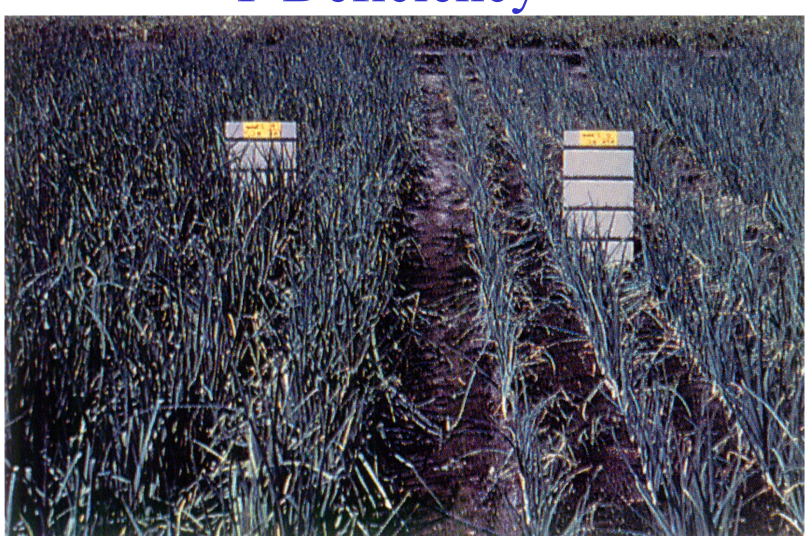
P Deficiency



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P Deficiency in Corn

Grand View, ID
6-21-2011

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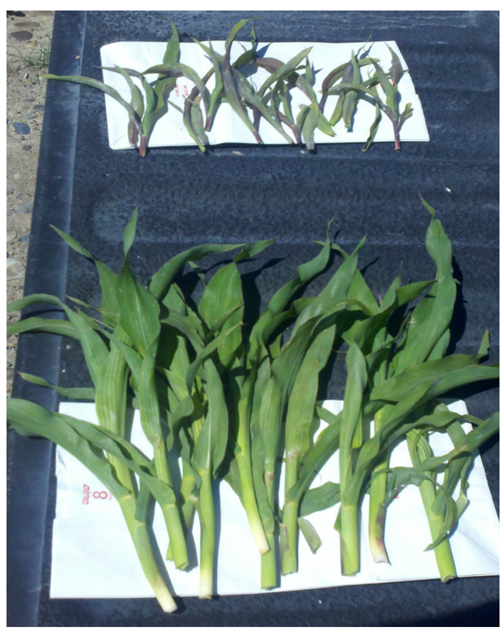
9

P Deficiency in Corn

Grand View, ID
6-21-2011



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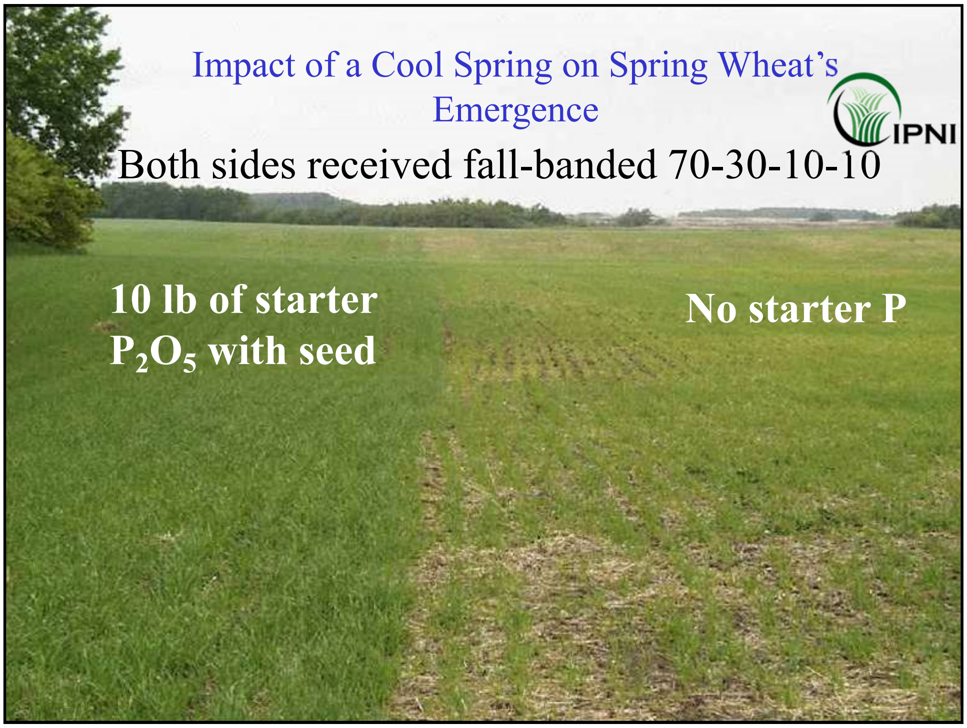
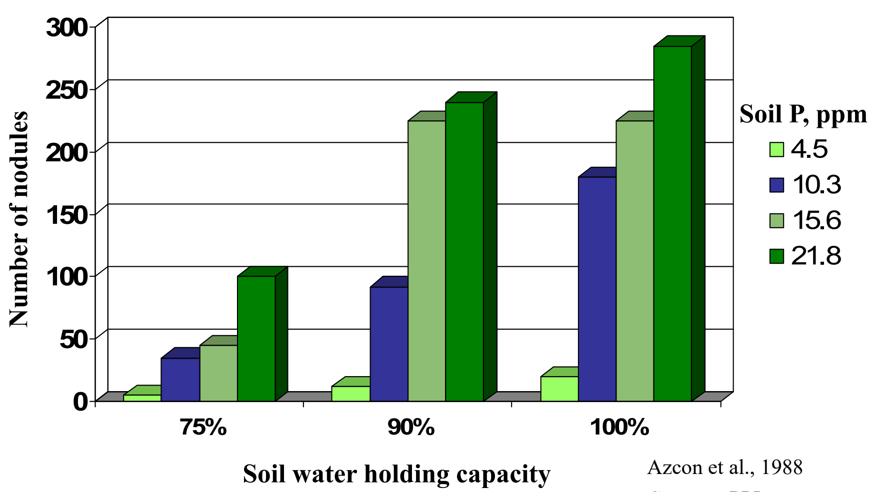
10



11

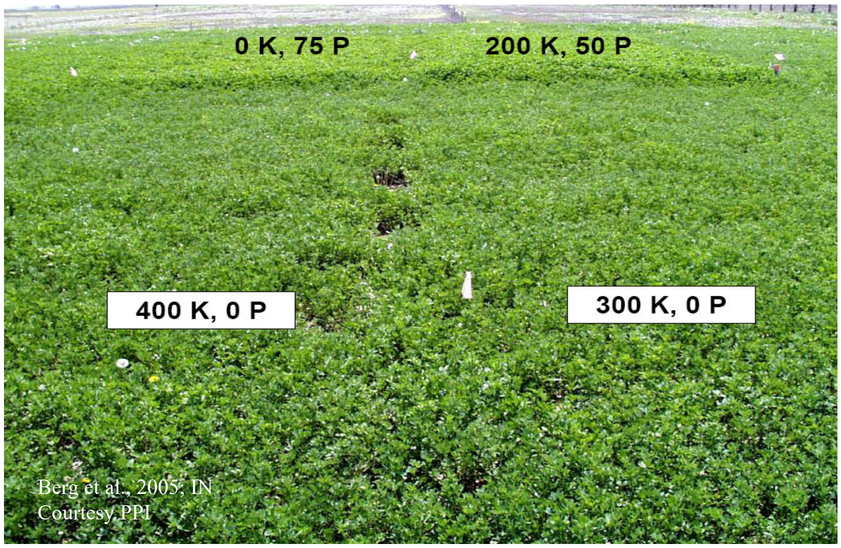
P Fertilization Increases Nodulation



Azcon et al., 1988
Courtesy PPI

12

P and K



13

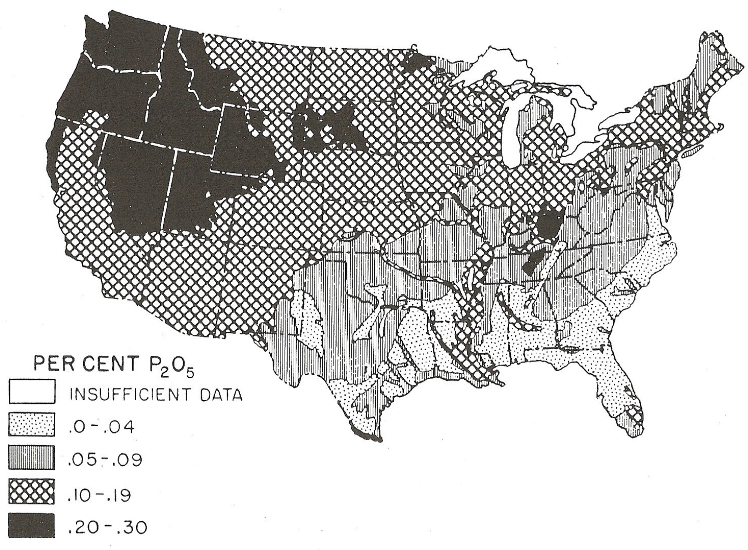


FIGURE 6.1 Phosphate content in the surface foot of soils in the United States.
Pierre and Norman, Eds., Agronomy, Vol. 4, p. 401, 1953

14

pH and Phosphorus

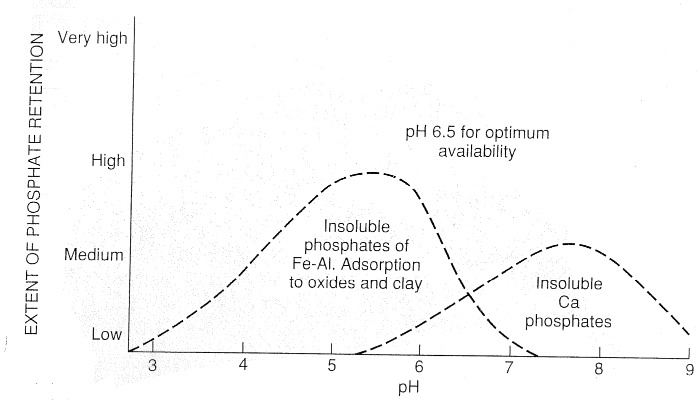


FIGURE 6.11 Soil pH effect on P adsorption and precipitation. *Adapted from Stevenson,* Cycles of Soil, *p. 250, John Wiley & Sons, 1986.*

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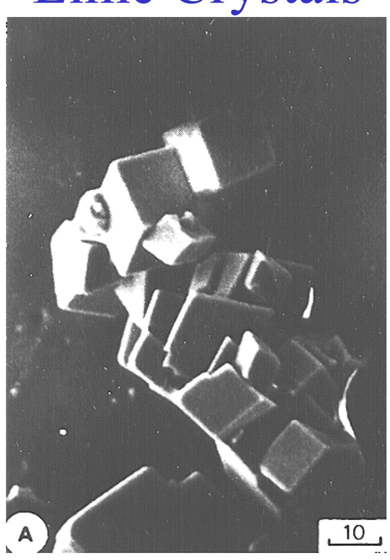
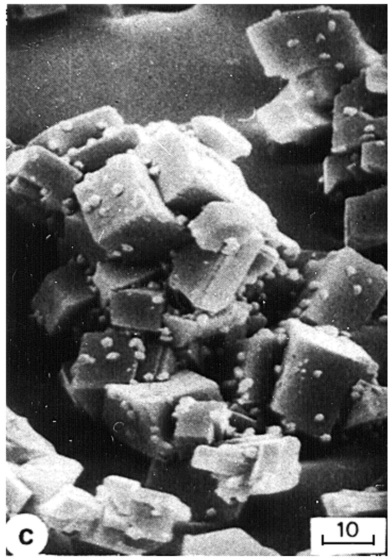
15

Lime Crystals



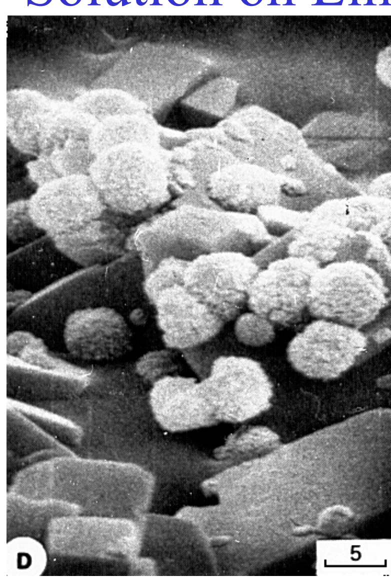
16

P Solution on Lime



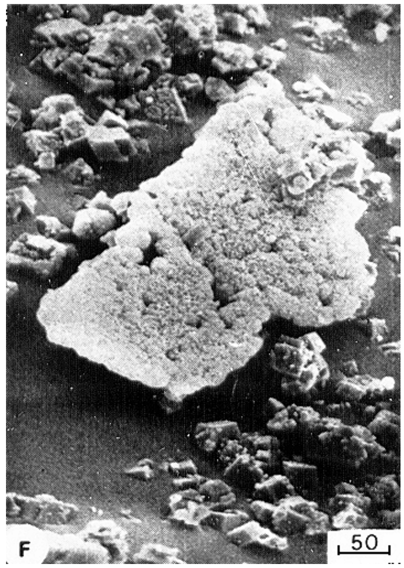
17

P Solution on Lime



18

P Solution on Lime



19

Total vs. Available P_2O_5 at pH of 8.1 5% Excess Lime

Total in Soil	Soil Solution	Labile
0.05-0.25%	0.02-0.05 ppm	10-30 ppm
2000-8000 lbs/Ac·ft	0.1-0.2 lbs/Ac·ft	40-80 lbs/Ac·ft

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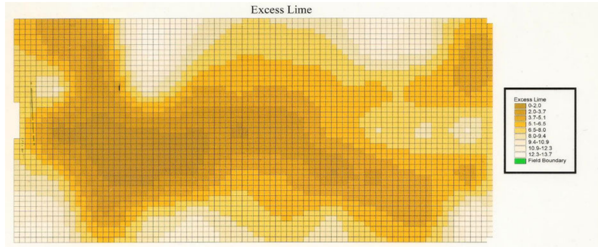
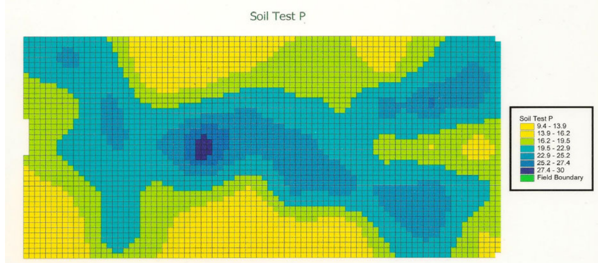
20





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21

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2924 Addison Avenue East, P.O. Box 353 Twin Falls, ID 83301

3009 208-734-3050 Fax: 208-734-3919 [illegible]

STUKENHOLTZ, PAUL
2924 ADDISON AVE. EAST
TWIN FALLS, ID 833030353

Tel: 208-734-3050 Fax: 208-734-3919
Report No: 148473
Date Received: 11/14/2023
Date Reported: 11/15/2023

SOIL TEST DATA	Sample 1		Sample 2
pH	**8.0**	H	
Salts, mmhos/cm	**1.7**	M	
Chlorides, ppm	**15**	L	
Sodium, meq/100g	**0.20**	VL	
CEC, meq/100g	**17.5**	M	
Excess Lime, %	**3.3**	M	
Organic Matter, %	**2.80**	H	
Organic N, lb/Acre	**110**	H	
Ammonium - N, ppm	**2.8**	VL	
Nitrate - N, ppm	**5**	VL	
Phosphorus, ppm	**6**	L	
Potassium, ppm	**129**	L	
Calcium, meq/100g	**13.9**	VH	
Magnesium, meq/100g	**3.0**	M	
Sulfate - S, ppm	**20**	M	
Zinc, ppm	**0.5**	VL	
Iron, ppm	**12.3**	H	
Manganese, ppm	**2.4**	L	
Copper, ppm	**0.5**	L	
Boron, ppm	**0.79**	M	

	Sample 1	Sample 2
Grower	**U OF WY**	
Sample Identity	**JHNSN 1 ALF/GRS**	
Crop	**ALF/GRASS**	
Yield Goal	**4 T**	
Acres	**300**	
Prev Crop T/Acre	**ALF/GRASS**	
Manure T/Acre		
Prev Applied Nut		
RECOMMENDATIONS, lbs Nutrients or Units per Acre		
Nitrogen	**70**	
P_2O_5 – Phosphate	**170**	
K_2O - Potash	**40**	
Calcium	**0**	
Magnesium	**0**	
Sulfate - Sulfur	**0**	
Zinc	**6**	
Iron	**0**	
Manganese	**0**	
Copper	**0**	
Boron	**0**	
Elemental Sulfur	**0**	
Gypsum	**0**	
Lime	**0**	

Base Saturation, %			
Potassium	(Ideal 3 - 6)	**2.4**	L
Calcium	(Ideal 65 - 80)	**79.4**	M
Magnesium	(Ideal 15 - 25)	**17.1**	M
Sodium	(Ideal < 3)	**1.1**	M

Relation of CEC to Soil Texture

0-5 Sand	18-24 Silt Loam
5-12 Loamy Sand	24-36 Clay Loam
12-18 Sandy Loam	36+ Clay

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SOIL TEST DATA	Sample 1		Sam
pH	8.0	H	
Salts, mmhos/cm	1.7	M	
Chlorides, ppm	15	L	
Sodium, meq/100g	0.20	VL	
CEC, meq/100g	17.5	M	
Excess Lime, %	3.3	M	
Organic Matter, %	2.80	H	
Organic N, lb/Acre	110	H	
Ammonium - N, ppm	2.8	VL	
Nitrate - N, ppm	5	VL	
Phosphorus, ppm	6	L	
Potassium, ppm	129	L	
Calcium, meq/100g	13.9	VH	
Magnesium, meq/100g	3.0	M	
Sulfate - S, ppm	20	M	
Zinc, ppm	0.5	VL	
Iron, ppm	12.3	H	
Manganese, ppm	2.4	L	
Copper, ppm	0.5	L	
Boron, ppm	0.79	M	

Moderately High Lime

Very Low Phosphorus

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What is P_2O_5?

RECOMMENDATIONS, lbs Nutrients or Units per Acre

Nitrogen	35
P_2O_5 – Phosphate	135
K_2O - Potash	200
Calcium	0
Magnesium	0
Sulfate - Sulfur	35
Zinc	7
Iron	0

Pound of Phosphorus nutrient expressed as an oxide

=

“Units Phosphate”

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P vs. P_2O_5

P = Phosphorus

PO_4^{-3} = Phosphate Ion

P_2O_5 = Diphosphorus Pentoxide

Slang name "Phosphate"

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P vs. P_2O_5

$P_2O_5 \times 0.44 = P$

$P \times 2.3 = P_2O_5$

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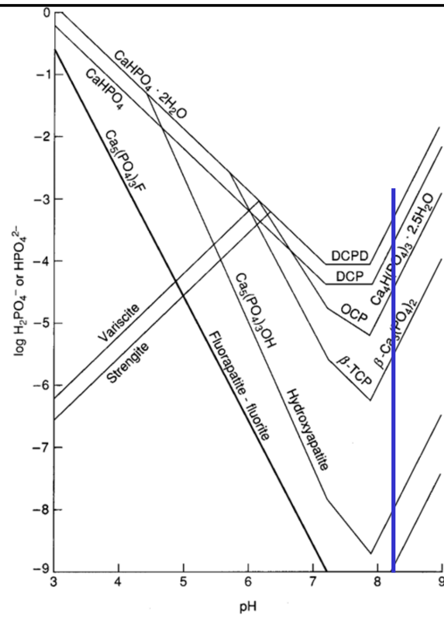


FIGURE 6.12 Solubility of Ca, Al, and Fe phosphate minerals in soils. *Lindsay*, Chemical Equilibria in Soils, *Wiley Interscience, p. 181, 1979*

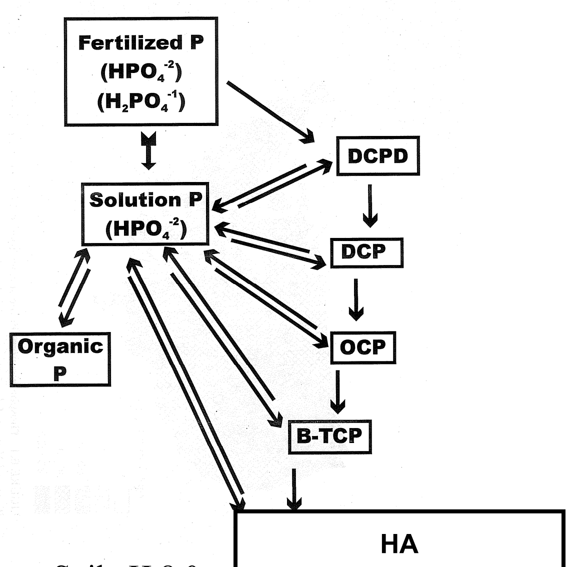
TABLE 6.6 Common P Minerals Found in Acid, Neutral, and Calcareous Soils

Acid soils*	
Variscite	$AlPO_4 \cdot 2H_2O$
Strengite	$FePO_4 \cdot 2H_2O$
Neutral and calcareous soils	
Dicalcium phosphate dihydrate (DCPD)	$CaHPO_4 \cdot 2H_2O$
Dicalcium phosphate (DCP)	$CaHPO_4$
Octacalcium phosphate (OCP)	$Ca_4H(PO_4)_3 \cdot 2.5H_2O$
ß-tricalcium phosphate (ßTCP)	$Ca_3(PO_4)_2$
Hydroxyapatite (HA)	$Ca_5(PO_4)_3OH$
Fluorapatite (FA)	$Ca_5(PO_4)_3F$

*Minerals are listed in order of decreasing solubility.

27

In Fertilized Soils



Soil pH 8.0

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- DCPD
  - Dicalcium phosphate dihydrate $CaHPO_4 \cdot 2H_20$
  - Ca:P ratio: 1:1
- DCP Dicalcium phosphate $CaHPO_4$
  - Ca:P ratio: 1:1
- OCP
  - Octacalcium phosphate $Ca_4H(PO_4)_3 \cdot 2.5H_20$
  - Ca:P ratio 4:3
- BTCP
  - Beta-tricalcium phosphate $Ca_{18}(Mg,Fe)H_2(PO_4)_{12}$
  - Ca:P ratio 3:2
- HA Hydroxyapatite $Ca_5(PO_4)_3OH$
  - Ca:P ratio 5:3

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Phosphorus Immobilization Can Occur Quickly

- In laboratory incubations, DCPD to HA in 20 hours
- In soil tests, generally DCPD to OCP in 4 months
- OCP to B-TCP in 8-10 months

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It isn't this simple

- Technical phrase: "not completely understood"
- Clay, Organic Matter, & metals may bind and release Phosphorus ions.
- In some soils, DCPD, OCP, or B-TCP dominate, even when they "shouldn't".
- Solution P "holds" at certain levels.
- New forms of soil P are continuously being discovered.

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Compound	Mineral name	Compound	Mineral name
$AlPO_4 \cdot 2H_2O$	Variscite	$FePO_4 \cdot 2H_2O$	Metastrengite
$AlPO_4 \cdot 2H_2O$	Metavariscite	$Fe_3(PO_4)_2 \cdot 8H_2O$	Vivianite
$Al(NH_4)_2H(PO_4)_2 \cdot 4H_2O$	—	$FeNH_4(HPO_4)_2$	—
$Al_2(NH_4)_2H_4(PO_4)_4 \cdot H_2O$	—	$Fe_3NH_4H_6(PO_4)_6 \cdot 6H_2O$	—
$Al_5(NH_4)_3H_6(PO_4)_8 \cdot 18H_2O$	NH_4-taranakite	$Fe_3KH_6(PO_4)_6 \cdot 6H_2O$	—
$AlNH_4PO_4OH \cdot 2H_2O$	—	$Fe_2K(PO_4)_2OH \cdot 2H_2O$	K-leucophosphite
$AlNH_4PO_4OH \cdot 3H_2O$	—	$MgHPO_4 \cdot 3H_2O$	Newberryite
$Al_2NH_4(PO_4)_2OH \cdot 2H_2O$	—	$Mg_3(PO_4)_2 \cdot 4H_2O$	—
$Al_2NH_4(PO_4)_2OH \cdot 8H_2O$	—	$Mg_3(PO_4)_2 \cdot 22H_2O$	—
$AlKH_2(PO_4)_2 \cdot H_2O$	—	$MgNH_4PO_4 \cdot 6H_2O$	Struvite
$Al_5K_3H_6(PO_4)_8 \cdot 18H_2O$	K-taranakite	$Mg(NH_4)_2(HPO_4)_2 \cdot 4H_2O$	Schertelite
$Al_2K(PO_4)_2OH \cdot 2H_2O$	Leucophosphite	$Mg_3(NH_4)_2(HPO_4)_4 \cdot 8H_2O$	Hannayite
$AlKPO_4OH \cdot 0.5H_2O$	—	$MgKPO_4 \cdot 6H_2O$	—
$AlKPO_4OH \cdot 1.5H_2O$	—	$Mg_2KH(PO_4)_2 \cdot 15H_2O$	—
$Al_2K(PO_4)_2(F,OH) \cdot 3H_2O$	Minyulite	$Al(NH_4)_2P_2O_7OH \cdot 2H_2O$	—
$CaHPO_4$	Monetite	$Ca_2P_2O_7 \cdot 2H_2O$	—
$CaHPO_4 \cdot 2H_2O$	Brushite	$Ca_2P_2O_7 \cdot 4H_2O$	—
$Ca_8H_2(PO_4)_6 \cdot 5H_2O$	Octocalcium phosphate	$Ca_3H_2(P_2O_7)_2 \cdot 4H_2O$	—
$Ca_{10}(PO_4)_6(OH)_2$	Hydroxyapatite	$Ca(NH_4)_2P_2O_7 \cdot H_2O$	—
$Ca_{10}(PO_4)_6F_2$	Fluorapatite	$Ca_3(NH_4)_2(P_2O_7)_2 \cdot 6H_2O$	—
$CaAlH(PO_4)_2 \cdot 6H_2O$	—	$Ca_5(NH_4)_2(P_2O_7)_3 \cdot 6H_2O$	—
$CaAl_6H_4(PO_4)_3 \cdot 20H_2O$	—	$CaNH_4HP_2O_7$	—
$CaNH_4PO_4 \cdot H_2O$	—	$Ca_2NH_4H_3(P_2O_7)_2 \cdot 3H_2O$	—
$Ca(NH_4)_2(HPO_4)_2 \cdot H_2O$	—	$CaK_2P_2O_7$	—
$Ca_2NH_4H_7(PO_4)_4 \cdot 2H_2O$	NH_4-Flatt's salt	$Ca_3K_2(P_2O_7)_2 \cdot 2H_2O$	—
$Ca_2(NH_4)_2(HPO_4)_3 \cdot 2H_2O$	—	$Ca_6K_2(P_2O_7)_3 \cdot 6H_2O$	—
$CaKPO_4 \cdot H_2O$	—	$Ca_2KH_3(P_2O_7)_2 \cdot 3H_2O$	—
$CaK_3H(PO_4)_2$	—	$CaNa_2P_2O_7 \cdot 4H_2O$	—
$Ca_2KH_7(PO_4)_4 \cdot 2H_2O$	K-Flatt's salt	$Fe(NH_4)_2P_2O_7 \cdot 2H_2O$	—
$CaFe_2H_4(PO_4)_4 \cdot 5H_2O$	—	$Mg(NH_4)_2P_2O_7 \cdot 4H_2O$	—
$CaFe_2H_4(PO_4)_4 \cdot 8H_2O$	—	$Mg(NH_4)_6(P_2O_7)_2 \cdot 6H_2O$	—
$Ca_3Mg_3(PO_4)_4$	—	$Mg(NH_4)_2H_4(P_2O_7)_2 \cdot 2H_2O$	—
$FePO_4 \cdot 2H_2O$	Strengite	$Ca(NH_4)_3P_3O_{10} \cdot 2H_2O$	—

From Sample et al., 1986. *The Role of Phosphorus in Agriculture*, Khasawneth, F.E., Sample, E.C., and Kamprath, E.J., Eds., p. 284. With permission of American Society of Agronomy.

32

Predicting P Fertilizer Response

- An “Extract” is used to pull some of the P from the soil.
- The amount of P removed should correlate to the amount of increased growth from a fertilizer addition.

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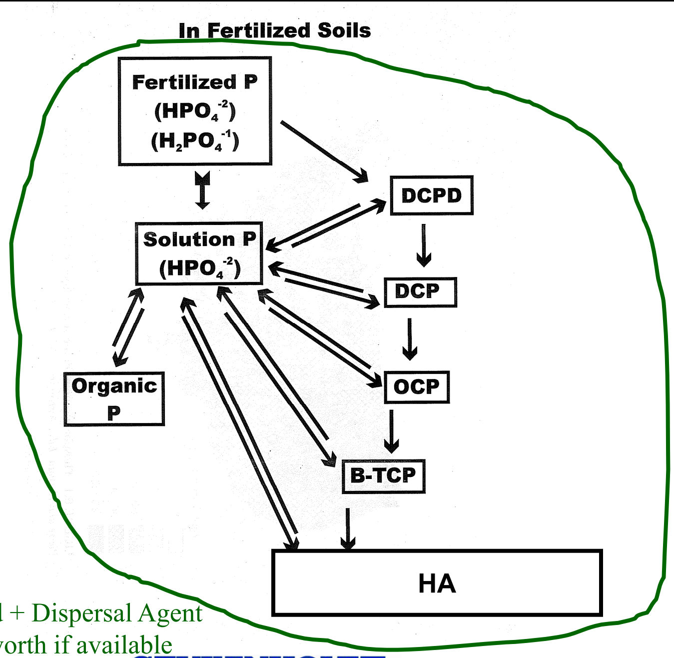
33



Total Soil P
Strong Acid + Dispersal Agent
500 years worth if available
Mostly not available

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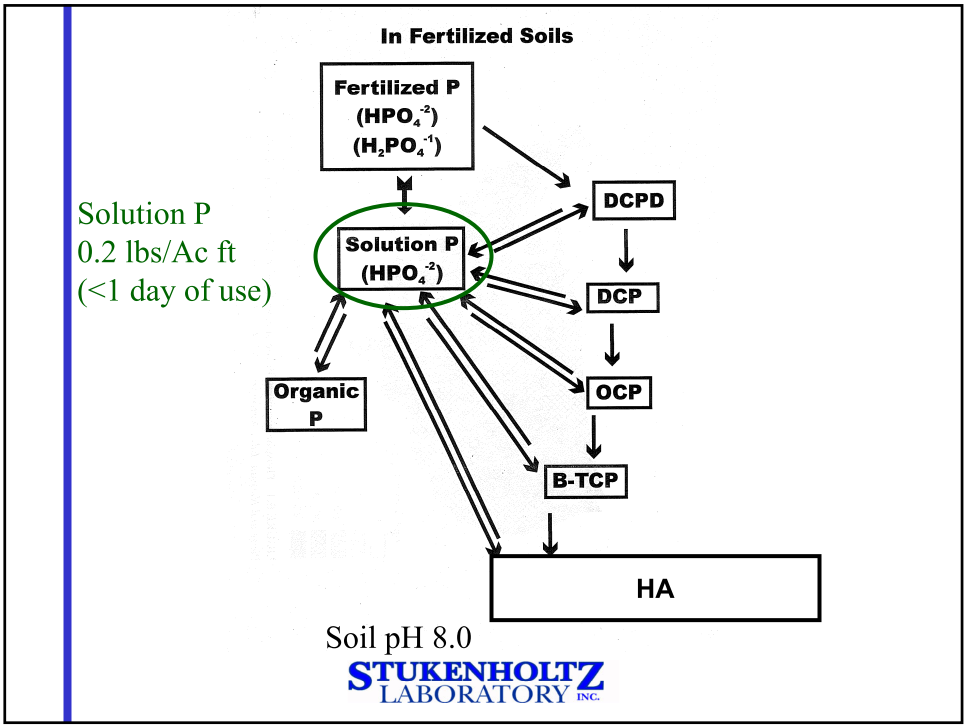
Soil pH 8.0

34


In Fertilized Soils
Fertilized P (HPO_4^{-2}) ($H_2PO_4^{-1}$)
Solution P
0.2 lbs/Ac ft
(<1 day of use)
Solution P (HPO_4^{-2})
DCPD
DCP
OCP
Organic P
B-TCP
HA
Soil pH 8.0
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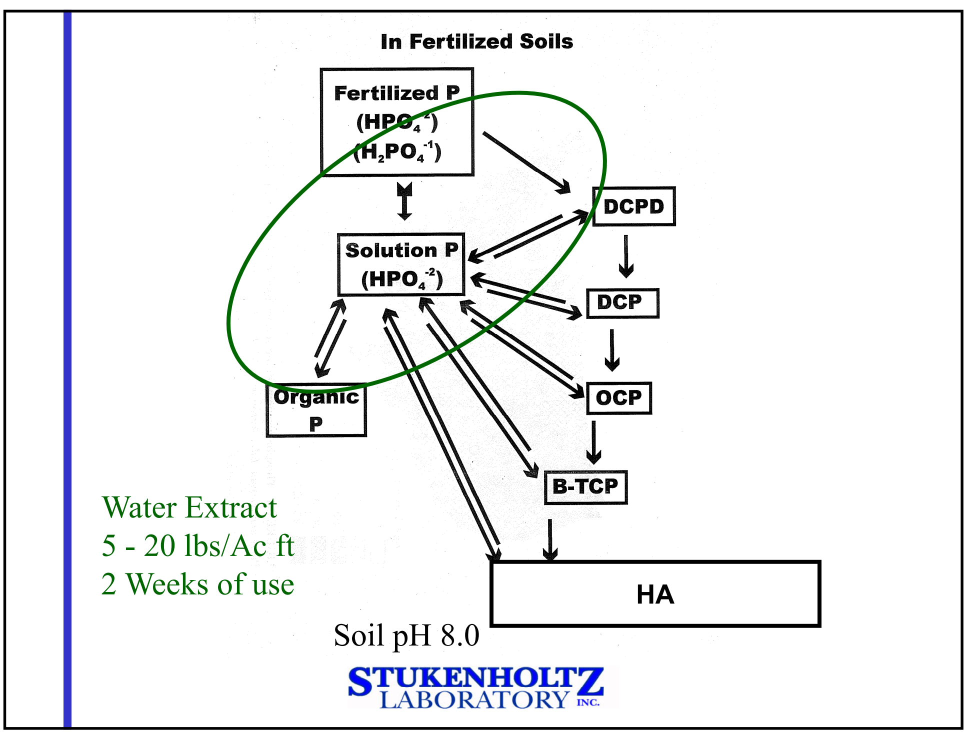
35


In Fertilized Soils
Fertilized P (HPO_4^{-2}) ($H_2PO_4^{-1}$)
Solution P (HPO_4^{-2})
DCPD
DCP
OCP
Organic P
B-TCP
Water Extract
5 - 20 lbs/Ac ft
2 Weeks of use
HA
Soil pH 8.0
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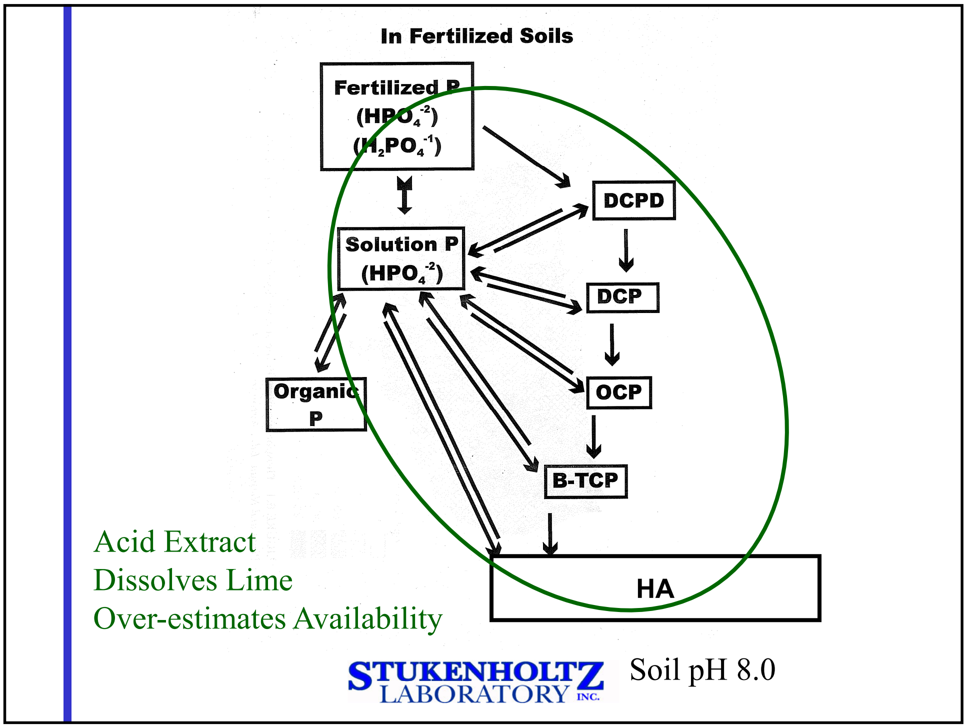
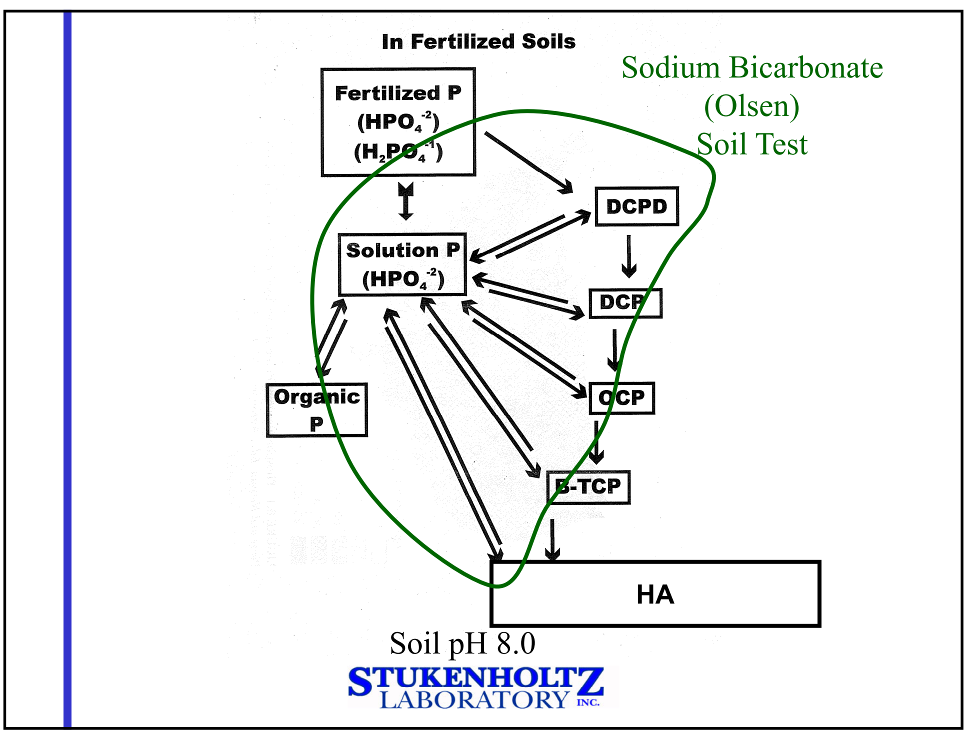
36


In Fertilized Soils
Fertilized P
(HPO4-2)
(H2PO4-1)
DCPD
Solution P
(HPO4-2)
DCP
Organic P
OCP
B-TCP
HA
Acid Extract
Dissolves Lime
Over-estimates Availability
STUKENHOLTZ LABORATORY INC.
Soil pH 8.0

37


In Fertilized Soils
Sodium Bicarbonate
(Olsen)
Soil Test
Fertilized P
(HPO4-2)
(H2PO4-1)
DCPD
Solution P
(HPO4-2)
DCP
Organic P
OCP
B-TCP
HA
Soil pH 8.0
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38

Sodium Bicarbonate (Olsen) Extract

Sodium Bicarbonate (pH 8.5)

$Na^+ + HCO_3^-$

$$2HCO_3^- + Ca^{2+} \longrightarrow CaCO_3 + H_2O + CO_2 \uparrow$$

$CaHPO_4$ $\longrightarrow$ HPO_4^{2-}

Calcium Phosphate(s)

Measured by Extract

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39

Major P Extraction Methods

Method	Contains	Ext. pH	Soil pH
Olsen (Na-Bicarb)	$NaHCO_3$	8.50	6.0-10.0
Bray 1	HCl NH_4F	2.60	4.0-7.5 (no Lime)
Mehlich 3	Acetic acid HNO_3 NH_4F EDTA	2.50	4.0-7.5 (no Lime)

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40

NAPTP Sample Exchange

Soils					2015-103				2015-106	
		Units		# Labs	Median	MAD		# Labs	Median	MAD
pH	Water (1:1)			85	7.59	0.09		90	8.16	0.08
XS Lime				15	9.70	0.84		13	2.00	0.30
Phosphorus										
PO4-P	Bray P (1:10)	mg/kg		47	14.1	2.53		47	27.7	2.37
PO4-P	Bray P1 (1:7)	mg/kg		9	14.3	2.72		12	22.1	3.65
PO4-P	Olsen/Bicarb	mg/kg		53	31	3.95		58	10.6	1.31
PO4-P	AB-DTPA	mg/kg		1	24.5	0		2	4.36	0.359
PO4-P	Modified Morgan	mg/kg		6	27.8	6.76		7	27.1	2.1
PO4-P	TRUE Morgan	mg/kg		7	21	2.5		7	25.8	1.4
PO4-P	Mod. Kewlona	mg/kg		1	34.5	0		3	20	1.5
PO4-P	Strong Bray (1:10)	mg/kg		9	399	70.9		9	130	7
PO4-P	Water Soluble	mg/kg		0	6.1			0	5.2	0
Mehlich-1 Multi Element		mg/kg		5	76.4	19.2		6	26.8	9.46
Mehlich-3 Mult-Element		mg/kg		50	94	7.7		50	41.1	2.94

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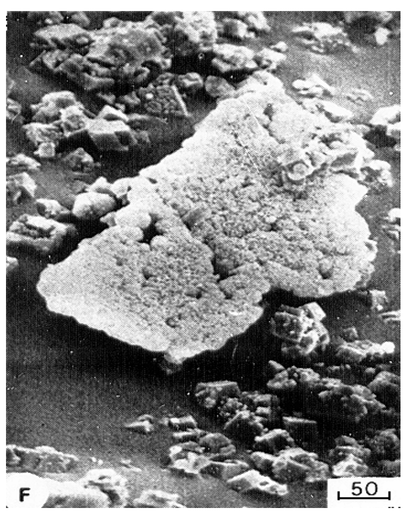
41

The Sodium Bicarbonate Test Alone is not Good Enough



42

Early Research on Lime & Phosphorus

Dr. Dale Stukenholtz, Stukenholtz Laboratory

Dr. Jeff Stark, University of Idaho

Dr. Dale Westermann, USDA ARS

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Lime Effects on Phosphorus Availability in a Calcareous Soil

D.T Westermann, USDA-ARS, 3793 N 3600 E, Kimberly, ID 83341, 19 Apr 1991

Soil Science Society of America Journal 56:489-494 (1992) 677 Sough Segoe Rd., Madison WI 53711 USA

44

Materials & Methods

- Bulk Portneuf Silt Loam soil collected
  - A Horizon (topsoil)
  - pH 7.5, 0.6% excess lime
- CaO mixed with soil at 3 rates
  - Mixed, wetted, dried repeatedly over 13 weeks
  - CaO converted to CaCO3,
  - pH 8.0
- 1 RB Minituber added to each pot
- Roots and tops harvested after 35 days

45

Table 2. Treatments, selected soil P characteristics, plant dry-matter yield, and P uptake for potato and sudangrass in Exp. 2a and 2b†, respectively.

Experiment	Treatments		Soil characteristics				Plant	
	Lime	P application	$NaHCO_3$-P	Resin-P	Solution P	EBC‡	Yield	P uptake
	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg L^{-1}	L kg^{-1}	g pot^{-1}	mg pot^{-1}
2a Potato	6	0	19.6	35.6	0.277	48	12.45	42
	6	25	32.8	61.0	0.455	38	14.29	62
	6	75	58.7	113.6	1.094	21	14.86	74
	30	0	12.5	43.3	0.172	104	8.65	25
	29	25	23.3	63.2	0.260	78	11.55	41
	28	75	43.8	104.1	0.763	53	12.55	59
	75	0	9.5	29.9	0.139	182	7.43	17
	75	25	19.5	48.3	0.172	129	10.88	33
	75	75	40.0	81.7	0.251	94	11.47	43
	126	0	7.2	20.1	0.020	624	6.52	10
	125	25	14.9	29.4	0.022	540	6.94	14
	126	75	32.7	51.2	0.030	338	7.53	20

D.T. Westermann, USDA-ARS, 3793 N 3600 E, Kimberly, ID 83341. Contribution from USDA-ARS. Received 19 Apr. 1991.
*Corresponding author.

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46

Lime %	P Application ppm	Olsen-P ppm	Solution-P ppm	Yield g/pot	P Uptake mg/pot
0.6	0	19.6	0.277	12.45	42
0.6	25	32.8	0.455	14.29	62
0.6	75	58.7	1.094	14.06	74
3.0	0	12.5	0.172	8.65	25
2.9	25	23.3	0.260	11.95	41
2.8	75	45.8	0.763	12.95	59
7.5	0	9.5	0.139	7.43	17
7.5	25	19.5	0.172	10.88	33
7.5	75	42.0	0.251	11.47	43
12.6	0	7.2	0.020	6.52	10
12.5	25	14.9	0.022	6.94	14
12.6	75	32.7	0.030	7.43	20

47

Lime %	P Application ppm	Olsen-P ppm	Solution-P ppm	Yield g/pot	P Uptake mg/pot
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0.6	25	32.8	0.455	14.29	62
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2.9	25	23.3	0.260	11.95	41
2.8	75	45.8	0.763	12.95	59
7.5	0	9.5	0.139	7.43	17
7.5	25	19.5	0.172	10.88	33
7.5	75	42.0	0.251	11.47	43
12.6	0	7.2	0.020	6.52	10
12.5	25	14.9	0.022	6.94	14
12.6	75	32.7	0.030	7.43	20

3x fertilizer for same Olsen value, 1/15 sol^n P, 1/2 yield

48

Alfalfa P Recommendation Comparison

Test 0-12"	Free Lime 0%		Free Lime 12%	
ppm P	--- pounds P_2O_5 per acre ---			
0	210	300	325	420
4	190	225	300	345
8	150	150	235	270
12	110	100	170	220
16	90	50	140	170
20	80	0	125	120
24	70	0	115	70
	SL	U of I	SL	U of I

Assuming 6 T/Ac Yield Potential

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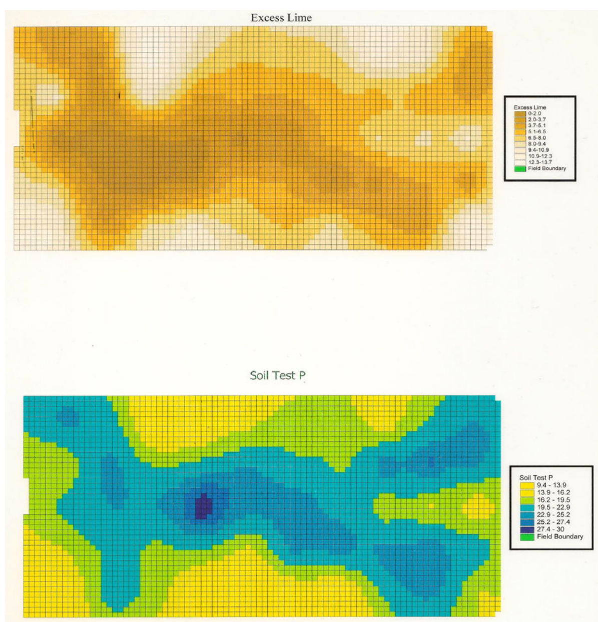

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Phosphorus Fertilizer

Rock P

(fluoroapatite)
(hydroxyapatite)
15% P_2O_5

Benefication

$Ca_5(PO_4)_3$-F or OH

35% P_2O_5
1-5% water soluble

H_2SO_4 (green acid)

Phosphoric Acid
52-55% P_2O_5

Burning (white acid)

+ Rock Phosphate

TSP
$Ca(H_2PO_4)_2$
0-45-0

+ Aqua ammonia

MAP
$NH_4H_2PO_4$
11-52-0

Remove Water (polyphosphate)
10-34-0 11-37-0

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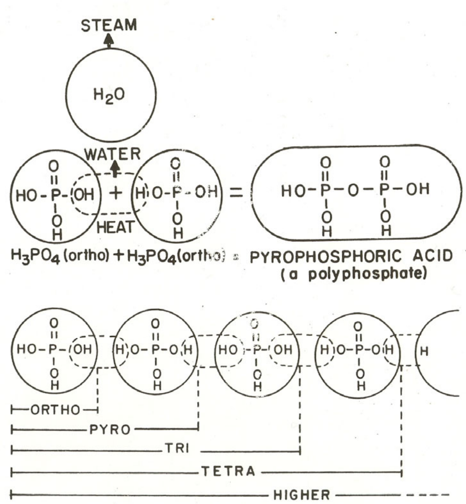
Polyphosphate



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Dry P Fertilizers

- Monoammonium Phosphate
  MAP
  11-52-0
  $NH_4H_2PO_4$
- 11% N, 52% P_2O_5,
- Good source of N & P
  - especially in high pH soils
- Acid forming
- Has oily outer coating

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Liquid P Fertilizers

- Phos Acid
  0-52-0
  H_3PO_4
- 50 - 52% P_2O_5
- pH < 0
- Not acid forming (it's already acid)
- 100% Orthophosphate
- Often blended with other nutrients

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Phos Acid

- Phos Acid
  - Will work in high Ca & bicarbonate water.
  - Improves water penetration
  - Dissolves lime, immediately reduces pH.
  - Is vulnerable to tie-up by excess lime.
  - Soil, water, and foliar applied phos acid is immediately available to the plant.
  - Best initial P movement

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Liquid P Fertilizers

- Ammonium Polyphosphate
  10-34-0
  11-37-0
- 34-37% P_2O_5
- pH 5.8-6.4
- Acid forming
- 50-65% Polyphosphate

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Ammonium Poly-P

- 10-34-0 & 11-37-0
  - Will not work through the water if the water has high Ca and bicarbonates.
  - Is safer through the water, especially if the water is pure (low buffering capacity).
  - Contains NH_4-N, which reduces soil pH near the fertilizer over time.
  - Can be used foliarly, but is ~60% polyphosphate which is not absorbed through the leaves.
  - More expensive per unit of P than 11-52-0.

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Liquid P Fertilizers

Neutral Liquid Phosphates

- 3-18-18
  3%N, 18% P_2O_5, 18% K_2O
  100% Ortho-P
  pH 7.4-7.8

- 6-24-6
  6%N, 24% P_2O_5, 6% K_2O
  80% Ortho-P
  pH 6.3-7.0

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Improving P Efficiency

- Prevent P from making $Ca_x(PO_4)_x$
  - Remove Ca from system
  - Use Manure or Compost
  - Blend with Humic or Fulvic Acids
  - Apply in Organic P form
  - Combine with Carbon & Sugars

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Improving P Efficiency

- Apply P when needed
  - Liquid starter fertilizer
  - Water application during growing season
  - Foliar application

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How to Improve P Efficiency

- In the soil
  - Use manure or compost
  - If topdressed, apply 11-52-0 in the fall
  - Blend 11-52-0 with dry humic acid
  - Incorporate
  - Liquid P during the growing season
  - Humic acids, Fulvic acids, with liquid applications
  - Acid forming sulfur with liquid P
  - Broadcast & band apply

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Improving P Efficiency

- Reduce Soil pH near P
  - Elemental Sulfur with dry P
    - Uniprill works best
  - Acid Forming Sulfur with liquid P
    - Thio-Sul
    - Flowable elemental sulfur
  - Acid-Forming fertilizers with P
  - Acid P

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How to Improve P Efficiency

- Applied through the water
  - Phos acid vs. 10-34-0
  - Add when needed, usually early in spring
  - Add Humic or Fulvic acid
    - About 1 gallon of each per 10 gallons 10-34-0
  - Apply with Thio-Sul or reduced Sulfur

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How to Improve P Efficiency

- Foliar application
  - 5 to 8 times more efficient than water or soil application
  - Often costs less than equivalent soil or water application
  - Avoids excess lime / high pH problems

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65