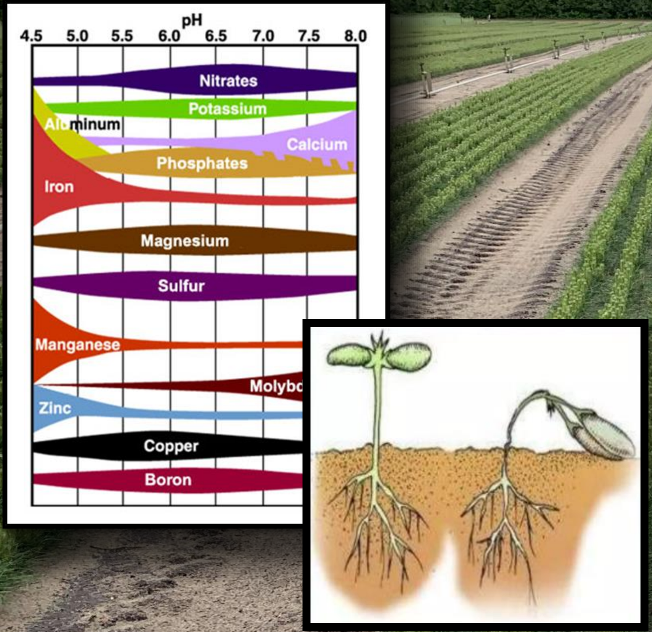
Soil pH at WSN: *"slow and steady wins the race"*



Dr. Nick Balster
Department of Soil and Environmental Sciences
University of Wisconsin-Madison

Soil pH at WSN: *"slow and steady wins the race"*

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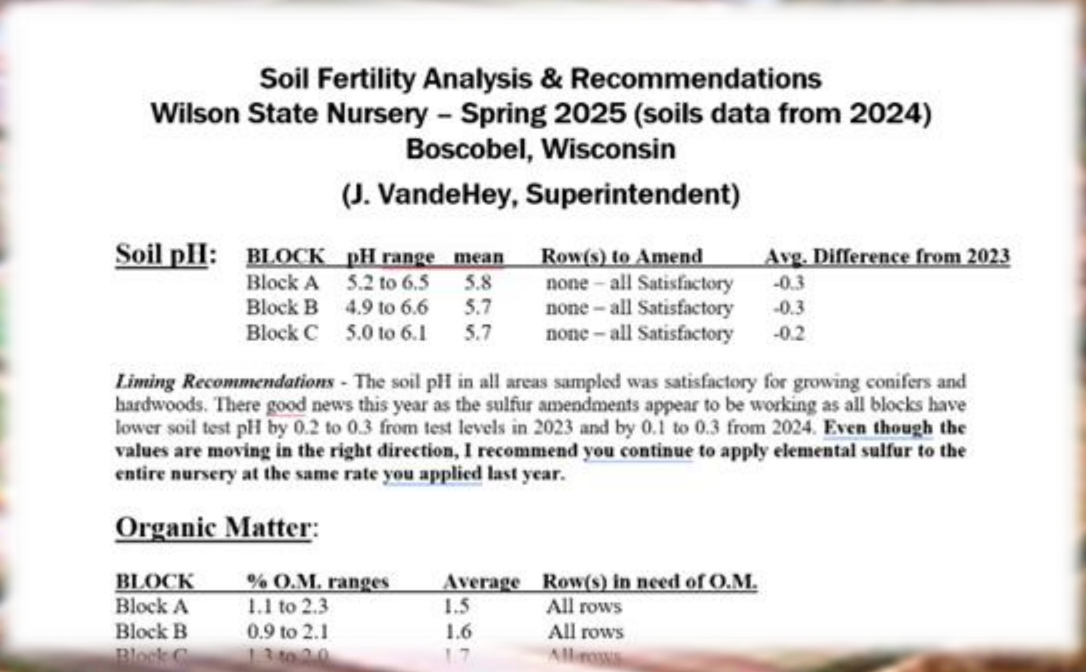
Department of Soil Science
University of Wisconsin-Madison



Soil Fertility Analysis & Recommendations
Wilson State Nursery – Spring 2025 (soils data from 2024)
Boscobel, Wisconsin

(J. VandeHey, Superintendent)

Soil pH:

BLOCK	pH range	mean	Row(s) to Amend	Avg. Difference from 2023
Block A	5.2 to 6.5	5.8	none – all Satisfactory	-0.3
Block B	4.9 to 6.6	5.7	none – all Satisfactory	-0.3
Block C	5.0 to 6.1	5.7	none – all Satisfactory	-0.2

Liming Recommendations - The soil pH in all areas sampled was satisfactory for growing conifers and hardwoods. There good news this year as the sulfur amendments appear to be working as all blocks have lower soil test pH by 0.2 to 0.3 from test levels in 2023 and by 0.1 to 0.3 from 2024. **Even though the values are moving in the right direction, I recommend you continue to apply elemental sulfur to the entire nursery at the same rate you applied last year.**

Organic Matter:

BLOCK	% O.M. ranges	Average	Row(s) in need of O.M.
Block A	1.1 to 2.3	1.5	All rows
Block B	0.9 to 2.1	1.6	All rows
Block C	1.3 to 2.0	1.7	All rows

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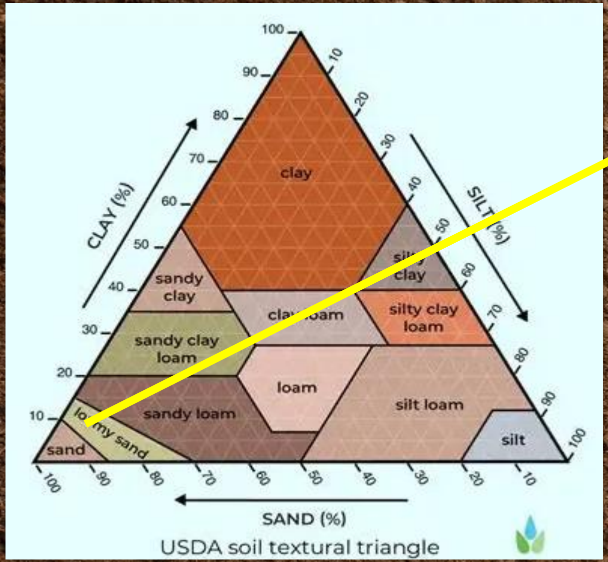
Soil pH at WSN: *"slow and steady wins the race"*



USDA soil textural triangle

70 – 90% Sand
0 – 30% Silt
0 – 15% Clay

~2% Organic Matter (*peat*)
Calcareous Parent Material
1.25 – 2.5 inches/hour
Altered microbial community

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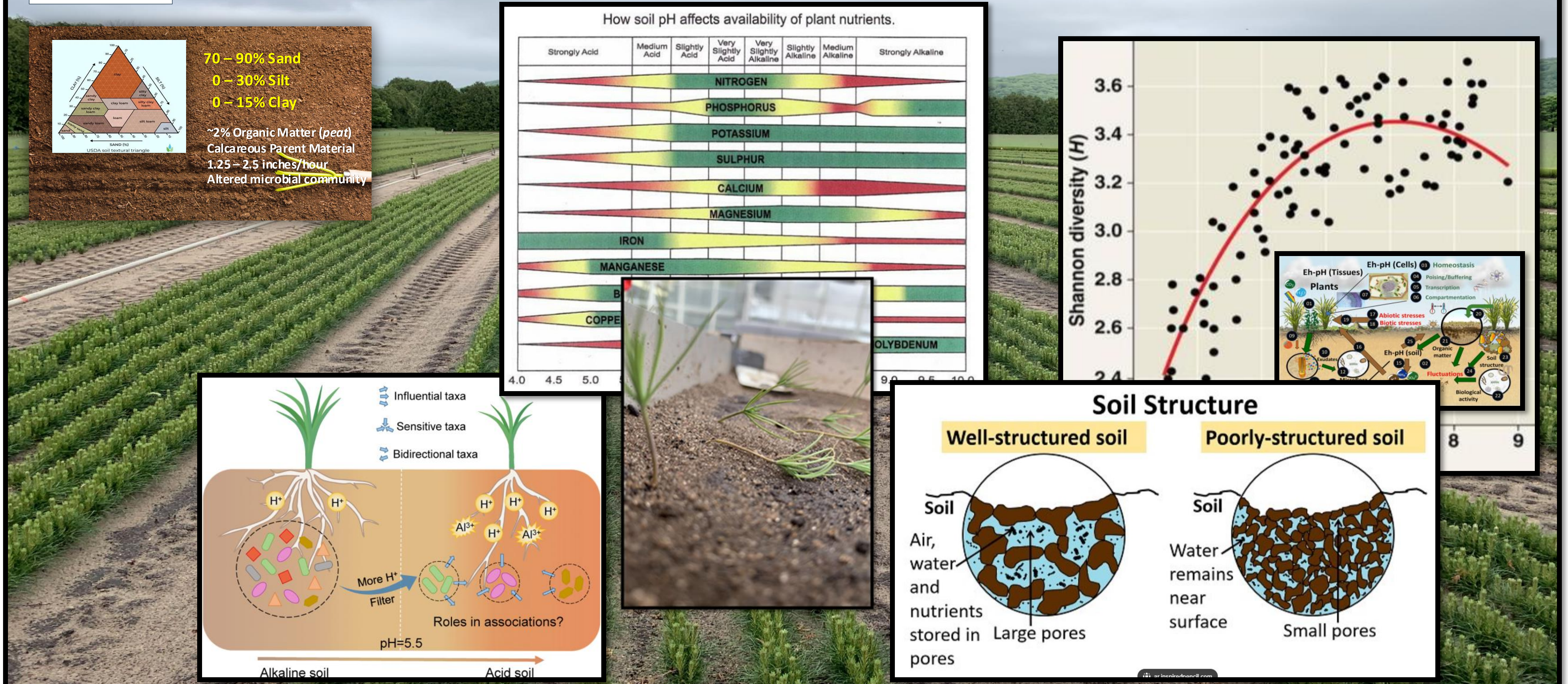
$$pH = -\log\left[H^{+}\right]$$



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How soil pH affects availability of plant nutrients.

Soil Structure

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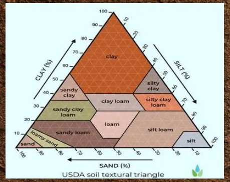

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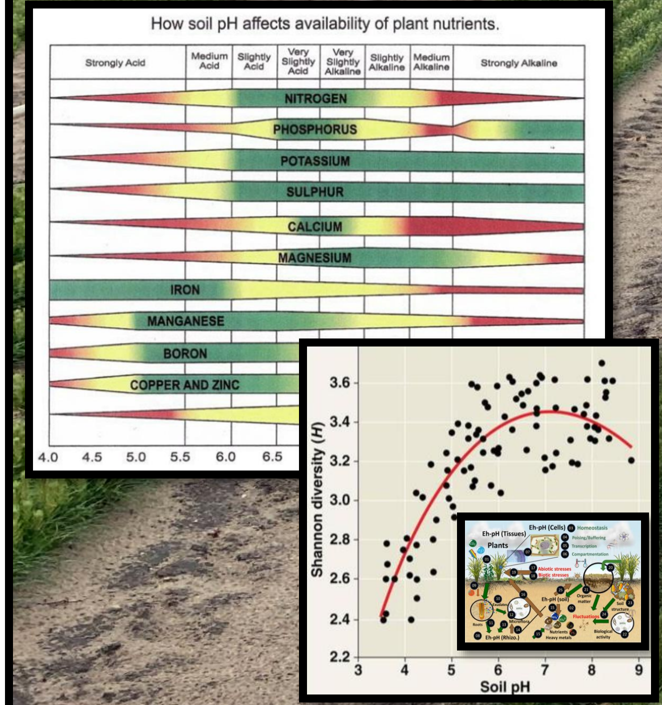
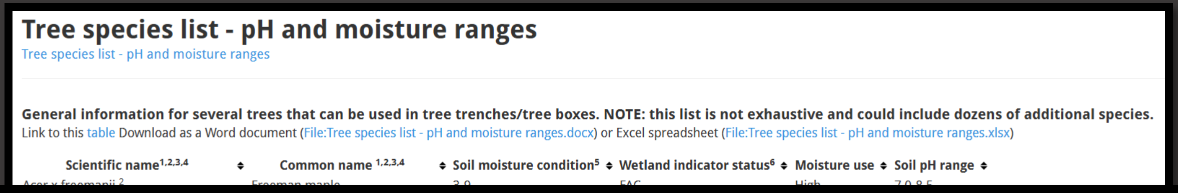

How soil pH affects availability of plant nutrients.

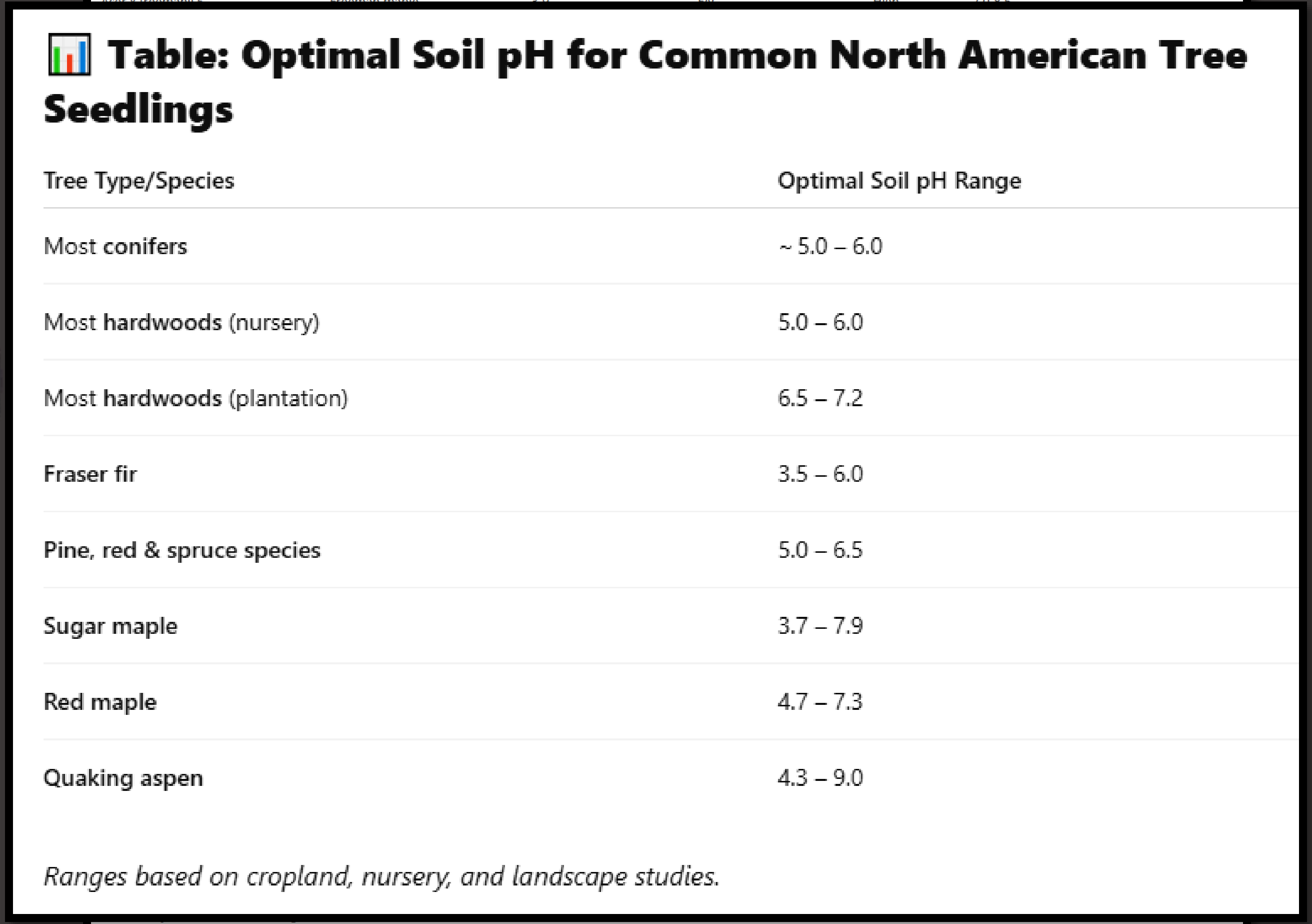
Target pH?



Tree species list - pH and moisture ranges

Tree species list - pH and moisture ranges

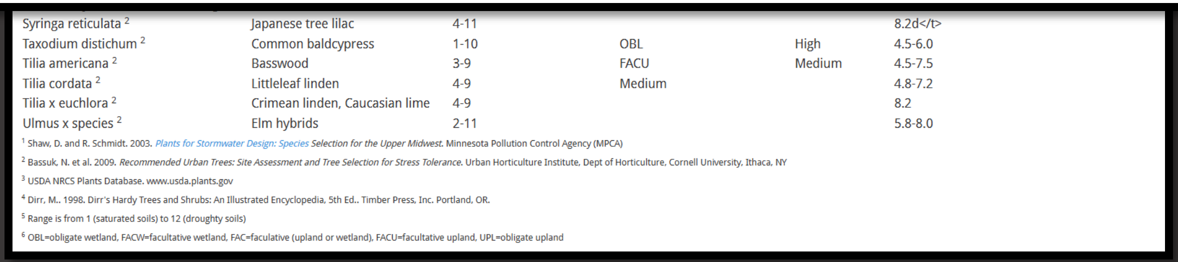
General information for several trees that can be used in tree trenches/tree boxes. NOTE: this list is not exhaustive and could include dozens of additional species.
Link to this table Download as a Word document (File:Tree species list - pH and moisture ranges.docx) or Excel spreadsheet (File:Tree species list - pH and moisture ranges.xlsx)



📊 Table: Optimal Soil pH for Common North American Tree Seedlings

Tree Type/Species	Optimal Soil pH Range
Most conifers	~ 5.0 – 6.0
Most **hardwoods** (nursery)	5.0 – 6.0
Most **hardwoods** (plantation)	6.5 – 7.2
Fraser fir	3.5 – 6.0
Pine, red & spruce species	5.0 – 6.5
Sugar maple	3.7 – 7.9
Red maple	4.7 – 7.3
Quaking aspen	4.3 – 9.0

Ranges based on cropland, nursery, and landscape studies.



Scientific name[1,2,3,4]	**Common name** [1,2,3,4]	**Soil moisture condition**[5]	**Wetland indicator status**[6]	**Moisture use**	**Soil pH range**
Syringa reticulata [2]	Japanese tree lilac	4-11			8.2d</t>
Taxodium distichum [2]	Common baldcypress	1-10	OBL	High	4.5-6.0
Tilia americana [2]	Basswood	3-9	FACU	Medium	4.5-7.5
Tilia cordata [2]	Littleleaf linden	4-9	Medium		4.8-7.2
Tilia x euchlora [2]	Crimean linden, Caucasian lime	4-9			8.2
Ulmus x species [2]	Elm hybrids	2-11			5.8-8.0

[1] Shaw, D. and R. Schmidt. 2003. *Plants for Stormwater Design: Species Selection for the Upper Midwest.* Minnesota Pollution Control Agency (MPCA)

[2] Bassuk, N. et al. 2009. *Recommended Urban Trees: Site Assessment and Tree Selection for Stress Tolerance.* Urban Horticulture Institute, Dept of Horticulture, Cornell University, Ithaca, NY

[3] USDA NRCS Plants Database. www.usda.plants.gov

[4] Dirr, M.. 1998. Dirr's Hardy Trees and Shrubs: An Illustrated Encyclopedia, 5th Ed.. Timber Press, Inc. Portland, OR.

[5] Range is from 1 (saturated soils) to 12 (droughty soils)

[6] OBL=obligate wetland, FACW=facultative wetland, FAC=faculative (upland or wetland), FACU=facultative upland, UPL=obligate upland

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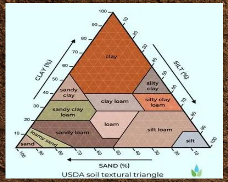
$$pH = -\log\left[H^{+}\right]$$

Liming ($CaCO_3$)?



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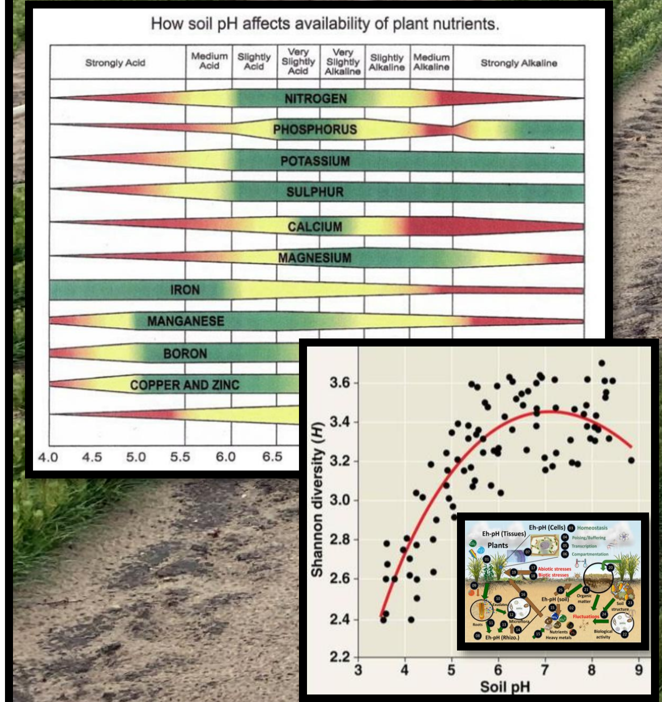
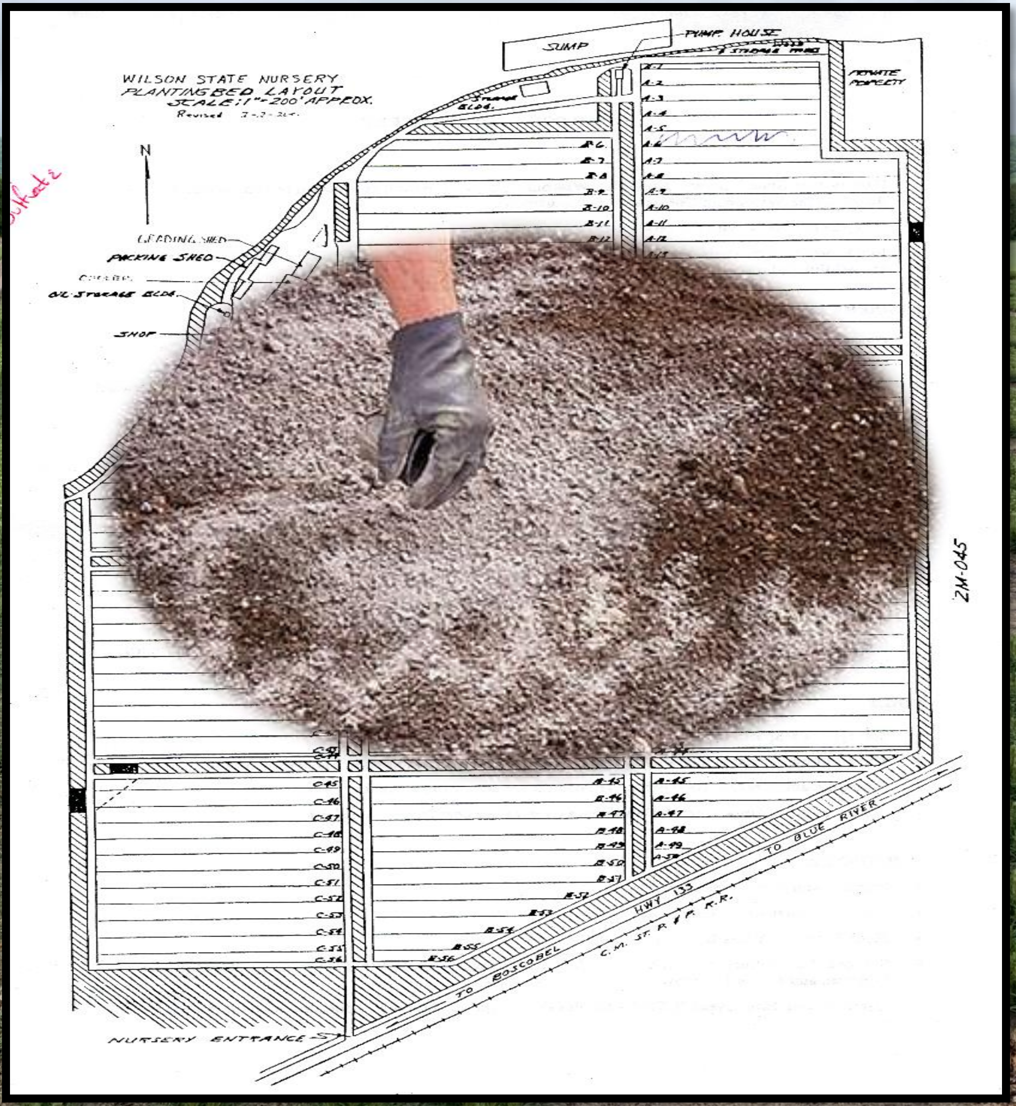
1.25 – 2.5 inches/hour
Altered microbial community


How soil pH affects availability of plant nutrients.



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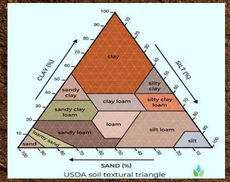

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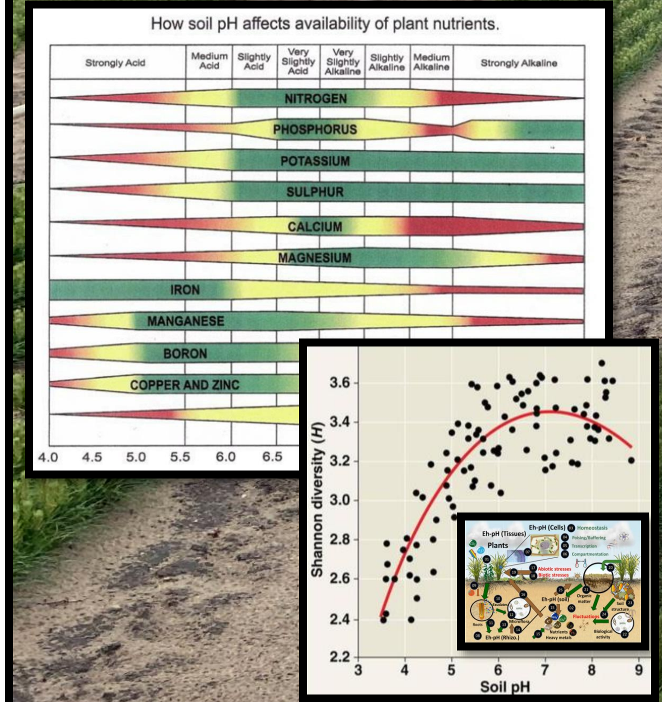
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Organic Matter?

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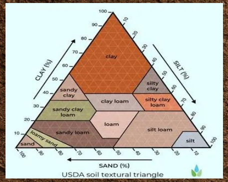

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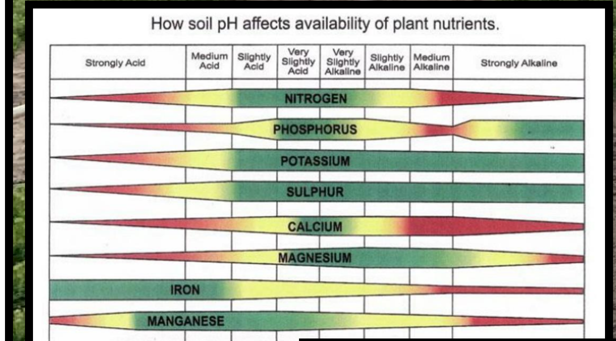

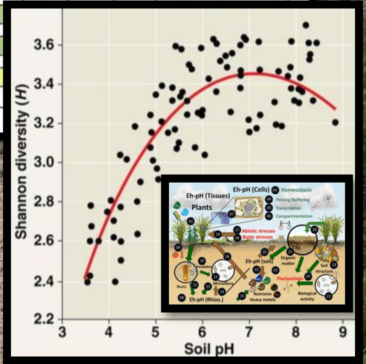

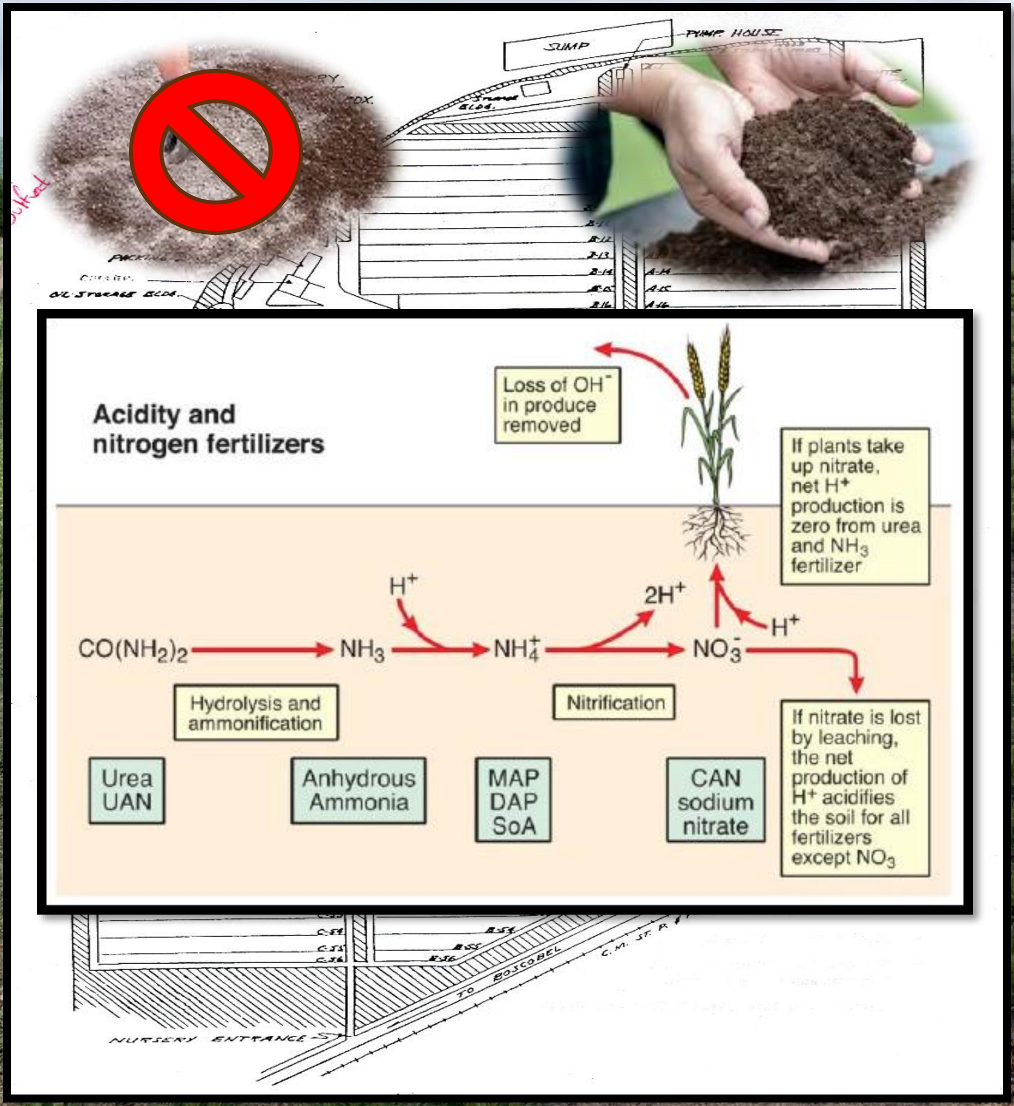

Acidity and nitrogen fertilizers

Loss of OH^- in produce removed

If plants take up nitrate, net H^+ production is zero from urea and NH_3 fertilizer

$$CO(NH_2)_2 \longrightarrow NH_3 \xrightarrow{H^+} NH_4^+ \longrightarrow NO_3^- \quad 2H^+ \quad H^+$$

Hydrolysis and ammonification

Nitrification

If nitrate is lost by leaching, the net production of H^+ acidifies the soil for all fertilizers except NO_3

Urea
UAN

Anhydrous Ammonia

MAP
DAP
SoA

CAN
sodium nitrate

Liming ($CaCO_3$)?
Organic Matter?
Nitrogen Fertilizer?

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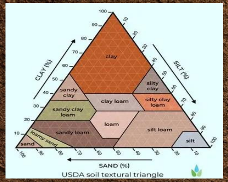

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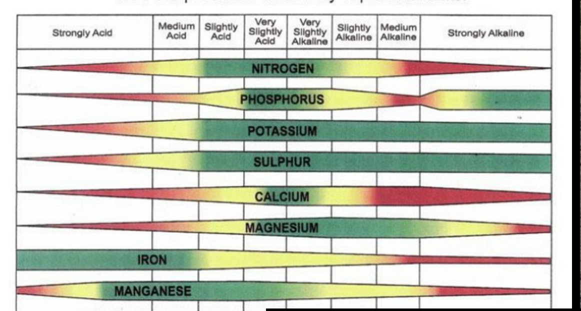
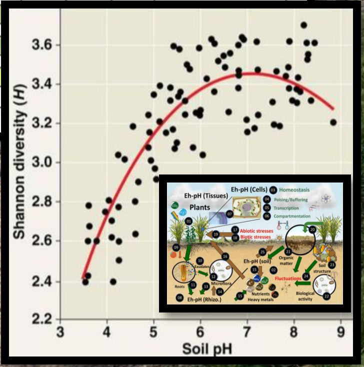
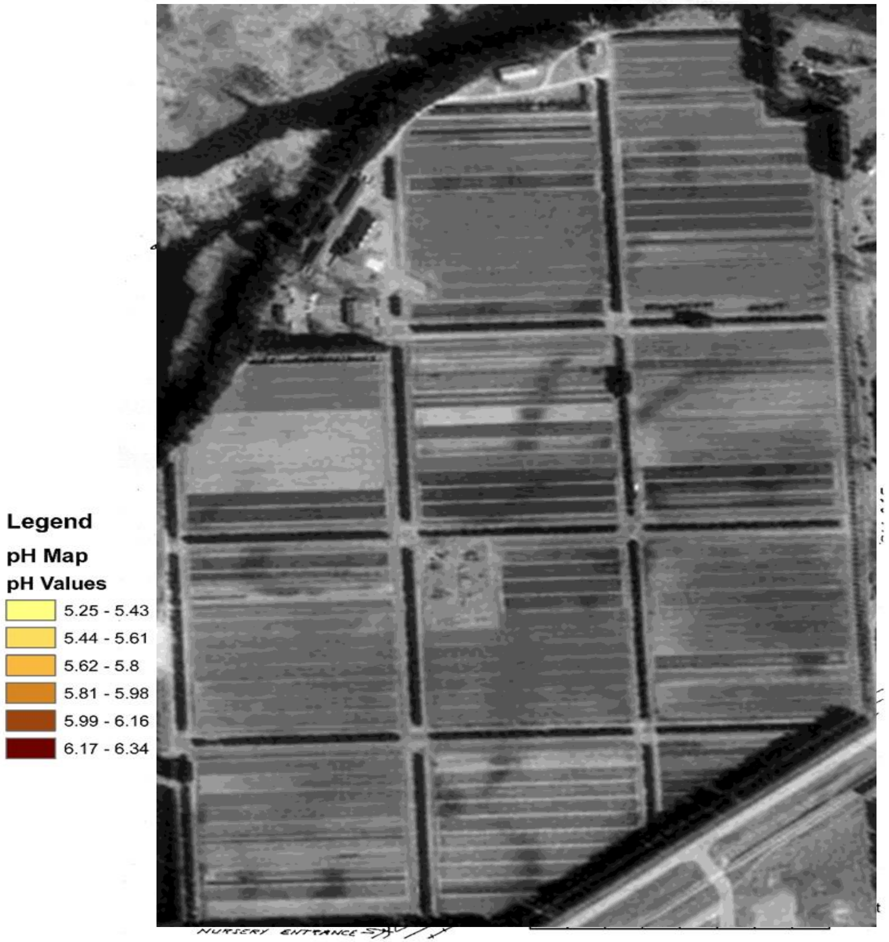




pH Map of Wilson Nursery 2007

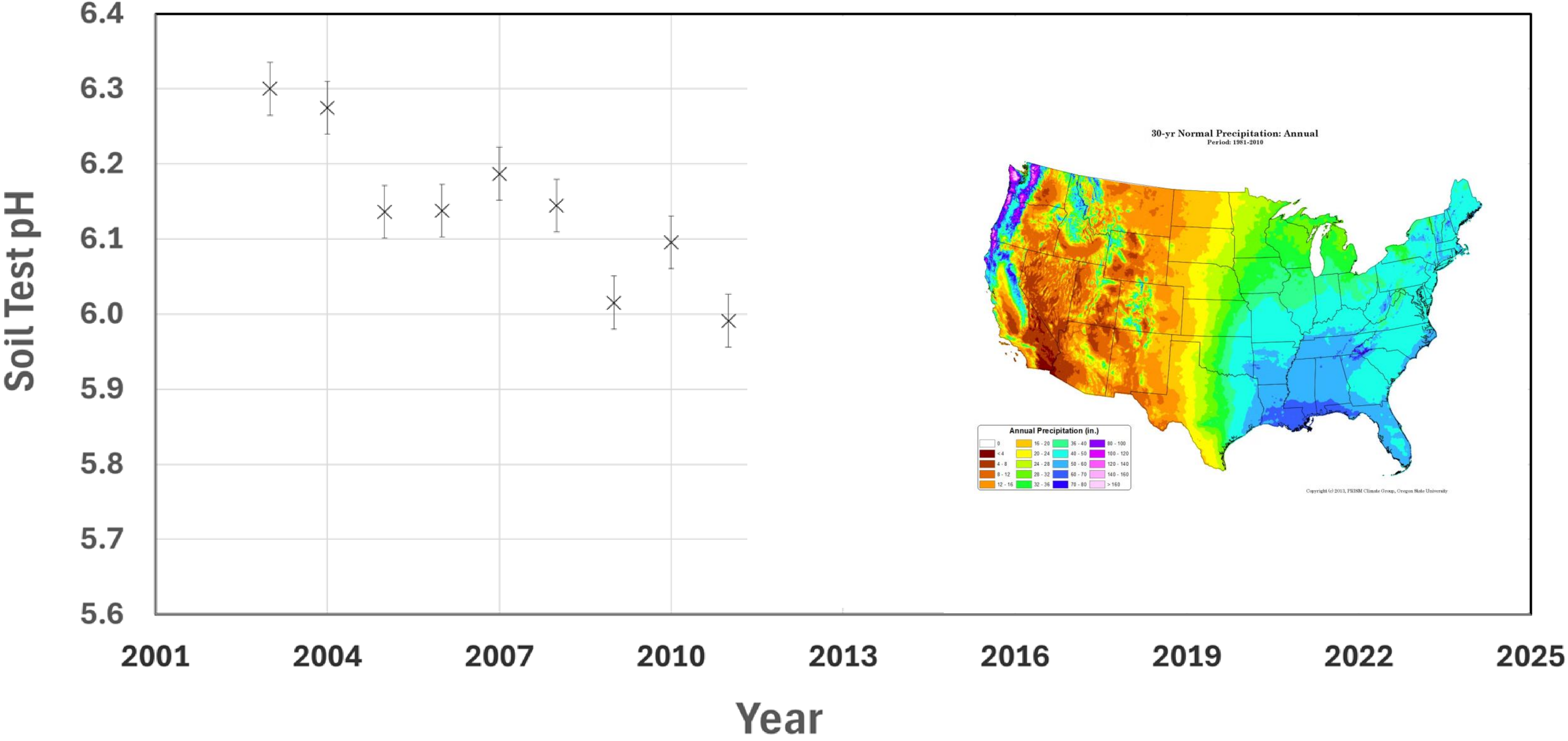


Legend
pH Map
pH Values

🟨	5.25 - 5.43
🟨	5.44 - 5.61
🟧	5.62 - 5.8
🟧	5.81 - 5.98
🟫	5.99 - 6.16
🟥	6.17 - 6.34

Liming ($CaCO_3$)?
Organic Matter?
Nitrogen Fertilizer?
Land-Use History?

Nursery Soil pH
(yearly averages)



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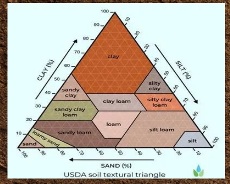

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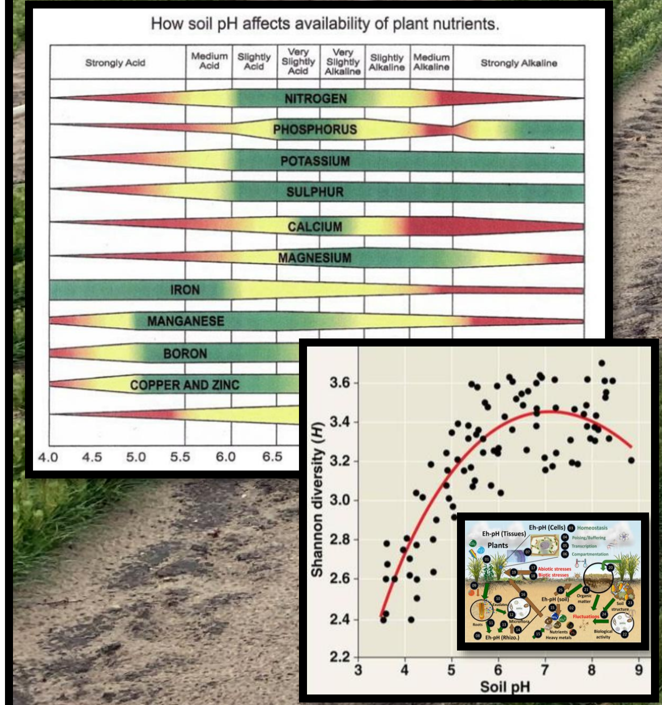

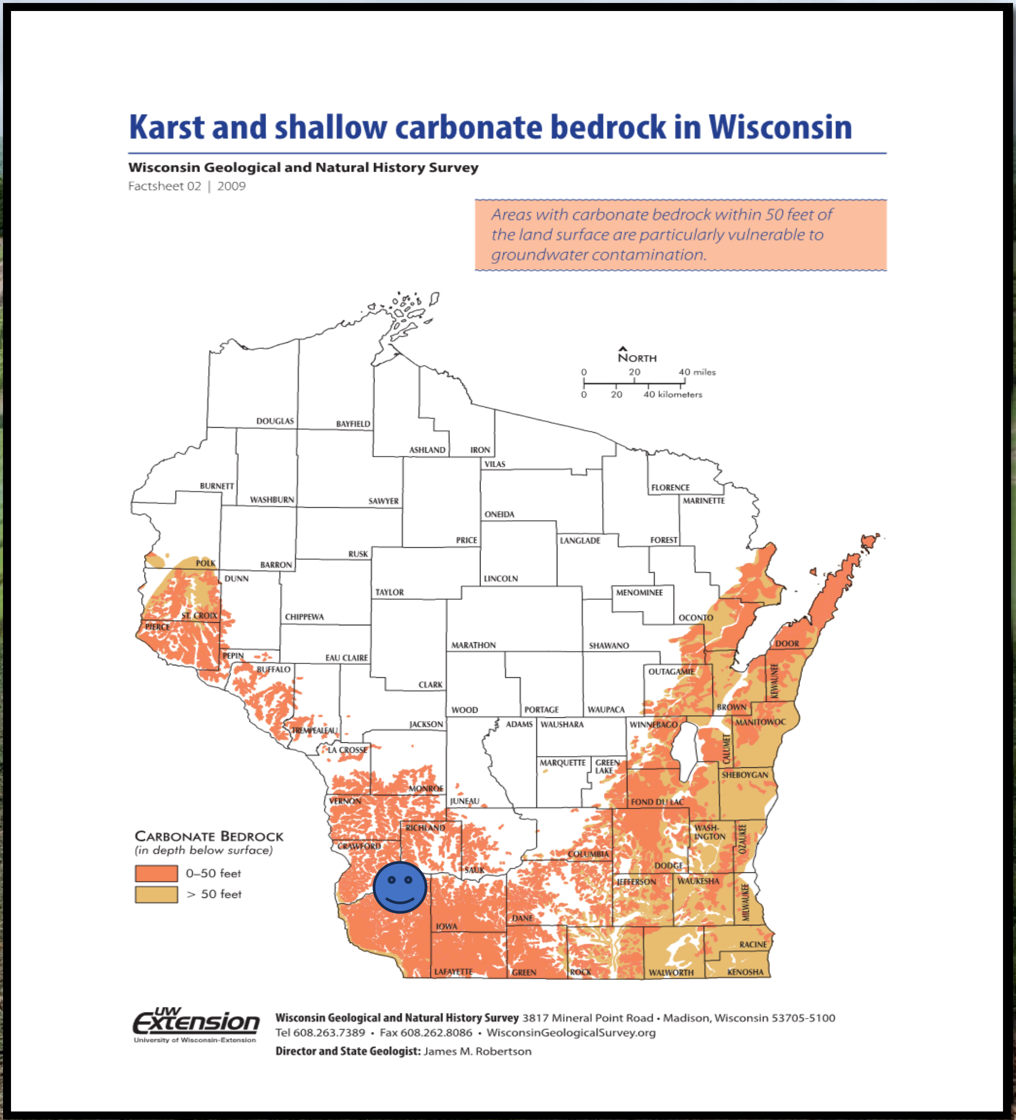

Karst and shallow carbonate bedrock in Wisconsin

Wisconsin Geological and Natural History Survey
Factsheet 02 | 2009

Areas with carbonate bedrock within 50 feet of the land surface are particularly vulnerable to groundwater contamination.

Carbonate Bedrock
(in depth below surface)
🟧 0–50 feet
🟨 > 50 feet

UW Extension
University of Wisconsin-Extension

Wisconsin Geological and Natural History Survey 3817 Mineral Point Road • Madison, Wisconsin 53705-5100
Tel 608.263.7389 • Fax 608.262.8086 • WisconsinGeologicalSurvey.org
Director and State Geologist: James M. Robertson

Liming ($CaCO_3$)?
Organic Matter?
Nitrogen Fertilizer?
Land-Use History?
Water Source?

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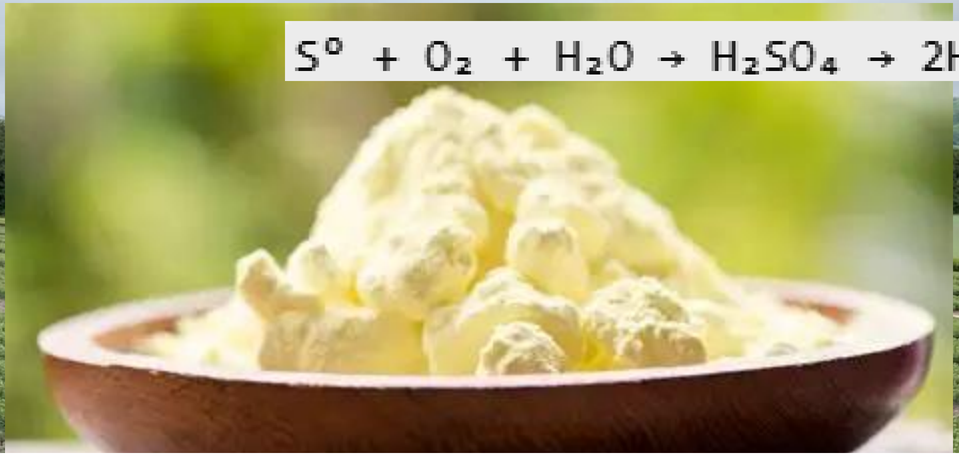


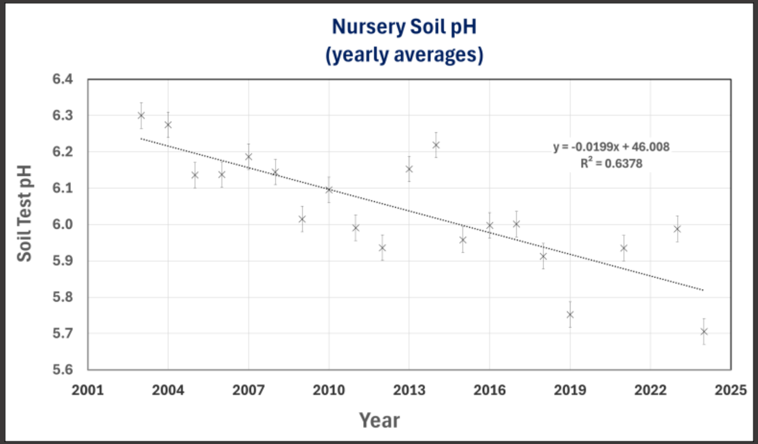
$$S^0 + O_2 + H_2O \rightarrow H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$$

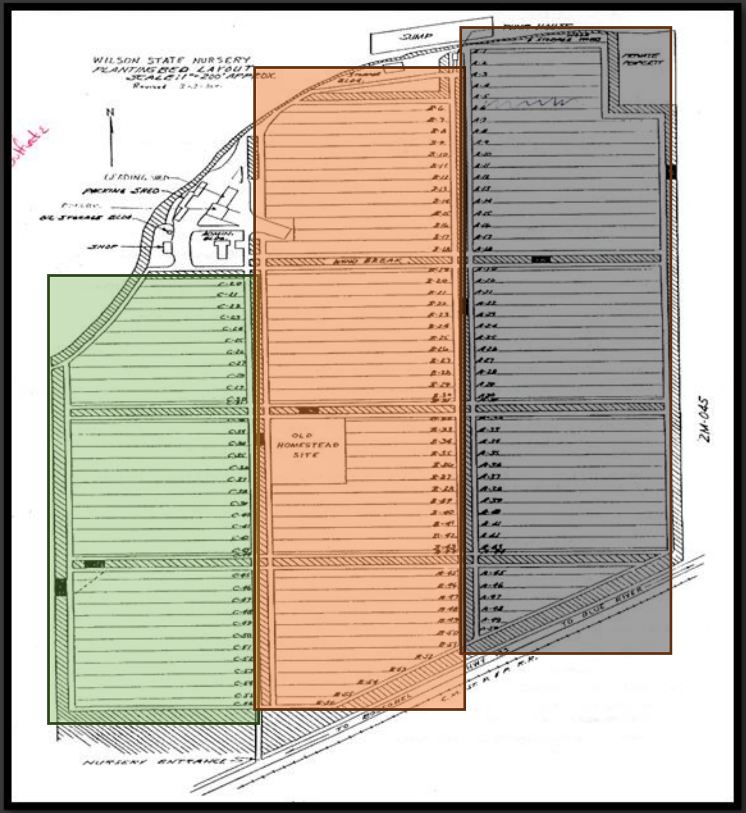
Approximate pounds of finely ground elemental sulfur needed to increase soil acidity.

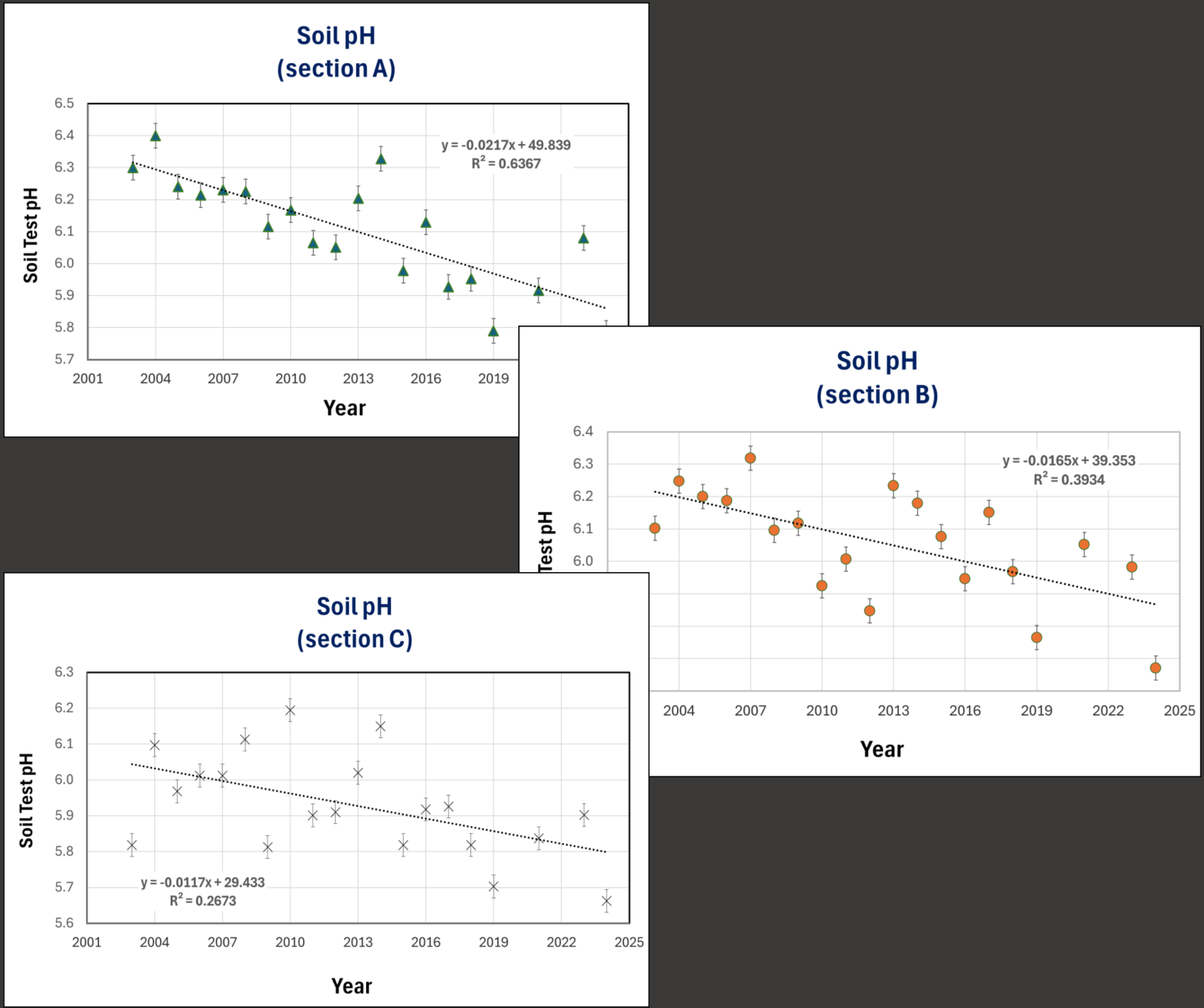
Change in pH desired	Soil organic matter content, %					
	0.5 to 2	2 to 4	4 to 6	6 to 8	8 to 10	>10
	-------------- pounds of sulfur per 1000 sq. ft. -------------					
0.25	6	18	28*	40*	53*	62*
0.50	12	35*	56*	80*	106*	125*
1.00	24*	70*	112*	120*	212*	250*

* Do not apply more than 20 lbs of sulfur per 1000 sq. ft. per year. Retest soil between applications.

Combs, S. (2007, October 27). *Reducing Soil pH*. University of Wisconsin–Madison Division of Extension. XHT-1151.

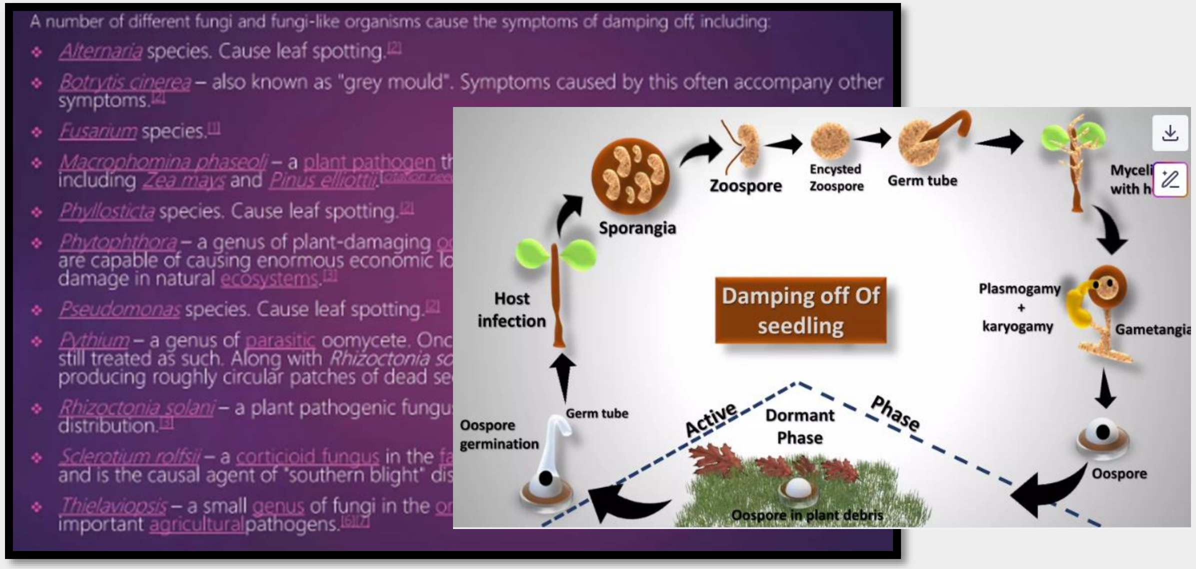

Nursery Soil pH
(yearly averages)
y = -0.0199x + 46.008
R² = 0.6378
Soil Test pH
6.4
6.3
6.2
6.1
6.0
5.9
5.8
5.7
5.6
2001
2004
2007
2010
2013
2016
2019
2022
2025
Year


WILSON STATE NURSERY
PLANTING BED LAYOUT
SCALE 1" = 200' APPROX.
SUMP
N
LOADING
PACKING SHED
OIL STORAGE BLDG
SHOP
ADMIN. BLDG.
WIND BREAK
OLD HOMESTEAD SITE
NURSERY ENTRANCE
TO BLUE RIVER
2M-045


Soil pH
(section A)
y = -0.0217x + 49.839
R² = 0.6367
Soil Test pH
6.5
6.4
6.3
6.2
6.1
6.0
5.9
5.8
5.7
2001
2004
2007
2010
2013
2016
2019
Year
Soil pH
(section B)
y = -0.0165x + 39.353
R² = 0.3934
Test pH
6.4
6.3
6.2
6.1
6.0
2004
2007
2010
2013
2016
2019
2022
2025
Year
Soil pH
(section C)
y = -0.0117x + 29.433
R² = 0.2673
Soil Test pH
6.3
6.2
6.1
6.0
5.9
5.8
5.7
5.6
2001
2004
2007
2010
2013
2016
2019
2022
2025
Year

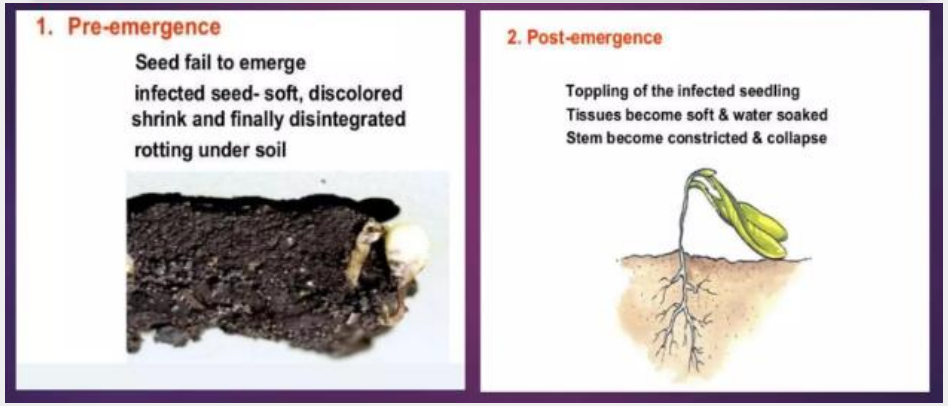
“Damping Off” Disease

- Fungal soil-borne disease
- Infection at soil level on hypocotyl or upper taproot
- Poor germination
- Particularly susceptible during rapid seedling growth
- Only preventable, not curable
- Infects before 6 week mark (for red pine)
    - Before woody tissue develops
    - Lamichhane et al., 2017
- Common preventative measures:
    - Fungicides
    - Lowering pH (Cruz et al., 2020)
    - Cleaning equipment
    - Preventing excess moisture
    - Warm temperatures
    - Lack of soil aeration
    - Too much shade



A number of different fungi and fungi-like organisms cause the symptoms of damping off, including:

- *Alternaria* species. Cause leaf spotting.[2]
- *Botrytis cinerea* – also known as "grey mould". Symptoms caused by this often accompany other symptoms.[2]
- *Fusarium* species.[1]
- *Macrophomina phaseoli* – a plant pathogen th
  including *Zea mays* and *Pinus elliottii*.
- *Phyllosticta* species. Cause leaf spotting.[2]
- *Phytophthora* – a genus of plant-damaging o
  are capable of causing enormous economic lo
  damage in natural ecosystems.[3]
- *Pseudomonas* species. Cause leaf spotting.[2]
- *Pythium* – a genus of parasitic oomycete. Onc
  still treated as such. Along with *Rhizoctonia* so
  producing roughly circular patches of dead se
- *Rhizoctonia solani* – a plant pathogenic fungu
  distribution.[3]
- *Sclerotium rolfsii* – a corticioid fungus in the fa
  and is the causal agent of "southern blight" dis
- *Thielaviopsis* – a small genus of fungi in the or
  important agricultural pathogens.[6][7]

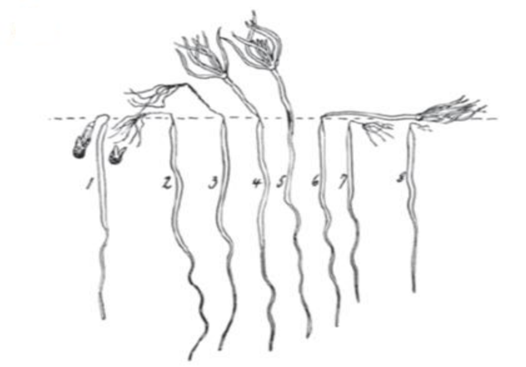


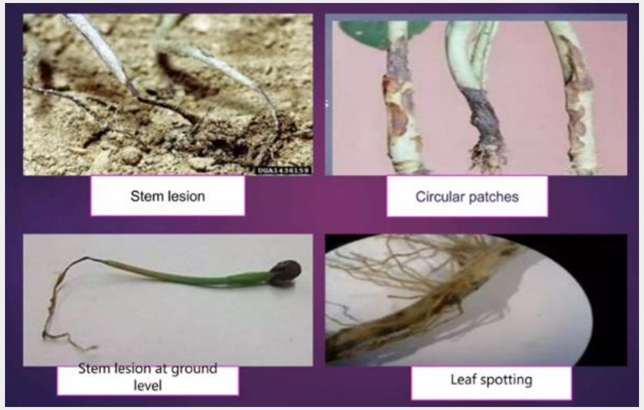
1. Pre-emergence

Seed fail to emerge
infected seed- soft, discolored
shrink and finally disintegrated
rotting under soil

2. Post-emergence

Toppling of the infected seedling
Tissues become soft & water soaked
Stem become constricted & collapse





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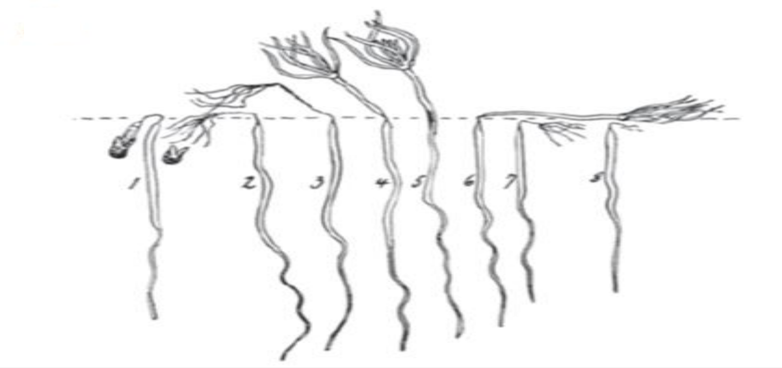
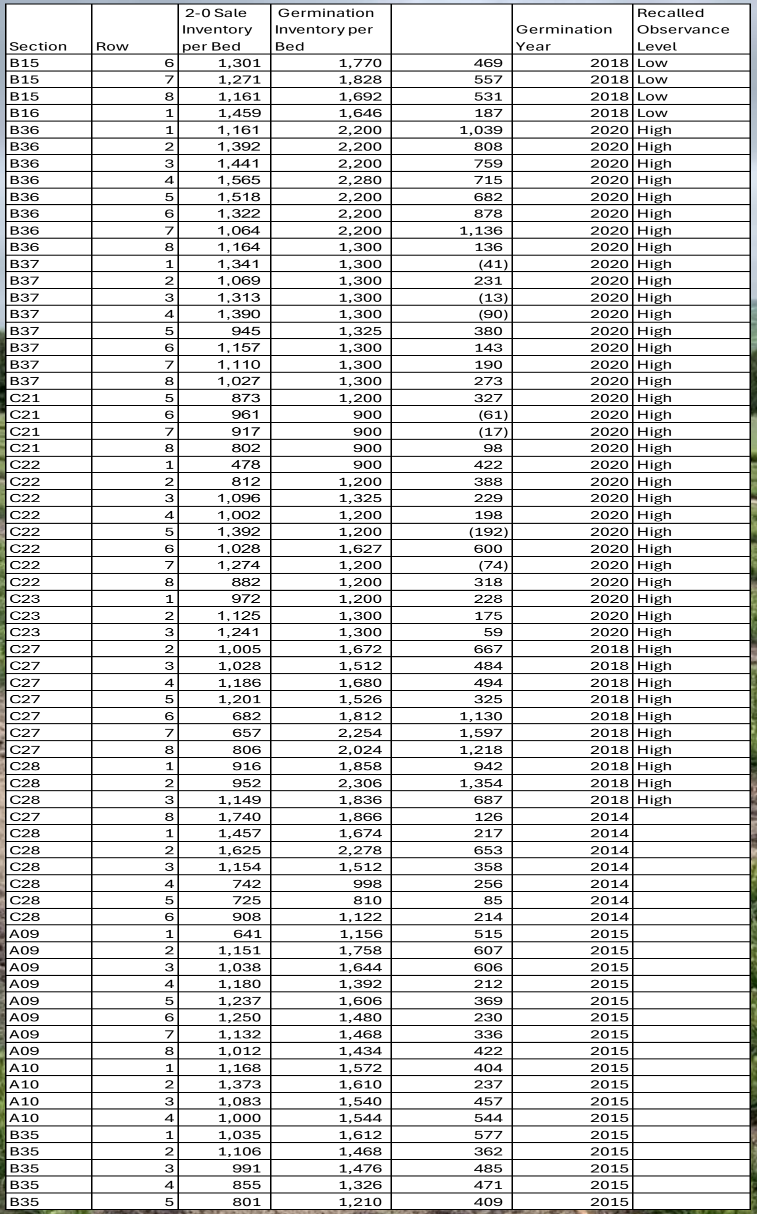


Example of healthy red pine seedlings in the “bird cage” stage

Example of a red pine seedling dying from damping off disease

Patches of dead seedlings from damping off

Seedlings that likely survived the disease, but are permanently stunted; not ideal for selling the trees later on



Section	Row	2-0 Sale Inventory per Bed	Germination Inventory per Bed		Germination Year	Recalled Observance Level
B15	6	1,301	1,770	469	2018	Low
B15	7	1,271	1,828	557	2018	Low
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B36	5	1,518	2,200	682	2020	High
B36	6	1,322	2,200	878	2020	High
B36	7	1,064	2,200	1,136	2020	High
B36	8	1,164	1,300	136	2020	High
B37	1	1,341	1,300	(41)	2020	High
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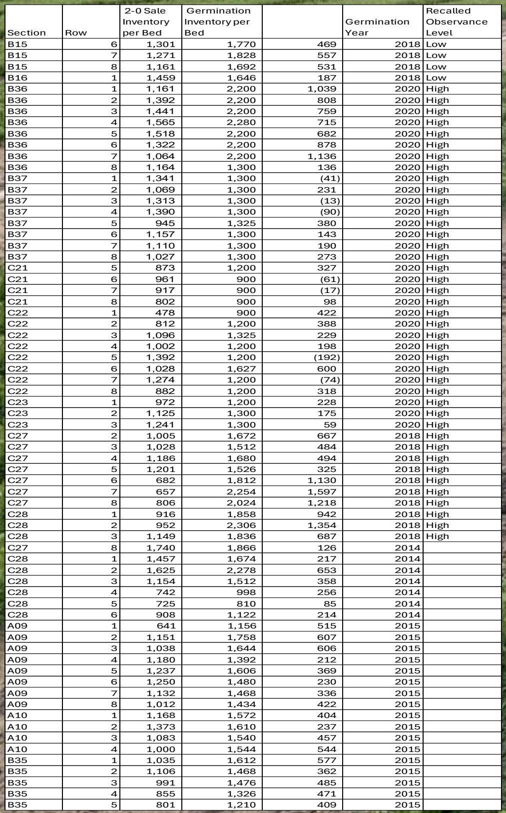

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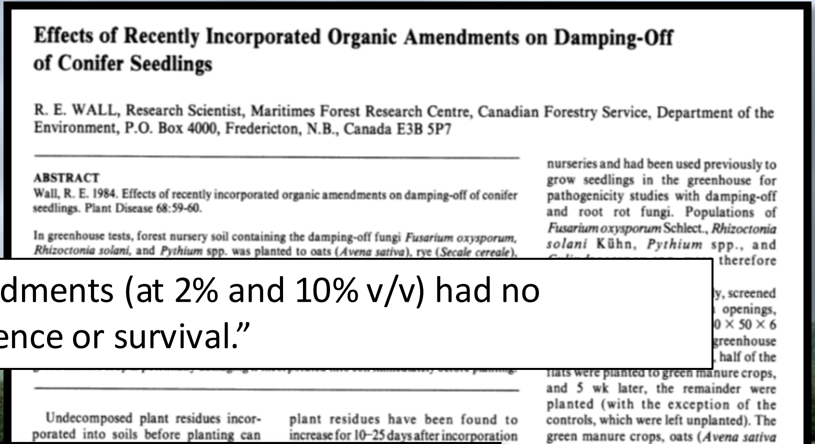


Effects of Recently Incorporated Organic Amendments on Damping-Off of Conifer Seedlings

R. E. WALL, Research Scientist, Maritimes Forest Research Centre, Canadian Forestry Service, Department of the Environment, P.O. Box 4000, Fredericton, N.B., Canada E3B 5P7

ABSTRACT

Wall, R. E. 1984. Effects of recently incorporated organic amendments on damping-off of conifer seedlings. Plant Disease 68:59-60.

In greenhouse tests, forest nursery soil containing the damping-off fungi *Fusarium oxysporum*, *Rhizoctonia solani*, and *Pythium* spp. was planted to oats (*Avena sativa*), rye (*Secale cereale*),

Undecomposed plant residues incorporated into soils before planting can

plant residues have been found to increase for 10–25 days after incorporation

nurseries and had been used previously to grow seedlings in the greenhouse for pathogenicity studies with damping-off and root rot fungi. Populations of *Fusarium oxysporum* Schlect., *Rhizoctonia solani* Kühn, *Pythium* spp., and
therefore

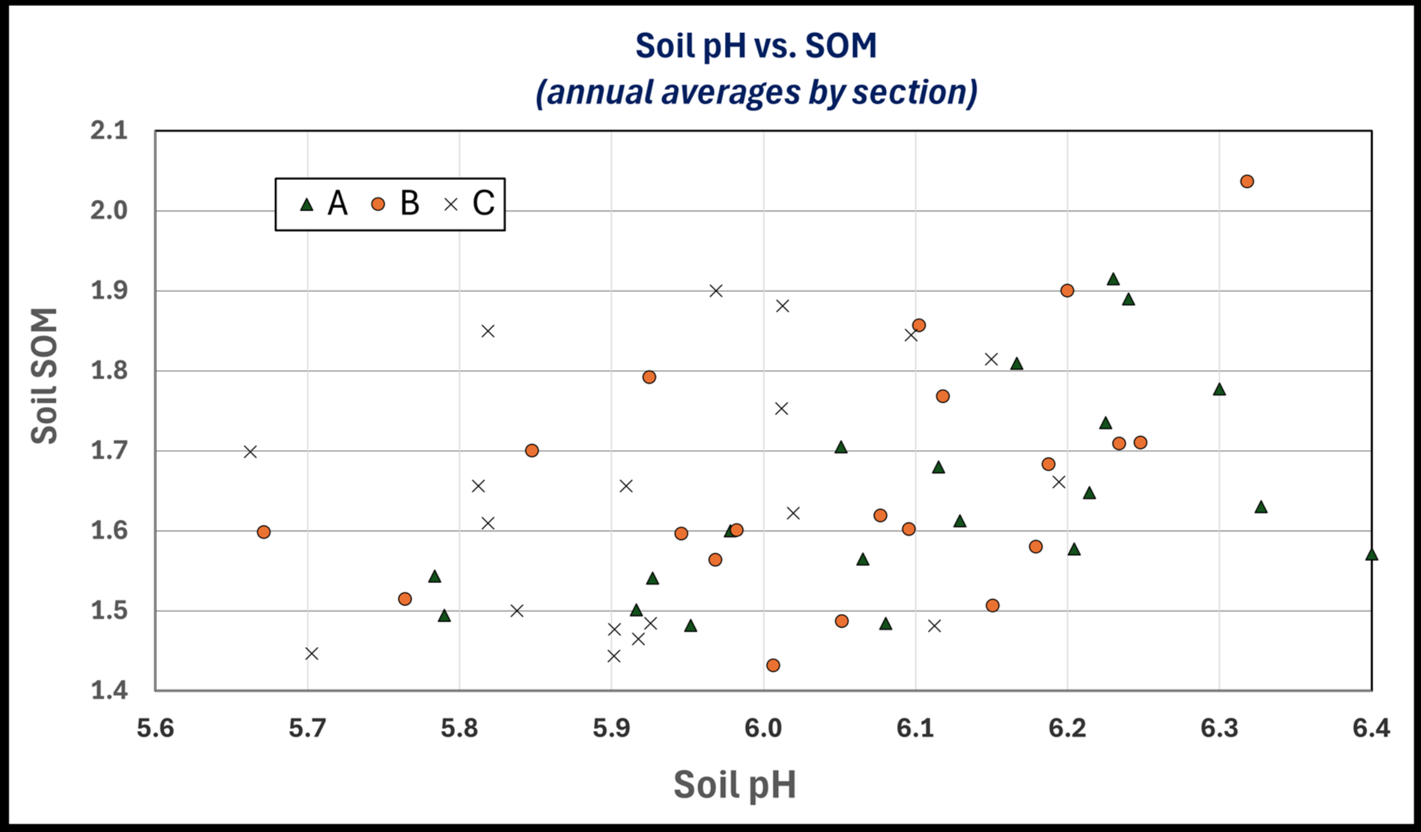
y, screened
openings,
0 × 50 × 6
greenhouse
, half of the
flats were planted to green manure crops, and 5 wk later, the remainder were planted (with the exception of the controls, which were left unplanted). The green manure crops, oats (*Avena sativa* L. 'Stormont'), rye (*Secale cereale* L. 'Kustro'), buckwheat (*Fagopyrum esculentum* 'Redstraw'), and red clover (*Trifolium pratense* L.), were grown during the summer in a glass greenhouse and weeded regularly. Flats of rye were placed in a coldroom at 5 C from the ninth through the 13th week after planting to simulate vernalization.

Twenty weeks after the first planting, all green manure crops were chopped into 2-cm or smaller segments and incorporated into the soils on which they had been grown. At the time of incorporation, the first planting of oats was nearly ripe and the second planting was in the dough stage. The first planting of rye was about 30 cm tall and had not begun to flower; the second was about 10 cm tall. The first planting of buckwheat had been ripe for about 3 wk; the second still had green leaves and some ripened seed. The first planting of red clover was about 20 cm tall and had a few flower buds; the second was 15 cm tall and had not begun to flower.

The soils were reworked and watered every 2–3 days for 2 wk. Each was then divided into five equal parts; one served as a control and four were amended with 1) 10% (v/v) fresh spruce-fir sawdust from a local sawmill, 2) 2% sawdust, 3) 10% (v/v) comminuted Fafard sphagnum peat, and 4) 2% peat. Each of the 45 soil mixtures was placed in a clay pot with a 12.5-cm top diameter and watered for the next 2 days. Triplicate pots of each type were planted to either jack pine (*Pinus banksiana* Lamb.) or black spruce (*Picea mariana* (Mill.) B.S.P.), 30 seeds per pot. Seeds were covered with 0.5 cm of coarse silica sand and pots were placed in a glass greenhouse at 20 C night temperature and

Plant Disease/January 1984 59

"Sawdust and sphagnum peat amendments (at 2% and 10% v/v) had no significant effect on seedling emergence or survival."



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[illegible]	[illegible]	[illegible]	[illegible]	682	2020	High
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Forest Nursery Notes Winter 2013

Forest Nursery Pests: Damping-off

by Thomas D. Landis

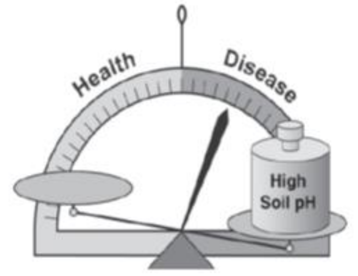

Figure 5 - Many of the pests causing damping-off are considered weak or opportunistic pathogens, which are aided by favorable environmental factors such as soils that have a high pH or don't drain well (modified from Landis 2000).

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DOI 10.1007/s13593-017-0417-y

REVIEW ARTICLE

Integrated management of damping-off diseases. A review

Jay Ram Lamichhane[1] · Carolyne Dürr[2] · André A. Schwanck[3] · Marie-Hélène Robin[4] · Jean-Pierre Sarthou[5] · Vincent Cellier[6] · Antoine Messéan[1] · Jean-Noël Aubertot[3]

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ract Damping-off is a disease that leads to the decay of
inating seeds and young seedlings, which represents for
ers one of the most important yield constraints both in
ries and fields. As for other biotic stresses, conventional
icides are widely used to manage this disease, with two
r consequences. On the one hand, fungicide overuse
tens the human health and causes ecological concerns.
he other hand, this practice has led to the emergence of
cide-resistant microorganisms in the environment. Thus,
are increasing concerns to develop sustainable and du-
damping-off management strategies that are less reliant
nventional pesticides. Achieving such a goal requires a
r knowledge of pathogen biology and disease epidemiol-
n order to facilitate the decision-making process. It also
nds using all available non-chemical tools that can be
ted to regional and specific production situations. However, this still is not the case and major knowledge gaps must be filled. Here, we review up to 300 articles of the damping-off literature in order to highlight major knowledge gaps and identify future research priorities. The major findings are (i) damping-off is an emerging disease worldwide, which affects all agricultural and forestry crops, both in nurseries and fields; (ii) over a dozen of soil-borne fungi and fungus-like organisms are a cause of damping-off but only a few of them are frequently associated with the disease; (iii) damping-off may affect from 5 to 80% of the seedlings, thereby inducing heavy economic consequences for farmers; (iv) a lot of research efforts have been made in recent years to develop biocontrol solutions for damping-off and there are interesting future perspectives; and (v) damping-off management requires an integrated pest management (IPM) approach combining both preventive and curative tactics and strategies. Given the complex nature of damping-off and the numerous factors involved in its occurrence, we recommend further research on critical niches of complexity, such as seeds, seedbed, associated microbes and their interfaces, using novel and robust experimental and modeling approaches based on five research priorities described in this paper.

Keywords Abiotic stresses · Best management practices · Economic losses · Integrated pest management · Interactions · Seed germination · Seedling decay · Soil-borne pathogens

Contents

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A09	3	1,038				
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A09	7	1,132				
A09	8	1,012				
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A10	2	1,373				
A10	3	1,083				
A10	4	1,000				
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B35	2	1,106				
B35	3	991				
B35	4	855				
B35	5	801				

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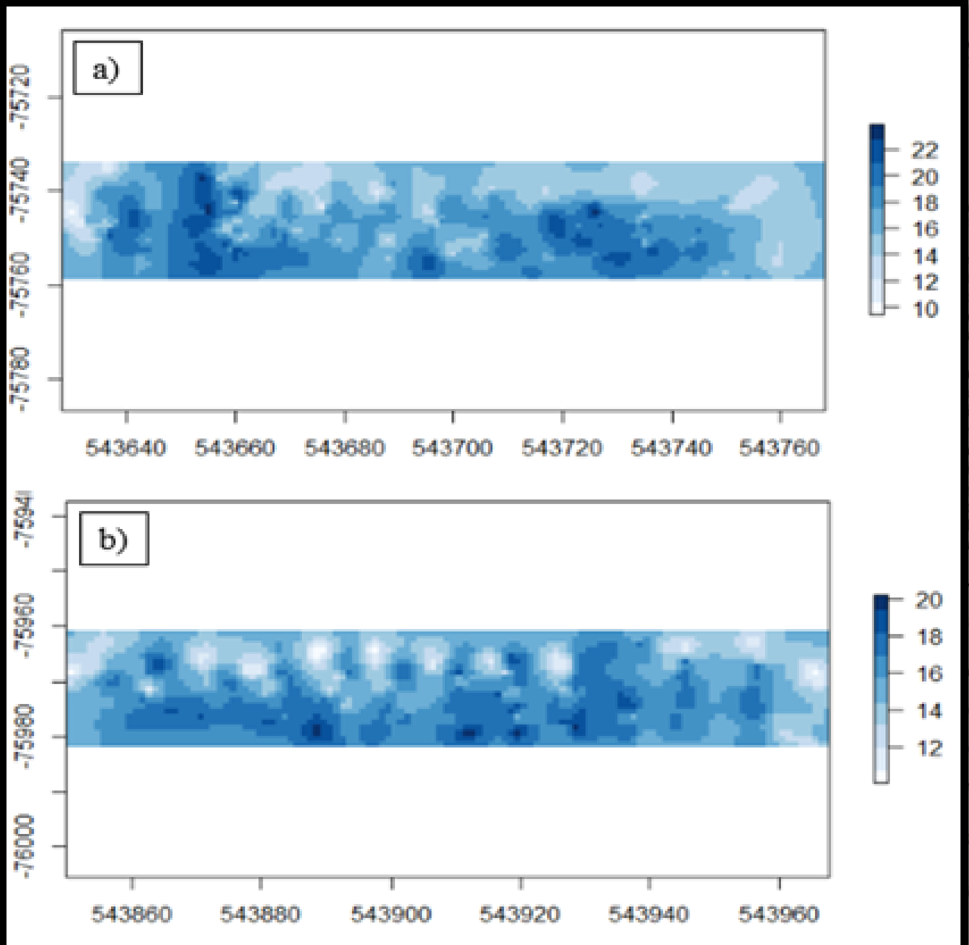

Fig. 1 The volumetric moisture content of (a) diseased red pine and (b) healthy red pine

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However, this still is not the case and major knowledge gaps must be filled. Here, we review up to 300 articles of the damping-off literature in order to highlight major knowledge gaps and identify future research priorities. The major findings are (i) damping-off is an emerging disease worldwide, which affects all agricultural and forestry crops, both in nurseries and fields; (ii) over a dozen of soil-borne fungi and fungus-like organisms are a cause of damping-off but only a few of them are frequently associated with the disease; (iii) damping-off may affect from 5 to 80% of the seedlings, thereby inducing heavy economic consequences for farmers; (iv) a lot of research efforts have been made in recent years to develop biocontrol solutions for damping-off and there are interesting future perspectives; and (v) damping-off management requires an integrated pest management (IPM) approach combining both preventive and curative tactics and strategies. Given the complex nature of damping-off and the numerous factors involved in its occurrence, we recommend further research on critical niches of complexity, such as seeds, seedbed, associated microbes and their interfaces, using novel and robust experimental and modeling approaches based on five research priorities described in this paper.

Keywords Abiotic stresses · Best management practices · Economic losses · Integrated pest management · Interactions · Seed germination · Seedling decay · Soil-borne pathogens

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Contents

Hypothesis

We hypothesize that the severity of damping off, measured by frequency of death, of response to Fusarium by red pine seedlings will increase with soil moisture content and decrease with lower soil pH.

Section	Row	2-0 Sale Inventory per Bed	Germination Inventory per Bed		Germi Year	
B15	6	1,301	1,770	469		
B15		1,271	1,828	557		
B15			1,692	531		
			1,646	187		
			,200	1,039		
			200	808		
				759		
				715		
				682		
				878		
				1,136		
				136		
			300	(41)		
			1,300	231		
			1,300	(13)		
B37			1,300	(90)		
B37		945	1,325	380		
B37	6	1,157	1,300	143		
B37	7	1,110	1,300	190		
B37	8	1,027	1,300	273		
C21	5	873	1,200	327		
C21	6	961	900	(61)		
C21	7	917	900	(17)		
C21	8	802	900	98		
C22	1	478	900	422		
C22	2	812	1,200	388		
C22	3	1,096	1,325	229		
C22	4	1,002	1,200	198		
C22	5	1,392	1,200	(192)		
C22	6	1,028	1,627	600		
C22	7	1,274	1,200	(74)		
C22	8	882	1,200	318		
C23	1	972	1,200	228		
C23	2	1,125	1,300	175		
C23	3	1,241	1,300	59		
C27	2	1,005	1,672	667		
C27	3	1,028	1,512	484		
C27	4	1,186	1,680	494		
C27	5	1,201	1,526	325		
C27	6	682	1,812	1,130	2018	High
C27	7	657	2,254	1,597	2018	High
C27	8	806	2,024	1,218	2018	High
C28	1	916	1,858	942	2018	High
C28	2	952	2,			
C28	3	1,149	1,			
C27	8	1,740	1,			
C28	1	1,457	1,			
C28	2	1,625	2,			
C28	3	1,154	1,			
C28	4	742				
C28	5	725				
C28	6	908	1,			
A09	1	641	1,			
A09	2	1,151	1,			
A09	3	1,038	1,			
A09	4	1,180	1,			
A09	5	1,237	1,			
A09	6	1,250	1,			
A09	7	1,132	1,			
A09	8	1,012	1,			
A10	1	1,168	1,			
A10	2	1,373	1,			
A10	3	1,083	1,			
A10	4	1,000	1,			
B35	1	1,035	1,			
B35	2	1,106	1,			
B35	3	991	1,			
B35	4	855	1,			
B35	5	801	1,			

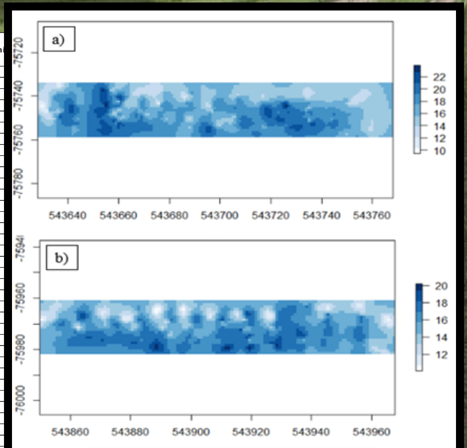


Fig. 1 The volumetric moisture content of (a) diseased red pine and (b) healthy red pine

Forest Nursery Notes Winter 2013

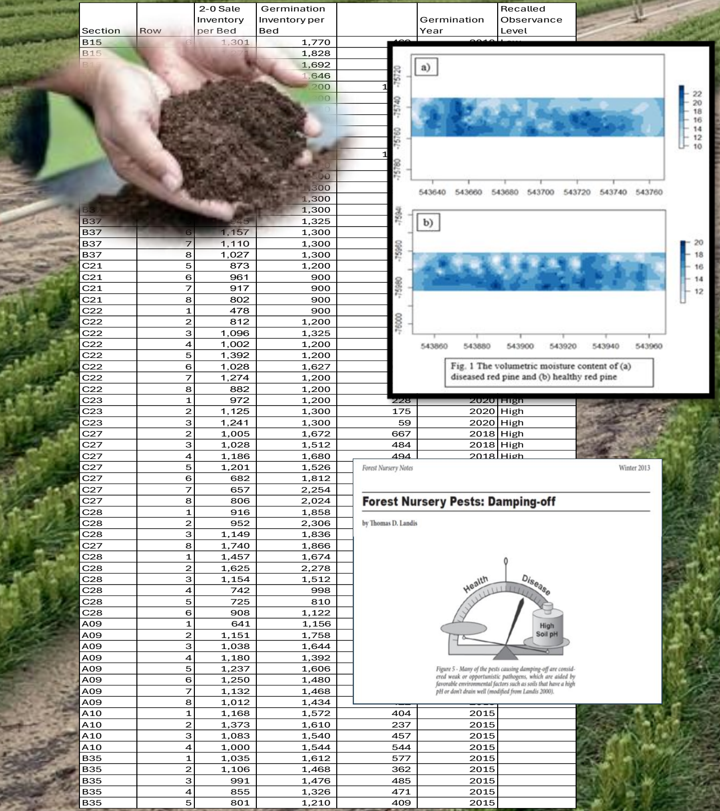
Forest Nursery Pests: Damping-off

by Thomas D. Landis

Figure 5 - Many of the pests causing damping-off are considered weak or opportunistic pathogens, which are aided by favorable environmental factors such as soils that have a high pH or don't drain well (modified from Landis 2000).

Methods

- **Barrel setup**
    - 14 total barrels planted – 2 barrels not enough germinated seedlings
    - 2 ft of WSN soil
    - Each half of each barrel had 1 sensor, 2 inches below surface
        - 5-TM METER Temperature and Moisture Sensor probe
        - 1 sensor placed lower in barrel (~12 inches from surface)
- **4 Treatment groups**
    - High moisture/ambient pH
    - Low moisture/ambient pH
    - High moisture/lower pH
    - Low moisture/lower pH
    - Each barrel was assigned either low/high moisture, and ambient/low pH
- **Barrel soil pH**
    - Soil pH was adjusted with 200mL solution of 1.3 g ammonium sulfate and DI water
    - Tested every 3 days and adjusted accordingly
- **Barrel soil moisture**
    - 7/14 barrels chosen as high moisture, other half were low moisture
    - High moisture: 0.12-0.14 m^3 water/ m^3 soil
    - Low moisture: 0.09-0.11 m^3 water/ m^3 soil



Section	Row	2-0 Sale Inventory per Bed	Germination Inventory per Bed		Germination Year	Recalled Observance Level
B15	6	1,301	1,770			
B15		1,271	1,828			
B15			1,692			
			1,646			
			1,200			
			1,200			
			1,300			
			1,300			
B37			1,300			
B37		945	1,325			
B37	6	1,157	1,300			
B37	7	1,110	1,300			
B37	8	1,027	1,300			
C21	5	873	1,200			
C21	6	961	900			
C21	7	917	900			
C21	8	802	900			
C22	1	478	900			
C22	2	812	1,200			
C22	3	1,096	1,325			
C22	4	1,002	1,200			
C22	5	1,392	1,200			
C22	6	1,028	1,627			
C22	7	1,274	1,200			
C22	8	882	1,200			
C23	1	972	1,200	228	2020	High
C23	2	1,125	1,300	175	2020	High
C23	3	1,241	1,300	59	2020	High
C27	2	1,005	1,672	667	2018	High
C27	3	1,028	1,512	484	2018	High
C27	4	1,186	1,680	494	2018	High
C27	5	1,201	1,526			
C27	6	682	1,812			
C27	7	657	2,254			
C27	8	806	2,024			
C28	1	916	1,858			
C28	2	952	2,306			
C28	3	1,149	1,836			
C27	8	1,740	1,866			
C28	1	1,457	1,674			
C28	2	1,625	2,278			
C28	3	1,154	1,512			
C28	4	742	998			
C28	5	725	810			
C28	6	908	1,122			
A09	1	641	1,156			
A09	2	1,151	1,758			
A09	3	1,038	1,644			
A09	4	1,180	1,392			
A09	5	1,237	1,606			
A09	6	1,250	1,480			
A09	7	1,132	1,468			
A09	8	1,012	1,434			
A10	1	1,168	1,572	404	2015	
A10	2	1,373	1,610	237	2015	
A10	3	1,083	1,540	457	2015	
A10	4	1,000	1,544	544	2015	
B35	1	1,035	1,612	577	2015	
B35	2	1,106	1,468	362	2015	
B35	3	991	1,476	485	2015	
B35	4	855	1,326	471	2015	
B35	5	801	1,210	409	2015	

Fig. 1 The volumetric moisture content of (a) diseased red pine and (b) healthy red pine

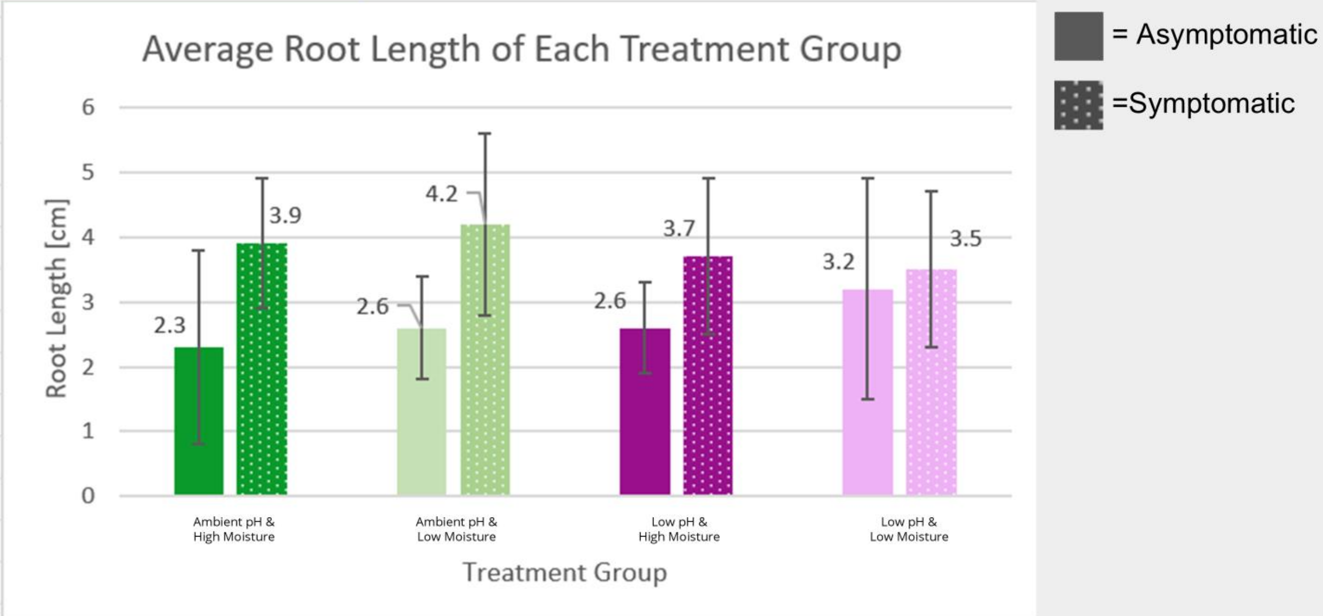
Forest Nursery Notes Winter 2013

Forest Nursery Pests: Damping-off

by Thomas D. Landis

Figure 5 - Many of the pests causing damping-off are considered weak or opportunistic pathogens, which are aided by favorable environmental factors such as soils that have a high pH or don't drain well (modified from Landis 2000).

Results


Average Root Length of Each Treatment Group

Section	Row	2-0 Sale Inventory per Bed	Germination Inventory per Bed		Germination Year	Recalled Observance Level
B15	6	1,301	1,770			
B15			1,828			
			1,692			
			1,646			
			1,300			
			1,300			
B37			1,325			
B37	6	1,157	1,300			
B37	7	1,110	1,300			
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C23	3	1,241	1,300	59	2020	High
C27	2	1,005	1,672	667	2018	High
C27	3	1,028	1,512	484	2018	High
C27	4	1,186	1,680	494	2018	High
C27	5	1,201	1,526			
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A09	1	641	1,156			
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A09	3	1,038	1,644			
A09	4	1,180	1,392			
A09	5	1,237	1,606			
A09	6	1,250	1,480			
A09	7	1,132	1,468			
A09	8	1,012	1,434			
A10	1	1,168	1,572	404	2015	
A10	2	1,373	1,610	237	2015	
A10	3	1,083	1,540	457	2015	
A10	4	1,000	1,544	544	2015	
B35	1	1,035	1,612	577	2015	
B35	2	1,106	1,468	362	2015	
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B35	4	855	1,326	471	2015	
B35	5	801	1,210	409	2015	

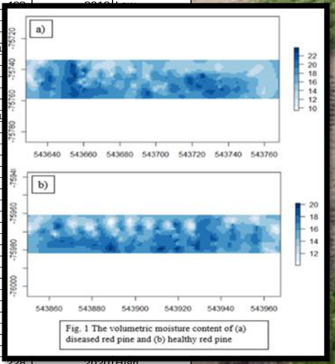

Fig. 1 The volumetric moisture content of (a) diseased red pine and (b) healthy red pine


Forest Nursery Notes

Winter 2013

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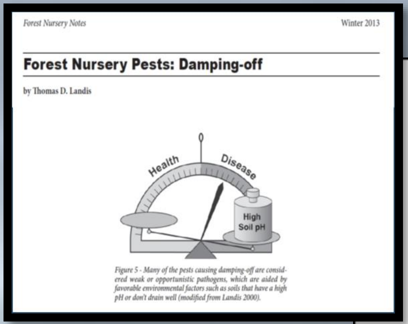

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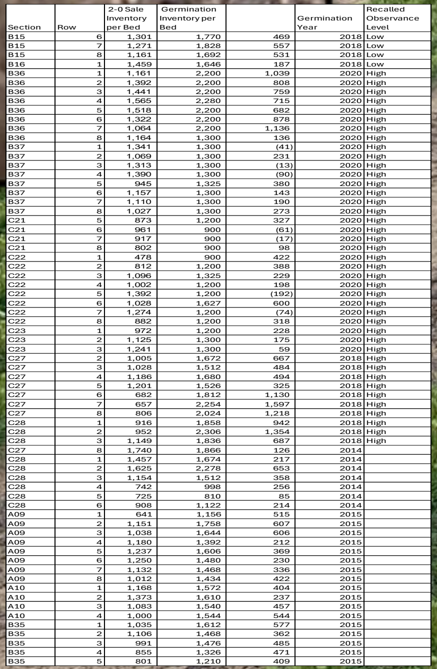

Section	Row	2-0 Sale Inventory per Bed	Germination Inventory per Bed		Germination Year	Recalled Observance Level
B15	6	1,301	1,770	469	2018	Low
B15	7	1,271	1,828	557	2018	Low
B15	8	1,161	1,692	531	2018	Low
B16	1	1,459	1,646	187	2018	Low
B36	1	1,161	2,200	1,039	2020	High
B36	2	1,392	2,200	808	2020	High
B36	3	1,441	2,200	759	2020	High
B36	4	1,565	2,280	715	2020	High
B36	5	1,518	2,200	682	2020	High
B36	6	1,322	2,200	878	2020	High
B36	7	1,064	2,200	1,136	2020	High
B36	8	1,164	1,300	136	2020	High
B37	1	1,341	1,300	(41)	2020	High
B37	2	1,069	1,300	231	2020	High
B37	3	1,313	1,300	(13)	2020	High
B37	4	1,390	1,300	(90)	2020	High
B37	5	945	1,325	380	2020	High
B37	6	1,157	1,300	143	2020	High
B37	7	1,110	1,300	190	2020	High
B37	8	1,027	1,300	273	2020	High
C21	5	873	1,200	327	2020	High
C21	6	961	900	(61)	2020	High
C21	7	917	900	(17)	2020	High
C21	8	802	900	98	2020	High
C22	1	478	900	422	2020	High
C22	2	812	1,200	388	2020	High
C22	3	1,096	1,325	229	2020	High
C22	4	1,002	1,200	198	2020	High
C22	5	1,392	1,200	(192)	2020	High
C22	6	1,028	1,627	600	2020	High
C22	7	1,274	1,200	(74)	2020	High
C22	8	882	1,200	318	2020	High
C23	1	972	1,200	228	2020	High
C23	2	1,125	1,300	175	2020	High
C23	3	1,241	1,300	59	2020	High
C27	2	1,005	1,672	667	2018	High
C27	3	1,028	1,512	484	2018	High
C27	4	1,186	1,680	494	2018	High
C27	5	1,201	1,526	325	2018	High
C27	6	682	1,812	1,130	2018	High
C27	7	657	2,254	1,597	2018	High
C27	8	806	2,024	1,218	2018	High
C28	1	916	1,858	942	2018	High
C28	2	952	2,306	1,354	2018	High
C28	3	1,149	1,836	687	2018	High
C27	8	1,740	1,866	126	2014	
C28	1	1,457	1,674	217	2014	
C28	2	1,625	2,278	653	2014	
C28	3	1,154	1,512	358	2014	
C28	4	742	998	256	2014	
C28	5	725	810	85	2014	
C28	6	908	1,122	214	2014	
A09	1	641	1,156	515	2015	
A09	2	1,151	1,758	607	2015	
A09	3	1,038	1,644	606	2015	
A09	4	1,180	1,392	212	2015	
A09	5	1,237	1,606	369	2015	
A09	6	1,250	1,480	230	2015	
A09	7	1,132	1,468	336	2015	
A09	8	1,012	1,434	422	2015	
A10	1	1,168	1,572	404	2015	
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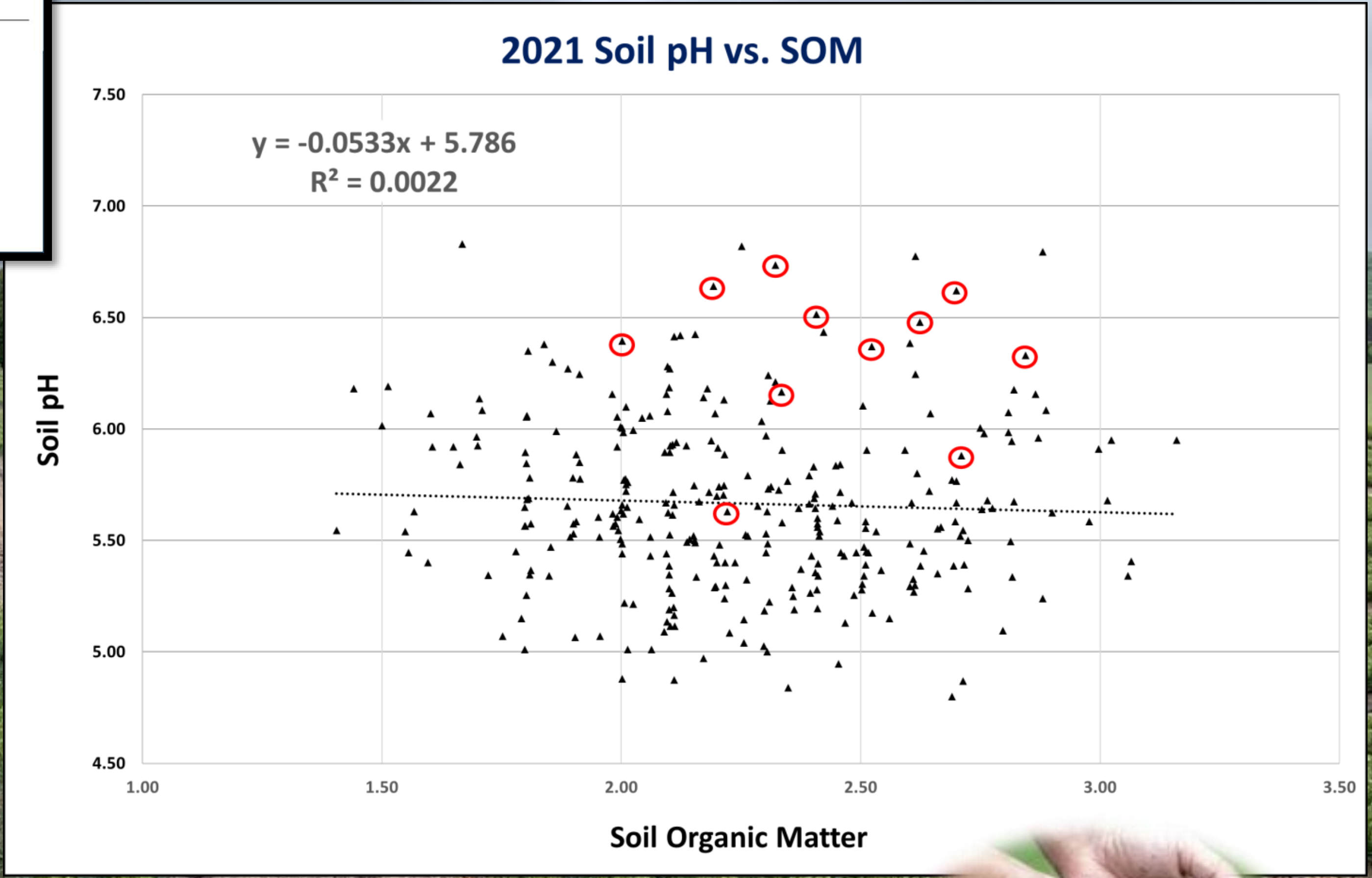
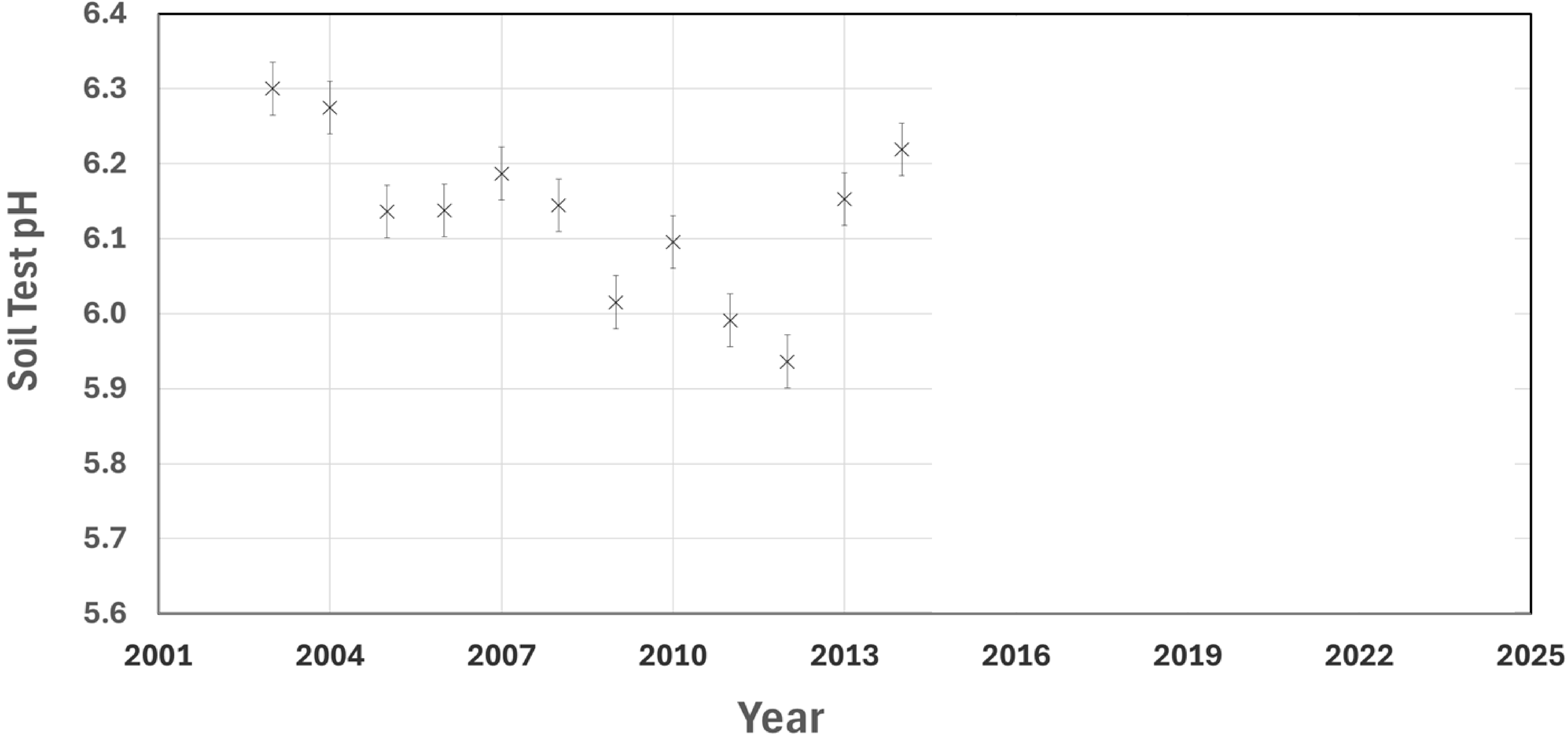


Nursery Soil pH (yearly averages)



Research Collaborations in Urban Ecosystems and Environmental Education
Department of Soil Science
University of Wisconsin-Madison

Association of Soil Organic Matter, pH and Soil Moisture in a Wisconsin Forest Nursery

WI DNR

Lydia White[1], Nick J. Balster[1,2] , and Janet Silernagel Balster[3]
Environmental Science Major [1], Soil Science Department[2] , Silvernail Studio for Geodesign, LLC[3]
University of Wisconsin, Madison, College of Agriculture and Life Sciences (CALS)

This case study investigated whether a relationship between soil organic matter (SOM), soil volumetric moisture content (VMC), and soil pH could be detected with two different (3-point vs. 5-point) sampling protocols in a sandy soil of a Wisconsin State Forest Nursery. Data were collected from
the Wilson State Nursery in Boscobel, Wisconsin, during spring of 2024. … was obtained *in situ* at the nursery using a TDR moisture meter. Data were analyzed using an Inverse
Distance Weighting function with ArcGIS Pro and correlations (regression … results showed no relationship between SOM and VMC ($R^2 = 0.01$) or soil pH ($R^2 = 0.01$) across the
study area. However, the coefficients of variation were higher for all variab… sampling regimes. There were no significant spatial patterns in SOM, as the Moran's I Index found it
to be randomly distributed across the study area. These results suggest that … warranted for sampling the rest of the nursery. Potential explanations are offered to explain these results
and inform future soil management at the nursery to meet production goals.

Hypotheses

Soil Organic Matter (SOM) is a major determinant in nutrient and water retention especially in sandy soils. Therefore, SOM distribution will be positively correlated with soil volumetric water content and negatively correlated with soil pH across the study site.

Spatial sampling at a coarse scale will represent sufficient precision to capture the site spatial variability, as expressed through the coefficient of variation, compared to a finer resolution.

Photos by Lydia White and Aundrea Taylor

Background

Wilson State Nursery is a bare-root forest nursery spanning 175 acres in Boscobel, Wisconsin. The nursery produces over five million seedlings annually, including a variety of hardwood, conifer, and ornamental species. Production at the nursery is critical for reforestation and afforestation efforts in Wisconsin (WDNR, n.d.). The nursery soil is characterized as a sand, which requires annual amendments of fertilizer and continued irrigation during the summer months to ensure sufficient tree growth. Sand represents the largest particle fraction of soil making coarse texture soil poor retainers of water and nutrients. Therefore, fertility management is challenging, requiring fertilization and irrigation which, if overapplied, can cause significant eutrophication of adjacent waterways; Wilson state Nursery is adjacent to the Wisconsin River. Refining management practices based on physiochemical soil properties that affect water and nutrient cycling and that are spatially variable will help minimize production costs and environmental damage from runoff. This empirical study aims to investigate the relationship between three proximate variables at the center of this nutrient-water-biology matrix, namely, of soil organic matter (SOM) to volumetric moisture content and pH to elucidate their spatial relationships and variability given two levels of field sampling.

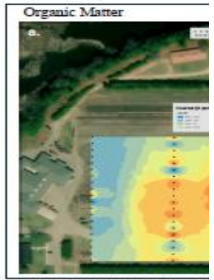
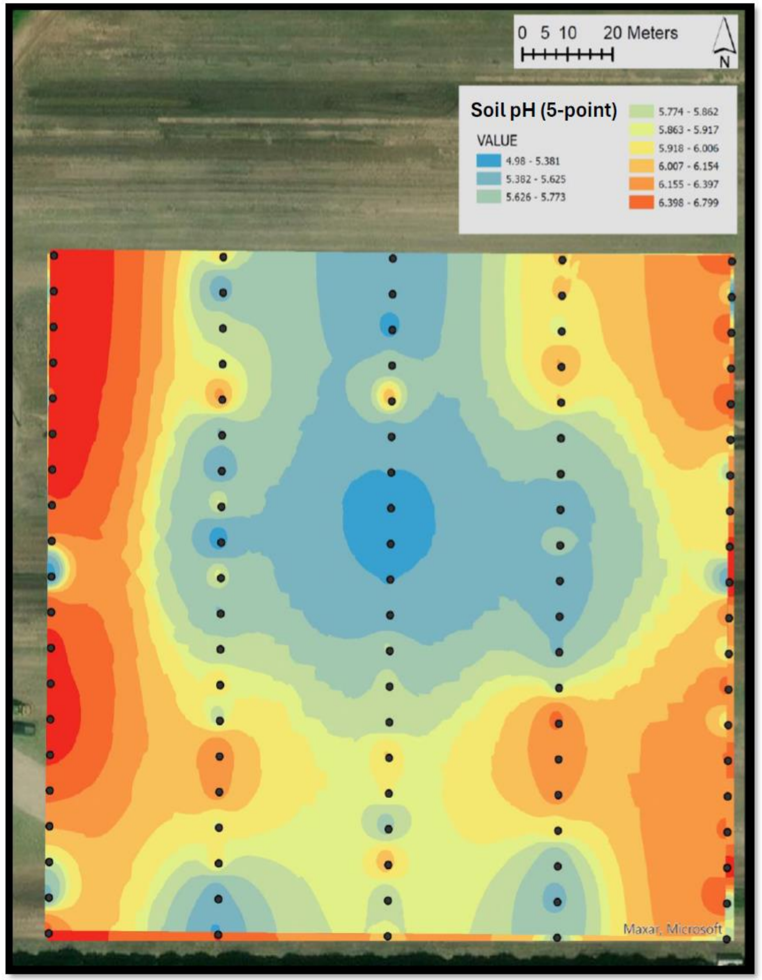
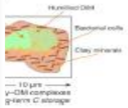


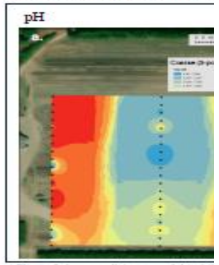
Figure 1: *Inverse distance weighted (I… study area sampled coarsely (a) and fi… p=0.789 for a and b, respectively). The … the fine sampling yielded a 25% coeffi… withing Wilson Nursery and the Wiscon…*





1
305
.0%

…e and z statistics.



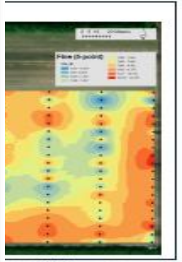


Figure 2: *Inverse distance weighted (I… Clustering was spatially correlated (p … of variation for the course sampling w…*

…ntent (VWC) sampled …nd p <0.001 for a and b, …0% while the fine sampling

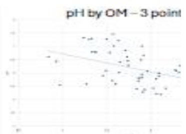
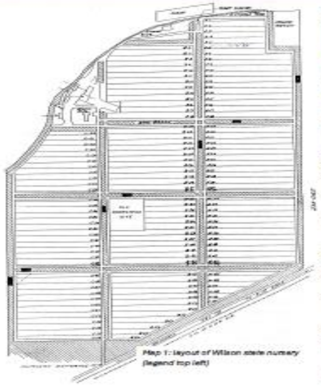


Figure 4: *Relationship between … point). The model explained ap… variables for the (a) coarse (3-p…*

…VC) and organic matter …r VMC is insignificant (R^2 =

The relationship between O… …M across the study site was random (figure 1, table 1). Conversely, spatial distribution for pH and VMC it showed significant clustering (figure 2 & 3, table 1). Finally, fine sampling showed slightly more precise measurements than the coarse sampling method (table 1).

Materials and Methods



Nursery and sample setup:
- Sections containing 8 rows each (east-west) identified by number (1-56).
- Fields in columns (north-south) identified by letter (A,B,C).
- Study sampling in A 19-30 (course sampling, see map 2) and B 9-18 (fine sampling).

Sampling method:
- Three soil probes to 10 cm depth per sample.
- One probe from each of the three outermost rows was homogenized into one sample.
- VMC read instantaneously with TDR300 soil moisture meter using same three readings and averaged to report.

Sample processing:
- 100 samples reported here, apps. 780 samples total.
- Loss on ignition (LOI) protocol from Blake & Hartge, 1886.
- pH testing on FischerScientific accuvet pH meter using a 1:1 soil to water ratio. Samples tested twice and averaged.

1	2	3
4	5	6

1	2	3	4	5
6	7	8	9	10

Map 2: shows coarse sampling (top) and fine sampling (bottom) patterns. Sample is taken in the center of each box

Analysis: Samples were analyzed using linear regression (Microsoft Excel) for correlative statistical analysis, and Inverse Distance Weighting (IDW) and Moran's I index for determination of spatial statistics (ArcGIS Pro). The linear regression reports how much variation of the dependent variable (VMC or pH) can be attributed to the independent variable (%OM). IDW interpolates values of any parameter and presents them spatially, predicting distribution of features across a study area. Moran's I index determines the dispersion of the data across the study area, specifically if it is clustered, random, or dispersed.

Discussion

This pilot study failed to reject the null hypothesis that soil pH and VMC are unrelated to OM across the study site. Yet, there is significant clumping of the two latter edaphic factors, implying that there may be another (or multiple) drivers of the distribution of these variables or that their spatial variation is sufficiently independent of one another. However, the second hypothesis was supported in that the course sampling method yielded similar precision as the finer (5-point) method.

We hypothesize that many unquantified variables may explain these results. First, sampling error may have contributed to the findings. After drying the soil in the lab, it had a fine granular structure, which could have protected organo-mineral complexes from combustion during the determination of LOI (Basile-Doelsch, 2009) Thus, we recommend that subsequent studies consider grinding the soil before beginning the LOI process. Second, the low levels and soil heterogeneity in SOM may have masked a spatial correlation between the three edaphic factors. No predictable spatial distribution of SOM was found, and the mean levels of SOM were well below recommended levels for a typical agricultural soil (Cornell University Cooperative Extension). Finally, because the vegetation type varied in both species and penology across the site, the frequent species rotation between sections may have confounded our results.

Despite the lack of relationship between variables, taken independently, this study suggest that fine-scale sampling at five points per section is not required to capture the spatial heterogeneity of these variables compared to the coarse sampling. And it may be that relationships will be found when the entire nursery is analyzed, a next step well justified. Explaining the spatial relationship or lack thereof between these variables is essential to environmentally sound and economically sustainable management practices such as the implementation of precision fertilization and irrigation to reduce the impact on nearby water bodies while maintaining efficient nursery production.

References
Ayles et al., 2015: *Soil carbon sequestration in cool-temperate dryland pastures: Mechanisms and management options.* Soil Research 53(4).
Basile-Doelsch et al., 2009: *Effect of landuse on organic matter stabilized in organomineral complexes: A study combining density fractionation, mineralogy and δ13 C.* Geoderma 151, 3-4, p. 77-86.
Blake & Hartge, 1986: *Bulk density.* In *Methods of Soil Analysis, Pt. 1. Physical and Mineralogical Methods* (Klute, A.), Agronomy Monographs 9-2nd edition, Madison, WI, American Society of Agronomy, p. 363-382.
Cornell University Cooperative Extension (2008): *Agronomy Fact Sheet Series, Fact Sheet 41.* Department of Crop and Soil Sciences, College of Agriculture and Life Sciences, Cornell University.
WDNR, n.d.: *Tree Planting: Reforestation in Wisconsin.* Accessed online 4/25/24.

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References

Cram, Michelle M., et al. *Forest Nursery Pests*. U.S. Dept. of Agriculture, Forest Service, 2012.

Cram, M. M. (n.d.). *Damping-off in Tree Nurseries*. Pacific Northwest Pest Management Handbooks. Retrieved February 6, 2021, from https://pnwhandbooks.org/plantdisease/pathogen-articles/common/fungi/damping-tree-nurseries

How to prevent seedling damping off. (2018). Umn.edu. https://extension.umn.edu/solve-problem/how-prevent-seedling-damping#:~:text=Identifying%20damping%20off%20symptoms&text=Seedling%20stems%20become%20water%20soaked,plant%20parts%20under%20high%20humidity.

Lamichhane, J. R., Dürr, C., Schwanck, A. A., Robin, M.-H., Sarthou, J.-P., Cellier, V., Messéan, A., & Aubertot, J.-N. (2017). Integrated management of damping-off diseases. A review. *Agronomy for Sustainable Development*, *37*(2), 1–25. https://doi.org/10.1007/s13593-017-0417-y

🧪 Key Characteristics of the Scale

•**Logarithmic**: Each unit change = **10× difference** in H^+ concentration.

→ A soil with pH 5 has **10× more H^+** than pH 6, and **100× more** than pH 7.

•**Inverse relationship**:

→ **Lower pH = more acidic (more H^+)**

→ **Higher pH = more basic (fewer H^+)**