Utilizing HYDRUS 1-D to Guide Farmers with Fields at Risk of Increased Phosphorus Leaching due to Global Climate Change

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Introduction

- The goal of this project was to create a model that predicts phosphorus retention based on chemical sorption within the root zone.
- Heightened rainfall caused by climate change could lead to greater leaching of phosphorus outside of the root zone
- Farmers could use a guide created from this model to determine if their field is at risk of leaching phosphorus.
- Fields not at risk now could be with increasing rainfall.

Why Phosphorus?

- Phosphorus fertilizer is largely responsible for modern agricultural output.[1]
- Mining non-renewable phosphate rocks (phosphorite) is the main source of this resource.[1]
- No substitutes for phosphorus available
- A significant number of United States rivers and streams have excessive levels of phosphorus and as much as 72% of it is from agriculture.[2]

1. Chowdhury, R. B., Moore, G. A., Weatherley, A. J., & Arora, M. (2017). Key sustainability challenges for the global phosphorus resource, their implications for global food security, and options for mitigation.
2. Lombardo, P. (2006). Phosphorus Geochemistry in Septic Tanks , Soil Absorption Systems , and Groundwater.

Phosphate mine near Flaming Gorge, Utah

https://en.wikipedia.org/wiki/Phosphate_mining_in_the_United_States

Impact on Farmers

- At the current rate, existing phosphate rock reserves are predicted to be exhausted within 70–140 years[1]
- "Diammonium phosphate, the most widely used phosphorus fertilizer in the world, rose from less than $480 a ton in December 2020 to about $826 a ton in November 2021, according to an analysis of retail fertilizer prices from the U.S. Department of Agriculture."[2]
- Phosphorus utilization efficiencies in most countries are below 20% [3]
- Demand will only increase as the world's population grows.

1. Li, B., Boiarkina, I., Young, B., Yu, W., & Singhal, N. (2017). Prediction of future phosphate rock: a demand based model. Journal of Environmental Informatics.
2. Jared , George. "Dramatic Spikes in Fertilizer Prices Could Impact Row Crop Farmers." *Talk Business & Politics*, 9 Jan. 2022, https://talkbusiness.net/2022/01/dramatic-spikes-in-fertilizer-prices-could-impact-row-crop-farmers/.
3. Li, Bing, Udugama, I. A., Mansouri, S. S., Yu, W., Baroutian, S., Gernaey, K. V., & Young, B. R. (2019b). An exploration of barriers for commercializing phosphorus recovery technologies.

Scenario Determination

- To represent around 96% of MI's corn grain production, 39 counties were selected based on average values of total corn grain production (Bu) in each county from 2014-2019[1]
- 179 scenarios were selected and sorted by total corn grain production
- Lowest production scenarios were removed until 80% of corn production remained.

1. USDA/NASS. (2019a). USDA/NASS QuickStats Ad-hoc Query Tool. Retrieved June 18, 2020, from National Agricultural Statistics Service website: https://quickstats.nass.usda.gov/results/3571458D-F070-3AA1-8430-E66323B8B02B

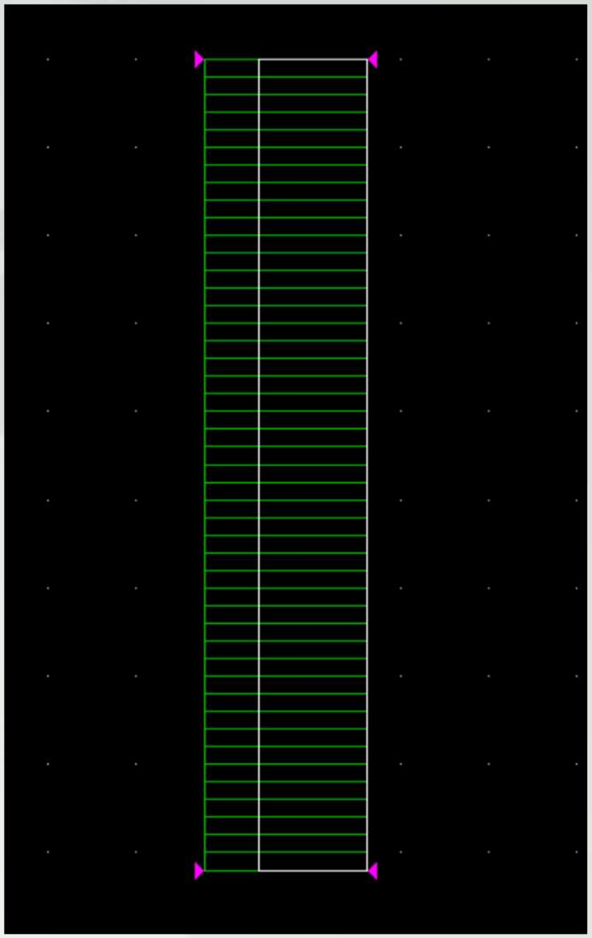
Model Parameters

- Model simulates a 2-month period from April 15 through June 15
  - Constitutes critical period between fertilization and germination
- Legacy phosphorus not present
- Weather data from 2019 was utilized
  - Year with high rainfall
- 46 cm of depth was selected based on a USDA recommendation
  - "In addition, an effective root zone of corn is 30.5 cm, so the water table should be held no higher than 45.7 cm beneath soil surface."[1]
- 4 years of P application is allowed at one time at 205.3 and 263.96 lbs P_2O_5 $acre^{-1}$. [2]
- Moisture content 50% of field capacity

1. USDA. (2001). Part 624 Drainage Chapter 10. National Engineering Handbook,.
2. EGLE. (2020). MPRA Application Spreadsheet Example. Duke Law Journal, 1(1), 1–13. https://doi.org/10.1017/CBO9781107415324.00

What is HYDRUS?

- Hydrus is a 1-D modeling program for analyzing water and solute flow in porous media.[1]
- The model utilizes finite element modeling to numerically solve the governing equations
- Uses the Richards' equation for water flow, the advection-dispersion equation for solute flow.



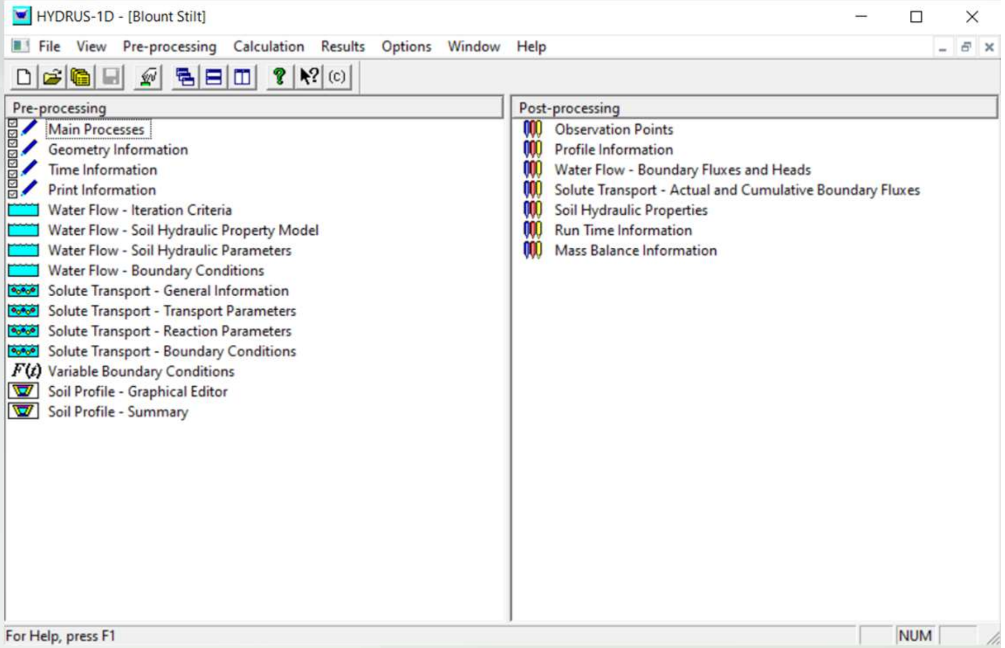
Nodes used as finite elements for solving numerically

1.Šimůnek, J., M. Th. van Genuchten, and M. Šejna, Recent developments and applications of the HYDRUS computer software packages, Vadose Zone Journal, 15(7)

Setting up the Model

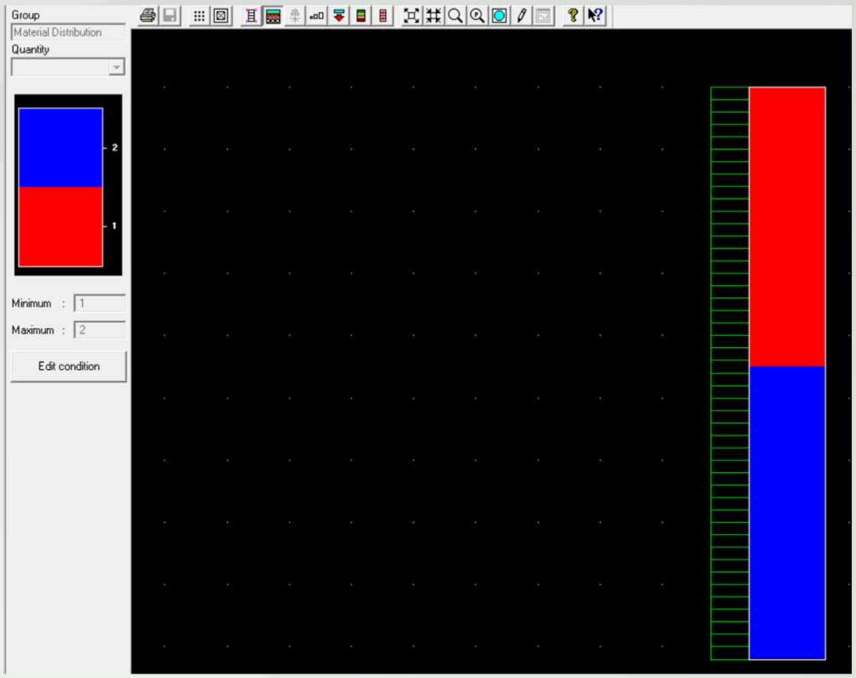
- Shown to the right is the main menu of a HYDRUS 1-D model.

- Within this menu the number of layers in the soil, water flow properties, and advection-dispersion properties are entered.



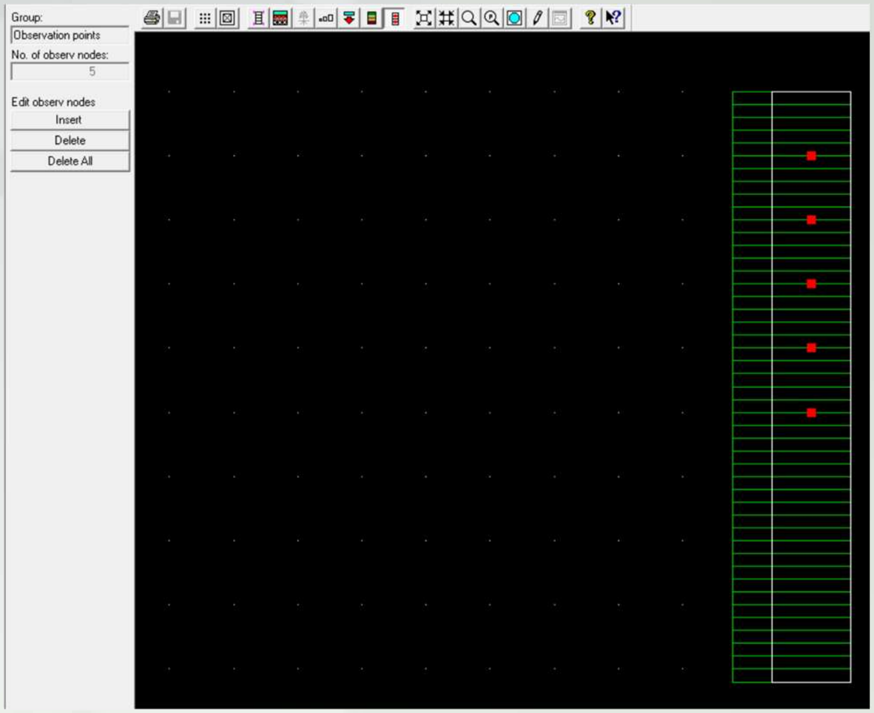
Graphical Editing

- Allows for editing based on horizon properties
  - Soil texture is correlated to material type early in the model
- Also allows to account for variations in soil saturation at the start of the model



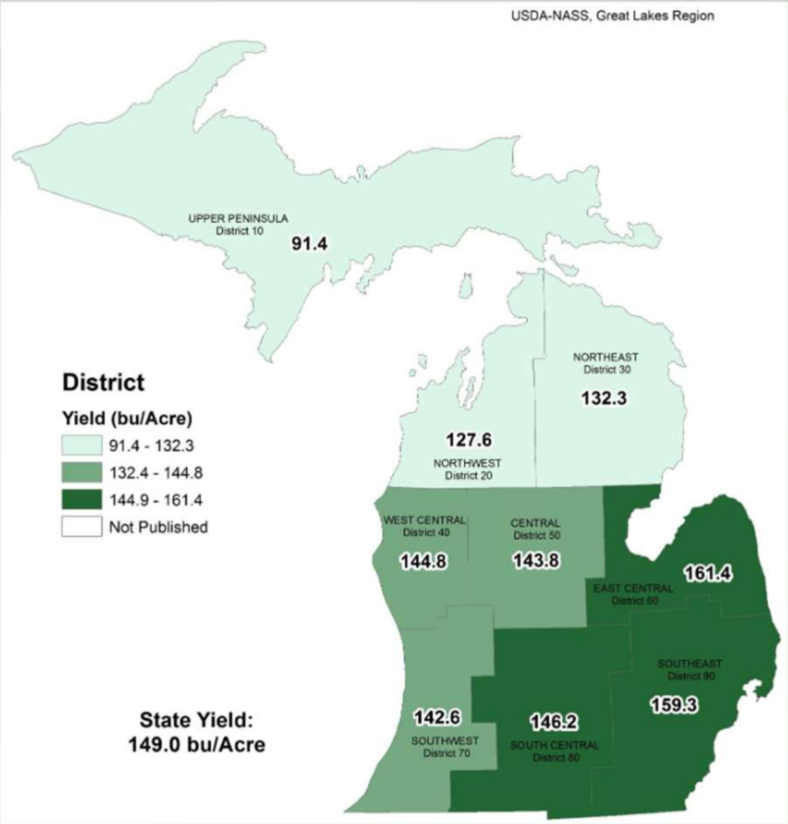
Observation Nodes

- Observation nodes were used to specify depths to observe
- By default, the highest and lowest depth are observed.
- Due to program limits 5 cm intervals were used



Rain Data

- According to The Michigan Department of Transportation, the state can be considered one homogenous region.[1]
- Saginaw county was selected as the source of rainfall data.
  - Closely mirrors Michigan precipitation and temperature
  - Held the second largest amount of corn growth
- Michigan State University's Enviroweather program was used to collect the data



Corn Yield per acre by region[2]

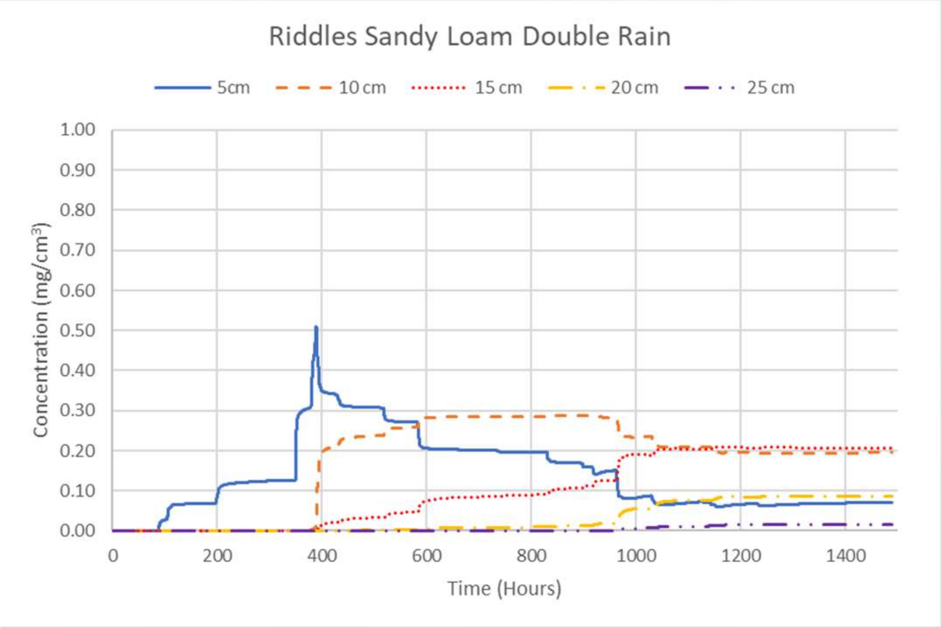
1. MDOT. (2001). Michigan Department of Transportation- Rainfall Intensity Report., from https://www.michigan.gov/mdot/0,4616,7-151-9621_11041_91575_91583-95451--,00.html
2. USDA. (2018). County Estimates. Nass, 48823(517). Retrieved from https://www.nass.usda.gov/Statistics_by_State/Mississippi/Publications/County_Estimates/index.php

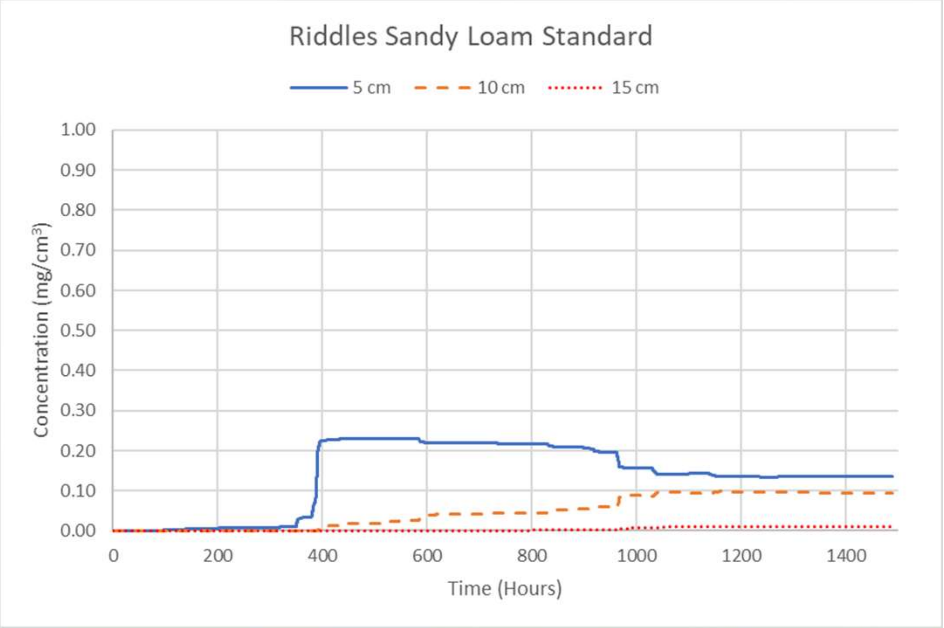
Categorizations

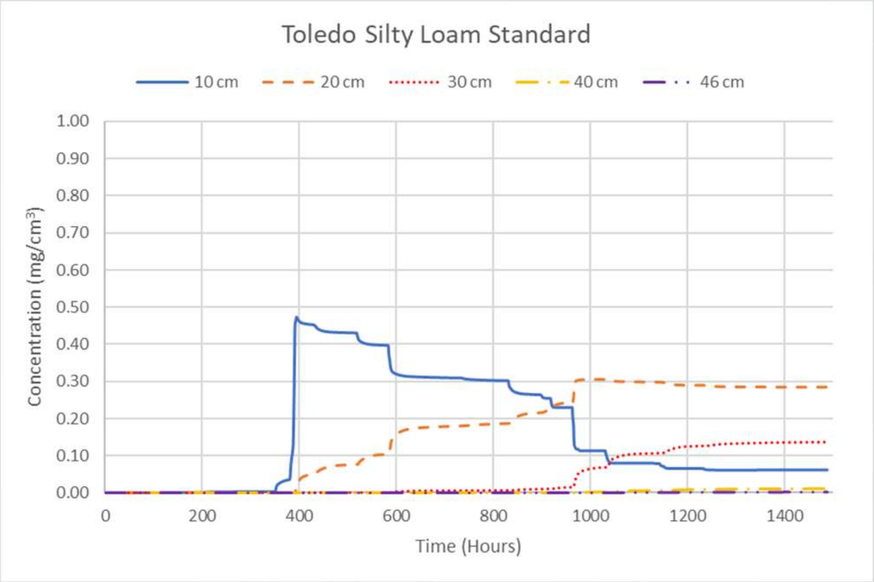
- Three categories of soils were created
    - No leaching: 28% corn grown in MI
    - Partial leaching: 49% of corn grown on this soil
    - Full leaching: 0.36% of corn is grown on this soil
- No leaching soils had the highest clay content
    - 16% clay content and higher
- Full leaching soils were fully sand
- Partial leaching lies between the other two categories
    - Most leached 10-20cm

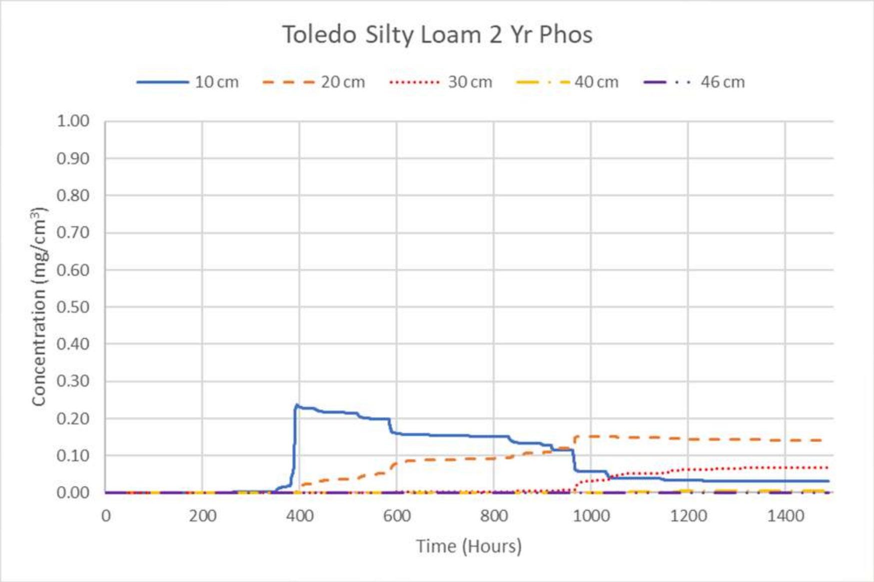
Effect of Rainfall

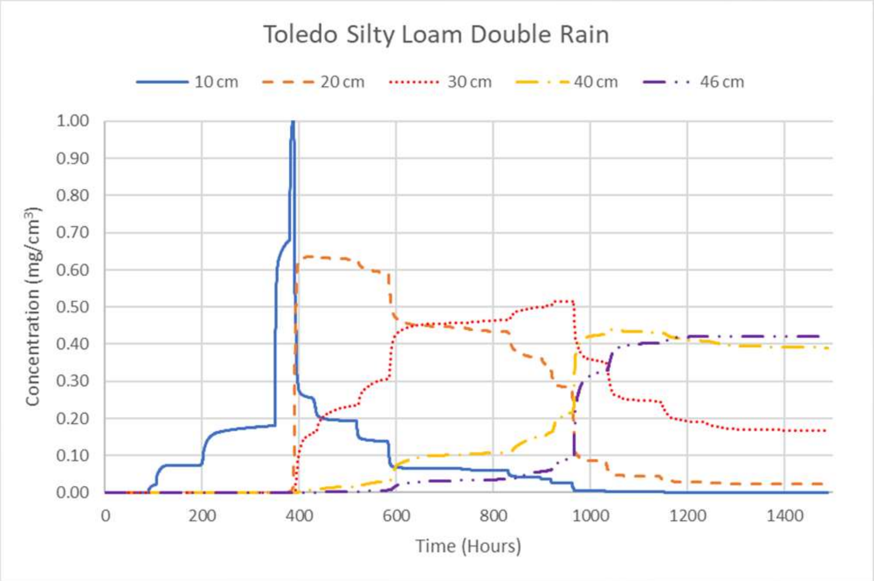
- Riddles sandy loam represents 1.43% of Michigan's corn growing soil
  - This soil series is 91.5% sand and 8.5% clay in the observed depth
  - Under 2019 weather conditions 15cm of leaching occurred

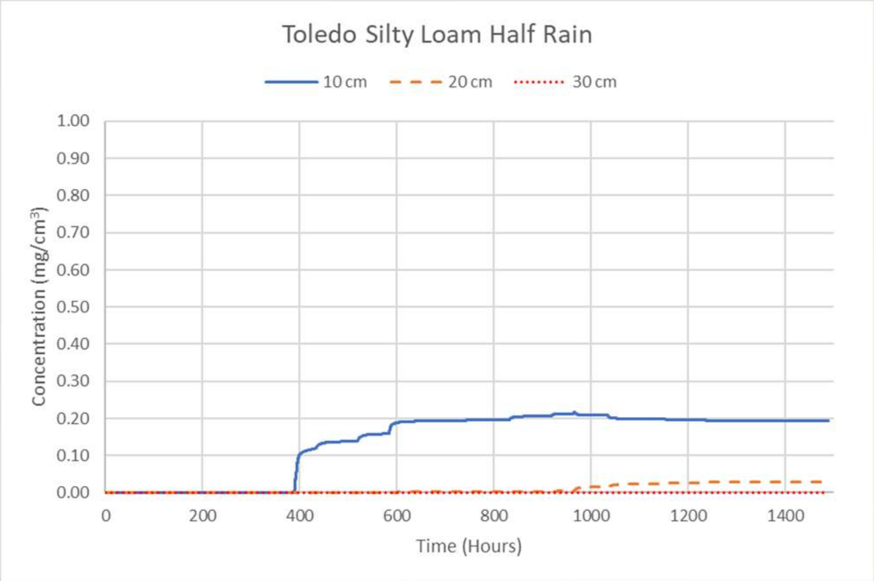





Toledo Silty Loam Standard
10 cm
20 cm
30 cm
40 cm
46 cm
Concentration (mg/cm³)
Time (Hours)


Toledo Silty Loam 2 Yr Phos
10 cm
20 cm
30 cm
40 cm
46 cm
Concentration (mg/cm³)
Time (Hours)


Toledo Silty Loam Double Rain
10 cm
20 cm
30 cm
40 cm
46 cm
Concentration (mg/cm³)
Time (Hours)


Toledo Silty Loam Half Rain
10 cm
20 cm
30 cm
Concentration (mg/cm³)
Time (Hours)

Key Points

- Fields with higher clay content are more resilient to heightened rainfall
  - Farmers with these fields are of low concern and can apply larger amounts of phosphorus at once.
- Fields that possess low clay and high quantities of sand are the most susceptible
  - Farmers should pay close attention to changing weather patterns and apply less phosphorus at once.
- Greater fertilizer waste is another future consequence of climate change.

Future work

1. Incorporate projected rainfall into best-management practices for future climate change
2. Simulate entire growing season
3. Expand the model with soils from various regions
4. Incorporate macropores
5. Calibrate and Verify the Model
6. Compare Runoff and Subsurface phosphorus flow