Abstract

# Intro

The water retention curve is the relationship between the soil water content and the soil water potential. The curve can be used to predict the soil water storage and water supply to plants.

Potential vs water content. Capillary binding of water at potentials close to 0. As potentials become more and more negative water is bound in small pores (adhesive and osmotic binding).

Van Genuchten very common

# Methods and Materials

## Site descriptions

Three long-term sites were used for this study (**Figure 1**), with one site having two experiments. Therefore, a total of four experiments were used for this study (**Table 1**). Each experiment consisted of two treatments that had been in place for at least 10 years: (1) a maize/soybean rotation (either grain- or silage-based) with a winter rye cover crop planted yearly in the fall following cash crop harvest and terminated in the spring, and (2) the same rotation without a cover crop. Every trial was arranged in a randomized complete block design with four (West and East) or five (Central) replicates. The plots within each trial were managed identically save for the planting of the cover crop in the fall. The exact herbicide and nutrient programs varied by site, reflective of their particular managers and contexts (**supplementary material**). More detailed accounts of agronomic management at the Central site have been published elsewhere (Moore et al., 2014). All sites had sub-surface tile drainage and were managed without tillage since initiation of the trials.

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| **Longitude Latitude** | **Year Started** | **# of Reps.** | **Plot Size** | **30-year Annual Mean** | | **Mean Cover Crop Biomass (Mg ha-1)** | | **2018 Crop** | **2019 Sampling Date** |
| ***Air Temp (⁰C)*** | ***Precip (mm)*** | ***5-year*** | ***10-year*** |
| *West-grain (commercial farm)* | | | | | | | | | |
| 42⁰03’N  94⁰20’W | 2008 | 4 | 25 x 250 m | 9.5 | 880 | 0.24 | 0.45 | Soybean | May 17 |
| *Central-silage (research plots)* | | | | | | | | | |
| 42⁰00’N  94⁰12’W | 2002 | 5 | 3.8 x 55 m | 9.8 | 907 | 2.38 | 1.98 | Soybean | May 8 |
| *Central-grain (research plots)* | | | | | | | | | |
| 42⁰00’N  94⁰12’W | 2009 | 5 | 3.8 x 55 m | 9.8 | 907 | 1.53 | 0.88 | Soybean | May 8 |
| *East-grain (commercial farm)* | | | | | | | | | |
| 41⁰19’N  92⁰17’W | 2009 | 4 | 25 x 275 m | 10.2 | 947 | 1.73 | 1.32 | Maize | May 6 |

The West-grain and East-grain experiments were production fields on commercial farms, and only one phase of the maize/soybean rotation was present each year. The Central site was a larger research study managed by the United States Department of Agriculture and included both phases of each rotation (Kaspar et al., 2007, 2012). For this study, only the soybean phase of each rotation was sampled due to time constraints. Cover crop biomass sampling occurred each spring at every experiment, details about methodology and yearly values are reported elsewhere (my paper, maybe somewhere else).

## Soil Sampling

An aluminum ring 7.62 cm in diameter and 7.62 cm tall was used to take in-tact soil samples. Sampling occurred in May of 2019 after maize (West) or soybean (East, Central-grain, Central-silage) emergence at each site. Sampling was done immediately following crop emergence to minimize the effects of live roots in the samples.

At all locations, samples were taken in the middle of the plots between planted rows. A hole 10 cm deep was dug, and soil was smoothed by hand to create a flat area approximately 30 cm square. The ring was placed on the soil surface in the center of the flat area, and a XX weight was used to evenly drive the ring into the undisturbed soil. Once the ring was fully inserted into the soil, a hole was dug around the ring. A flat sheet of metal was slid under the ring to extract it, and a knife was used to remove soil from the top and bottom of the ring using a Z-cutting motion. The ring was wrapped in aluminum foil with the soil orientation (top, bottom) marked. The foil-wrapped ring was then placed in an individual plastic container, then placed in a cooler. This process was repeated for each plot.

## Measurements

### Soil-water-retention curve

## The equipment could accommodate 12 samples at a time, so each experiment’s samples were run together in a batch. A given experiment’s cores had cheesecloth taped to the bottom of each core and an additional ring taped to the top. They were then placed in a vacuum chamber for at least 12 hours in a solution of 0.01 M CaCl2 filled to the top of the first ring, allowing the solution to move upward to saturate the soils with minimal air entrapment. The top ring was removed from the cores, then the saturated cores were weighed, then transferred to a custom-built pressure cell apparatus (Ankeny et al. 1992). Measurements were made according to the protocol described by Kool et al. 2019. Briefly, the cores were drained at atmospheric pressure for 12 hours to obtain a measurement for gravity-drained values (Ψ = -3.8 cm H2O = −0.38 kPa XX Andrea calls this -33 kPa…hmmm). Subsequent measurements were taken at Ψ of -1, -2.5, -5, -10, -20, -50 kPa. The samples were then oven dried at 60 deg C for at least 48 hours, then weighed. Bulk densities were estimated by dividing the oven-dried weight of soil by the ring volume (XX).

### Texture

The oven-dried soil was ground and passed through a 2 mm sieve. Soil texture was measured using laser diffractometry (Miller and Schaetzel 2012) with a Malvern Mastersizer 3000 and a HydroEV attachment (Malvern Panalytical Ltd, UK).

### Organic carbon

Agsource.

## Statistical analysis

All model fitting and figures were done using R (CITE) and the tidyverse meta-package (CITE). Non-linear models were fit using nls (CITE) and nlraa (CITE) package functionality, with specific equation fits from the HydroMe ©TE) and soilphysics (CITE) packages. Linear models were fit and summarized using the lme4 (CITE) and emmeans (CITE) packages. The meta-analysis of individual plot’s fitted parameters was performed using the metaphor package (CITE).

### Texture and organic matter

The effects of experiment, cover crop treatment, and their interaction on soil texture components and organic matter were assessed using mixed-effect models. Experiment, cover crop, and their interaction were included as fixed effects, with a random intercept effect for replicates nested within site.

### Water retention curve

We fit the Gardener equation (CITE) and Van Genutchen models (the 1980 one) to describe the relationship between soil moisture and soil water matric potential in our datasets. We found the models produced similar Akaike’s Information Criteria values (CITE), with the Gardner model showing a slightly better fit, consistent with other studies (Too et al. 2014). We chose to use the results from the Gardener model due to its simplicity and biologically meaningful parameters. The Gardener equation is as follows:

Where θ is the volumetric moisture content at a given soil water potential , θr and θs are the residual and saturated water contents, respectively, a is the inverse of the air-entry potential, and n is an index for the pore size distribution, with higher values indicating a larger distribution.

Models were fit using both a fixed- and mixed-effect approach to account for differences between experiments. We found the two models produced similar fit statistics. The results from 2.4.1 indicated clay contents were higher in plots without a cover crop, and varied by site. Clay can influence soil water retention curves (CITE), we controlled for the differences in clay by using it as a covariate.

We fit the Gardner equation to each experimental unit, then performed a meta-analysis on the parameters, weighting by their estimated uncertainties (CITE). We included experiment as a random intercept, cover crop as a modifier, and percent clay as a covariate.

# Results

Organic matter values ranged from 1.8 to 4.6%. Cover cropping significantly increased the amount of organic matter in the sampled soil at the East-grain experiment from an estimated 3.30% in the no-cover plots to 4.03% in the cover-cropped plots, corresponding to a an estimated 22% increase from the no-cover control (p=0.01). Cover crops did not significantly effect soil organic matter at the other three experimets (Fig X). Bulk densities varied from 1.2 g cm-3 to 1.7 g cm-3, with no significant effect of experiment, cover crop treatment, or their interactions. In all experiments, the percent clay of the soil was found to be higher in cover cropped plots compared to no cover plots (numerically so in three of the experiments, and statistically so in one). We therefore included clay as a covariate in models assessing the significance of the effect of cover crops on the curve parameters (see Methods and Materials).

The meta-analysis of curve parameters indicated the soil water content at

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| Fig X. The soil water content (SWC) at plant wilting (this might not be right, need to double check the pressures as reference) was the only Gardner equation parameter significantly affected by cover cropping. Points represent estimates of the mean value, line ranges the 95% confidence intervals for the mean. Values greater than zero indicate an increase in response to cover cropping. |

# Discussion

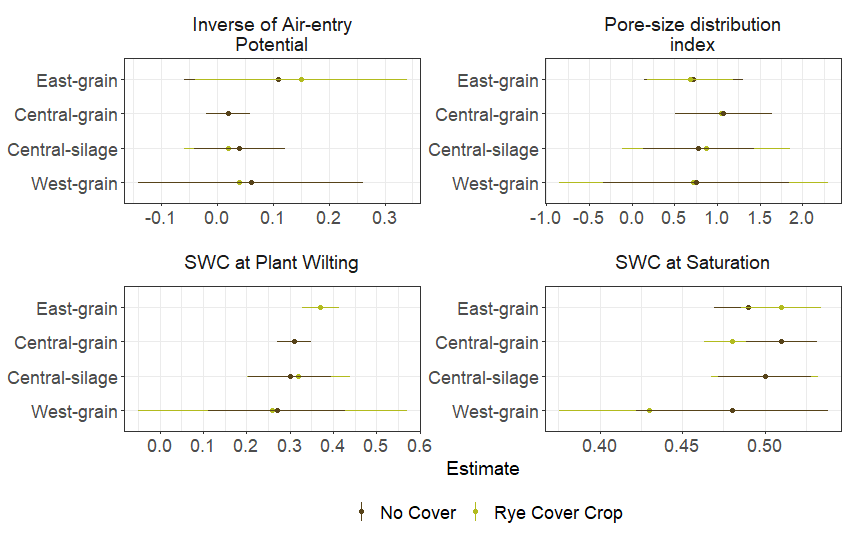
Organic matter

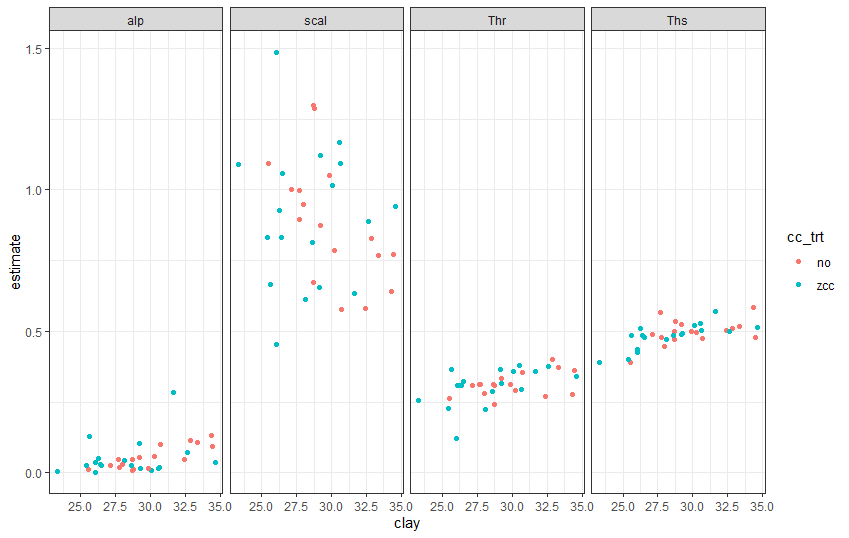
The effect of cover cropping on organic matter in maize-based systems is inconsistent (<https://www.agevidence.org>). Our early spring sampling likely amplified differences in organic matter, due to the recently terminated cover crop residue and roots being less than a month old. A 20% increase at a 10-17cm depth is within the range observed in other studies looking at 0-30 cm depths.

Soil water

Several studies have compared the effect of cover crops on soil water relations (see Basche et al. XX), and on average have found cover crops improve soil’s storage capacities. However, to our knowledge, there is only one published study that compares soil water retention measurements in maize-based systems with and without winter cover cropping treatments (Basche et al. 2016). The authors found that in the 0-15 cm depths, cover cropping significantly increased the soil water at -33 kPa (field capacity) from 0.31 to 0.35, while having no effect on the soil water at -1500 kPa (plant wilting point). This difference translated to an increased amount of planta-availble-water. In contrast, we found cover cropping had no effect on soil water contents at 3

https://www.agevidence.org/#&Practice=Cover%20Crops&Outcome=Climate%20Mitigation&GLII=Carbon%20Storage&PracticeFilters=Duration%20of%20Study!\_Number%20of%20Species!Three%20or%20more%20species\_Type%20of%20Species!Non-legume%20Mixture^Non-legume%20%2B%20Legume%20Mixture\_Soil%20Sample%20Depth!Not%20measured





Citations

Ankeny, M.D., Brown, H.J., Cruse, R.M., 1992. Means and method of soil water desorption. U.S. Patent 5,161,407.