Roots as drivers of the rotation effect?

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**Abstract**

**Intro**

**Methods and Materials**

***Sampling***

Treatments consisted of two maize-based rotations: a 2-year rotation of maize-soybean, and a 4-year rotation of maize-soybean-oat/alfalfa-alfalfa that periodically received cattle manure. Detailed accounts of plot management are reported elsewhere (Hunt). Each phase of the rotation treatments was present each year in four replicate blocks within a 9-hectare experiment established in 2001 at the Iowa State University Marsden Farm in Boone County Iowa (Liebman xxx).

Maize grain yield was taken 2013-2020, and additional measurements were taken in select years (Table 1).

Table 1. Summary of measurements used for this study

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| Measurement | Measurement years | Description |
| Maize grain yield | 2013-2020 | Maize grain yield was determined using a 6-row combine equipped with a yield monitor and moisture meter. Sampling areas for yield were the middle rows of the plots, approximately 4.6 m x 84 m. All yields are reported on a dry weight basis. |
| Maize above-ground biomass | 2013, 2014, 2018, 2019, 2020 | Maize above-ground biomass was measured periodically throughout the season. Eight plants were cut at ground level, separated into leaf, stem, and reproductive components, dried at X deg C for at least X hours, then weighed. |
| Maize maximum rooting depth | 2018, 2019, 2020 | Maximum maize rooting depth was measured starting at 20, 23, and 41 days after planting in 2018, 2019, and 2020 respectively. Sampling was repeated approximately every 2 weeks until 84, 106, and 151 days after planting in 2018, 2019, and 2020, respectively. Maximum rooting depth was determined visually using the protocol of Ordonez et al. 20xx. A soil core was drawn with a 19-mm-diameter soil probe, white roots were identified, and their depth estimated to the nearest inch using a meter stick. Samples were repeatedly taken from the same core location until no white roots were identified in the core. Four cores were taken per plot at each sampling date. |
| Soil moisture at 15 and 45 cm depths | 2018, 2019 | 5TM soil moisture and temperature sensors (METER Group Inc., Pullman, WA, USA) were installed at two depths (15 and 45 cm) in each plot. Data were recorded hourly during the growing season using EM50 data loggers. |
| Penetration resistance | 2018, 2019 | Penetration resistance was measured using a FieldScout 900 Soil Compaction Meter (Spectrum Technologies, Inc., Aurora, IL, USA). Values were recorded every 2.54 cm to 45 cm depth immediately following planting and approximately 60 days after planting. Ten measurements were taken randomly throughout each plot. |
| Maize root mass 0-60 cm | 2019, 2020 | Maize root mass to a soil depth of 60 cm was measured at 3 and 105 days after planting in 2019, and at 4 and 117 days after planting in 2020. Four soil samples per plot were drawn at a location 10 cm from corn rows in 15 cm depth increments using a 32-mm-diameter soil probe. Soil from each depth increment within a plot was composited and roots were recovered using a sequence of elutriation (washing), flotation, recovery from organic debris using tweezers and a stereo microscope, drying, and weighing (Dietzel). |

***Statistical Analysis***

All statistics were done using R version 4.0.2 and the tidyverse suite of packages (CITE).

The effect of rotation treatment on maize grain yields was assessed using a mixed effects linear model with rotation as a fixed effect and block and a year factor as random intercepts. The lme4 package (CITE) was used for model fitting, and the emmeans package (CITE) was used for comparisons and statistical summaries.

We chose to filter the data to remove measurements taken after the maximum seasonal depth had been reached and roots began to senesce following flowering (CITE), and to plot rooting depth as a function of the cumulative maize growing-degree-days accrued since planting (base temperature 10 deg C, maximum temperature X deg C)to facilitate comparisons between years. A three-parameter logistic curve (CITE Miguez) was found to be the best fit according to Akaike’s Information Criteria (AIC; cite):

Where rootdepth(GDD) is the maximum rooting depth at a given cumulative GDD after planting and Asym, xmid, and scal are estimated parameters. Asym represents the maximum rooting depth achieved, xmid represents the cumulative GDD value at which half of the maximum rooting depth is achieved, and scal describes the steepness of the curve (CITE?). Models were fit using the nlraa package (CITE) augmented with nlme package functionality (CITE).

We allowed rotation to have a fixed effect on Asym, xmid, and scal; a random effect of year on Asym, xmid, and scale, a random effect of block on Asym; and a power variance structure.

No year effect on corn root mass was detected (p=0.65). In contrast, we found a significant sampling date x rotation interaction (p=0.015). Corn root mass increased 108%, from 515 to 1,073 kg ha-1, in the 2-year rotation, whereas root mass increased 49%, from 782 to 1,160 kg ha-1, in the 4-year rotation. If the initial levels of root residue decayed at an equal rate in the two rotation treatments, or if they persisted equally in the two rotations, these results would indicate that the 2-year rotation added more root mass during the growing season than did the 4-year rotation.

Maximum corn root depth was measured throughout the 2018-2020 cropping seasons in both rotation systems. Maximum root depth was determined five times in 2018, seven times in 2019, and eight times in 2020, based on four cores per plot drawn with a 19-mm-diameter soil probe. Maximum root extension was determined visually and quantified with a meter stick. Maximum root depth differed among years (p<0.0001) and rotation systems (p=0.0013), but no year x rotation system interaction occurred (p=0.66). Averaged over rotation treatments, root depth was greatest in 2019 (102.5 cm), least in 2018 (53.7 cm), and intermediate in 2020 (90.0 cm). Averaged over years, maximum root depth was 14% higher in the 4-year rotation (87.4 cm) than in the 2-year rotation (76.7 cm). These observations corroborated our hypothesis that maximum corn root depth would be greater for corn following alfalfa in the 4-year rotation than following soybean in the 2-year rotation.

. Corn yield was affected by a significant year x rotation interaction (p=0.0096): yield was 23% greater (p=0.0006) in the 4-year rotation (14.0 Mg ha-1) than in the 2-year rotation (11.3 Mg ha-1) in 2018 but did not differ between rotation systems in 2019 (p=0.62) and 2020 (p=0.56). Averaged over rotation systems, mean corn yield in both of the latter two years was 12.6 Mg ha-1.

Results and Discussion