LONG-TERM CROP ROTATION IMPACT ON SOIL PROPERTIES AND CROP RESPONSE

S.L. Osborne, R.M. Lehman, W.E. Riedell and B.K. Chim
North Central Agricultural Research Laboratory, USDA–ARS, Brookings, SD
Shannon.osborne@usda.gov (605) 693-5251

ABSTRACT

Crop rotations can be part of sustainable agriculture production by their effectiveness depends on understanding how crop rotations affect above- and below-ground crop characteristics. Objectives were to investigate crop rotation effects on shoot dry weight and root characteristics of cereal and grain legume crops at anthesis as well as on grain yield. Rotations were corn (*Zea mays* L.)-soybean [*Glycine max* (L.) Merr.], (CS); corn-soybean-spring wheat (*Triticum aestivum* L.)-field pea (*Pisum sativum* L.), (CSSwP); corn-soybean-spring wheat-sunflower (*Helianthus annuus* L.), (CSSwSf); corn-field pea-winter wheat-soybean (CPWwS); and corn-oat (*Avena sativa* L.)-winter wheat-soybean (COWwS). Rotations were established in 2000 with plants measured in 2015 and 2016. Rotations had no significant effects on shoot dry weight at anthesis. Small grains had greater root length density than grain legumes between 0-60 cm soil depths. Rotation treatments had significant effects only on soybean root length density at 0-90 cm soil depths. Soybean following winter wheat (CPWwS and COWwS) had significantly less root length density than soybean following corn. Soybean grain yield was significantly greater following winter wheat (CPWwS and COWwS) than other rotations. Thus, smaller root systems at anthesis in soybean following winter wheat were associated with higher grain yield at maturity.

INTRODUCTION

Diverse crop rotations have the potential to facilitate water and nutrient uptake from different soil-profile positions as well as to improve soil health. Cultivation of rotational crops may also improve economic outcomes of farm operations by expanding the time frame of planting and harvest activities as well as by reducing the impact of crop losses to transient weather extremes. In the northwestern U.S. Corn Belt, diversification of the ubiquitous corn-soybean rotation using alternate crops grown in diverse rotations is essential for improving soil health and decreasing yield loss caused by diseases, weeds, and insect pests (Riedell et al., 2013; Riedell and Osborne, 2017). Information on root characteristics of crops that have the potential to diversify the corn-soybean rotation will help when designing these diverse cropping systems as well as assessing their effects on soil health.

Soil physical, chemical and biological properties have a significant impact on root growth, and distribution throughout the soil profile. Researchers have found that soils with a low nutrient supply, and low soil quality produce plants with enhanced root growth compared to soils rich in nutrients (Coutts and Philipson, 1977; Philipson and Coutts, 1977; Garwood and Williams, 1967 and Ma et al, 2001). The impact of crop rotation and crop species on specific soil properties have been the current focus of a number of studies with the recent interest in soil health. Specifically, Maiga et al, 2019 found that in a 4-yr rotation that included small grain had higher particulate organic matter and soil organic matter compared to a 2-yr corn/soybean rotation. Soil water-stable aggregation and microbial biomass was greater following wheat residue (Le Guillou et al.,2012) and Blanco-Canqui and Jasa, (2019) found that grass species (rye) had a positive impact on soil aggregation and organic matter comparted to legume.

The objective of the research presented here was to measure root length density at soil depths to 120 cm for seven crop species (corn, soybean, spring wheat, winter wheat, oat, field pea, and sunflower) that were used to investigate crop rotations that diversify the ubiquitous corn-soybean rotation in the northwestern U.S. Corn Belt. The experimental approach was a 2-yr field study of roots of these seven species of crops that had been grown under rotational treatments since 2001. Root sampling activities, conducted when each crop reached the anthesis stage of development, were repeated over a 2-yr period to enable the potential effect of different growing season environments on root distribution to be assessed. Research focused on root growth characteristics under simple and diverse crop rotations could illustrate the potential contributions of roots to soil ecology and health.

MATERIALS AND METHODS

Experiments investigating simple and diverse crop rotations were conducted at the Eastern South Dakota Soil and Water Research Farm near Brookings, SD. Soils at the research farm are Barnes clay loam soils (fine-loamy, mixed, superactive, frigid Calcic Hapludoll). The field study consisted of 4 replicate blocks of 5 crop rotation treatments arranged in a randomized complete block experimental design: a 2-yr corn-soybean rotation (CS), a 4-yr rotation of corn-soybean-spring wheat-field pea (CSSwP), a 4-yr rotation of corn-soybean-spring wheat-sunflower (CSSwSf), a 4-yr rotation of corn-field pea-winter wheat-soybean (CPWwS), and a 4-yr rotation of corn-oat-winter wheat-soybean (COWwS). Rotation experimental treatments were initiated under no-till soil management with winter wheat being planted in the fall of 2000 and the following crops being planted in the spring of 2001, with all crop present each year. Presented crop data were collected in 2015 and 2016. More information regarding fertilization for each crop during growing season were reported in Lehman et al (2019). During the growing season, weeds were controlled by 2,4-dichlorophenozyacetic acid and glyphosate across the plots.

At anthesis, crop shoots were harvested just above the ground level using shears and pruning tools. Shoots harvested from 0.5 m of crop row were bagged in the field, transferred to a forced air oven maintained at 60 ºC, and dried to constant weight. Shoot tissue was weighed. Root sampling procedures for each crop species were initiated on the same dates as shoot harvests. A 3.175-cm dia. soil probe was positioned as close as possible to the center of the crop row and in-between plants. The probe was pushed into the soil to a depth of at least 122 cm using a hydraulic soil sampler (Giddings Machine Co., Windsor, CO). Two soil cores were taken within each of the crops grown in rotation and within four replications each year. The two soil cores were cut into segments of 0-15 cm, 15-30 cm, 30-45 cm, 45-60 cm, 60-90 cm, and 90-120 cm. Core segments from the two cores were combined. Roots were separated from the soil with a hydropneumatic root washer and stored in a 30% aqueous-ethanol solution (v/v). Root samples in ethanol solution were transferred to a transparent, 20 X 25 cm2 plastic tray, maneuvered by hand to reduce root overlap on a desktop scanner and scanned at 400 dpi (horizontal and vertical). The resulting images were digitized, and WinRHIZO software (Regent Instruments, CA.) was used to calculate root length present in each sample. Past research by Bauhus and Messier, (1999) found that root detection limit with the RHIZO Image Analysis was 85 µm when the scanner was set at 300 dpi and 42 µm when set at 600 dpi, at a scanned resolution of 400 dpi root detection limit would be 64 µm. Root length density (cm of root length cm^{-3} of soil) was then calculated for each sampling depth segment.

A research plot combine (Massey Ferguson 8-XP; Kincaid Equipment Manufacturing, Haven, KS) equipped with an electronic weigh bucket was used to measure grain yield harvested from research plots. Harvested grain samples were measured for moisture using a grain analysis computer (Dickey-John GAC2000, Johnston, IA). Prior to analysis, grain yields were mathematically adjusted to specific moisture contents: 155 g kg^{-1} for corn, 130 g kg^{-1} for soybean and field pea, 135 g kg^{-1} for wheats, 140 g kg^{-1} for oat, and 100 g kg^{-1} for sunflower.

RESULTS AND DISCUSSION

A significant crop x rotation interaction (statistical results not shown) suggests that grain yields for the crops in this experiment responded differently to rotation treatments. Data analysis suggested that corn, soybean and field pea yields were affected by rotation treatments (Table 1). Differences in corn yield found that corn following field pea in the CSSwP were significantly greater than any of the other crop rotations (Fig 1). There was no significant difference in corn yield when corn was grown in the 2 yr rotation of CS compared to 4 yr rotations of COWwS and CPWwS. In general corn grown following field pea had the greatest yield, corn following soybeans were intermediate, while corn following sunflowers were the lowest (Fig. 1). Differences in soybean yield appear not only to be impacted by differences from the previous crop but also differences in the length of crop rotation. Soybean grown in a 2 yr rotation resulted in lower yield compared to any of the 4 yr crop rotations (Fig. 1). In a 4-yr rotation, soybean yield was significantly greater when soybean followed winter wheat (CPWwS and COWwS rotation treatments) than when soybean was grown after corn (Fig. 1). Additionally, field pea following spring wheat resulted in significantly greater yield compared to following corn (CSSwP vs CPWwS, 3429 and 2673 kg ha^{-1} respectively).

There was no statistical difference between the other rotational crops at the 0-15 and 15-30 cm depth except for the sunflower crop which had significantly lower roots at the 15-30 cm interval compared to corn, field pea and soybeans. Root length density for the 30-45 cm interval found an increase in corn roots equal to that of the small grain crops, while soybean and sunflower had significantly lower root length density. Similar to our findings, Merrill et al. (2002) also found that field pea at anthesis had greater root length density values than soybean at the 0-50 cm soil depth during growing seasons with average and below average rainfall. Taken together, our findings are consistent with those of Hamblin and Tennant (1987) who found that root length densities of small grain cereal crops were substantially and consistently greater than those of grain legumes in the top 80 cm of the soil profile. Root length densities for the 90-120 cm were very low and equivalent for all crops.

Of interest are the significant crop x rotation interactions for root length density at soil depth increments of 0-90 cm (Table 2). These interactions suggest that root length density across crop species responded differently to rotational treatments at these soil depth increments. Soybean grown after cereal grains (COWwS and CPWwS) had less root length density than when soybean followed corn at all sampling depths except for 90-120 cm, but this was not statistically significant (α=0.05) at all depths. Additionally, pea root length density was lower when pea was grown following a small grain compared to following corn although it was not significantly different. Soybean root length density was greatest for the 2 yr CS rotation for sampling depths 15-30, 30-45, 45-60 and 60-90 (Fig 2). These differences suggest that soybean and pea root systems showed phenotypic plasticity in response to rotation treatments. It is likely that the driving forces behind these different soybean root system characteristics were differences in soil physical, chemical or biological properties under the different rotational treatments.

CONCLUSIONS

Soybeans that followed winter wheat had greater grain yield, suggesting that increased root system efficiency carried on past anthesis and continued to crop maturity. The difficulty in this speculation is that soybean root systems at R1 are just beginning to enter a grand phase of growth which results in soybean roots having a two to three fold increase in rooting depth between R1 and R2 (Kaspar et al., 1978). Additionally, Mitchell and Russell (1971) and Coale and Grove (1990) found that soybean root dry matter continued to accumulate throughout flowering, pod formation, and seed fill. However, Izumi at al. (2004) found that there was no correlation between root length density measured at beginning pod developmental stage and soybean grain yield at maturity. Thus, the relationship between differences in root length density at anthesis and final soybean yield needs further investigation to understand the mechanisms that may have resulted in the differences in soybean root systems when grown following winter wheat in 4-year crop rotations, including understanding changes in soil properties and soil processes that are induced by complex rotations.

REFERENCES

Bauhus, J., and C. Messier. 1999. Evaluation of fine root length and diameter measurements obtained using RHIZO image analysis. Agron. J. 91:142-147.

Blanco-Canqui, H., and P.J. Jasa. 2019. Do grass and legume cover crops improve soil properties in the long term? Soil Sci. Soc. Ame. J. 83:1181–1187. doi:10.2136/sssaj2019.02.0055

Coale, F.J., and J.H. Grove. 1990. Root distribution and shoot development in no-till full-season and double-crop soybean. Agron. J. 82:606-612.

Coutts, M.P., and J.J. Philipson. 1977. The influence of mineral nutrition on the root development of trees: III. Plasticity of root growth in response to changes in the nutrient environment. J. Exp. Bot. 28:1071–1075. doi:10.1093/jxb/28.5.1071

Garwood, E.A., and T.B. Williams. 1967. Growth, water use and nutrient uptake from the subsoil by grass swards. J. Agric. Sci. 69:125–130. doi:10.1017/S002185960001652X

Hamblin, A., and D. Tennant. 1987. Root length density and water uptake in cereals and grain legumes: How well are they correlated? Aust. J. Agric. Res. 38:513-527.

Izumi, Y., K. Uchida, and M. Iijima. 2009. Crop production in successive wheat-soybean rotation with no-tillage practice in relation to the root system development. Plant Prod. Sci. 7:329-336.

Kaspar, T.C., C.D. Stanley, and H.M. Taylor. 1978. Soybean root growth during the reproductive stages of development. Agron. J. 70:1105-1107.

Le Guillou, C., D.A. Angers, P.A. Maron, P. Leterme, and S. Menasseri-Aubry. 2012. Linking microbial community to soil water-stable aggregation during crop residue decomposition. Soil Biol. Biochem. 50:126–133. doi:10.1016/j.soilbio.2012.03.009

Lehman, R.M., Osborne, S.L., and McGraw, K. 2019. Stacking agricultural management tactics to promote improvements in soil structure and microbial activities. Agron. 9(9), 539. https://doi.org/10.3390/agronomy9090539.

Ma, Z., D.G. Bielenberg, and K.M. Brown. 2001. Regulation of root hair density by phosphorus availability in Arabidopsis thaliana. Plant. Cell Environ. 24:459–467. doi:10.1046/j.1365.3040.2001.00695.x

Maiga, A., A. Alhameid, S. Singh, A. Polat, J. Singh, S. Kumar, and S. Osborne. 2019. Responses of soil organic carbon, aggregate stability, carbon and nitrogen fractions to 15 and 24 years of no-till diversified crop rotations. Soil Res. 57:149–157. doi:10.1071/SR18068

Merrill, S.D., D.L. Tanaka, and J.D. Hanson. 2002. Root length growth of eight crop species in Haplustoll soils. Soil Sci. Soc. Am. J. 66:913-923.

Mitchell, R.L., and W.J. Russell. 1971. Root development and rooting patterns of soybeans (Glycine max (L.) Merrill) evaluated under field conditions Agron. J. 63:313-316.

Riedell, W.E., and S.L. Osborne. 2017. Row and forage crop rotation effects on maize mineral nutrition and yield. Can. J. Plant Sci. 97:645-653

Riedell, W.E., S.L. Osborne, and J.L. Pikul, Jr. 2013. Soil attributes, soybean mineral nutrition, and yield in diverse crop rotations under no-till conditions. Agron. J. 105:1231-1236.

Table 1. Crop species means for shoot dry weight and grain yield measured across the rotation treatments near Brookings, SD, 2015–2016.

Crop species	df†	Anthesis shoot biomass	P value‡	Grain yield	P value‡
		------------kg ha^{-1}---------		------kg ha^{-1}-----	
Corn	4	11589 ± 190	0.3770	5911 ± 162	0.0013
Soybean	4	548 ± 24	0.3739	2277 ± 45	<0.0001
Spring wheat	1	2395 ± 88	0.3899	2712 ± 52	0.5224
Winter wheat	1	4261 ± 312	0.9897	3553 ± 239	0.8730
Field pea	1	1796 ± 127	0.0608	3051 ± 110	<0.0001
Sunflower		10348 ± 769§		2775 ± 120§	
Oat		2924 ± 474§		3422 ± 177§	

†df represent the degree of freedom for rotation treatments within crop species.
‡ P value represent the probability due to the crop rotation treatments within each crop species.
§Data from sunflower and oat, which were not included in the original PROC GLIMMIX analysis (see data analysis section in Materials and Methods), are included in this table for the benefit of the reader.

Table 2. Analysis of variance of year, replication, rotation, crop and interactions for root length density, Brookings SD in 2015 and 2016.

Effect	**df†**	**0-15 cm**	**15-30 cm**	**30-45 cm**	**45-60 cm**	**60-90 cm**	**90-120 cm**
		Pr < F‡					
Year	1	0.2654	0.0054	0.1230	0.0004	0.0135	0.2938
Replication	3	0.3218	0.6365	0.4232	0.0483	0.4004	0.4494
Rotation	4	0.4027	0.0174	0.6155	0.1956	0.3458	0.7952
Crop	6	<0.0001	<0.0001	<0.0001	<0.0001	0.0049	0.1042
Rotation*Crop	7	0.0008	0.0010	0.0012	<0.0001	0.0058	0.2597
Year*Rotation	4	0.3561	0.2279	0.9193	0.4273	0.1847	0.2854
Year*Crop	6	0.0088	0.0006	0.1625	0.3523	0.0444	0.5726
Year*Rotation*Crop	7	0.8803	0.6843	0.8056	0.3751	0.2556	0.8866

† df represent the degree of freedom for root length density in different soil depth
‡ Probabilities of the main effects for the different soil depth increments.

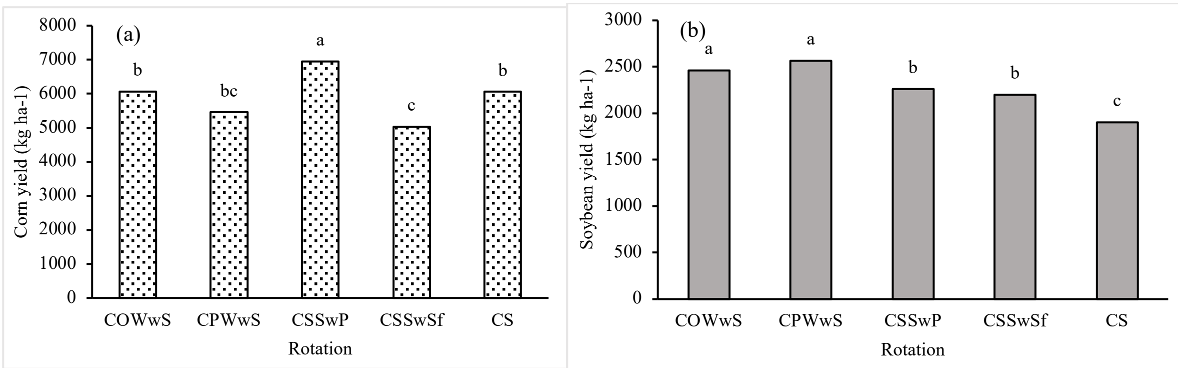

Figure 1. Grain yield of (a) corn and (b) soybean grown under five rotation treatments across the two years of the experiment. Columns marked with the same letter are not statistically different (PDIFF test, $\alpha = 0.05$).

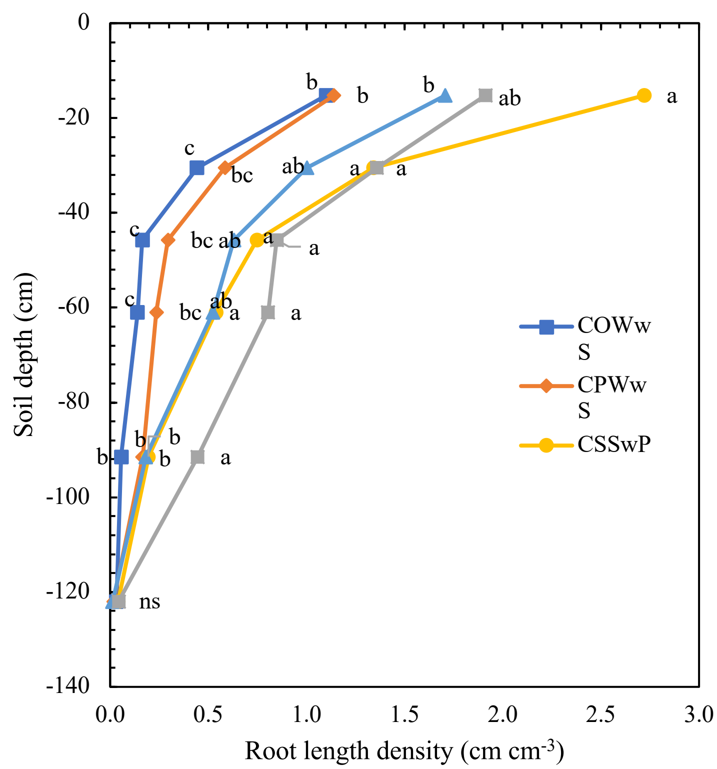

Figure 2. Root length density (cm cm^{-3}) as a function of soil depth for soybean crops within crop rotation treatments at crop anthesis across the two years of the experiment. Symbols denote average root length density values at 0-15, 15-30, 30-45, 45-60, 60-90, and 90-120 cm sampling depths. Symbols followed by the same letter within each soil depth are not statistically different (PDIFF test, $\alpha = 0.05$).