Objectives:

The objective of this project is to quantify the effects of the continuous corn, corn-soybean, and corn-corn-soybean rotations on soil quality and crop yields. This is important as producers seek to develop sustainable practices to mitigate and minimize environmental consequences that are often associated with intensive farming practices.

Locations and experimental design: The experiments were set up as a RCBD with each phase of the rotation present each year and with 4 reps at 5 locations in Illinois. Three subsamples to 3ft deep were taken from each plot at all locations on the fall of 2014, after 12 yrs. of research establishment by Dr. Nafziger and his crew. The cores were cut in the lab at 4 successive depths for the analysis of soil physical and chemical properties.

Status: We are currently conducting the analysis of the soil biological properties. Once we have all the soil data set complete, we will rerun the statistical analysis trying to develop an index of soil quality that could be related to the yield of crops in the rotations.

Statistical analysis: A multivariate analysis of variance (MANOVA) was performed on the soil data set that included BD, WAS, pH, CEC, SOM, TN, P, K, S, Ca, Mg, Na, B, Fe, Mn, Cu, Zn, and Al. Water content (W) was used as a covariate. Independent variables or factors were location (L), rotations (R), and Depth (D). The GLM procedure of SAS software version 9.4 (SAS Institute, Cary, NC) was used to conduct the MANOVA on standardized data (mean=0, std=1). Since the MANOVA detected significant overall main effects of L and R as well as a significant overall L x R interaction effect (Table 1), we further explored the variables that contributed to maximized L, R and L x R group differences with canonical discriminant analysis (CDA) using the CANDISC procedure in SAS.

Results:
Tables and Figures:

Table 1. MANOVA Table showing Wilks' lambda and the Pillai's trace tests results for the hypotheses of No overall effects for each of the factors under study: locations (L); blocks within locations; rotations (R); the interaction effects L x R; and studied depth (D) along with water content that was used as a covariate (W).

Source of variation	Value	p-value
Location (L)		
Wilk's lambda	0.0009	<.0001
Block (L)		
Wilk's lambda	0.0546	<.0001
Rotation (R)		
Wilk's lambda	0.6367	<.0001
L x R		
Wilk's lambda	0.2880	<.0001
Depth (D)		
Wilk's lambda	0.0264	<.0001
W		
Wilk's lambda	0.4794	<.0001

Table 2. Mean values of bulk density (BD, Mg/m3), water aggregate stability (WAS, %), soil pH, cation exchange capacity (CEC, UNIT), soil organic matter (SOM, %), total inorganic N (TIN, mg/kg), available phosphorus (P, mg/kg), and extractable nutrients (K, S, Ca, Mg, Na, B, Fe, Mn, Cu, Zn, and Al in mg/kg), averaged for the entire soil depth (3ft), after 12 years of crop rotations (CCC, CCS, and CS with all phases present each year) established at Brownstown (BT), Dixon Springs (DS), Mounmouth (MN), Orr (OR), and Urbana (UR) Research Centers.

L	R	Bd	WAS	pH	CEC	TC	TIN	Pa	K	S	Ca	Mg	Na	B	Fe	Mn	Cu	Zn	Al
BT	**CCC**	1.47	49	5.95	19	1.12	5	9	101	24	1486	404	282	0.16	136	66	1.27	0.72	901
	CCS	1.46	52	5.47	18	1.02	4	8	107	24	1345	325	163	0.15	134	53	1.20	0.86	925
	CS	1.46	48	5.70	19	1.08	4	10	100	23	1381	381	246	0.28	138	66	1.21	1.54	934
	CSC	1.45	53	5.66	19	1.03	4	12	112	26	1362	361	284	0.15	158	62	1.31	1.00	921
	SC	1.47	48	5.85	19	1.12	7	10	96	25	1529	433	310	0.19	134	58	1.23	1.14	896
	SCC	1.44	51	5.45	19	1.02	6	14	104	27	1321	270	131	0.15	180	47	1.32	3.11	952
DS	**CCC**	1.44	32	5.04	17	0.85	8	6	83	21	975	292	62	0.26	155	72	1.23	0.75	1019
	CCS	1.47	38	4.86	18	0.94	8	8	86	23	938	292	61	0.16	156	72	1.27	0.81	1076
	CS	1.47	31	5.17	16	0.86	7	7	76	23	1017	252	62	0.29	148	84	1.23	0.75	1008
	CSC	1.48	38	5.13	18	0.92	9	7	78	20	1194	267	53	0.19	148	76	1.25	0.71	1034
	SC	1.50	39	4.97	19	0.92	6	7	82	22	1141	309	57	0.20	155	51	1.34	0.67	1052
	SCC	1.48	36	4.97	16	0.87	5	6	75	22	978	257	58	0.20	144	74	1.28	0.68	1034
MN	**CCC**	1.32	65	6.47	22	1.86	13	10	148	7	2990	485	23	0.51	136	36	1.95	1.25	794
	CCS	1.29	66	6.53	21	1.75	11	10	126	7	2897	467	24	0.44	127	27	1.85	1.14	815
	CS	1.28	63	6.52	21	1.77	12	11	127	7	2912	473	25	0.41	129	30	1.94	1.29	816
	CSC	1.31	66	6.60	21	1.78	14	10	130	7	2907	466	27	0.48	119	27	1.74	1.16	811
	SC	1.29	67	6.64	22	1.86	16	12	141	8	3015	488	29	0.45	123	35	1.89	1.35	797
	SCC	1.29	66	6.56	21	1.90	13	11	135	8	2934	462	27	0.51	116	32	1.78	1.28	789
OR	**CCC**	1.39	51	6.07	17	1.34	10	14	125	7	1967	354	21	0.51	237	63	2.75	1.69	599
	CCS	1.40	53	6.24	14	1.29	10	12	96	7	1652	244	18	0.52	207	86	2.57	1.70	521
	CS	1.42	51	6.18	16	1.30	10	14	117	7	1900	295	19	0.46	202	76	2.76	1.51	586
	CSC	1.40	59	6.30	14	1.37	11	16	106	7	1879	248	22	0.48	186	67	2.59	1.69	519
	SC	1.38	56	6.24	14	1.36	15	14	110	7	1788	239	20	0.41	197	76	2.49	1.64	528
	SCC	1.40	60	6.29	16	1.32	11	15	109	7	1972	290	16	0.39	225	78	2.80	1.81	534
UR	**CCC**	1.37	77	5.87	26	1.93	14	8	152	7	2610	629	24	0.46	126	29	2.07	0.78	847
	CCS	1.34	79	5.88	26	2.01	13	8	158	9	2668	589	19	0.55	130	33	2.17	0.85	892
	CS	1.36	74	5.88	27	1.87	13	9	152	8	2677	658	37	0.49	135	29	2.26	0.94	856
	CSC	1.38	78	6.11	24	1.79	11	6	136	8	2619	631	21	0.58	119	36	2.01	0.72	847
	SC	1.34	82	5.86	26	1.99	13	10	173	9	2695	624	20	0.47	132	28	2.34	0.84	908
	SCC	1.36	82	5.76	24	1.92	15	10	155	9	2401	571	21	0.53	130	23	2.23	0.95	873

Table 3. Main effects of soil depth (D, cm) on bulk density (BD, Mg/m3), water aggregate stability (WAS, %), soil pH, cation exchange capacity (CEC, UNIT), soil organic matter (SOM, %), total inorganic N (TIN, mg/kg), available phosphorus (P, mg/kg), and extractable nutrients (K, S, Ca, Mg, Na, B, Fe, Mn, Cu, Zn, and Al in mg/kg), averaged across locations and rotations and after 12 years of establishment of treatments.

Depth	Bd	WAS	pH	CEC	TC	TIN	Pa	K	S	Ca	Mg	Na	B	Fe	Mn	Cu	Zn	Al
0-15	1.35	60	6.03	16	1.92	16	19	170	9	1934	262	22.31	0.47	191	106	1.91	1.78	637
15-30	1.40	60	5.80	19	1.60	9	7	93	12	2084	278	33.10	0.39	149	55	1.89	1.12	817
30-60	1.40	55	5.82	20	1.17	8	6	96	17	1919	433	94.26	0.32	132	20	1.76	0.86	943
60-90	1.44	54	5.85	24	0.93	6	8	108	17	1951	635	141.13	0.29	136	31	1.82	0.94	948

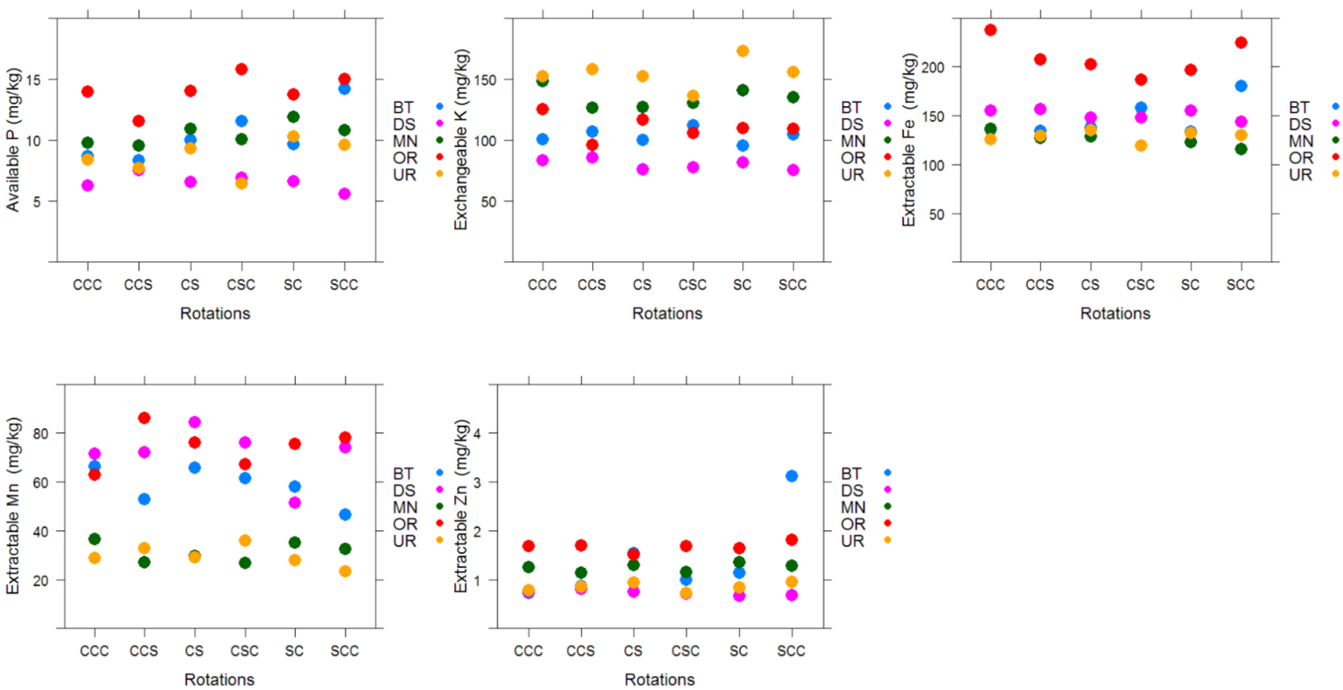


Figure 1. From top left: Available P (mg/kg), exchangeable K (mg/kg), and extractable Fe, Mn, and Zn (mg/kg) for each of the rotations/phases under study at each location [Brownstown (BT), Dixon Springs (DS), Monmouth (MN), Orr (OR), and Urbana (UR)], averaged across depths and locations after 12 years of establishment of treatments.

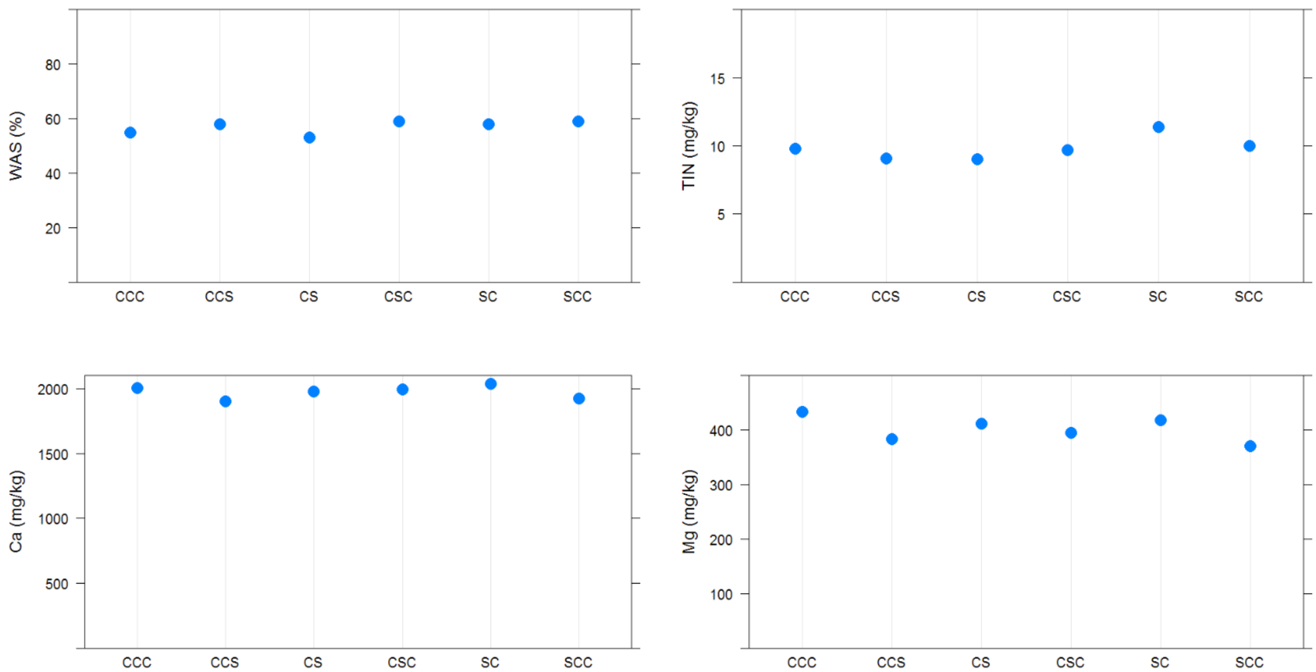
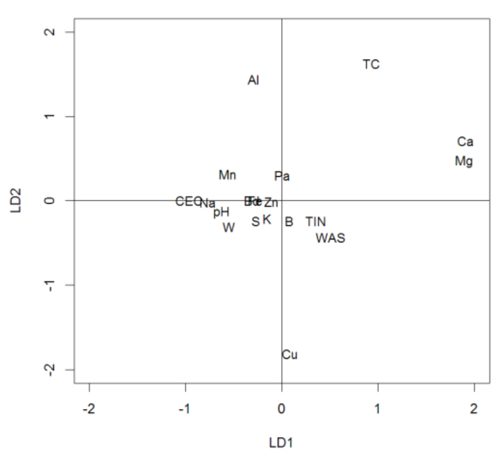


Figure 2. Main effects of rotations on water aggregate stability (WAS, %), total inorganic N (TIN, mg/kg), and Ca and Mg (mg/kg) averaged for the entire soil depth (3ft) and across locations, after 12 years of crop rotations in place (CCC, CCS, CS, CSC, SC, SCC).

3A)



3B)

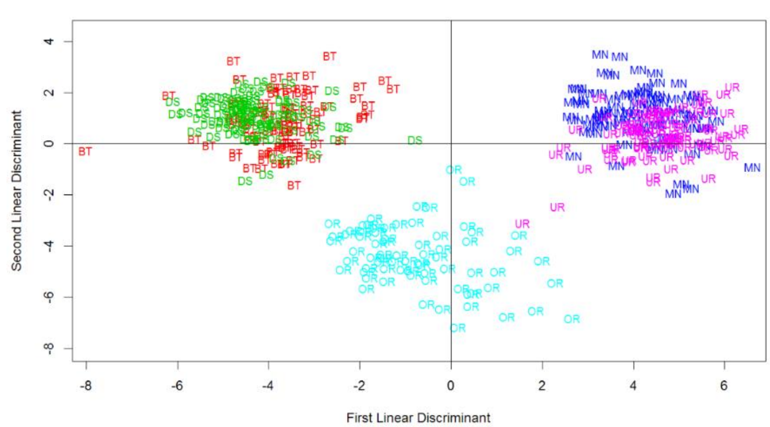


Figure 3. Plot of the linear discriminant functions (LD1 and LD2) that maximize the differences among locations (L) showing **A)** the relative contribution of the original soil variables to each LD, and **B)** the predicted location (L) scores.

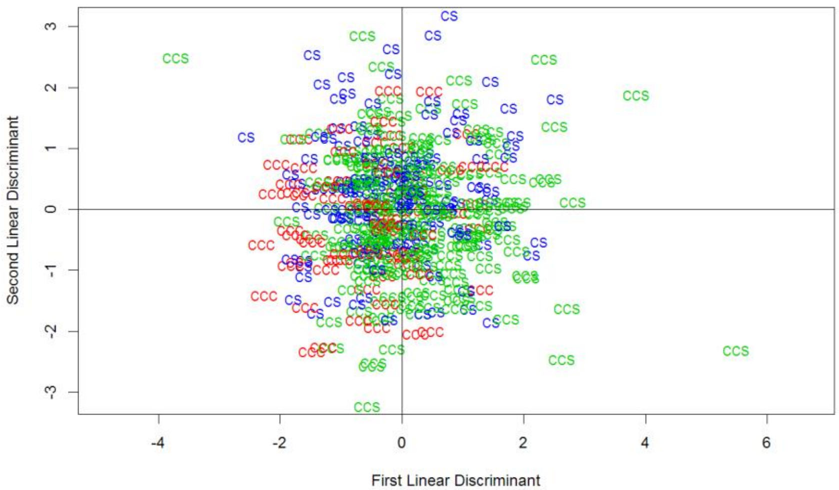


Figure 4. Plot of the LD scores for the first two linear discriminants (LD1 and LD2) maximizing the separation among rotation groups (phases averaged) showing the predicted Rotation group scores.

Preliminary findings:
Our multivariate approach indicated a strong overall effect of locations, rotations and depth on the set of soil properties evaluated, along with an overall interaction effect of location and rotation (**Table 1**). Mean values for all properties analyzed so far for each phase of the rotation locations are presented in **Table 2**; values are averages for the entire depth studied. No overall interactions of factors location or rotation with depth were observed indicating a consistent response of soil properties across both factors (**Table 3**). Soil properties of available P, exchangeable K, Fe, Mn, and Zn showed significant effects of the rotation yet these were not consistent across locations (**Figure 1**). A small set of properties: WAS, TIN, Ca and Mg levels, were consistently affected by rotations in all locations (**Figure 2**).
Using the discriminant rules created with the CDA approach, we were able to successfully identify the location of origin of the soil samples with minimum error (<5%, **Figure 3**) due to strong signals that characterize each location. The separation of rotation groups on the other hand is only achieved successfully for the corn-corn-soybean rotation (**Figure 4**) which might have a particular soil environment that allows that easy separation. Mollie Adams, the MSc candidate on this project is currently working on understanding and interpreting these findings.

Outreach: Dr. Villamil and Mollie Adams had the opportunity of sharing results from this project Agronomy Days at Urbana and at Orr Research and Education Centers during the summer of 2015. Also, Mollie developed a poster for the ASA-CSSA-SSSA Annual conference in Minneapolis, MN, Nov 16-18.

Selected high resolution pictures from this project are in a folder in BOX with descriptions included in their titles. The folders are shared with this link
https://app.box.com/s/mphbxyxkribq6ize43tb977bchkeseq5