All Appendices, 1 through 5

APPENDIX 1

META-ANALYSIS OF INITIAL SOIL QUALITY PROPERTIES

Materials and Methods

Composite soil samples were collected at 15-cm increments from a 30-cm depth using GPS guided sampling grids and placed in sealable plastic bags. A portion of the field-moist soil was gently sieved through a 2-mm mesh followed by incubation in sealable plastic bags at room temperature (~25^{0}C) for 7-day to stabilize biological activity prior to analyze for microbial biomass and biological activities. Another portion of the field-moist soil was 4-mm sieved and air-dried at room temperature for 15-day prior to soil chemical and physical analysis.

Soil Biological Properties

Total soil microbial biomass (SMB) was measured by the rapid microwave irradiation and extraction method (Islam and Weil 2000) as follows:

$$SBM\ (mg\ kg^{-1}) = (Ext\text{-}C_{mw} - Ext\text{-}C_{umw})/K_f$$

Where Ext-C_{mw} is the 0.5M K_2SO_4 extractable C in microwaved soil, Ext-C_{umw} is the 0.5M K_2SO_4 extractable C in unmicrowaved soil, and Kf is the proportion (0.213) of the microbial biomass carbon that is extracted from the soil.

Metabolic quotient (qR) was calculated by dividing the total amount of SMB carbon with the total organic carbon (TC) in soil (Anderson and Domsch 1990).

Soil chemical properties

Soil pH was determined by a glass electrode in 1:2 soil-distilled water suspensions. Electrical conductivity was measured with soil to distilled water ratio of 1:1 by a conductivity meter. The concentration of total organic C (TC) and total N (TN) was determined on finely ground (<0.1 mm) air-dried soil by the dry combustion method using Elementar® CN analyzer. Active C (AC) was measured as a 0.02-M neutral $KMnO_4$ oxidizable C (Weil et al. 2003).

Soil physical properties

For aggregate stability (AS) measurement, a 51-g sample of 4-mm sieved air-dried soil aggregates was wetted by capillary rise followed by shaking in distilled water through a stack of 4.0, 2.0, 1.0, 0.5, 0.25, 0.125 and 0.053-mm sieves, respectively for 30 min (48 oscillations per min) using the modifications of wet sieve method (Kemper et al. 1985). After the water treatment, the aggregates retained on sieves were collected separately and oven-dried at 1050C in a forced-air oven until a constant weight was obtained. Aggregate stability was calculated by adding the aggregate fractions retained on the 4.0, 2.0, 1.0, 0.5 and 0.25-mm sieves, respectively and divided by the total amount of soil aggregates taken after excluding rock particles.

Soil quality calculation

An additive inductive approach based on normalization of selected biological, chemical and physical properties considering “higher values of soil properties were better indicators of soil quality” followed by summation and average of data into a single integrator to calculate a soil quality index (Aziz et al. 2013).

$$SQ_{index} = \Sigma\ (X_o\ X_{max}^{-1})\ n^{-1}$$

The SQ_{index} was ranged from > 0 to 100 with 100 being excellent soil quality and 0 being extremely poor soil quality.

Results and Discussion

Baseline soil quality was evaluated in Alabama, Hoytville (OH), Indiana and Piketon (OH) on loamy sand, silt loam, and a silty clay loam soil in 2011 and 2012 (Table 1). Results showed that soil quality properties varied significantly among the selected sites and also between soil depths except pH. However, site x depth was significant only for pH, active C (AC), metabolic quotient (qR), total N (TN) and soil quality index (SQ_{index}).

Results showed that Alabama site has lower soil pH compared to other sites in Indiana and Ohio (Table 2). Soil Ec was highest in Hoytville and Indiana and lowest in Piketon site. Hoytville and Indiana had the highest concentration of total organic (TC), intermediate in Piketon, and lowest in Alabama. Likewise, a significantly higher AC concentration was measured in Indiana and Hoytville as compared with Piketon and Alabama. Soil microbial biomass, as a sensitive indicator of soil quality, was significantly higher in both Piketon and Indiana sites compared with Hoytville and Alabama sites. The qR, as a measure of biologically labile C pool in TC, significantly varied among the sites. Piketon had the largest pool of biologically labile C and Alabama had the lowest biologically labile C pool in TC. Like TC, a similar variation was observed on the TN concentration among the sites. Highest AS was measured in Hoytville, intermediate AS was measured in Indiana and Piketon, and lowest AS measured in Alabama.

Irrespective of site locations, higher concentration of TC, AC, and SMB TN was observed (Table 2). Surface soil (0 to 15-cm) had higher AS than sub-surface soil (15 to 30-cm).
Among the soil quality properties, pH, qR and TN were significantly influenced by site x depth interaction.

Results showed that initial quality at each site varied significantly ($p<0.05$) between depths (Fig 1). The effect of depth on soil quality was more contrasting in Alabama and Piketon (Ohio) compared with other sites. When soil quality was calculated and compared among the sites, there was a significant difference in soil quality among the sites and between depths (Fig 2). Alabama had the poor soil quality followed by Piketon (Ohio), as compared with Hoytville (Ohio) and Indiana. On average, surface soil has higher soil quality than the sub-surface soil. However, differences in soil quality between depths were highest in Piketon (Ohio).

Table 1. Analysis of variance summary for initial soil quality properties in the continuous soybean cropping during 2011 and 2012 seasons.

Sources of Variation	DF	pH	Ec	TC	AC	SMB	qR	TN	AS	SQ_{index}
		(probability)								
Site	3	<.0001	<.0001	<.0001	<.0001	<.0001	<.001	<.0001	<.0001	<.000
Depth	1	0.2752	<.0001	<.0001	<.0001	<.0001	<.001	<.0001	<.0001	<.0001
Site x depth	3	0.0038	0.2271	0.2681	<.0001	0.3948	0.028	<.0001	0.0788	<.0001

DF=Degrees of freedom, Ec=Electrical conductivity, TC=Total organic carbon, AC=Active carbon, SMB=Total soil microbial biomass, qR=Metabolic quotient (SMB/TC), TN=Total nitrogen, AS=Aggregate stability, and SQ_{index}=Soil quality index.

Table 2. Initial soil quality properties at different site locations, 2011 to 2012.

Site Location	Depth (cm)	pHw (1:2)	Ec (µS)	TC (%)	AC (mg/kg)	SMB	qR (%)	TN	AS
Alabama		5.7b	135c	0.47c	320c	25c	0.58c	0.03d	64.0c
Hoytville (OH)		6.1a	278a	1.93a	518b	139b	0.73c	0.21a	86.0a
Indiana		6.1a	203b	1.83a	693a	331a	1.92b	0.17b	77.2b
Piketon (OH)		6.1a	68d	0.88b	367c	340a	3.83a	0.09c	74.6b
	0-15	6.0X	191X	1.41X	552X	270X	2.32X	0.14X	78.9X
	15-30	6.0X	151Y	1.14Y	397Y	148Y	1.65Y	0.11Y	72.0Y
				Site x depth interaction					
Alabama	15	5.9$^{\delta}$	170^{ns}	0.57^{ns}	376$^{\delta}$	28^{ns}	0.50$^{\delta}$	0.03$^{\delta}$	66.0^{ns}
	30	5.5	101	0.37	264	22	0.65	0.03	62.0
Hoytville	15	6.0	292	2.00	551	169	0.85	0.23	88.8
	30	6.2	263	1.85	484	110	0.60	0.20	83.3
Indiana	15	6.1	226	1.95	764	406	2.30	0.18	80.1
	30	6.2	179	1.71	622	255	1.55	0.15	74.2
Piketon	15	6.1	77	1.10	516	477	4.40	0.12	80.7
	30	6.0	60	0.65	218	204	3.27	0.07	68.5

Means separated by same lower letter were not significant at $p<0.05$ among site locations.
Means separated by same upper case letter were not significant at $p<0.05$ between soil depths.
$^{\delta}$ indicates significant interaction of site location and soil depth.

DF=Degrees of freedom, Ec=Electrical conductivity, TC=Total organic carbon, AC=Active carbon, SMB=Total soil microbial biomass, qR=Metabolic quotient (SMB/TC), TN=Total nitrogen, AS=Aggregate stability.

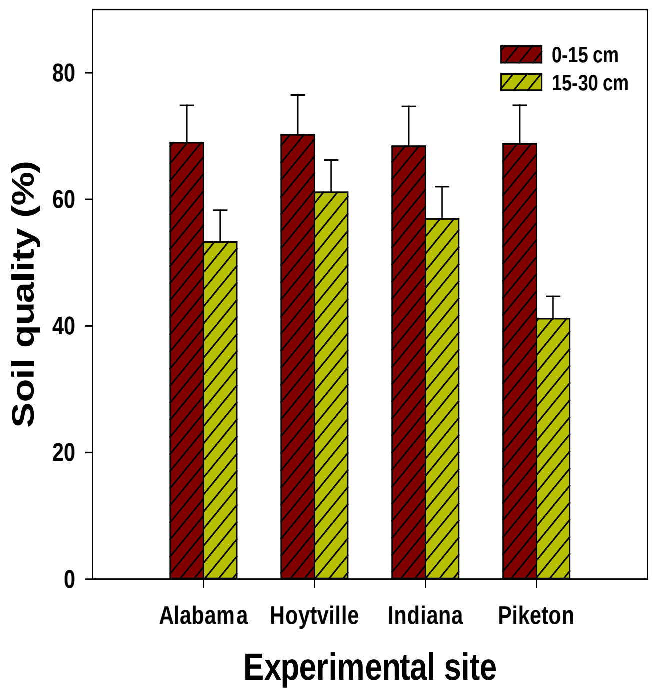

Fig. 1. Initial individual soil quality

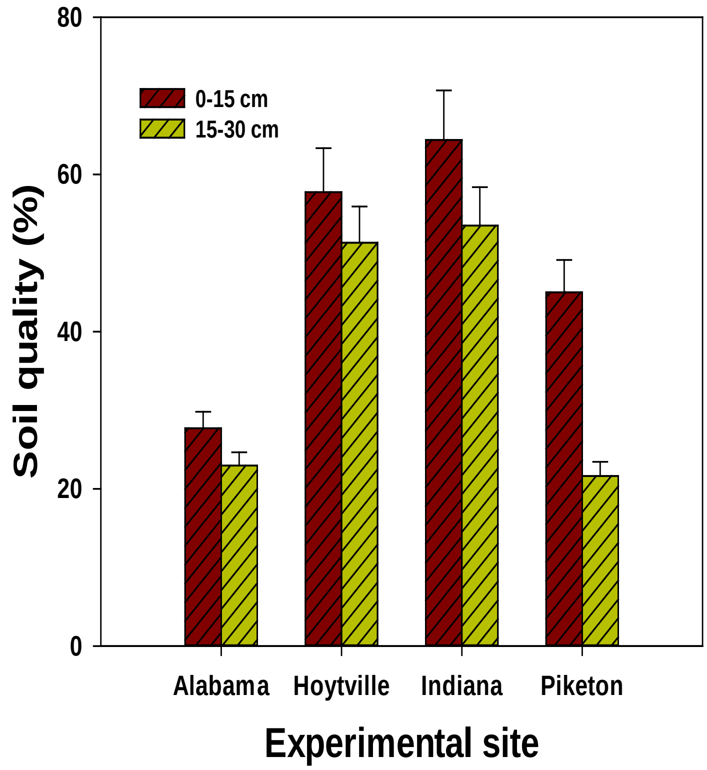

Fig. 2. Initial combined soil quality

Appendix 2

Greenhouse Gas Emissions from the Continuous Soybean Cropping System

Greenhouse gas (GHG) emissions have increased at an unprecedented rate since the beginning of the industrial revolution. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), the most important long-lived GHGs in the atmosphere, are believed to have contributed to global warming and shifts in climate change within the last 25 years. This has sparked interest among the scientific community to identify novel approaches to minimize and mitigate emissions from these GHGs. One area of particular interest in GHG mitigation is agricultural production. Agriculture occupies 37% of the earth's land surface producing approximately 20% of total GHG emissions (Smith et al. 2008). Agricultural production has been identified as the largest contributor of anthropogenic CH_4, and N_2O emissions accounting for 52% and 84% respectively, of annual anthropogenic global emissions (Smith et al 2008). Thus, the development of best management practices to reduce CO_2, CH_4, and N_2O emissions from agricultural systems is needed. This will entail altering current agricultural production practices. These improvements to current management practices would not only reduce the environmental impact, but could also benefit growers financially through increased soil nutrient retention. Thus, one of the objectives with this USB grant was to evaluate the impact gypsum and cover crop management has on greenhouse gas emission from a continuous soybean cropping system.

Material and Methods

Greenhouse gas emissions were evaluated in Alabama, Indiana, and Piketon, OH on loamy sand, silt loam, and a silty clay loam soil, respectively, during the 2012 and 2013 growing seasons. Treatments evaluated for greenhouse gas emissions were no gypsum, gypsum at 2000 lb acre^{-1}, no gypsum with cover crop, and gypsum at 2000 lb acre^{-1} with a cover crop. Gas measurements were taken from soil using custom-made static flux chambers. Briefly, a base ring was permanently placed into soil after planting the summer crop and remained in the field until harvest. On the day of sampling, flux measurements were taken by placing a vented chamber on top of the base ring and collecting gas samples at 0, 20, and 40 min intervals following chamber closure. At each time interval, gas samples were collected by inserting a needle attached to a gastight polypropylene syringe through a rubber septum embedded in the chamber tops. The sample was then injected into evacuated glass vials fitted with butyl rubber stoppers and transported back to the laboratory for analysis. Gas samples were analyzed using gas chromatography for CO_2, CH_4, and N_2O. Gas flux calculations were determined from the rate of change in trace gas concentrations (CO_2, CH_4, and N_2O) within the chamber's headspace at 0 and 40 min intervals during chamber closure. These calculations were used to express data as kg trace gas hectare^{-1} per growing season.

Results and Discussion

Minimal differences in cumulative growing season CO_2, CH_4, and N_2O fluxes were observed in this study (tables with data below). During the 2012 growing season, cumulative CO_2 fluxes for Alabama, Indiana, and Ohio were 1271, 1775, and 1353 kg ha^{-1}, respectively. Cumulative growing season CO_2 fluxes in 2013 for Alabama, Indiana, and Ohio were 1980, 1764, and 1069 kg ha^{-1}, respectively. No significant differences in CO_2 flux were observed between the two growing seasons (2012 and 2013). The 2-year average growing season fluxes were 1625, 1770, 1227 kg ha^{-1} for Alabama, Indiana, and Ohio, respectively. No response was observed for the effects of cover crop (with cover vs. no cover) or gypsum application (with gypsum vs. no gypsum). However, CO_2 flux was significantly different among locations, with the Alabama and Indiana sites producing significantly higher emissions than Ohio.

Cumulative growing season CH_4 fluxes during the 2012 growing season were -0.4481, 0.0159 and -0.1063 kg ha^{-1} for Alabama, Indiana, and Ohio, respectively. In 2013, cumulative CH_4 fluxes were -0.5596, 0.0143 and -0.0255 kg ha^{-1} for Alabama, Indiana, and Ohio, respectively. Methane fluxes followed the same pattern among treatments and locations in 2012 and 2013, as evidenced by no statistical differences between years. An evaluation of gypsum and cover crop effects on CH_4 flux showed that these treatments did not influence the rate of release from soil. On the other hand, CH_4 flux was significantly impacted by location. The lowest CH_4 flux was observed in Alabama compared to the Indiana and Ohio locations. No differences were observed between Indiana and Ohio.

Cumulative release of N_2O from soil during the 2012 growing season was 0.3486, 1.638, and 0.2882 kg ha^{-1} for Alabama, Indiana, and Ohio, respectively. In 2013, cumulative N_2O flux was 0.3181, 1.6336, and 0.4213 for Alabama, Indiana, and Ohio, respectively. Similar to both CO_2 and CH_4, no significant pattern for N_2O flux was observed between years. When averaging across years, growing season fluxes were 0.3333, 1.6367, and 0.3474 for Alabama, Indiana, and Ohio, respectively. The addition of neither gypsum nor cover crops significantly impacted N_2O flux during the two years studied. Nitrous oxide was significantly influenced by location. The Indiana soils significantly produced higher N_2O flux compared to both Alabama and Ohio. No differences were observed between the Alabama and Ohio locations.

Based on these observations, it appears that neither the addition of gypsum nor a cover crop to a continuous soybean cropping system influences greenhouse gas emissions of CO_2, CH_4, and N_2O. However, differences in climatic conditions and soil types may influence the release of these gases to the atmosphere.

Analysis of variance summary for experimental effects on cumulative soil CO_2, CH_4, and N_2O fluxes measured in the continuous soybean cropping during 2012 and 2013 growing seasons.

Source of variation	df	CO_2 flux	CH_4 flux	N_2O flux
		----------------------------------	*P* value	--------------------------------
		2012 Growing Season		
Site	2	0.0030	0.2209	0.0012
Gypsum	1	0.2553	0.2094	0.6684
Crop	1	0.8847	0.3705	0.6672
Site*Gypsum	2	1.0000	0.4118	0.6743

Site*Gypsum*Crop	5	0.5349	0.3038	0.9833
		2013 Growing Season		
Site	2	<0.0001	0.0029	0.0040
Gypsum	1	0.6330	0.5017	0.5612
Crop	1	0.1555	0.4925	0.7946
Site*Gypsum	2	0.7360	0.2520	0.7419
Site*Gypsum*Crop	5	0.5999	0.9418	0.9723
		2012 and 2013 Growing Season Combined		
Year	1	0.1052	0.8992	0.7464
Site	2	<0.0001	0.0036	<0.0001
Gypsum	1	0.2648	0.4633	0.4510
Crop	1	0.3217	0.2544	0.5924
Site*Gypsum	2	0.9464	0.7921	0.4483
Site*Gypsum*Crop	5	0.9324	0.2590	0.8948

Effects of site location, gypsum addition, and cover crops on cumulative greenhous gas emissions (CO_2, CH_4, and N_2O) during the 2012 and 2013 growing season.

Treatment effect	CO_2 flux	CH_4 flux	N_2O flux
	---------------------------------- Kg ha^{-1} --------------------------------		
	2012 growing season		
Site			
Alabama	1270.7 b†	-0.4481 a	0.3486 b
Indiana	1775.3 a	0.0159 a	1.6380 a
Piketon Ohio	1353.1 b	-0.1063 a	0.2882 b
Gypsum			
No gypsum	1530.4 a	-0.0262 a	0.7836 a
with gypsum	1395.3 a	-0.3004 a	0.6515 a
Cover crop			
With cover	1449.7 a	-0.0840 a	0.6614 a
Without cover	1466.8 a	-0.2786 a	0.9740 a
	2013 growing season		
Site			
Alabama	1979.6 a	-0.5596 b	0.3181 b
Indiana	1763.8 a	0.0143 a	1.6336 a
Piketon Ohio	1068.6 b	-0.0255 a	0.4213 b
Gypsum			
No gypsum	1578.8 a	-0.1424 a	0.8885 a
with gypsum	1629.8 a	-0.2381 a	0.6935 a
Cover crop			
With cover	1526.4 a	-0.1414 a	0.7474 a
Without cover	1681.6 a	-0.2392 a	0.8346 a
	2012 and 2013 growing season combined		
Site			
Alabama	1625.1 a	-0.5038 b	0.3333 b
Indiana	1769.5 a	0.0151 a	1.6367 a
Piketon Ohio	1226.6 b	-0.0704 a	0.3474 b
Gypsum			
No gypsum	1479.72 a	-0.2275 a	0.8320 a
with gypsum	1580.06 a	-0.1322 a	0.6725 a
Cover crop			
With cover	1485.11 a	-0.1105 a	0.7011 a
Without cover	1574.22 a	-0.2589 a	0.8143 a

† Mean without a letter in common differ significantly at the 0.05 probability level.

Appendix 3

Meta-analysis of metal elements in 2013 soybean grain[1]

Element	Site					Cover			FGD Gypsum Rate (lbs/acre)	
	Piketon	Indiana	Alabama	Hoytville		No	Yes		0	2000
Al[2]	13.1	10.7	6.50	78.0		12.2	42.0		14.2	40.0
B	16.9 b	31.2 a	12.0 c	32.0 a		23.1	22.9		22.8	23.3
Ca	2.07 b	1.75 c	3.62 a	2.03 b		2.38	2.36		2.35	2.39
Cd	0.476 a	0.248 b	0.522 a	0.140 c		0.325	0.368		0.336	0.357
Co	0.272 ab	0.232 b	0.317 a	0.271 ab		0.268	0.278		0.267	0.279
Cr	2.26 b	3.69 a	1.44 c	0.404 d		1.87	2.03		1.88	2.02
Cu	10.4 b	9.87 b	3.22 c	12.0 a		9.27 a	8.48 b		9.02	8.72
Fe	92.9	88.4	102	108		87.7	108		88.2	107
Hg	3.20	1.35	1.18	3.50		2.97	1.65		2.31	2.29
K	16.0 b	18.1 a	15.6 b	18.1 a		17.3 a	16.6 b		17.1	16.7
Mg	2.16 b	2.31 a	2.32 a	1.88 c		2.19	2.15		2.19	2.14
Mn	31.7 b	25.0 c	39.7 a	21.7 c		29.8	29.3		29.0	30.1
Mo	3.12 c	7.52 b	1.96 c	13.0 a		6.13	6.67		7.43 a	5.37 b
Ni	0.908 b	0.987 b	0.860 b	5.68 a		2.37 a	1.85 b		2.08	2.14
P	5.82 a	5.69 a	5.43 b	5.34 b		5.70 a	5.44 b		5.66 a	5.48 b
S	2.59 c	3.31 a	2.64 c	2.78 b		2.87 a	2.79 b		2.81	2.85
Si	158 ab	33.6 c	112 bc	222 a		108	155		114	148
Zn	30.5 c	45.1 a	20.8 d	37.1 b		33.5	33.2		32.9	33.9

[1]Concentrations of elements not detected in soybean grain (with lowest detection limits shown in parentheses) are As (1.93), Be (0.069). Pb (0.863), Sb (1.50), Se (2.46), Tl (0.641), V (0.782).

[2]Within an element and factor (Site, Cover Crop, or FGD Gypsum Rate), means followed by no letters or by a similar letter are not significantly different at $P < 0.05$ using Duncan's multiple range test.

Appendix 4

Soybean yield: The table below summarizes the soybean yield data for 2012 and 2013. Yields were different between years and between locations as indicated by the letters A, B, C, and D in the table. There were no yield differences or trends due to the FGD treatments or the cover crop treatments. The site differences primarily reflect differences in the productive potential of the soils at these sites. The year differences reflect issues related to drought in 2012 and associated weed pressure.

Site		Year	Yield bu/ac	Mean
Alabama		2012	28.6	33.4 C
		2013	38.3	
Indiana		2012	48.9	53.0 B
		2013	57.2	
Ohio-Hoytville		2012	59.3	58.5 A
		2013	57.7	
Ohio-Piketon		2012	12.3	39.2 C
		2013	59.4	
Mean		2012	41.4 A	
		2013	53.2 B	

Appendix 5

Profitability analysis of the experimental data.

The purpose of this section is to utilize soybean performance data for the various treatments and locations studied, to represent the costs and returns for production under each of the treatment systems, and to calculate expected profitability of these systems for a commercial scale farm. We accomplished this by first estimating costs and returns for each production system at each of the four locations. Receipts are limited to the market value of soybean crops harvested from the plots, expressed on a per acre basis. Soybean prices of $10.75/bu (2012) and $12.89/bu (2013) were used in this calculation. Production costs are based on soybean crop enterprise budgets developed at each of the state Land Grant universities in the three study states, all assuming a no-till production system and based on a machinery set appropriate for a farm size of 2,000 cropped acres. For plots receiving gypsum, a cost of $50 per ton of gypsum purchased and applied is charged. For cover crops, the cost of cover crop seed is charged, along with $4.50 per acre for a single pass with a no-till drill is levied. No difference in soybean seed costs were assumed for the high oil seed varieties. A cash rental charge, based on USDA and other cash rental surveys, is applied to represent the cost of land, Table 1 presents a summary the costs of production assumed for each site and production method.

Table 1. Soybean production costs and returns used in profitability analyses[a]

	Ohio	Indiana	Alabama
		$ / Acre	
Receipts[b]		Yield X Price	
Variable Costs[c]	220	220	265
Fixed Costs[d]	375	405	215
Total Costs	595	625	480
Additional costs for various treatments:			
Gypsum[e]		$50 / ton delivered and applied	
Cover Crop[f]		Cost of cover crop seed + $4.50 per acre for No-Till Seeder pass	
High Oil Variety[g]		No additional costs	

a Production costs are based on a 2,000 acre corn/soybean farm using no-till farming practices. Estimates are published in the Ohio Enterprise Budgets (Ohio State University), 2014 Cost and Returns Guide (Purdue University) and 2013 Enterprise Planning Budget Summary (Auburn University).

b Soybean price is $10.75 / bushel for all sites in 2012 and $12.89 / bushel in 2013. The only source of returns is assumed to be the market value of the crop.

c Variable costs include all costs for seed, fertilizer, agrichemicals, fuel and repair for the base production system. Additional costs for gypsum, cover crops and other treatments are added for applicable treatments.

d Fixed costs include 2 hours per acre of labor ($15/hour), machinery ownership costs, and a cash rental rate for land. The only residual input is management. Hence, our measure of profit is *Return to Management*.

e Transportation costs will vary with distance from gypsum source to farm.

f Cereal rye is used as the cover crop in Ohio and Indiana. Oil seed radish was used in Alabama

g No additional cost is applied for the high oil variety.

Results for the 2013 production year

The year 2013 marked the second year of the study, and the first without extreme drought impacting crop yields. We will discuss these results in detail in the following. In a later section, we will also present the results for the first year of the study.

Presented in Table 2 are the average yields and imputed per acre profitability for the four research sites. These numbers are averages across all treatment types and replicates. Per acre yields were quite good in Ohio and Indiana, ranging from 57.3 to 59.4 bushel per acre, but somewhat lower in Alabama, although still in alignment with Alabama state average yields. As a result, calculated return to management was negative in Alabama (even though their per acre production costs are lower than for the Midwest, especially for land rental), but ranged from $80 to $139 per acre in Indiana and Ohio.

Table 2. Per acre average yields and profitability by test site, 2013

Site	Average Yields (bu/ac)	Average profit ($ / ac)
Alabama	38.34	-32.87
Hoytville, Ohio	57.73	117.24
Indiana	57.34	79.91
Piketon, Ohio	59.38	138.62

Table 3 provides a breakout of yield performance and profitability by treatment type and state. Across the four test locations, yields increased slightly, though not significantly, with increases of gypsum from zero to 1,000 pounds per acre. Highest yields were associated 2,000 pounds per acre of gypsum application at the Piketon site, but highest yields at the Alabama, Hoytville and Indiana sites were obtained with gypsum application rates of 1,000 pounds per acre. However, the yield increases were only large enough to cover the increased costs of gypsum at the Piketon site: Calculated profitability diminished with increased applications of Gypsum in the other three sites.

Addition of a cover crop resulted in a more uniform impact across the four production sites. For the four sites, average yield increased by just over 3.6 bushel per acre for plots with a cover crop treatment relative to those without cover crops. Yields were higher in plots with cover crops for all four test sites. Calculated profitability was increased with the addition of a cover crop at all four test sites, indicating that the yield increase (valued at the 2013 soybean price of $12.89 per bushel) were more than sufficient to pay the additional costs of establishing a cover crop.

For all four test sites, plots that were in soybeans following a 2012 corn crop resulted in higher soybeans yields. For the four states, the C/S rotation yielded 6.65 bushel per acre more. The yield advantage was greatest in Alabama, but was negligible in Indiana. The yield differential translated into a profit advantage for crops in rotation, averaged for the four sites, of $72.80/acre.

Two soybean varieties were grown at each test site: a high oil variety and a variety with traditional oil levels. At each site, the high oil variety yielded both higher yields, and higher calculated profitability. Across the four sites, the high oil variety yielded an average of 4.6 bushel per acre more, and earned an average $59 more per acre, again assuming 2013 soybean prices.

Table 3. Per acre average yields and profitability by treatment for four test sites, 2013.

	All sites		Average Yields (bu/ac)				Average Profits ($/ac)			
	Average Yields	Average profit								
Treatment	(bu/ac)	($ / ac)	Alabama	Hoytville	Indiana	Piketon	Alabama	Hoytville	Indiana	Piketon
Gypsum=0 lbs/acre	53.01	98.28	38.21	58.23	58.19	57.40	-9.56	116.42	148.23	138.03
Gypsum=1,000 lbs/acre	53.47	79.18	38.79	58.25	57.83	58.99	-27.14	91.70	118.64	133.50
Gypsum=2,000 lbs/acre	53.12	49.71	38.03	55.53	57.15	61.77	-61.93	31.59	84.86	144.33
Covercrop=no	51.38	63.24	35.44	55.21	57.55	57.32	-48.17	61.63	121.19	118.30
Covercrop=yes	55.01	88.21	41.24	59.47	57.90	61.45	-17.58	98.18	113.29	158.94
Continuous Soybeans=no	57.12	113.30	44.28	61.03	58.02	60.39	43.62	127.57	121.04	151.54
Continuous Soybeans=yes	50.47	40.51	32.41	53.64	57.43	58.38	-109.37	32.25	113.44	125.71
High oil variety=no	50.91	46.20	34.38	54.94	55.77	58.53	-83.94	49.07	92.01	127.66
High oil variety=yes	55.49	105.25	42.30	59.73	59.68	60.24	18.19	110.74	142.47	149.59

The previous analyses do not adequately sort out the impacts of each of the treatments. That is, the averages in Table 3 look only at a single treatment regime. To sort out the individual impacts of treatments, and to apply tests of significance to these differences, a regression model is estimated for the combined yield and profitability results across the four production sites. Table 4 provides results for the soybean yield data. The model adjusted R-Square coefficient is 0.77, suggesting that about 77 percent of the variation in soybean yields is explained by this simple model. The model F-statistic is significant at the 0.01 probability level, suggesting that at least one of the estimated coefficients is significantly different than zero.

In order to control for differences in productivity and/or growing conditions across the four sites, three binary variables are included to represent the Alabama, Piketon and Indiana sites. The Hoytville, OH site is the excluded (comparison) location. The regression coefficient for Alabama was significant (P<0.01), indicating that yields at that location were 19.4 bushel per acre lower than for the Hoytville site. Yields at the Piketon and Indiana sites were not significantly different (P<0.10) from the Hoytville site.

The estimated coefficient for gypsum application level was 0.0001, and was not statistically different zero (P<0.10). That is, with location, the presence of a cover crop, crop rotation, and the presence of a high oil variety all controlled, gypsum applications did not impact yield in 2013.

The estimated cover crop for the presence of a cover crop was 3.63, and was statistically significant at P<0.01. Thus, in 2013, plots with cover crops produced an average 3.63 additional bushels of soybean yield, again with location and other treatment levels held constant.

The regression coefficient for high oil variety was 4.58 and was statistically larger than zero (P<0.01). Again will all other treatments and location effects held constant, the high oil soybean variety yielded 4.58 bushels more than the conventional oil variety.

Finally, two rotations were studied: a continuous soybean rotation and soybeans following corn. The estimated coefficient for continuous soybeans was -5.46 and was significantly smaller than zero (P<0.01). Thus, in 2013, soybean yields on continuous soybean plots (with all else controlled) averaged 5.46 bushels less than for soybeans following corn.

Table 4. Multivariate regression model of soybean yields for four sites and all treatments, 2013.

Regression Statistics	
Multiple R	0.88
R Square	0.78
Adjusted R Square	0.77
Standard Error	5.22
Observations	96

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	7	8656	1236.6	45.37	0.00
Residual	88	2398	27.3		
Total	95	11054			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	56.30	1.55	36.24	0.00
Gypsum application level[a]	0.00	0.00	0.09	0.93
Cover Crop (1=yes)	3.63	1.07	3.41	0.00
High oil variety (1=yes)	4.58	1.07	4.30	0.00
Continuous soybeans (1=yes)[b]	-5.46	1.07	-5.13	0.00
Alabama=1[c]	-19.38	1.51	-12.86	0.00
Indiana=1[c]	-0.39	1.51	-0.26	0.80

Pike=1[c]	1.66	1.51	1.10	0.27

a Gypsum application levels were 0, 1,000 and 2,000 pounds per acre

b Corn/Soybean rotation is the excluded category (=0)

c The Hoytville, OH site is the excluded location (=0)

A similar regression model was estimated with per acre profitability as the dependent variable. These results are presented in Table 5. Again, the model was highly significant ($P<0.01$), as determined by the model F-Statistic. The regression model explain about 60 percent of the variation in soybean profitability.

The site location variable again determines the difference in profitability that is attributable primarily to location of these test site. The estimated coefficient for Alabama was -$150, suggesting that profits per acre were $150 per acre lower than for Hoytville. This is primarily due to the significantly lower soybean yields at that site. The regression coefficient for Indiana also was significantly lower ($P<0.10$) than for Hoytville, suggesting profits were $37.34 per acre lower in Indiana. This was due to somewhat higher production costs in Indiana, principally a cash rental rate for land that was $30 per acre higher than for Ohio. There was no significant difference in profitability for the Hoytville and Piketon sites.

The regression coefficient for gypsum application was $-0.02 and was statistically significant ($P<0.01$). Thus, for 2013, each additional pound of gypsum applied resulted in a $0.02 reduction in per acre profitability, with location and all other treatment levels held constant. The estimated coefficient for cover crop was 24.97 (significant at $P<0.10$) indicating that plots with cover crops, *ceteris paribus*, earned $24.97 more per acre than those without cover crops. The estimated coefficient for high oil variety was 59.04 (significant at $P<0.01$), indicating an average increase in per acre profitability of $59.04 per acre for high oil varieties relative to traditional soybean varieties. Finally, the regression coefficient for continuous soybeans as -70.43 (significant at $P<0.01$), indicating that continuous soybean plots earned $70.43 less profits than did soybeans following corn in 2013.

These results represent the combined experiences of the four test sites in 2013. It should be underscored that this represents only the second year experience with each of these treatments. One must be careful to draw conclusions from this short-term set of results. For instance, a survey of gypsum-using farmers conducted in 2013 by Batte and Forster (2014)[1] found that these farmers observed yield increases for gypsum use on a number of crops, and that the magnitude of yield premium increased for farmers who had applied gypsum for four or more years. This may suggest that the gypsum use may display positive impacts in our own study as we continue the study over time. Likewise, we may see changes in magnitudes of other treatments (especially cover crops and continuous soybeans) as we track these over an extended study period.

[1] Batte, Marvin T., and D. Lynn Forster. 2014. "Economic Impact of Gypsum: A Study of Midwestern Crop Growers". January 14, 2014.

Table 5. Multivariate regression model of soybean profitability for four sites and all treatments, 2013.

Regression Statistics	
Multiple R	0.80
R Square	0.63
Adjusted R Square	0.60
Standard Error	66.69
Observations	96

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	7	675246	96464	21.69	0.00
Residual	88	391407	4448		
Total	95	1066653			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	134.74	19.84	6.79	0.00
Gypsum application level[a]	-0.02	0.01	-2.91	0.00
Cover Crop (1=yes)	24.97	13.61	1.83	0.07
High oil variety (1=yes)	59.05	13.61	4.34	0.00
Continuous soybeans (1=yes)[b]	-70.44	13.61	-5.17	0.00
Alabama=1[c]	-150.12	19.25	-7.80	0.00
Indiana=1[c]	-37.34	19.25	-1.94	0.06

Pike=1[c]	21.38	19.25	1.11	0.27

a Gypsum application levels were 0, 1,000 and 2,000 pounds per acre

b Corn/Soybean rotation is the excluded category (=0)

c The Hoytville, OH site is the excluded location (=0)

Results for the 2012 production year

We also include the results for our first year experiments. The same set of results are presented for 2012, with abbreviated discussion. However, extreme caution is urged for these results. First, it represents the first year of the experiment, so impact of each treatment may be expected to be less. But, most importantly, 2012 was an extreme drought year. At some locations yields were extremely impacted.

Table 6 presents the average soybean yields and profitability for each of the study locations. Because of variation in the severity of drought conditions at the various locations, soybean yields ranged from just over 15 bushel per acre in Piketon to nearly 59 bushel per acre in Hoytville. Calculated per acre profits were negative at three of the four sites, ranging from $-414 per acre at Piketon to $55/acre in Hoytville.

Table 6. Per acre average yields and profitability by test site, 2012

Site	Average Yields (bu/ac)	Average profit ($ / ac)
Alabama	28.56	-132.05
Hoytville	58.94	54.92
Indiana	48.88	-62.21
Piketon	15.39	-413.95

Table 7 presents estimates of per acre yields and profits by sites and treatments. Again, we emphasize that these results consider only the impacts of a single treatment without controlling for other impacts. The impact of gypsum on soybean yields was greatest in Piketon and Alabama, the two most severely drought impacted sites. For both of these sites, the highest level of gypsum application was associated with the highest average yields. Hoytville exhibited its highest yields at the 1,000 pound per acre gypsum application, and Indiana exhibited highest yields at the zero gypsum application rates. Highest profits were observed at the middle gypsum application rate for two of the four sites (Hoytville and Alabama), and at the zero application rate for Indiana and Piketon.

Table 7. Per acre average yields and profitability by treatment for four test sites, 2012.[a]

Treatment	All Sites: Average Yields (bu/ac)	All Sites: Average profit ($ / ac)	Average Yields (bu/ac): Alabama	Hoytville	Indiana	Piketon	Average Profits ($/ac): Alabama	Hoytville	Indiana	Piketon
Gypsum=0 lbs/acre	40.46	-83.43	25.91	58.06	50.15	14.97	-142.21	70.52	-23.60	-393.42
Gypsum=1,000 lbs/acre	41.73	-89.06	29.23	61.15	48.75	13.84	-111.55	78.76	-63.63	-430.62
Gypsum=2,000 lbs/acre	41.30	-124.35	30.55	57.59	47.75	17.36	-142.40	15.49	-99.42	-417.82
Covercrop=no	42.18	-79.69	27.46	63.77	49.17	14.44	-135.14	114.54	-50.44	-415.72
Covercrop=yes	40.15	-118.21	29.67	54.10	48.59	16.34	-128.96	-4.70	-73.99	-412.18
High oil variety=no	38.12	-131.66	25.89	53.54	46.62	14.75	-160.80	-3.08	-86.48	-420.86
High oil variety=yes	44.21	-66.24	31.24	64.33	51.14	16.03	-103.31	112.93	-37.94	-407.04

a 2012 was a severe drought year, impacting the four sites very differently. Hoytville, OH suffered the least damage to yields from this drought.

Multivariate regression was used to parse out the effects of each site and treatment, and to allow statistical tests of difference across each site and treatment. Table 8 provides regression results for the soybean yield data. The model estimated is identical to the one estimated for the 2013 production year except the continuous soybean variable is omitted. Since 2012 was the beginning year of the experiments, a rotation effect is not appropriate in that year. The model adjusted R-Square coefficient is 0.93, suggesting that about 93 percent of the variation in soybean yields is explained by this simple model. The model F-statistic is significant at the 0.01 probability level, suggesting that at least one of the estimated coefficients is significantly different than zero.

In order to control for differences in productivity and/or growing conditions across the four sites, three binary variables are included to represent the Alabama, Piketon and Indiana sites. The Hoytville, OH site is the excluded (comparison) location. All three site regression coefficients were significantly less than zero (P<0.01): Yields in Alabama averaged 30.3 bushel per acre less than Hoytville, Indiana soybean yields were 10 bushel/acre less than Hoytville, and Piketon yields were 43.5 bushel/acre lower than Hoytville.

The estimated coefficient for gypsum application level was 0.0003, and was not statistically different from zero (P<0.10). That is, with location, the presence of a cover crop, and the presence of a high oil variety all controlled, gypsum applications did not impact yield in 2012.

The estimated cover crop for the presence of a cover crop was -2.03, and was statistically significant at P<0.05. Thus, in 2012, plots with cover crops produced an average 2.03 fewer bushels of soybean yield than plots without a cover crop, again with location and other treatment levels held constant.

Finally, the regression coefficient for high oil variety was 6.08 and was statistically larger than zero (P<0.01). Again will all other treatments and location effects held constant, the high oil soybean variety yielded 6.08 bushels more per acre than the conventional oil variety.

Table 8. Multivariate regression model of soybean yields for four sites and all treatments, 2012.

Regression Statistics	
Multiple R	0.97
R Square	0.93
Adjusted R Square	0.93
Standard Error	4.46
Observations	84

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	21663	3610	181.48	0.00
Residual	77	1532	20		
Total	83	23195			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	56.58	1.28	44.22	0.00
Gypsum application level[a]	0.00	0.00	0.56	0.57
Cover Crop (1=yes)	-2.03	0.97	-2.08	0.04
High oil variety (1=yes)	6.08	0.97	6.25	0.00
Alabama=1[b]	-30.29	1.30	-23.35	0.00
Indiana=1[b]	-10.06	1.29	-7.81	0.00
Pike=1[b]	-43.55	1.58	-27.61	0.00

a Gypsum application levels were 0, 1,000 and 2,000 pounds per acre, with the exception of Alabama, which applied 0, 200 and 2,000 pounds per acre.

b The Hoytville, OH site is the excluded location (=0). This site had the least impact from drought conditions.

A similar regression model was estimated with per acre profitability as the dependent variable. These results are presented in Table 9. Again, the model was highly significant (*P*<0.01), as determined by the model F-Statistic. The regression model explain about 91percent of the variation in soybean profitability.

The site location variable again determines the difference in profitability that is attributable primarily to location of these test site. Given the previous yield results, it is not surprising at Alabama, Indiana and Piketon all exhibited lower profitability than did the comparison site (Hoytville). Alabama, Indiana and Piketon displayed average profitability acoss all plots that were $193, $117, and $469 less than for Hoytville. This is primarily due to the differential impact of the drought in 2012: Hoytville clearly was the least impacted by these conditions.

The regression coefficient for gypsum application was $-0.02 and was statistically significant (*P*<0.01). Thus, for 2012, each additional pound of gypsum applied resulted in a $0.02 reduction in per acre profitability, with location and all other treatment levels held constant. The estimated coefficient for cover crop was -38.53 (significant at *P*<0.01) indicating that plots with cover crops, *ceteris paribus*, earned $38.53 less per acre than those without cover crops. The estimated coefficient for high oil variety was 65.41 (significant at *P*<0.01), indicating an average increase in per acre profitability of $65.41 per acre for high oil varieties relative to traditional soybean varieties..

These results represent the combined experiences of the four test sites in 2012. It should be underscored that this represents only the first year experience with each of these treatments, and occurred in a severe drought year.

Table 9. Multivariate regression model of soybean profitability for four sites and all treatments, 2012.

Regression Statistics	
Multiple R	0.96
R Square	0.92
Adjusted R Square	0.91
Standard Error	47.68
Observations	84

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	1966131	327689	144.13	0.00
Residual	77	175060	2274		
Total	83	2141191			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	62.97	13.68	4.60	0.00
Gypsum application level[a]	-0.02	0.01	-3.47	0.00
Cover Crop (1=yes)	-38.53	10.40	-3.70	0.00
High oil variety (1=yes)	65.41	10.40	6.29	0.00
Alabama=1[c]	-192.71	13.86	-13.90	0.00
Indiana=1[c]	-117.14	13.76	-8.51	0.00
Pike=1[c]	-468.88	16.86	-27.81	0.00

a Gypsum application levels were 0, 1,000 and 2,000 pounds per acre, with the exception of Alabama, which applied 0, 200 and 2,000 pounds per acre.

b Corn/Soybean rotation is the excluded category (=0)

c The Hoytville, OH site is the excluded location (=0). This site had the least impact from drought conditions.