Cover Crops and Gypsum Applications: Soybean and Corn Yield and Profitability Impacts

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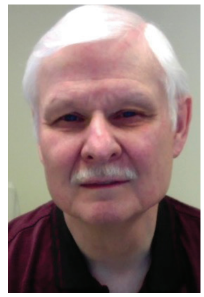
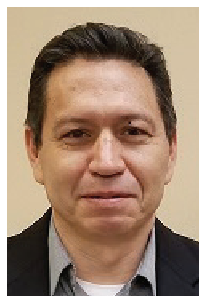
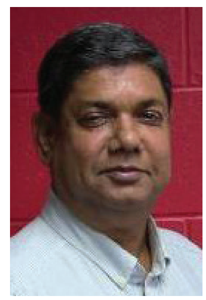
ABSTRACT

This study evaluated no-tillage management systems for soybeans and corn with and without cover crops and FGD gypsum treatments. Replicated field experiments were conducted in Ohio (two locations), Indiana and Alabama during 2012-2016. This article addresses yield and profitability consequences of these systems. Results provided no evidence of yield change associated with gypsum application. There were significant differences in yield at all four sites for plots with cover crops (three positive and one negative). Profitability was negatively impacted by gypsum application at all four sites, while cover crop impacts on profits were statistically significant (negative) for only one site.

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Introduction and Literature Review

Farmers and agricultural scientists are continuously in search of improved production methods: means to achieve not only greater farm profitability but also to reduce negative environmental impacts and to make our system of agriculture more sustainable. Previously used production practices gaining increased scrutiny include the use of gypsum as a soil amendment and greater usage of winter cover crops.

Sulfur is a nutrient necessary for crop growth. In the past, sulfur deficiencies have not been typical in many eastern U.S. soils due to atmospheric deposits of sulfur from the burning of coal for power generation. However, soil sulfur levels are on the decline due to requirements of the Clean Air Act Amendments of 1990 that required coal power plants to remove sulfur dioxide from their emissions. This, combined with crop removal of sulfur, has resulted in declining soil sulfur inventories. Kost, Chen, and Dick (2008) evaluated 1,473 soil samples representing 443 of 475 soil series in Ohio. They found that for a crop that required 15 kg/hectare sulfur (13.4 pounds/acre), most (62.6%) Ohio soils were classified as variably deficient. This implies that in these soils, for crops such as corn and soybeans, the production response to sulfur is variable but often is positive. Although similar studies have not been done in other states, we anticipate that as time passes increasing percentages of US soils will benefit from sulfur supplementation as sulfur continues to be drawn down through crop removal.

Sawyer, et al. (2012) reported that sulfur fertilization studies on small plots in Iowa show significant, but inconsistent, corn yield response to sulfur application. Sixty percent of the plots had statistically significant yield increases to applied sulfur fertilizer. Soil types affected yield response: 68 percent of sites with loam, silt loam, fine sandy loam, loamy fine sand, and sandy loam textural classes had statistically significant yield increases; however, only 14 percent of sites with silty clay loam or clay loam textural classes had statistically significant yield increases. The across-site yield increases averaged 19 bu/acre for the responsive sites.

In Minnesota, Rehm (2002) found that gypsum had a positive effect on crop yields on sandy textured soils deficient in sulfur. Wolkowski, et al. (2010) reported several studies conducted in Wisconsin in 2010 to evaluate the efficacy of relatively high rates of gypsum. None of the studies demonstrated substantial yield effects, but they did observe that gypsum's effects on crop yields were strongly influenced by soil characteristics.

Soil structure influences many soil processes including water and chemical transport, soil aeration, wind and water erosion, seed germination, and root penetration (Chen & Dick, 2011). They observed that gypsum can improve soil physical properties by reducing soil dispersion and promoting flocculation. This helps reduce soil crust formation which improves seed emergence and plant establishment. It also improves surface infiltration rates and water movement though the soil. This impact may be especially beneficial with clay loam or silty clay loam soils (Chen & Dick, 2011; Zoca & Chen, 2017; Wang & Yang, 2017).

Batte and Forster (2015) surveyed farmers experienced with flue gas desulfurization (FGD) gypsum applications. These farmers perceived several benefits of gypsum usage. The most frequently cited benefit was improved crop yields. More than 84 percent of farmers indicated gypsum related yield improvement, and 77 percent rated these benefits as moderately to extremely important. Long-term users of gypsum (five years or more) perceived greater benefits than did shorter-term users.

Batte and Forster also asked farmers to estimate the private economic benefits of their usage of gypsum. Specifically, they asked questions to derive an estimate of the private benefit to cost (B/C) ratio for gypsum use on that farm. The mean B/C ratio for all respondents was 1.68 (i.e., each dollar of expenditure for gypsum resulted in $1.68 of benefits). The median gypsum user cited a B/C ratio of 1.5. Nearly one-half of gypsum users reported a B/C in the range of 1.0-2.0, and 15 percent estimated a B/C of 2.0-3.0. Just 2.5% reported the B/C to exceed 4.0. One-third of gypsum users reported a B/C ratio less than 1.0, suggesting that gypsum usage was not profitable on these farms.

Myers and Watts (2015) reported a survey of farmers experiences with cover crops. In each of the three years (2012-2014), corn and soybean producers who had fields with and without cover crops were asked to give yield data for fields with comparable management practices (e.g., variety, planting date, and soil type). In each year they found statistically significant yield increases associated with cover crop usage. Yield increases were largest in 2012, a year of widespread drought, when farmers reported yield increases associated with cover crop usage of 9.6 percent for corn and 11.6 percent for soybeans. In 2013 and 2014, under more typical rainfall, farmers reported yield advantages with cover crops of 3.1 percent and 2.1 percent for corn, and 4.3 percent and 4.2 percent for soybeans for the two years, respectively.

Marcillo and Miguez (2017) reported a meta-analysis of winter cover crop studies on corn yield. They found that on average grass cover crops neither increased nor decreased corn yields. However, legume cover crop species resulted in subsequent higher corn yields, on average approaching 30-33 percent improvement. Cover crop mixtures of grass and legume also were associated with increased corn yields. Their results also suggested no corn yield penalties due to cover crops if managed properly.

Externalities associated with agricultural production also are of concern to broader society. For instance, in Ohio toxic algae growth in Grand Lake St. Mary's and the western portion of Lake Erie have been a problem in recent years, due largely to off-site movement of phosphorus. Application of gypsum or other amendments containing calcium is a potential method to mitigate phosphorus and nitrogen losses through runoff. Gypsum application to soils increases ionic strength and calcium concentration in the soil solution, and as a result, adsorption of phosphate (PO_4) becomes stronger. Also, solubility of organic phosphorus is decreased. Endale et al. (2014) and Torbert and Watts (2014) evaluated the effects of using FGD gypsum to reduce P loss and increase water infiltration under simulated rainfall events. They found significant increases in water infiltration for soils treated with gypsum, and up to a 61 percent reduction in soluble reactive P concentration in runoff water. Erosion also decreases due to improved water infiltration caused by change in the physical condition of the soil (Ekholm et al., 2012; Murphy & Stevens, 2010). The combined effect is less phosphorus and nitrogen moving off-site with ground water or attached to eroded soil particles. Winter cover crops also may reduce offsite impacts of fertilizer nutrients, both by reducing soil erosion and through plant uptake of soil nutrients.

Methodology

This article reports results of a research project designed and conducted to evaluate the potential crop yield and profitability benefits of an innovative, holistic soybean and corn farming system incorporating no-till practices with cover crops and applications of flue gas desulfurization (FGD) gypsum soil amendments. Replicated field experiments were conducted in Ohio (2 locations), Indiana, and Alabama during a five-year period (2012-2016 crop years) to encompass a range of soil, climate, and weather conditions. Treatments consisted of three levels of annual gypsum application (0, 1,000 and 2,000 lbs/ac), each with and without cover crops, and with two crop rotations considered (corn-soybeans and continuous soybeans). The cover crop employed was cereal rye. Two soybean varieties also were planted each year at most sites.

There were widespread drought conditions that impacted the entire study region in 2012. Hoytville, Ohio was least impacted by this drought and displayed yields that were not substantially different than during the remainder of the study. The Piketon, Ohio, and Randolph County, Indiana plot sites were most impacted, with Piketon averaging just over 12 bushels per acre (bu/ac) of soybean yields that year. Another drought year was observed in 2016, this one primarily impacting crop growth at the Macon County, Alabama site. Average yields for all plot sites and years are presented in Table 1.

Profitability was modeled for each of the systems at each site. Variable costs of production were derived from soybean and corn enterprise budgets developed by each State's Agricultural Extension Service for a soybean/corn rotation employing a no-till farming practice. Fertilizer, weed, disease and pest control applications recommended by each state were incorporated to reflect pest, disease, and soil conditions common to that state. Fixed costs are comprised of operator labor, machinery ownership costs, and land costs (cash rental rate). The machinery complement employed was standardized across the four sites and was sized to be appropriate for a 2,000-acre production system. Costs of owning and operating this machinery complement were estimated using information from the University of Minnesota Machinery Cost Estimates (Lazarus, 2012). Labor per acre was standardized across the study sites (2 hours per acre of soybeans, 3 hours per corn acre) and was valued at $13.50/hour (rising to $15/hour in 2016). Cash rental rates for the state and county of each study site reflected opportunity costs for land at that site (National Agricultural Statistical Service, Cash Rents Survey, various years).

Table 2 summarizes the variable, fixed and total costs for the base production scenario by year and location. Total fixed costs increased in the second year due to increases observed in farmland rental rates, but then flattened and actually decreased in the latter years of the study, again due primarily to decreases in farmland rental rates resulting from lower commodity prices and decreased farm profitability. Variable costs were somewhat higher for Alabama due to greater fertilizer and agrochemical requirements. Total costs were lowest for Alabama, primarily due to lower cash rental rates for farmland, and were largest for Indiana due mainly to greater cash rental rates for farmland.

This profitability calculation was modified for gypsum application, cover crops, and continuous soybeans by adding or subtracting costs reflective of the changed practice. For gypsum application, we assumed that the gypsum material could be purchased (delivered to the farm) for \$40 per ton, with an additional \$10 per acre application fee.[1] No other input costs changed under this scenario. For cover crops, the cost of cereal rye seed was included at the seeding rate employed at each site plus \$10.80 per acre for a single pass with a no-till seeder, the lower range estimate for no-till seeding in the 2012 Ohio Farm Custom Rate survey. For continuous soybeans, fixed costs of machinery were reduced by \$10.60 per acre to reflect lower investment in corn-specific equipment (e.g., a corn head for the combine), again, based on Minnesota Machine Cost estimates. Two soybean varieties were planted in most years and sites, but no costs differences were modeled for these varieties.

Revenue was modeled using the actual yield for each plot multiplied by the season average crop price. Annual soybean prices used in profit calculations were \$14.63, \$13.03, \$10.17, \$9.09, and \$9.73 per bushel for the five years 2012-2016, respectively (USDA, Crop Values Summary, various years). These represent averages for the states of Ohio, Indiana, and Alabama. Corn prices over this period were \$7.17, \$4.53, \$3.76, \$3.85, and \$3.55 per bushel, respectively. Farm program impacts were not included. Per acre profitability (return to management) is then the difference in these revenues and the costs described above.

The purpose of this article is to report the impacts of cover crops and soil-applied gypsum at four test plot locations over a five-year study period. Multiple regression models were formulated to sort out the individual impacts of the studied treatments and to allow tests of significance of yield and profitability differences by treatment. Because soil and weather events differ among the four locations, yield and profit regression models are estimated for each production site and year as well as for the combined five years at each site. In preliminary analyses, gypsum and gypsum-squared variables were included to test for a nonlinear response of crop yield to gypsum application levels. In no case was the squared term significant. Explanatory variables also were included in the preliminary models to test for interactions of gypsum application levels with presence/absence of cover crops, high oil varieties, and continuous soybean rotations as well as interaction of cover crops and continuous soybeans. Regression coefficients for these interaction variables were not statistically significant (*P≤0.10*) and lowered the adjusted R-Squared statistic, and were excluded from the final models reported. Thus, the annual models for soybean yield (and profit) were:

(1) $Yield = B_0 + B_1\, Gypsum + B_2\, CoverCrop + B_3\, High\_Oil + B_4\, Cont\_Beans + e_i$

and

(2) $Profit = B_0 + B_1\, Gypsum + B_2\, CoverCrop + B_3\, High\_Oil + B_4\, Cont\_Beans + e_i$

Where:

Yield is the plot soybean yield measured in bushels per acre (average for four replicates).

Profit is return to management (\$/acre) calculated for each plot reflecting the various practices employed on that plot and the actual yield observed for that plot.

Gypsum is the pounds of gypsum material applied per acre (0, 1,000, 2,000).

CoverCrop is 1 if a cover crop precedes the soybean crop and is zero otherwise.

High_Oil is 1 if a high-oil soybean variety is planted and is zero otherwise.

Cont_Beans is 1 if the plot is continuously planted in soybeans and is zero if it follows a soybean/corn rotation.

e_i is a random error term with mean zero.

We also estimated a five-year combined model for each of the four study sites. These models are the same as in (1) and (2) above, with the addition of four binary variables, YEAR 2013 – YEAR2015, where YEAR201X=1 if year=201X and is 0 otherwise. Year=2012 is excluded to prevent collinearity in the model. These variables are included to control for systematic differences in yields (and profits) due to variations in annual environmental factors such as weather, pest and disease pressure, and, for profitability, annual variation in soybean, fuel and other prices and farmland rental rates. Each annual binary variable reflects the difference in average yields (profits) for that year relative to 2012, the excluded year.

Tables 3-6 provide regression results for the soybean yield and profitability models for each of the four study sites. Sensitivity analyses for soybean price and gypsum costs are reported in Table 7. Corn crop regression results of yield and profitability for the combined five-year period are reported in Table 8.

Results

Hoytville, Ohio

Table 3 provides regression estimates for the Hoytville, Ohio test site. The top panel of Table 3 provides estimates for crop yields. The adjusted R-squared statistics for individual years range from 0.28 to 0.74 and indicate the proportion of total yield variation in each year that is explained by the model. The model F-statistic is a joint test that all regression coefficients are zero. The F-statistic is significant ($P \leq 0.05$) in all models.

For the Hoytville site, the regression coefficient for gypsum application is not significantly different from zero in any of the five annual regression models. With the impact of all other plot treatments controlled, there was no statistically significant evidence of a yield impact for increased gypsum application: that is, we cannot reject the null hypothesis that gypsum application has no effect on crop yield.

The regression coefficient for the presence of a cover crop was significantly different from zero and negative in sign in four of the five years. With all other explanatory variables controlled, soybean yields for plots with cover crops were 9.67 bu/ac lower ($P \leq 0.01$) than for soybeans not following a cover crop in 2012. Soybean yields with cover crops were 2.4 bu/ac less ($P \leq 0.05$) in 2014, 11.5 bu/ac less ($P \leq 0.01$) in 2015, and 2.4 bu/ac lower ($P \leq 0.05$) in 2016.

Two soybean varieties were planted for each treatment regime at Hoytville. One was a high-oil yield variety and the other a standard oil content variety. With all other treatment variables held constant, the high oil variety produced significantly greater yields ($P \leq 0.05$) in four of the five years studied. The yield advantages for the high oil variety ranged from zero in 2015 to 10.8 bu/ac in 2012.[2]

Finally, the regression coefficients for continuous soybeans indicates the yield benefits or penalties for continuous soybeans relative to soybeans following corn. This variable was significant in two of the five years at the Hoytville site. With all other treatments held constant, continuous soybean plot yields were 4.9 bu/ac larger ($P \leq 0.05$) in 2015 but were 3.1 bu/ac lower ($P \leq 0.01$) in 2016.

The right-most columns of Table 3 represent an analysis of the combined five years of yield data for Hoytville. Four binary variables are included to control for systematic variation in yields due to annual environmental factors, all measured relative to 2012, the excluded year. For example, the regression coefficients for Year2013 and Year2014 are not statistically significant (*P≤0.10*), suggesting that there were no significant differences in average yield for these two growing seasons as compared to 2012. However, regression coefficients for Year2015 and Year2016 are statistically significant: for Year2015, the regression coefficient of -11.8 suggests that all plots averaged 11.8 bu/ac less in 2015 than the average of all plots in 2012. To verify this, the yield for all plots in 2015 at Hoytville (Table 1) is 47.1. This is 11.8 bu/ac less than the 58.9 bu/ac yield in 2012. By controlling this systematic year to year variation, the estimated coefficients for other explanatory variables will be reflective of their individual contributions to yield.

For the five-year combined model, the regression coefficient for gypsum application level is not significantly different from zero (*P≤0.10*), thus there is no evidence over the five-year period of changes in yield due strictly to gypsum application level. The regression coefficient for cover crops, with all other variables held constant, was -5.12 (significant at *P≤0.01*), indicating that for Hoytville the average impact of cover crops was a 5.12 bu/ac yield reduction. The regression coefficient for the high oil variety was 4.13 (significant at *P≤0.01*), indicating that for the five-year period the high oil variety produced an added 4.13 bu/ac, with all else controlled. The continuous soybean variable was not significantly different from zero (*P≤0.10*), suggesting equal yields for continuous soybeans and soybeans following corn over this five-year period.

The bottom panel of Table 3 includes results of the profitability models. The dependent variable in these analyses is per acre profitability (return to management) and reflects all costs and returns for the various production practices of each test plot. The explanatory variables are identical to those included in the yield model. Adjusted R-square statistics indicate that 68 to 78 percent of the variation in annual profitability estimates is explained by the model. The F-statistics are highly significant (*P≤0.01*) for each model.

The regression coefficients for gypsum application are statistically significant (*P≤0.10*) for all years and display a negative sign in each year. The gypsum regression coefficient for the 2012-2016 combined model is -0.025 (significant at *P≤0.01*). Because gypsum application is measured in pounds per acre, this estimated coefficient indicates that an additional pound of gypsum applied per acre results in a reduction of profitability of $0.025 per acre for the five-year combined model, or $50 per acre for a 2,000-pound application. For Hoytville, the yield model results suggested no change in yield due to gypsum application. However, gypsum was applied at a cost of $40/ton plus $10/acre application fee.

The regression coefficients for the presence of cover crop at Hoytville are all negatively signed and statistically significant (*P≤0.05*). Again, this is not surprising because yields at Hoytville were smaller for plots with cover crops in four of the five years and there were additional costs of establishing the cover crop. The estimated regression coefficient for cover crops at Hoytville for the 2012-2016 combined model was -78.68, indicating that cover crops reduced profitability by nearly $79 per acre relative to no cover crops, with all other treatment effects controlled.

The regression coefficients for the high-oil soybean variety were positive in sign and statistically significant (*$P \leq 0.05$*) in four individual years and in the five-year combined model. This result occurred because the high-oil variety tested was higher yielding, and we modeled no increase in cost for this variety. The regression coefficient in the five-year combined model showed an increased profit for the high oil variety of $53.60 per acre. This estimate suggests, that for the Hoytville site with all else equal, farmers could pay up to $53.60 per acre more to seed the higher yielding soybean variety and earn equal or higher profits.

The binary variable indicating continuous soybeans was statistically significant (*$P \leq 0.05$*) in only two years: The estimated coefficient was positive (indicating higher profitability) in 2015, but negative in 2016. This estimated coefficient was not statistically different from zero in the five-year combined model, suggesting essentially a breakeven between corn/soybean and continuous soybean rotations over the five years at Hoytville.

Finally, for the five-year combined model, the binary variables for year are included to control for systematic annual events which, for the profitability dependent variable, includes variation in soybean and other prices as well as annual weather induced yield variability. All four annual control variables were statistically significant (*$P \leq 0.01$*) and negative in sign. For Hoytville, the base year (2012) was a year of above average yields and high soybean prices. Profits in 2013 were $130.92 less per acre than in 2012. For our purposes here, these coefficient estimates are not particularly interesting, but are important to control for these annual events, providing more accurate estimates of the impact of the experimental variables on profitability.

Piketon, Ohio

Table 4 provides regression estimates for the Piketon, Ohio test site. The results are reported in an identical format as for the Hoytville site. Although the results are presented for individual years, we will limit discussion largely to the 2012-2016 combined model results. The five-year yield model was highly significant (*$P \leq 0.01$*) as indicated by the model F-statistic. The adjusted R-squared statistic suggests that the five-year model explains about 88 percent of the variation in soybean yields. The production year control variables all were significant (*$P \leq 0.01$*), indicating greater yields in the last four years relative to 2012, the severe drought year at Piketon.

The estimated regression coefficient for gypsum application was not statistically significant (*$P \leq 0.10$*) in the five-year combined model, providing no evidence of a yield impact from gypsum application. This variable was significant in only the 2012 production year: there, a one-pound increase in gypsum application was associated with a 0.001 bu/ac increase in yields, or about 2 bu/ac for a one ton application of gypsum.

The presence of a cover crop prior to soybeans was statistically significant (*$P \leq 0.10$*) and positive, suggesting that over the five-year period the presence of a cover crop was associated with a 2.21 bu/ac increase in yield. This was true despite the fact that this variable was not statistically significant in any individual year.

The high oil variety and continuous soybean variables were not statistically significant (*$P \leq 0.10$*) in the five-year models. The continuous soybeans variable was statistically significant (*$P \leq 0.05$*) in two individual year models. The estimated coefficient suggests an increase of 8.55 bu/ac over the corn/soybeans rotation in 2012, however in 2015 continuous soybeans yielded 6.25 bu/ac less than soybeans following corn. This may suggest an important interaction between weather, insect, or disease pressures or other environmental variables with continuous soybean yields.

The bottom panel of Table 4 provides model estimates for per acre profitability at Piketon. The five-year model F-statistic was highly significant (*P≤0.01*). The adjusted R-squared for the model was 0.87. Again, the annual control variables were all highly significant, showing a substantial increase in profitability for the named years relative to the 2012 drought year.

For the five-year model, the gypsum application variable was statistically significant (*P≤0.05*) and suggested that each additional pound of gypsum applied reduced per acre profits by $0.021, or about $42/acre for a 2,000-pound application. Again, with no demonstrated yield improvement, this amount is roughly equivalent to the cost of the applied gypsum.

The estimated regression coefficients for presence of cover crop, the high-oil variety, and a continuous soybean rotation were not significantly different from zero (*P≤0.10*) in the five-year combined model, again suggesting essentially a breakeven for each relative to the base case of no cover crop, typical variety, and corn/soybean rotation. Results for individual years indicated a mixture of positive and negative regression estimates, suggesting much variability in these variables due to annual weather and commodity price events. The most notable individual year estimate was the $136/acre advantage for continuous soybeans in 2012. This coefficient is large in part because the 8.55-bushel yield advantage occurred in the high price year ($14.63/bu), resulting in a $125/ac boost in total revenue.

Randolph County, Indiana

Table 5 provides results for the soybean yield and profitability models for the Indiana test site. The soybean yield model for the combined five-year period was highly significant (*P≤0.01*) and explained about 45 percent of the variation in soybean yields. The individual year control variables were all significant (*P≤0.01*) and positive in sign, indicating that average yields were higher in the last four years of the study relative to the 2012 drought year. Note that Indiana did not include the high oil variety in the last three years of the study. For this reason, this variable is not included in the five-year model and high oil variety observations for the first two years were excluded in the estimation of the five-year model.

As with the previous two sites, the regression coefficient for gypsum application level was not statistically different from zero (*P≤0.10*), suggesting no yield impact from gypsum application. The presence of a cover crop prior to the soybean crop displayed a significant (*P≤0.05*) positive regression coefficient estimate. The model suggest that the presence of a cover crop was associated with a 2.6 bu/ac yield advantage for cover crop practices. Note that this variable was significant and positive in two of the five individual years, suggesting a four to five bushel yield improvement in those years, but was not significantly different from zero in the other three years. The continuous soybeans regression coefficient was not statistically different from zero (*P≤0.10*), suggesting no difference in yields of the continuous soybeans and soybeans following corn rotations. For individual years, continuous soybeans were estimated to produce 14.4 bu/ac greater yields than soybeans following corn in 2015, but 7.4, 7.1, and 3.7 bu/ac lower yields than soybeans following corn in 2013, 2014, and 2016, respectively. Again, this suggests significant interaction of this practice with environmental events of weather, pests and/or disease.

The lower panel of Table 5 shows profitability model results for the Indiana site. The model F-statistic was highly significant, and model explained about 74 percent of the variation in profitability estimates. Three of the four annual control variables were significant and negative, reflecting the negative impact of declining soybean prices relative to 2012 which more than offset the higher yields in those years.

Even though gypsum did not influence soybean yields, it had a significant (*P≤0.01*) negative influence on soybean profitability because of added gypsum costs. Each additional pound of gypsum applied was estimated to reduce profitability by $0.035, or about $70 per acre for a one-ton application. The presence of cover crops and continuous soybean production did not result in significant differences in profitability (five-year model) relative to the base case of no cover crops and soybeans following corn. However, both variables displayed a mixture of statistically significant positive and negative regression coefficient estimates in individual years, driven almost entirely by the impact of yield changes in these years.

Macon County, Alabama

Soybean yield and profitability model results for the Alabama site are reported in Table 6. The five-year model F-statistic for the yield model is highly significant (*P≤0.01*). The combined model explains 80 percent of the variation in soybean yields. Soybean yields were significantly larger in 2013 and 2014, and significantly lower in 2016 (a drought year for Alabama), relative to the 2012 base year.

For the five-year model, gypsum application was not significantly (*P≤0.10*) different from zero, suggesting no impact of gypsum application level on soybean yields at the Alabama site. The gypsum application variable was statistically different from zero in two years: in 2012, each additional pound of gypsum was associated with a 0.002 bu/ac increase in yield, and in 2015 each added pound of gypsum applied was associated with a 0.001 bu/ac decrease in soybean yield.

The regression coefficient for the presence of a cover crop prior to soybeans was significant (*P≤0.01*) and positive for the five-year combined model. For Alabama, with all other variables controlled, the presence of a cover crop was associated with a nearly 3 bu/ac increase in soybean yields. This variable was significant and positive in four of the five individual year models.

The estimated coefficient for the high oil soybean variety was statistically significant (*P≤0.01*) and positive in sign in the combined model. In Alabama, the high oil variety yielded 5.36 bu/ac more than the traditional variety. Four of the five individual year regression coefficient estimates for this variable were significant and positive, with one year (2016, a drought year) significant and negatively signed.

Finally, the regression coefficient for continuous soybean production was statistically significant (*P≤0.01*) and negative in sign in the five-year model. With all other variables controlled, continuous soybeans were associated with just over 4 bu/ac lower yields than soybeans following corn. This variable displayed a mixture of significant positive and negative regression coefficients in individual years, again underscoring a strong interaction of this variable with environmental factors.

For the profitability models (lower panel of Table 6), the combined model displays a significant F-statistic ($P \leq 0.01$) and explains about 85 percent of the variation in enterprise profitability. All four annual control variables were statistically significant ($P \leq 0.01$): 2013 was more profitable than 2012 due to the higher yields, but 2014 and 2015 were lower in profitability primarily due to reduced soybean prices. The 2016 season was lowest in profitability for Alabama due to a combination of lower soybean prices and a nearly 14 bu/ac yield reduction relative to 2012.

The regression coefficient for gypsum application was significant ($P \leq 0.01$) and negative in sign, suggesting that each additional pound of gypsum applied decreased profits by $0.021, or $42/acre for a one-ton application. Four of the five individual year coefficients for this variable were significant and negative in sign.

The regression coefficient for the high oil soybean variety was significant ($P \leq 0.01$) and positive, suggesting just over $62 per acre improvement in soybean profits relative to the traditional variety. The coefficient estimate for continuous soybeans was significant ($P \leq 0.01$) and negative, suggesting a nearly $33 decrease in per acre profits relative to soybeans following corn. The presence of a cover crop prior to the soybean crop did not significantly impact soybean profitability in the five-year combined model. However, this variable was statistically significant ($P \leq 0.10$) in two years, suggesting that the presence of a cover crop decreased profits by $25.65 per acre in 2014, but increasing profitability by $16.80 per acre in 2015.

Sensitivity analysis on soybean price and gypsum cost

In order to explore the impact of soybean prices on these experimental results, profitability analyses were repeated with soybean prices that were 20 percent above and below the base prices. Results for the five-year combined models are shown in Table 7. For Hoytville, a 20 percent increase (decrease) in soybean prices results in the constant term increasing (decreasing) by about $173 per acre, demonstrating the change in profits in the base year (2012) not attributable to other explanatory variables. Likewise, the binary variables associated with annual variations in yields and prices all increase (decrease) in absolute value relative to the base model, reflecting that annual variation in yields are now valued at the higher (lower) soybean prices and thus have greater (lesser) impact on profitability. The regression coefficient estimate for gypsum is essentially unchanged from the base model, but the standard error of the estimate has increased with higher soybean prices and decreased with lower prices. The regression coefficient for cover crop decreases (increases) by nearly $12 per acre, reflecting the fact that the yield change associated with cover crops at Hoytville now has a greater (lesser) monetary value due to higher (lower) soybean prices. Similarly, the yield advantage of the high oil variety grown at Hoytville now has higher (lower) value due to the price increase (decrease), resulting in nearly $11/acre of additional (reduced) value. Although the regression coefficient associated with continuous soybeans increases with higher prices, that coefficient estimate is not statistically different from zero at the $P \leq 0.10$ level.

Similar results can be observed for the remaining three production sites (Table 7). It is interesting to note that in no case is a 20 percent change in soybean price sufficient to change the sign of estimated regression coefficients for the four studied parameters relative to the base model. That is, a 20 percent commodity price increase does not make, say gypsum usage, profitable when it was unprofitable at the lower price.

We also considered the sensitivity of the base model results to a change in the cost of gypsum material. The base model includes gypsum cost at $40 per ton delivered to the farm, plus a $10 per acre application fee. The rightmost two groups of columns in Table 7 show the impact of a $60 and $20 per ton cost of gypsum delivered to the farm. The $10 per acre application fee remains constant in these analyses.

Because the change in per acre gypsum cost is only a function of quantity applied and gypsum cost, the only regression coefficients that change in these sensitivity analyses, relative to the base model, are those for gypsum application level. For $60/ton gypsum cost at the Hoytville location, the regression coefficient of -0.035 suggests that each pound of gypsum applied reduces profits by 3.5 cents, or $70 per acre for a one-ton application. At a $20/ton cost of gypsum, that profit penalty is reduced to 1.5 cents per pound of gypsum, or about $30 per acre. Similar results can be observed for the other three test plot locations. In no case is the 50 percent reduction in gypsum cost sufficient to change gypsum application from a negative to a positive influence on profitability.

As suggested in our literature review, gypsum application may be useful to reduce the level of phosphorus in water runoff from a crop field and to reduce soil erosion with attached fertilizer nutrients. Society may value improved water quality from lessened nutrient pollution, and may be willing to pay to encourage such practices.[3] The fact that only the gypsum regression coefficient changes in response to the cost of gypsum applied allows us to calculate the magnitude of subsidy that would be required if policy makers wished to encourage gypsum application but to leave farm profitability unchanged relative to no gypsum application. For the base analysis with gypsum cost at $40 per ton, the breakeven subsidy at Hoytville would be $0.025 X 2,000 = $50 per acre of soybeans for a one ton per acre application.[4] That is, if the farmer pays $40 per ton of gypsum material and $10 per acre to apply the material, receives no yield benefit from this application, but receives a subsidy payment of $50 per treated acre, profits would be equal for treated and untreated acres. This breakeven subsidy level for our experimental results would be $42, $70, and $42 per acre for Piketon, Indiana, and Alabama, respectively.

Corn Enterprise Yields and Profitability

This study was funded primarily by a grant from the United Soybean Board. For this reason the primary focus was on the impact of the studied management systems on the soybean crop. However, one of the practices examined was a soybean following corn versus continuous soybean cropping sequence. Hence, we have 186 site-year observations for corn crop performance as impacted by gypsum treatment and for the presence or absence of a preceding cover crop. Table 8 reports the results of the combined five-year regression models for corn yields and profitability. Because of small sample sizes, individual year regressions are not reported for corn.

The top panel of Table 8 provides the regression model results for the five-year combined regression models on corn yields. The models are highly significant and explain 74 to 92 percent of the variation in corn yields across the four sites. Binary variables for year, included to control for systematic variations in corn yields due to annual weather events (relative to the 2012 base year), were significant for most years and sites.

The impact of gypsum application level on corn yields was significantly different from zero only at the Hoytville, Ohio site. Although the regression coefficient for Hoytville was significant ($P \leq 0.05$) the magnitude of that impact was relatively small: a one-pound increase in gypsum application was associated with only a 0.005 bu/ac increase in corn yield, or about 10 bu/ac for a 2,000 pound application of gypsum.

Similarly, the estimated impact of cover crops suggested little impact on corn yields. Hoytville, just as was the case for soybeans, saw a significant ($P \leq 0.01$) decrease in corn yields (13.4 bu/ac) for plots with cover crop relative to corn plots without a preceding cover crop. The estimated regression coefficients for presence of a cover crop were not statistically different from zero for the other three sites, suggesting no difference in yields due to the presence of a cover crop.

The bottom panel of Table 8 provides the regression estimates for the profitability models. Adjusted R-squared measures of goodness of fit ranged from 0.83 to 0.98. Regression coefficient estimates for gypsum application were significant ($P \leq 0.01$) and negative for two sites: per acre profits for a one-ton application were reduced by an estimated $63 and $41 per acre for Indiana and Alabama, respectively. For the other two sites, the estimated coefficients were not statistically different from zero, suggesting a near breakeven result for gypsum application. For the presence of a cover crop preceding corn, two sites display significant ($P \leq 0.01$) negative regression coefficient estimates. Hoytville estimates suggested an average $77.23 per acre reduction in profits for the five-year model, and Alabama a $37.01 reduction in profits associated with cover crop usage. Although the regression coefficients for Piketon and Indiana were negatively signed, neither was found to be statistically different from zero ($P \leq 0.10$).

Discussion and Conclusions

Although previous studies have suggested that gypsum applications and cover crops can increase crop yields and profitability, our study of soybean and corn production at four sites in three states found no supporting evidence of increased profitability of either practice. For gypsum, there was no statistically significant evidence that gypsum increased soybean crop yields at any site, and corn yields showed a significant increase only at the Hoytville site. The soil at the Hoytville site is a clay loam or silty clay loam. Gypsum is often applied to such soils to improve aggregation, water infiltration and aeration (Chen & Dick, 2011). It is somewhat surprising that a significant increase in corn yields due to gypsum application was observed for this site, but there was no indication of a yield impact for the soybean crop.

Results were more mixed and site specific for cover crop impacts on soybean yields, with a statistically significant negative effect at Hoytville, but significant positive impacts at the Piketon, Indiana and Alabama sites. Hoytville, is the northernmost site in this study and cover crop growth after soybean or corn harvest is more difficult in the more northern environments of the United States. The soybean yield improvement at the Piketon, Indiana, and Alabama sites was not sufficient to more than cover the cost of the cover crop practice, essentially resulting in a breakeven outcome for the practice at these sites. For corn, both Hoytville and Alabama showed significant decreases in profitability due to cover crop usage.

Although our results suggest little evidence of direct economic benefit to farmers of gypsum application and cover crop usage, there are limitations to our study that should be noted. Foremost, our study is limited to four specific sites and the soils that are located there. These are research sites for which the soils have typically been well maintained in terms of soil fertility, soil pH, and other soil maintenance practices. Previous research has suggested that gypsum applications may be most beneficial for soils that exhibit specific problems or structural characteristics. Had the experiment been conducted on such soils, a greater impact might have been observed.

Sulfur deficient soils also can benefit from gypsum application due to its high sulfur content (18.6%). For much of the last century, soil sulfur levels in the eastern US were sufficient for most crops. However, since the imposition of sulfur emissions standards on power plants, sulfur levels in soils have been drawn down through crop removal. If the soils at the study locations still retain a sufficient level of available sulfur for soybeans and corn crops, then the potential yield increases from gypsum may be muted. This may change over time as soil sulfur inventories are drawn down.

Another characteristic of our study may also discount potential economic benefits of gypsum applications. Our test plot research, as is typical, controls for as many variables as possible. Planting dates, fertility applications, pest treatments, and other management practices were identical for all plots at a given location. However, if gypsum applications improve water infiltration and drainage, then farmers on such soils may be able to plant earlier, perhaps capturing yield advantages of a longer growing season or of longer season varieties. Similarly, if gypsum allows greater retention or availability of soil nutrients, then fertility decisions might be altered for these circumstances, perhaps lowering fertility costs. Any such advantage of gypsum application is not captured in our study due to the standardization of management practices and planting dates across plots.

One other difference between our study and some actual on-farm gypsum practices is that producers often only apply 1-2 tons/acre of gypsum every 2-3 years, instead of every year. In the case of this economic study less frequent applications would decrease the FGD gypsum treatments costs and increase overall profitability.

Another potential limitation of the study concerns the cover crop component. Our study considers only the presence or absence of a cover crop of cereal rye. No other cover crop species or mixtures of species were studied. It is possible that other cover crop practices might have been more impactful on crop yields as suggested by the meta-analysis of corn yield response reported by Marcillo and Miguez (2017).

The economic analysis reported in this manuscript considers only private economic costs and benefits – that is the farmer's profit. However, there often are external costs or benefits of decisions taken – for instance, the costs to downstream residents of polluted waters, algae growth, increased water treatment costs, dredging of soil sedimentation, etc. To the extent that cover crops or gypsum application may reduce soil erosion, off-site movement of soil nutrients, or reduction in some other externality, then these practices have value to society beyond the farm owner. Estimation of these external costs and benefits was beyond the scope of our study.

Our study was performed assuming the farmer bore the full cost of gypsum or cover crop practices. However, to the extent that these practices positively impact environmental outcomes, society may have an interest in encouraging their adoption. The Natural Resources Conservation Service (NRCS) promotes the combined use of cover crops and gypsum in conservation tillage systems for the production of crops. Because of minimal crop residue left after harvest, and hence increased erosion hazard, soybean producers are targeted to increase the use of cover crops. Gypsum has also been approved as a best management practice and some states are cost sharing with farmers to apply gypsum to their fields. Our results suggest that the subsidy to encourage gypsum application would need to be in the range of $44 to $68 per acre for each 1 ton gypsum application if the goal is to leave farm profits unchanged. This subsidy would, however, reduce environmental costs and benefit society at large.

Endnotes

1. Because gypsum is a bulky product, transportation cost can be a significant portion of the cost of gypsum. This suggests that farmers will face varying costs for gypsum due to differences in farm proximity to the gypsum distribution center. In 2012, FGD gypsum was $28.50 per ton at the Hicksville, Ohio distribution point with delivery at $3.75 per loaded mile in truckload units of 20 tons. Thus, gypsum purchase and delivered in a radius of 60 miles costs 39.75 per ton. We have used $40 per ton delivered to the farm as our base scenario. Later, we will perform sensitivity analyses for this price.
2. The yield differential for the high oil variety was not necessarily due to the high oil trait of the variety studied, but more likely is due to other genetic differences associated with the variety.
3. Several states offer a cost sharing or subsidy to encourage gypsum usage. For instance, a cost share for gypsum application is available in select watersheds in Indiana to improve water quality. Also, the USDA National Resources Conservation Service offers a cost-share program for land application of gypsum products used to alter the physical or chemical characteristics of the soil to improve soil health and reduce the surface transport of phosphorus and other contaminants for soils that meet specific requirements.
4. This is the decrease in profits per pound of gypsum applied (the regression coefficient for gypsum) multiplied by the number of pounds of gypsum applied per acre.

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Table 1. Average soybean and corn yields by test location and year

	Year				
	2012[a]	2013	2014	2015	2016[b]
	Yield (bushels per acre), average of all plots [c]				
	Hoytville, Ohio				
Yield - Soybeans	58.94	57.73	56.90	47.11	63.42
Yield - Corn	124.24	183.92	175.78	149.48	156.35
	Piketon, Ohio				
Yield - Soybeans	12.33	59.38	31.14	63.25	47.15
Yield - Corn	91.42	88.17	87.23	175.91	139.05
	Randolph County, Indiana				
Yield - Soybeans	48.88	57.37	54.94	52.35	61.40
Yield - Corn	144.42	152.30	175.27	178.24	228.45
	Macon County, Alabama				
Yield - Soybeans	28.56	38.34	36.41	29.79	14.75
Yield - Corn	133.85	78.23	117.36	89.54	57.49

[a] There was a widespread drought that impacted all study sites to varying degrees in 2012.

[b] Macon County, Alabama experience another significant drought year in 2016.

[c] Treatments for all plots were identical except for gypsum application (3 levels), presence or absence of a preceding cover crop, rotation (continuous soybeans or soybeans following corn), and two varieties (traditional oil content versus a high-oil variety).

Table 2. Summary of base-case enterprise budgets for 4 locations, 2012-2016[a]

	2012	2013	2014	2015	2016
Hoytville, Ohio	Costs ($ per acre)[b]				
Total Variable Costs	230.14	220.50	219.44	218.13	195.07
Total Fixed Costs	252.10	280.10	280.10	280.10	256.10
Total Costs	482.24	500.60	499.54	498.23	451.17
Piketon, Ohio					
Total Variable Costs	216.60	205.30	202.92	197.94	195.07
Total Fixed Costs	198.10	229.10	229.10	220.10	212.10
Total Costs	414.70	434.39	432.02	418.03	407.17
Randolph County, Indiana					
Total Variable Costs	231.12	221.49	219.50	215.00	210.99
Total Fixed Costs	274.10	295.10	295.10	295.10	290.10
Total Costs	505.22	516.59	514.60	510.10	501.09
Macon County, Alabama					
Total Variable Costs	245.44	253.16	250.82	239.85	263.04
Total Fixed Costs	144.10	151.60	151.60	151.60	151.10
Total Costs	389.54	404.76	402.42	391.45	414.14

[a] Base-case costs represent a corn/soybean crop rotation using no-till methods and exclude costs of gypsum treatments and cover crops.

[b] Variable costs of production for the base case are derived from each state's extension enterprise budgets. Fixed costs are modeled with machinery and labor costs per acre consistent with a 2000 acre production unit. Identical machinery and labor costs are used for each site and are based on University of Minnesota Machinery Cost Estimates (Lazazus, 2012). Land rental rates for the appropriate county of each state are used.

Table 3. Regression of soybean yield and profitability, Hoytville, Ohio, by year

	Soybean Yield Models																	
	2012			2013			2014			2015			2016			2012-2016		
Variable	Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.	
Constant	58.50	2.02	***	56.40	0.75	***	56.59	1.07	***	49.80	2.06	***	63.75	1.15	***	59.13	1.26	***
Gypsum (lbs/acre)[a]	0.000	0.001		-0.001	0.000		0.000	0.001		0.001	0.001		0.000	0.001		0.000	0.000	
Cover Crop (1=yes, 0=no)	-9.67	1.73	***	0.36	0.64		-2.36	0.91	**	-11.53	1.76	***	-2.38	0.98	**	-5.12	0.82	***
High Oil variety (1=yes, 0=no)	10.79	1.73	***	3.91	0.64	***	2.21	0.91	**	-0.36	1.76		4.11	0.98	***	4.13	0.82	***
Continuous Soybeans (1=yes, 0=no)	0.22	1.73		-0.59	0.64		0.52	0.91		4.92	1.76	**	-3.11	0.98	***	0.39	0.82	
Year2013 (1 if 2013, zero otherwise)																-1.21	1.29	
Year2014 (1 if 2014, zero otherwise)																-2.04	1.29	
Year2015 (1 if 2015, zero otherwise)																-11.83	1.29	***
Year2016 (1 if 2016, zero otherwise)																4.48	1.29	***
R squared		0.79			0.68			0.40			0.73			0.64			0.68	
Adjusted R squared		0.74			0.61			0.28			0.67			0.56			0.66	
F-value		17.62	***		10.04	***		3.22	**		12.83	***		8.42	***		29.66	***
Degrees of Freedom		19			19			19			19			19			111	
	Soybean Profitability Models																	
	2012			2013			2014			2015			2016			2012-2016		
Variable	Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.	
Constant	371.97	29.12	***	232.68	9.81	***	74.30	10.83	***	-47.23	18.27	**	167.44	11.01	***	379.98	15.22	***
Gypsum (lbs/acre)[a]	-0.028	0.015	*	-0.032	0.005	***	-0.024	0.006	***	-0.018	0.010	*	-0.022	0.006	***	-0.025	0.006	***
Cover Crop (1=yes, 0=no)	-159.45	24.83	***	-18.32	8.37	**	-47.01	9.24	***	-125.52	15.58	***	-43.09	9.39	***	-78.68	9.88	***
High Oil variety (1=yes, 0=no)	157.88	24.83	***	51.01	8.37	***	22.44	9.24	**	-3.27	15.58		39.95	9.39	***	53.60	9.88	***
Continuous Soybeans (1=yes, 0=no)	13.76	24.83		2.92	8.37		15.92	9.24		55.31	15.58	***	-19.66	9.39	**	13.65	9.88	
Year2013 (1 if 2013, zero otherwise)																-130.92	15.62	***
Year2014 (1 if 2014, zero otherwise)																-303.36	15.62	***
Year2015 (1 if 2015, zero otherwise)																-451.35	15.62	***
Year2016 (1 if 2016, zero otherwise)																-215.10	15.62	***
R squared		0.82			0.81			0.73			0.81			0.75			0.91	
Adjusted R squared		0.78			0.77			0.68			0.77			0.70			0.90	
F-value		21.37	***		20.13	***		13.08	***		20.24	***		14.37	***		133.65	***
Degrees of Freedom		19			19			19			19			19			111	

* One, two and three asterisks indicate significance at the 0.10, 0.05, and 0.01 probability levels, respectively.

[a] Gypsum is applied at the rate of 0, 1,000 or 2,000 pounds per acre.

Table 4. Regression of soybean yield and profitability, Piketon, Ohio, by year

	Soybean Yield Models																	
	2012			2013			2014			2015			2016			2012-2016		
Variable	Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.	
Constant	3.98	1.05	***	55.29	3.91	***	31.21	2.84	***	65.91	3.31	***	51.23	2.15	***	11.50	2.07	***
Gypsum (lbs/acre)[a]	0.001	0.001	**	0.002	0.002		-0.001	0.001		-0.002	0.002		0.000	0.001		0.000	0.001	
Cover Crop (1=yes, 0=no)	1.56	0.90		4.12	3.33		2.72	2.42		2.97	2.82		-0.47	1.84		2.21	1.25	*
High Oil variety (1=yes, 0=no)	1.29	1.10		1.70	3.33		0.68	2.42		1.26	2.82		-9.29	1.84	***	-0.39	1.26	
Continuous Soybeans (1=yes, 0=no)	8.55	1.10	***	-2.00	3.33		-1.51	2.42		-6.25	2.82	**	1.68	1.84		-0.39	1.26	
Year2013 (1 if 2013, zero otherwise)																47.06	2.10	***
Year2014 (1 if 2014, zero otherwise)																18.81	2.10	***
Year2015 (1 if 2015, zero otherwise)																50.92	2.10	***
Year2016 (1 if 2016, zero otherwise)																34.82	2.10	***
R squared		0.89			0.15			0.10			0.27			0.58			0.89	
Adjusted R squared		0.86			0.00			0.00			0.12			0.49			0.88	
F-value		26.15	***		0.82			0.55			1.78			6.63	***		103.83	***
Degrees of Freedom[b]		13			19			19			19			19			105	

	Soybean Profitability Models																	
	2012			2013			2014			2015			2016			2012-2016		
Variable	Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.	
Constant	-358.10	16.25	***	284.38	50.98	***	-116.26	29.02	***	179.42	29.82	***	89.66	20.72	***	-252.27	23.27	***
Gypsum (lbs/acre)[a]	-0.004	0.008		0.003	0.027		-0.035	0.015	**	-0.040	0.016	**	-0.025	0.011	**	-0.021	0.009	**
Cover Crop (1=yes, 0=no)	5.23	13.85		30.74	43.48		4.68	24.75		6.36	25.43		-24.46	17.67		4.47	14.05	
High Oil variety (1=yes, 0=no)	18.81	16.97		22.17	43.48		6.91	24.75		11.46	25.43		-90.38	17.67	***	0.82	14.21	
Continuous Soybeans (1=yes, 0=no)	135.62	16.97	***	-15.51	43.48		-4.75	24.75		-46.23	25.43	*	26.91	17.67		12.18	14.21	
Year2013 (1 if 2013, zero otherwise)																571.20	23.63	***
Year2014 (1 if 2014, zero otherwise)																116.46	23.63	***
Year2015 (1 if 2015, zero otherwise)																389.85	23.63	***
Year2016 (1 if 2016, zero otherwise)																284.90	23.63	***
R squared		0.88			0.05			0.23			0.35			0.65			0.88	
Adjusted R squared		0.85			-0.16			0.06			0.21			0.58			0.87	
F-value		24.75	***		0.23			1.40			2.54	*		8.98	***		97.66	***
Degrees of Freedom[b]		13			19			19			19			19			105	

* One, two and three asterisks indicate significance at the 0.10, 0.05, and 0.01 probability levels, respectively.

[a] Gypsum is applied at the rate of 0, 1,000 or 2,000 pounds per acre.

[b] Piketon reported data only for a single soybean variety under the soybean/corn treatment in 2012.

Table 5. Regression of soybean yield and profitability, Randolph County, Indiana, by year

	Soybean Yield Models																	
	2012			2013			2014			2015			2016			2012-2016		
Variable	Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.	
Constant	48.70	1.20	***	57.86	1.08	***	57.20	1.35	***	43.76	3.39	***	63.28	1.05	***	46.67	1.98	***
Gypsum (lbs/acre)[a]	-0.001	0.001	*	-0.001	0.001	**	-0.001	0.001		-0.001	0.002		0.000	0.001		-0.001	0.001	
Cover Crop (1=yes, 0=no)	-0.58	1.03		4.26	0.92	***	4.74	1.27	***	3.91	3.20		-0.59	0.99		2.62	1.36	**
High Oil variety (1=yes, 0=no)	4.52	1.03	***	4.78	0.92	***												
Continuous Soybeans (1=yes, 0=no)	-1.18	1.03		-7.39	0.92	***	-7.14	1.27	***	14.38	3.20	***	-3.66	0.99	***	-1.12	1.36	
Year2013 (1 if 2013, zero otherwise)																8.32	2.15	***
Year2014 (1 if 2014, zero otherwise)																8.32	2.15	***
Year2015 (1 if 2015, zero otherwise)																5.72	2.15	***
Year2016 (1 if 2016, zero otherwise)																14.78	2.15	***
R squared		0.56			0.86			0.85			0.73			0.64			0.51	
Adjusted R squared		0.47			0.83			0.80			0.63			0.51			0.45	
F-value		6.16	***		29.73	***		15.71	***		7.26	**		4.77	**		7.77	***
Degrees of Freedom[b]		19			19			8			8			8			52	
	Soybean Profitability Models																	
	2012			2013			2014			2015			2016			2012-2016		
Variable	Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.	
Constant	205.61	17.70	***	235.71	13.69	***	65.49	13.52	***	-113.98	31.40	***	112.98	9.50	***	183.01	20.04	***
Gypsum (lbs/acre)[a]	-0.043	0.009	***	-0.043	0.007	***	-0.036	0.008	***	-0.030	0.018		-0.023	0.005	***	-0.035	0.008	***
Cover Crop (1=yes, 0=no)	-25.79	15.09		31.88	11.68	**	23.15	12.74		13.93	29.60		-26.53	8.95	**	7.11	13.75	
High Oil variety (1=yes, 0=no)	66.06	15.09	***	62.34	11.68	***												
Continuous Soybeans (1=yes, 0=no)	-6.63	15.09		-85.76	11.68	***	-62.02	12.74	***	141.30	29.60	***	-25.02	8.95	**	-9.52	13.75	
Year2013 (1 if 2013, zero otherwise)																19.34	21.74	
Year2014 (1 if 2014, zero otherwise)																-136.53	21.74	***
Year2015 (1 if 2015, zero otherwise)																-213.26	21.74	***
Year2016 (1 if 2016, zero otherwise)																-82.23	21.74	***
R squared		0.70			0.87			0.86			0.76			0.81			0.77	
Adjusted R squared		0.63			0.84			0.80			0.67			0.74			0.74	
F-value		10.87	***		31.34	***		15.99	***		8.59	***		11.19	***		25.06	***
Degrees of Freedom[b]		19			19			8			8			8			52	

* One, two and three asterisks indicate significance at the 0.10, 0.05, and 0.01 probability levels, respectively.

[a] Gypsum is applied at the rate of 0, 1,000 or 2,000 pounds per acre.

[b] Due to an interuption in funding in 2014, Indiana dropped the high-oil variety in 2014 and subsequent years. The five-year model also excludes the high-oil varieties in years 2012 and 2013.

Table 6. Regression of soybean yield and profitability, Macon County, Alabama, by year

	Soybean Yield Models																	
	2012			2013			2014			2015			2016			2012-2016		
Variable	Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.	
Constant	21.49	1.00	***	37.51	1.47	***	35.63	0.92	***	24.95	1.06	***	17.57	1.43	***	26.31	1.21	***
Gypsum (lbs/acre)[a]	0.002	0.001	***	0.000	0.001		-0.001	0.000		-0.001	0.001	*	0.000	0.001		0.000	0.000	
Cover Crop (1=yes, 0=no)	2.21	0.92	**	5.80	1.26	***	-0.19	0.78		4.19	0.91	***	2.75	1.22	**	2.95	0.82	***
High Oil variety (1=yes, 0=no)	5.35	0.92	***	7.92	1.26	***	8.39	0.78	***	8.09	0.91	***	-2.97	1.22	**	5.36	0.82	***
Continuous Soybeans (1=yes, 0=no)	4.12	0.92	***	-11.87	1.26	***	-5.42	0.78	***	-0.66	0.91		-6.27	1.22	***	-4.02	0.82	***
Year2013 (1 if 2013, zero otherwise)																9.74	1.30	***
Year2014 (1 if 2014, zero otherwise)																7.81	1.30	***
Year2015 (1 if 2015, zero otherwise)																1.19	1.30	
Year2016 (1 if 2016, zero otherwise)																-13.86	1.30	***
R squared		0.79			0.89			0.90			0.85			0.67			0.82	
Adjusted R squared		0.74			0.86			0.88			0.81			0.59			0.80	
F-value		17.51	***		37.55	***		41.23	***		26.17	***		9.46	***		61.17	***
Degrees of Freedom		19			19			19			19			19			111	
	Soybean Profitability Models																	
	2012			2013			2014			2015			2016			2012-2016		
Variable	Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.	
Constant	-79.66	13.51	***	82.28	19.10	***	-41.73	9.46	***	-166.34	10.28	***	-244.89	14.06	***	0.29	14.52	
Gypsum (lbs/acre)[a]	0.002	0.007		-0.026	0.010	**	-0.031	0.005	***	-0.034	0.005	***	-0.021	0.007	**	-0.021	0.006	***
Cover Crop (1=yes, 0=no)	14.29	12.51		25.09	16.29		-25.65	8.07	***	16.80	8.77	*	6.25	11.99		7.36	9.80	
High Oil variety (1=yes, 0=no)	78.24	12.51	***	103.23	16.29	***	85.33	8.07	***	73.55	8.77	***	-28.88	11.99	**	62.30	9.80	***
Continuous Soybeans (1=yes, 0=no)	70.91	12.51	***	-144.06	16.29	***	-44.51	8.07	***	4.59	8.77		-50.37	11.99	***	-32.69	9.80	***
Year2013 (1 if 2013, zero otherwise)																50.53	15.58	***
Year2014 (1 if 2014, zero otherwise)																-63.01	15.58	***
Year2015 (1 if 2015, zero otherwise)																-150.34	15.58	***
Year2016 (1 if 2016, zero otherwise)																-299.92	15.58	***
R squared		0.79			0.87			0.91			0.86			0.63			0.86	
Adjusted R squared		0.75			0.84			0.89			0.83			0.55			0.85	
F-value		18.14	***		31.91	***		48.08	***		28.47	***		7.95	***		88.60	***
Degrees of Freedom		19			19			19			19			19			111	

* One, two and three asterisks indicate significance at the 0.10, 0.05, and 0.01 probability levels, respectively.

[a] Gypsum is applied at the rate of 0, 1,000 or 2,000 pounds per acre.

Table 7. Sensitivity of regression of soybean crop profitability to soybean and gypsum prices

	Hoytville, Ohio														
	Base Analysis			Base + 20% crop price increase			Base + 20% crop price decrease			Base + 50% Gypsum Price Increase			Base + 50% Gypsum Price Decrease		
Variable	Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.	
Constant	379.98	15.22	***	552.70	18.31	***	207.26	12.14	***	379.98	15.22	***	379.98	15.22	***
Gypsum (lbs/acre)[a]	-0.025	0.006	***	-0.025	0.007	***	-0.025	0.005	***	-0.03	0.006	***	-0.015	0.006	**
Cover Crop (1=yes, 0=no)	-78.68	9.88	***	-90.24	11.88	***	-67.11	7.87	***	-78.68	9.88	***	-78.68	9.88	***
High Oil variety (1=yes, 0=no)	53.60	9.88	***	64.34	11.88	***	42.87	7.87	***	53.60	9.88	***	53.60	9.88	***
Continuous Soybeans (1=yes, 0=no)	13.65	9.88		14.26	11.88		13.04	7.87	*	13.65	9.88		13.65	9.88	
Year2013 (1 if 2013, zero otherwise)	-130.92	15.62	***	-152.94	18.79	***	-108.90	12.45	***	-130.92	15.62	***	-130.92	15.62	***
Year2014 (1 if 2014, zero otherwise)	-303.36	15.62	***	-360.55	18.79	***	-246.18	12.45	***	-303.36	15.62	***	-303.36	15.62	***
Year2015 (1 if 2015, zero otherwise)	-451.35	15.62	***	-538.29	18.79	***	-364.40	12.45	***	-451.35	15.62	***	-451.35	15.62	***
Year2016 (1 if 2016, zero otherwise)	-215.10	15.62	***	-264.13	18.79	***	-166.08	12.45	***	-215.10	15.62	***	-215.10	15.62	***
R squared		0.91			0.90			0.91			0.91			0.91	
Adjusted R squared		0.90			0.90			0.90			0.90			0.90	
F-value		133.65	***		130.45	***		138.97	***		135.68	***		132.31	***
Degrees of Freedom		111			111			111			111			111	
	Piketon, Ohio														
	Base Analysis			Base + 20% crop price increase			Base + 20% crop price decrease			Base + 50% Gypsum Price Increase			Base + 50% Gypsum Price Decrease		
Variable	Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.	
Constant	-252.27	23.27	***	-219.74	27.92	***	-284.80	18.61	***	-252.27	23.27	***	-252.27	23.27	***
Gypsum (lbs/acre)[a]	-0.021	0.009	**	-0.020	0.010	*	-0.022	0.007	***	-0.031	0.009	***	-0.011	0.009	
Cover Crop (1=yes, 0=no)	4.47	14.05		9.57	16.86		-0.63	11.23		4.47	14.05		4.47	14.05	
High Oil variety (1=yes, 0=no)	0.82	14.21		0.98	17.05		0.66	11.36		0.82	14.21		0.82	14.21	
Continuous Soybeans (1=yes, 0=no)	12.18	14.21		12.50	17.05		11.86	11.36		12.18	14.21		12.18	14.21	
Year2013 (1 if 2013, zero otherwise)	571.20	23.63	***	690.11	28.37	***	452.30	18.90	***	571.20	23.63	***	571.20	23.63	***
Year2014 (1 if 2014, zero otherwise)	116.46	23.63	***	143.58	28.37	***	89.35	18.90	***	116.46	23.63	***	116.46	23.63	***
Year2015 (1 if 2015, zero otherwise)	389.85	23.63	***	468.86	28.37	***	310.83	18.90	***	389.85	23.63	***	389.85	23.63	***
Year2016 (1 if 2016, zero otherwise)	284.90	23.63	***	340.75	28.37	***	229.06	18.90	***	284.90	23.63	***	284.90	23.63	***
R squared		0.88			0.88			0.88			0.88			0.88	
Adjusted R squared		0.87			0.87			0.87			0.87			0.87	
F-value		97.66	***		98.13	***		97.12	***		98.54	***		97.11	***
Degrees of Freedom		105			105			105			105			105	
	Randolph County, Indiana														
	Base Analysis			Base + 20% crop price increase			Base + 20% crop price decrease			Base + 50% Gypsum Price Increase			Base + 50% Gypsum Price Decrease		
Variable	Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.	
Constant	183.01	20.04	***	320.75	24.06	***	45.28	16.02	***	183.01	20.04	***	183.01	20.04	***
Gypsum (lbs/acre)[a]	-0.035	0.008	***	-0.037	0.010	***	-0.033	0.007	***	-0.045	0.008	***	-0.025	0.008	***
Cover Crop (1=yes, 0=no)	7.11	13.75		12.86	16.51		1.35	10.99		7.11	13.75		7.11	13.75	
High Oil variety (1=yes, 0=no)															
Continuous Soybeans (1=yes, 0=no)	-9.52	13.75		-13.54	16.51		-5.50	10.99		-9.52	13.75		-9.52	13.75	
Year2013 (1 if 2013, zero otherwise)	19.34	21.74		26.14	26.10		12.54	17.38		19.34	21.74		19.34	21.74	
Year2014 (1 if 2014, zero otherwise)	-136.53	21.74	***	-161.60	26.10	***	-111.46	17.38	***	-136.53	21.74	***	-136.53	21.74	***
Year2015 (1 if 2015, zero otherwise)	-213.26	21.74	***	-254.59	26.10	***	-171.92	17.38	***	-213.26	21.74	***	-213.26	21.74	***
Year2016 (1 if 2016, zero otherwise)	-82.23	21.74	***	-99.10	26.10	***	-65.36	17.38	***	-82.23	21.74	***	-82.23	21.74	***
R squared		0.77			0.77			0.78			0.78			0.76	
Adjusted R squared		0.74			0.74			0.75			0.75			0.73	
F-value		25.06	***		24.57	***		25.99	***		26.67	***		23.85	***
Degrees of Freedom		52			52			52			52			52	
	Macon County, Alabama														
	Base Analysis			Base + 20% crop price increase			Base + 20% crop price decrease			Base + 50% Gypsum Price Increase			Base + 50% Gypsum Price Decrease		
Variable	Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.		Reg. Coeff.	Std. Err.	
Constant	0.29	14.52		78.16	17.44	***	-77.57	11.60	***	0.29	14.52		0.29	14.52	
Gypsum (lbs/acre)[a]	-0.021	0.006	***	-0.020	0.007	***	-0.022	0.005	***	-0.031	0.006	***	-0.011	0.006	**
Cover Crop (1=yes, 0=no)	7.36	9.80		14.19	11.78		0.52	7.83		7.36	9.80		7.36	9.80	
High Oil variety (1=yes, 0=no)	62.30	9.80	***	74.76	11.78	***	49.83	7.83	***	62.30	9.80	***	62.30	9.80	***
Continuous Soybeans (1=yes, 0=no)	-32.69	9.80	***	-41.35	11.78	***	-24.02	7.83	***	-32.69	9.80	***	-32.69	9.80	***
Year2013 (1 if 2013, zero otherwise)	50.53	15.58	***	66.73	18.72	***	34.33	12.44	***	50.53	15.58	***	50.53	15.58	***
Year2014 (1 if 2014, zero otherwise)	-63.01	15.58	***	-72.97	18.72	***	-53.05	12.44	***	-63.01	15.58	***	-63.01	15.58	***
Year2015 (1 if 2015, zero otherwise)	-150.34	15.58	***	-180.00	18.72	***	-120.68	12.44	***	-150.34	15.58	***	-150.34	15.58	***
Year2016 (1 if 2016, zero otherwise)	-299.92	15.58	***	-355.03	18.72	***	-244.80	12.44	***	-299.92	15.58	***	-299.92	15.58	***
R squared		0.86			0.86			0.87			0.87			0.86	
Adjusted R squared		0.85			0.85			0.86			0.86			0.85	
F-value		88.60	***		87.68	***		90.28	***		91.03	***		86.91	***
Degrees of Freedom		111			111			111			111			111	

* One, two and three asterisks indicate significance at the 0.10, 0.05, and 0.01 probability levels, respectively.

[a] Gypsum is applied at the rate of 0, 1,000 or 2,000 pounds per acre.

Table 8. Corn enterprise yields and profitability

Regression, corn yields by site, 2012-2016 combined

	Hoytville, Ohio			Piketon, Ohio			Randoph County, Indiana			Macon County, Alabama		
Variable	Coefficient	Std. Err.		Coefficient	Std. Err.		Coefficient	Std. Err.		Coefficient	Std. Err.	
Constant	125.99	4.61	***	87.62	6.79	***	143.87	3.38	***	134.06	3.32	***
Gypsum (lbs/acre)	0.005	0.002	**	0.004	0.003		-0.001	0.002		0.001	0.001	
Cover Crop (1=yes)	-13.41	3.37	***	0.10	4.66		3.67	2.88		-1.95	2.02	
Year2013 (1 if 2013, zero otherwise)	59.69	5.33	***	-3.24	8.07		7.88	4.32	*	-55.90	3.73	***
Year2014 (1 if 2014, zero otherwise)	51.54	5.33	***	-4.19	8.07		30.85	4.32	***	-16.77	3.73	***
Year2015 (1 if 2015, zero otherwise)	25.25	5.33	***	84.49	6.99	***	33.82	4.32	***	-44.58	3.73	***
Year2016 (1 if 2016, zero otherwise)	32.12	5.33	***	47.63	8.07	***	84.04	4.32	***	-76.64	3.73	***
R squared		0.77			0.91			0.94			0.93	
Adjusted R squared		0.74			0.89			0.92			0.92	
F-value		29.5	***		47.84	***		69.2	***		105.4	***
Degrees of Freedom		53			29			29			47	

Regression, Corn profits by site, 2012-2016 combined

	Hoytville, Ohio			Piketon, Ohio			Randoph County, Indiana			Macon County, Alabama		
Variable	Coefficient	Std. Err.		Coefficient	Std. Err.		Coefficient	Std. Err.		Coefficient	Std. Err.	
Constant	225.65	20.62	***	19.64	28.64		322.69	14.44	***	416.70	13.56	***
Gypsum (lbs/acre)	-0.006	0.009		-0.010	0.012		-0.031	0.008	***	-0.020	0.005	***
Cover Crop (1=yes)	-77.23	15.06	***	-19.50	19.65		-6.33	12.32		-37.01	8.25	***
Year2013 (1 if 2013, zero otherwise)	-84.58	23.81	***	-286.19	34.03	***	-366.20	18.47	***	-625.63	15.22	***
Year2014 (1 if 2014, zero otherwise)	-228.57	23.81	***	-309.03	34.03	***	-375.65	18.47	***	-560.02	15.22	***
Year2015 (1 if 2015, zero otherwise)	-322.67	23.81	***	35.60	29.47		-351.90	18.47	***	-630.91	15.22	***
Year2016 (1 if 2016, zero otherwise)	-300.95	23.81	***	-137.25	34.03	***	-230.61	18.47	***	-735.96	15.22	***
R squared		0.85			0.88			0.96			0.98	
Adjusted R squared		0.83			0.86			0.95			0.98	
F-value		50.65	***		36.52	***		120.05	***		440.88	***
Degrees of Freedom		53			29			29			47	

* One, two and three asterisks indicate significance at the 0.10, 0.05, and 0.01 probability levels, respectively.

[a] Gypsum is applied at the rate of 0, 1,000 or 2,000 pounds per acre.

[b] Hoytville reported corn yields following both soybean varieties. Alabama reported corn yields following both soybean varieties except for 2012. Indiana report corn yields for both varieties only in 2012, and Piketon only in 2015.