ABSTRACT

Gypsum use on cropland offers a number of potential benefits. We surveyed a sample of farmers to learn more about their experiences with gypsum. Respondents' evaluations of gypsum suggest significant benefits in a number of areas related to soil fertility and condition, water management, and crop performance. Most estimated their gypsum use to be profitable, and their mean partial benefit to cost (B/C) ratio was 1.68. Benefits from gypsum usage were not instantaneous, but rather increased over time. Also, substantial off-farm benefits were likely realized with their gypsum use.

Old is New Again: The Economics of Agricultural Gypsum Use

By Marvin T. Batte & D. Lynn Forster

Introduction

George Washington and Benjamin Franklin: these are names that we associate with leadership in the foundation of our nation. But, they were also leaders of innovation in farming methods. One of those innovations was the introduction of the use of Plaster of Paris (gypsum) as a soil amendment (Chaptal). In the late 1700s, Franklin observed French farmers' use of gypsum on crops and was sufficiently impressed to import the product for use on his own farm. Washington was also renowned for his experimentation with new methods of agricultural production, especially for soil fertility (Mount Vernon Partnership). Plaster of Paris was one of those soil amendments that he embraced and promoted.

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Gypsum became one of the most widely used fertilizer materials during this era. Agricultural gypsum supplies were initially imported from Nova Scotia, and American farmers, considering it a miraculous fertilizer, were so anxious to acquire it that a lively smuggling trade began resulting in the so-called "Plaster War" of 1812. During these early years, the primary use of gypsum in the United States was as a soil additive. However, because the material was mined, sources were limited to natural deposits, and transportation costs made this material relatively expensive. Over time, the usage of the product diminished.

Today, we see resurgence in the use of agricultural gypsum. Soil scientists note that this material is not only important as a source of sulfur and calcium, but it also may promote changes in soil structure that facilitates better water management and plant growth.

There is also an abundance of low-cost gypsum available in the eastern United States. The Clean Air Act Amendments of 1990 required coal-fired utilities to remove sulfur dioxide (SO_2) from their emissions. The scrubber systems that have been installed by utilities produce as a byproduct a high-quality and very pure flue gas desulfurization (FGD) gypsum. Coal-fired utilities currently produce about eighteen million tons of FGD gypsum annually, with production expected to double over the next ten years. Other processing plants, including certain food grade corn fermentation plants, produce gypsum as well.

In the following sections we provide a brief discussion of the literature evaluating benefits of agricultural gypsum usage. We then provide results from our recent survey of farmers addressing agricultural gypsum usage, their evaluation of the sources of benefits, and the net economic benefits of gypsum use on their farms. Finally, we wrap up with concluding observations.

Literature Review

It has been suggested that gypsum has a number of potential beneficial impacts on soils, plant growth, and the environment. These include fertility impacts, beneficial changes in soil structure, and water management.

Plant nutrition

Calcium and sulfur are important nutrients necessary for plant growth. Gypsum ($CaSo_4$) contains both of these elements (pure gypsum is 23.3 percent calcium and 18.6 percent sulfur). Additionally, the sulfur in gypsum is in the sulfate form, a form that plants can readily utilize. For much of the last century, soil sulfur levels in the eastern United States were sufficient for most crops, due in large part to large amounts of atmospheric sulfur deposited through precipitation. The source of this sulfur was from the large number of coal-fired power plants in the region. However, since the imposition of sulfur emissions standards on power plants, sulfur levels in soils are being drawn down. Figure 1 shows the amount of wet sulfate deposition (sulfate that falls to the earth through rain, snow, and fog) on land across the United States for two points in time: prior to and following the regulation of sulfur emissions.

Kost, et al. (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 percent) 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. Hence, sulfur has value as a fertilizer nutrient in these cases. For crops requiring 30 kg/hectare (26.8 pounds/acre) of sulfur (e.g., alfalfa), they found that a positive crop response to sulfur will usually or always occur on most Ohio soils. Although similar studies have not been done in other states, we anticipate that increasing percentages of Corn Belt soils will benefit from sulfur supplementation over time as sulfur continues to be drawn down through crop removal.

Sulfur may also exhibit value through interaction effects with other fertilizer nutrients. Chen, et al. (2008) conducted field experiments to study the interaction effects of N and S fertilization on corn growth and yield. They found statistically significant interaction effects ($P<0.10$) for these nutrients in two of four study years. They concluded that sulfur applications of 30 lb./acre significantly ($P<0.05$) increased corn yield at the intermediate N rate of 120 lb./acre, and showed a general tendency to increase yield at lower N rates in 2004 and 2005. "These results suggest that application of S fertilizer, with N, can promote the uptake of N by corn in S-responsive soils," (Chen, et al., 2008, p. 1464).

Gypsum is not a liming agent even though it contains calcium. It does not affect the pH of the soil. This makes gypsum an attractive source of calcium in those cases where a crop's need for calcium is high (e.g., peanuts, melons, tomatoes, etc.) and soil pH is already in an appropriate range. However, if pH is too low, growers still need to correct this with appropriate levels of lime. For soils with highly acidic sub-soils, gypsum applications can help eliminate the toxicity that is associated with high levels of exchangeable aluminum.

Soil Structure Benefits

Soil structure influences many soil processes including water and chemical transport, soil aeration, wind and water erosion, seed germination, and root penetration (Chen, Liming, and Dick, 2011). Gypsum can improve soil physical properties by reducing soil dispersion and promoting flocculation. It helps reduce soil crust formation which improves seed emergence and plant establishment. It improves surface infiltration rates and water movement though the soil. Gypsum improves deep rooting so that water and nutrient uptake are improved in corn, wheat, and soybeans.

Highly-weathered, drought-prone soils in the southeastern United States are susceptible to runoff and erosion (Truman, et al., 2010). Rainfall patterns generate runoff-producing storms followed by extended periods of drought during the crop growing season. Gypsum has been shown to increase rainfall and/or irrigation water infiltration and retention while decreasing runoff and sediment in these soils. In a field study near Dawson, GA in 2006 and 2007, plots treated with gypsum averaged 26 percent more infiltration, 40 percent less runoff, and 58 percent less erosion than control plots (Truman, et al., 2010). Rhoton and McChesney (2011) found that FGD gypsum applications increased no-till cotton yields by increasing infiltration and soil water content, reducing runoff, ameliorating exchangeable aluminum problems, and by providing a readily available source of S, a limiting nutrient in many cotton soils. Another beneficial attribute of gypsum users in the Southeast is that gypsum mitigates the toxic aluminum layer often found in heavily weathered soils common in the south.

Environmental Benefits from Reduced Nutrient Losses/Erosion

Application of gypsum or other amendments containing calcium is a potential method to mitigate phosphorus and nitrogen losses by 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. Increased ionic strength and calcium concentration enhances the flocculation of soil particles, which reduces erosion. Erosion also decreases due to improved water infiltration caused by change in the physical condition of the soil (Ekholm et al., 2012; Murphy et al., 2010). The combined effect is less phosphorus and nitrogen moving off-site with ground water or attached to eroded soil particles.

Jaakkola, et al. (2012) incorporated the effects of gypsum on phosphorus losses into the field-scale simulation model. Their simulation results suggest gypsum reduced total phosphorus losses by 44 percent. Brauer, et al. (2005) also reported substantially reduced phosphorus runoff from field experiments. They suggest that gypsum induced changes in the aggregation of soil particles and reaction of soil phosphorus with organic constituents of soil may also be responsible for the reduced P runoff.

A Survey of Farm Gypsum Users

To learn more about the experiences of farmers who have adopted gypsum application to farmland, as well as the reasons that other farmers have not adopted gypsum usage, we administered a farmer survey addressing agricultural gypsum usage. Two lists were compiled. One included a list of 550 known Gypsoil™ brand gypsum customers who had previously applied gypsum. The second list was comprised of 3,333 subscribers of the *No-Till Farmers* magazine. This list was expected to include many non-farmers (land owners, farm advisors, farm input sales people, hobbyists, and others with an interest in agriculture) but these non-farmers were screened out with the letter of invitation and initial screening questions on the survey. Respondents from the *No-Till Farmers* list were expected to be highly representative of commercial farmers in several states who are knowledgeable about crop production and alternative production practices. For both producer lists, the survey was administered as an internet-based questionnaire during late November through early December, 2013.

Three hundred and nine responses were received from the *No-Till Farmers* group, a 9.3 percent response rate. Again, the low response rate is thought to be largely a feature of a magazine list that includes many who are not farmers. Of the respondents, 294 (95.1 percent) operated a farm in 2012 or 2013. Two hundred eighty five respondents were a principal decision maker in the business and completed at least a portion of the survey. For the Gypsoil™ customers list, 85 farmers responded, 79 (92.9 percent) were actively farming, and 77 represented a principal decision maker for the business.

Farmers were asked if they made agricultural gypsum applications in either 2012 or 2013. Twenty-six percent of farmers in the *No-Till Farmers* magazine sample reported that they applied gypsum during these years. To the extent that *No-Till Farmer* respondents are representative of commercial farmers, this low rate of current adoption suggests a very large potential for future adoption of this input. For Gypsoil customers, 87 percent made gypsum applications in either 2012 or 2013.

Gypsum adopting and non-adopting farmers were similar in terms of demographics and farm characteristics (Table 1). Gypsum adopters were approximately three years younger (significant at $P<0.05$) than non-adopters. There was no statistically significant difference ($P=0.10$) between the two groups in presence of a college degree, in total acreage farmed, or in the percentage of land control through either cash or share leases. Gypsum users had a mean gross sales nearly $300,000 greater than non-adopters ($P<0.10$), and received a higher share of gross income from livestock sales ($P<0.05$). Survey respondents represented 28 states. Gypsum users were present in 15 of those states, but three-fourths of gypsum users were concentrated in four states: Wisconsin, Illinois, Indiana, and Ohio.

Generally, non-adopters lacked knowledge of gypsum's properties and its use in crop production. Of the non-adopters, 26 percent indicated that they were not familiar with the use of gypsum as a soil amendment. Even for those non-adopters who indicated some degree of familiarity with gypsum (74 percent), the primary reason cited for not using gypsum (Table 2) was insufficient knowledge regarding agricultural gypsum (36 percent). Other reasons cited for not using gypsum were: not seeing a need for this material in their farming situation (29 percent); a perception that the input is too expensive (16 percent); and is unavailable in their area (27 percent). A modest number (5.5 percent) had previously tested the product but did not see a sufficient economic return to continue. It is important to note the landlord resistance was not a primary reason for farmers not making gypsum applications. Interestingly, just over eight percent indicated that they had been advised against use of this input by a farm supply dealer.

Gypsum was typically acquired from an intermediary such as a gypsum supplier or farm supply retailer. Table 3 provides information regarding gypsum acquisition, application method, and cost for those farmers reporting gypsum usage. Just fewer than 10 percent of these farmers purchased the gypsum at a distribution center and provided their own transportation, whereas 90 percent had the material delivered to the farm. One form of gypsum available to farmers in some regions is FGD gypsum. Although there are a number of uses for this product in addition to agricultural soil application, total supply of FGD gypsum greatly exceeds its demand in agriculture. If not applied to cropland, FGD gypsum must be used in industrial products (e.g., wallboard) or landfilled at significant cost to the power utilities. Generally, the cost of gypsum material at power plants is low; however, the material is bulky and transportation costs are significant. Transportation cost from power plants to distribution centers is borne by the gypsum supply companies, and transportation from the distribution center to the farm is borne by the farmer. The mean cost of gypsum at distribution centers reported by farmers was $20.86 per ton, with a standard deviation of $14.31 (Table 3). For farmers who had the material delivered to the farm, the mean cost of purchase and delivery was $35.09 per ton with a standard deviation of $16.87.

Land application of the gypsum material represents an additional cost to the farmer. Most survey respondents had others apply the material: about one-third (35 percent) indicated that the material was applied by the gypsum supplier, and just under a quarter of the respondents hired a custom applicator to apply the gypsum (Table 3). Twenty-eight percent applied the material using their own equipment and labor, and just over 12 percent applied the material themselves using a spreader provided by the gypsum supplier. The mean cost of custom application was $7.78/ton (standard deviation of $6.09/ton). Thus, the mean cost for a ton of gypsum purchased, delivered and custom applied at the rate of one ton/acre was $42.87/acre ($35.09/ton for material delivered to the farm plus $7.78/ton for application).

Adoption of agricultural gypsum use has been accelerating in recent years. Just under seven percent of gypsum-using farmers indicated that they first applied gypsum prior to 2000 (Table 4). Thirty-one percent first began using gypsum between 2000 and 2009. The remaining 62 percent adopted gypsum use in the period 2010-2013. We also see that the percentage of acres treated increases as the farmer gains more experience with the product. Only 15.3 percent of short-term users, here defined as those adopting since 2010, treated their entire cropland acreage, and gypsum was applied to an average of 33.8 percent of their cropland. Among longer-term users (adoption prior to 2010) a larger proportion treated their entire cropland base (29.2 percent), and these long-term users treated nearly one-half (46 percent) of their total cropland acreage. This suggests that not only can gypsum demand grow by converting more farmers to adopters, but that the percent of farmland being treated by adopters tends to grow with greater experience with the product.

The response of various crop species to gypsum applications is known to differ. Table 5 provides the percentage of treated acreage and application rates from five different crops. Although only 41 percent of gypsum-using farmers grew alfalfa, farmers treated an average 66.6 percent of their alfalfa acreage with gypsum. The most common application rates (modes) for alfalfa were 1,000 and 2,000 pounds per acre, with a mean application rate of 1,390 pounds per acre. Corn was grown by most (94 percent) gypsum-using farms, but gypsum was applied on only 50.9 percent of corn acres at a mean of nearly 1,400 pounds per acre. Soybeans, grown by 83 percent of gypsum-using farmers, received similar treatments as corn. Only about one-third of hay crops other than alfalfa (grown by only 20 percent of gypsum-using farmers) received gypsum treatment, and typically a lower rate of application was used than on the other crops.

Gypsum usage and performance

A wide range of potential benefits have been attributed to gypsum application. In order to understand farmers' perceptions of the importance of these benefits in their farm setting, we asked gypsum users to evaluate the degree to which they realized various benefits from gypsum application (Table 6). The list of benefits in Table 6 is ordered by decreasing mean importance of benefits for the full sample. At the top of the list is *gypsum helps improve crop yield*. Clearly, yield improvements derive from other benefit sources listed below (e.g., improved drainage or fertility improvements). More than 84 percent of farmers indicated that they saw yield improvement benefits on their farm, and 77 percent rated these benefits as moderately important to extremely important.

Fertility management benefits were important: *providing needed sulfur nutrients* was the second ranked item with a mean importance score (MIS) of 3.0, and 71 percent considered this benefit to be moderately to extremely important. *Providing need calcium fertility* ranked fifth (MIS=2.8), but *reducing the amount of phosphorus and potassium fertilizers* ranked near the bottom of the list with mean importance score less than 2.0.

Improvements in soil structure were reported as benefits widely observed and highly important. *Improved plant root depth* (MIS=2.9), *improved seedling emergence* (MIS=2.7), *enhanced biological activity* (MIS=2.6), *increased soil water retention* (MIS=2.6), *improved soil tilth* (MIS=2.6), *reduced soil compaction* (MIS=2.5), and *reduced crusting* (MIS=2.5) were benefits observed by more than three-fourths of users and rated as moderately to extremely important by most.

Benefits listed toward the bottom of Table 6 are those that are less frequently observed by gypsum users. Nearly two-thirds claimed that gypsum *reduced phosphorus and potassium fertilizer use*, but most did not rate these benefits as moderately to extremely important. Only about one-third of gypsum-using farmers observed *reduced sodium or aluminum toxicity*, and few rated these benefits as moderately to extremely important. This is likely due in large part to the location of gypsum-using farmers surveyed: most were located in the Midwestern United States, a region that does not widely utilize irrigation (potentially leading to sodium toxicity) nor has serious problems with aluminum toxicity.

Long-term users perceived greater benefits than short-term users. Those farmers who adopted prior to 2010 gave higher mean benefit scores for all 23 items (22 were statistically significant at $P<0.10$) than did those who adopted after 2010, as shown by the rightmost two columns in Table 6. There are two possible reasons for this result. First, it may be that benefits of gypsum applications increase over time and farmers who began applications since 2010 simply haven't realized the full benefits of gypsum application. Secondly, it is possible that those farmers with greater experience with gypsum may better understand its usage, may be getting more value from its application, or may simply better see gypsum's benefits. Regardless of which explanation one believes, it is a strong statement to see such positive reviews by farmers with significant experience with the product.

Most farmers using gypsum believed it improves crop yields (Table 7). More than three-fourths of respondents observed yield increases in alfalfa, corn, and soybeans; two-thirds observed yield increases in wheat; half observed yield increases in hay crops other than alfalfa. For the full sample, farmer estimates of crop yield increases with gypsum application ranged from 3.86 percent for wheat or other small grains to 8.52 percent for alfalfa. Again, the right two columns show mean yield improvements for long- and short-term gypsum users. Long-term gypsum users (those who began use prior to 2010) estimated higher mean yield improvements for all crops than did those who adopted gypsum use since 2010. For long-term users, mean yield increases for alfalfa, corn, and soybeans averaged about three percentage points higher than for short-term gypsum users.

Most farmers using gypsum (about 80 percent) have not changed fertilizer and lime application rates following gypsum adoption (Table 8). However, others indicated substantial changes in fertilizer rates after adopting application. For all gypsum-using farmers, reductions in N, P, and K fertilizers averaged about two percent. Long-term users indicated higher mean fertilizer reductions than did those who had adopted since 2010. Again, this differential in fertilizer use may indicate that gypsum users' understanding of fertility management increases with longer gypsum use, or that efficiency in the use of key fertilizer nutrients increases with multiple gypsum applications over time.

It is clear from farmers' responses that gypsum has value to most users, and that these benefits translate into increased yields and/or decreased fertilizer costs. However, gypsum also has costs to purchase, transport, and apply. In order to gain an insight as to the relative magnitude of these costs and benefits, we asked gypsum-using farmers to estimate the benefit/cost ratio for their farm situation. Specifically, we asked the following question with a clarifying example given: *For every dollar spent on gypsum (including hauling and application), how many extra dollars in returns do you estimate that you receive? Example: if you think that a $1,000 investment in gypsum resulted in $2000 in added crop sales and/or reduced fertilizer/input costs, then the benefit cost ratio is $2,000/1,000 = 2).* Results for this query are presented in Table 9.

The mean benefit to cost (B/C) ratio for 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 percent reported the B/C to exceed 4.0. One-third of gypsum users reported a B/C ratio less than 1.0, which might have indicated their questioning continued use of gypsum.

Again, there are important differences between short- and long-term gypsum users benefit/cost evaluations (Table 9). The mean B/C ratio was higher for long-term (1.76) versus short-term (1.63) users of gypsum, although this difference was not statistically significant at $P<0.10$. Fewer long-term gypsum users reported a B/C less than 1.0, and a greater proportion of long-term users gave B/C evaluations of 3.0 or greater.

In an alternative approach, we estimated the partial net benefits for various crops using crop yield improvements and fertilizer cost savings estimates for long-term gypsum users (Table 10). Nitrogen, phosphorus and potassium fertilizer costs savings were based on crop enterprise budget estimates provided by The Ohio State University Extension and long-term gypsum users estimates of fertilizer reductions. The lion's share of respondents' crop acreage was planted in corn and soybeans. For those crops our estimates of partial benefits and total costs of gypsum provide B/C ratios that are very similar to farmers' average ratios shown in Table 9. For alfalfa, the benefit/cost ratio is 6.6, suggesting a very large return for gypsum investment in this crop. Wheat, on the other hand, yielded a B/C ratio of 0.8 when using this method.

Even though farmers' estimates of B/C ratios given in Tables 9 and 10 suggest a healthy return on gypsum investment, we would suggest that these should be viewed as lower bounds estimates of the true B/C. Benefits received from gypsum use are more than just immediate yield impacts and reduced N, P, and K fertilizer use. For example, improved soil structure and reduced erosion enhance future yields and better water infiltration allows for improved timeliness of field operations and reduced production risks. Those benefits are more difficult to quantify than immediate yield impacts, and may be overlooked by the respondents in their B/C evaluations. Additionally, there may be significant off-farm benefits if fewer nutrients flowing off site with groundwater or eroded soils. Clearly, gypsum's role in reducing these externalities clearly increase the total (farm and societal) B/C ratios.

Conclusions

Soil scientists suggest a number of potential benefits associated with gypsum use in agriculture. These range from fertility value of sulfur and calcium nutrients, to improved soil characteristics and improved soil water management, to reduced offsite impacts of soil sediment and nutrient-laden surface water. Looking across the full range of results for the farmer survey, we are impressed with the apparent high level of satisfaction with gypsum as a soil amendment and nutrition source. Farmers' own evaluations of gypsum suggest significant benefits in a number of areas related to soil condition, water management and crop performance. Particularly important benefits were provision of sulfur and calcium nutrients, contribution to long-term soil productivity improvement, improved plant rooting depth, improvement in crop quality, and improved seedling emergence.

Farmer respondents indicated that the application of gypsum is profitable for most farmers in our study. The mean partial benefit to cost (B/C) ratio for respondents was 1.68 (each dollar of expenditure for gypsum resulted in $1.68 of benefits). The median gypsum user cited a B/C ratio of 1.5. Although one-third estimated the partial B/C ratio to be less than 1.0, 21 percent estimated this ratio to exceed 2.0 – more than two dollars return for each dollar invested in gypsum application.

A key finding is that benefits from gypsum usage are not instantaneous, but rather increase over time. Farmers who adopted prior to 2010 gave higher evaluation scores for all benefit categories than did farmers who adopted later. This strongly suggests that the benefits of gypsum use grow over time. They also reported significantly higher yields for all key crops, and greater reductions in usage of nitrogen, phosphorus, and potassium fertilizers and agricultural lime. Farmers' own estimates of partial B/C ratio showed longer-term users of gypsum gave higher values than did users with less than three years usage experience.

Finally, there is sufficient evidence to suggest that this may be a technology that will provide environmental benefits. To the extent that nitrogen, potassium, and phosphorus fertilizer nutrient applications are lessened, that gypsum helps retain these nutrients in the soil profile, that soil erosion is lessened, and that more water is retained in the soil profile, then off-site pollution of surface waters will be lessened, resulting in benefits to downstream neighbors.

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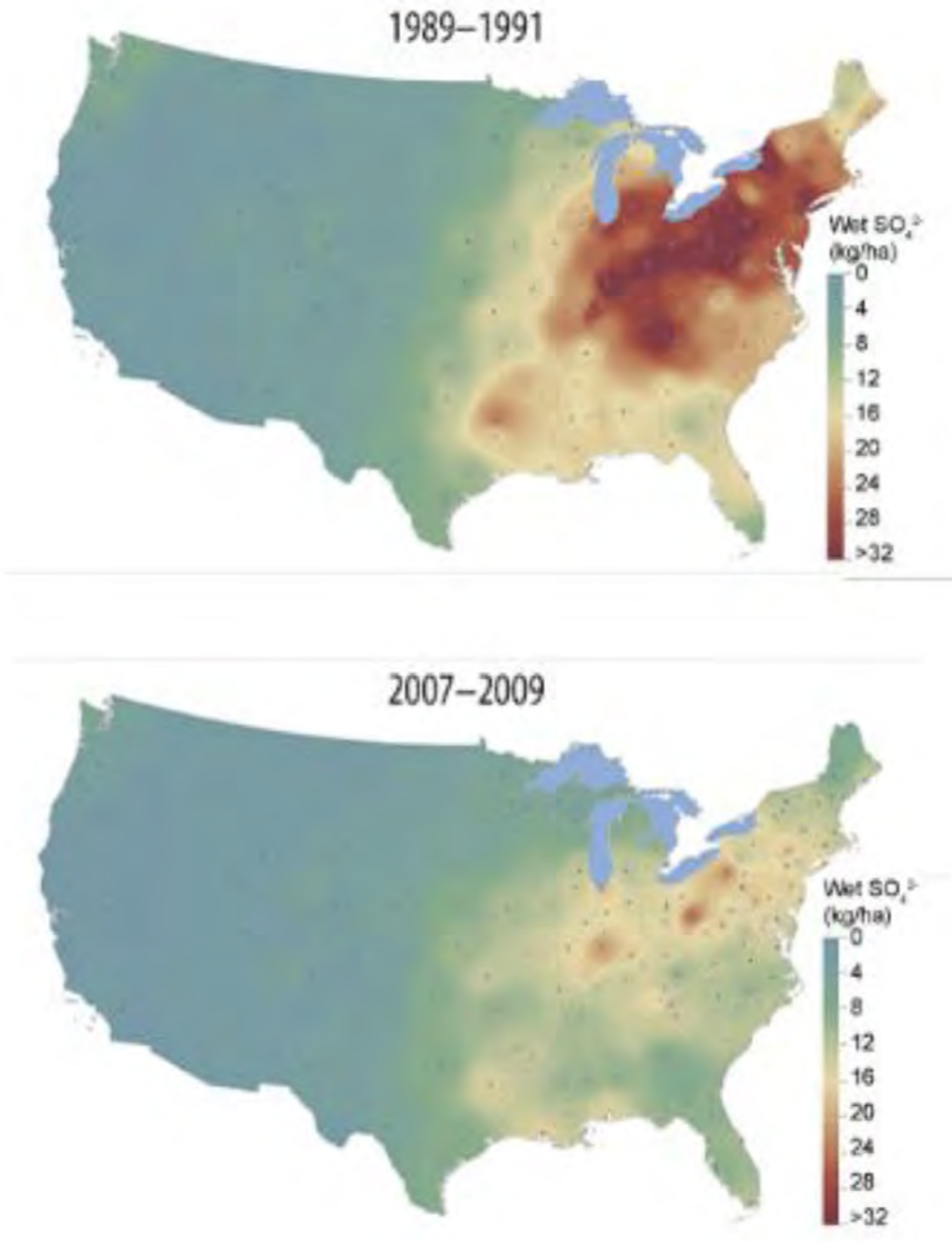
Figure 1. Mean annual wet sulfate deposition at two points in time.



Source: National Atmospheric Deposition Program, accessed July 8, 2014 at http://www.epa.gov/airmarkets/progress/ARP09_3.html.

Table 1. Demographics and business characteristics for gypsum users and non-users.[a]

Measure	Full Sample	Gypsum Users	Non-Users	
Number	294	102	192	
Percent male	99.3	99.0	99.5	
Age in years	54.1	52.0	55.3	**
Percent with a college degree	50.7	52.9	49.5	
Total acres farmed	1,266	1,237	1,281	
Percent of land share lease	11.0	8.9	12.1	
Percent of land cash lease	37.8	34.6	39.5	
Farm Gross Sales ($)	986,088	1,181,152	882,461	*
Percent of income from Livestock	16.2	20.5	13.9	**

[a] Includes both the Gypsoil™ customer and *No-Till Farmer* magazine samples.

* One, two or three asterisks indicates means for the user and non-user groups that are different at the 0.10, 0.05, and 0.01 probability levels, respectively.

Table 2. Primary reasons gypsum is not used on my farm.

Reason	Percent citing
I don't know enough about it	36.3
I don't see a need	28.8
My landlord or farm manager is against it	0.7
It's not available in my area	27.4
I tried it before but didn't see good enough results	5.5
It's too expensive	16.4
My farm supply dealer recommends against it	8.2
Other	20.5

Table 3. Sources of gypsum material, cost, and method of application.

	Percent or Mean
Percent who pick up gypsum at plant source	9.5
Percent who have gypsum delivered to farm	90.5
Cost per ton of gypsum	
For those picking up at source	$20.86
For those with delivery (including delivery charge)	$35.09
Gypsum application method (Percent)	
We apply it with our own spreader and labor	28.5
We applied with a gypsum supplier provided spreader	12.1
Gypsum supplier/local farm supply retailer applied it	35.3
It was custom-applied by applicator that spreads only	24.1
Cost per ton for commercial application	$7.78

Table 4. First year of gypsum usage and percent of acres treated.

First year gypsum was applied	Percent
Prior to 2000	3.9
2000-2009	31.0
Since 2010	62.1

	Percent treating all cropland	Percent treating a portion of cropland	Percent of cropland acres treated
Full Sample	20.70	79.30	38.30
Long-term users[a]	29.25	70.45	45.70
Short-term users[b]	15.28	84.72	33.80

[a] Those adopting 2009 or earlier.

[b] Those adopting since January 2010.

Table 5. Application of gypsum on various crops.

Crop	Percent of sampled farmers growing this crop	Mean percentage of crop acreage receiving gypsum[a]	Mean application rate (pounds per acre)	Most common application rate (pounds per acre)[b]
Alfalfa	41	66.6	1,390	1,000 & 2,000
Corn	94	50.9	1,397	2,000
Soybeans or other oilseed crops	83	48.1	1,436	2,000
Wheat or other small grains	46	45.3	1,532	2,000
Hay crops - other than Alfalfa	20	32.2	1,128	1,000

[a] Total of crop receiving gypsum / total crop acreage *100
[b] Mode(s) for the distribution.

Table 6. Benefits observed by gypsum using farmers.

	Degree of benefits observed						Mean Importance Score[a]			
Source of benefits	No benefit observed (0)	Some benefits but not important (1)	(2)	Benefits are moderately important (3)	(4)	Benefits are extremely important (5)	Full Sample	Adoption prior to 2010	Adoption 2010 and later	
Helps improve crop yields	15.6	3.7	3.7	24.8	27.5	24.8	3.2	3.7	2.9	**
Provides needed sulfur fertility	14.6	7.3	7.3	25.5	22.7	22.7	3.0	3.3	2.8	
Contributes to long-term soil improvement/productivity	22.0	2.8	10.1	17.4	20.2	27.5	2.9	3.6	2.5	***
Improve plant rooting depth/volume	18.5	7.4	6.5	23.2	25.0	19.4	2.9	3.5	2.5	***
Provides needed calcium fertility	16.5	11.9	7.3	20.2	22.9	21.1	2.8	3.3	2.5	**
Helps improve crop quality	22.6	2.8	7.6	25.5	23.6	17.9	2.8	3.2	2.5	**
Helps improve seedling emergence	20.0	9.5	6.7	21.9	26.7	15.2	2.7	3.2	2.4	**
Enhances beneficial biological activity of earthworms and soil microorganisms	22.9	7.3	11.9	21.1	19.3	17.4	2.6	3.1	2.3	**
Helps plants better absorb nutrients	22.2	8.3	11.1	24.1	16.7	17.6	2.6	3.2	2.2	***
Increases soil water retention	24.6	6.4	7.3	27.3	19.1	15.5	2.6	3.1	2.2	**
Improves yields under drought conditions	24.3	8.4	11.2	18.7	18.7	18.7	2.6	3.0	2.3	**
Improves soil tilth, increasing efficiency of machinery	25.7	2.8	15.6	20.2	18.4	17.4	2.6	3.2	2.1	***
Reduces rainwater runoff	26.2	5.6	8.4	26.2	15.9	17.8	2.5	3.1	2.2	***
Reduces soil compaction	23.6	8.2	10.9	23.6	18.2	15.5	2.5	3.0	2.2	**
Help reduce soil crusting	23.9	7.3	11.0	26.6	15.6	15.6	2.5	3.0	2.1	***
Decreases loss of soil nutrients to runoff	26.0	9.6	8.7	18.3	20.2	17.3	2.5	3.1	2.1	***
Allows for more timely field operations after rainfall due to better water infiltration	30.3	3.7	15.6	22.0	13.8	14.7	2.3	2.7	2.0	**
Decreases soil erosion	34.6	8.4	13.1	15.9	12.2	15.9	2.1	2.7	1.7	***
Reduces the amount of phosphorus fertilizer I use	31.8	16.8	19.6	18.7	5.6	7.5	1.7	2.2	1.4	***
Improves drainage enough to reduce tile investment	41.5	10.4	12.3	18.9	6.6	10.4	1.7	2.1	1.4	*
Reduces the amount of potassium fertilizer I use	33.6	15.9	20.6	15.0	7.5	7.5	1.7	2.3	1.3	***
Decreases sodium toxicity	63.0	11.1	13.0	5.6	1.9	5.6	0.9	1.3	0.6	*
Decreases Aluminum toxicity	66.7	12.0	10.2	5.6	2.8	2.8	0.7	1.0	0.6	*

[a] Mean Importance score is calculated with values of 0=no benefits, 1=Some benefits, 2, 3= Moderate benefits, 4, 5=extremely important benefits.

* One, two or three asterisks indicates means for the long- and short-term user groups that are different at the 0.10, 0.05, and 0.01 probability levels, respectively.

Table 7. Yield increases from gypsum by crop in a typical year.

Crop	Number Reporting	Percentage increase in yields: None	1-5%	6-10%	11-15%	15-20%	21-25%	More than 25%	Mean[a]: Full Sample	Adoption prior to 2010	Adoption 2010 and later	
Alfalfa	44	22.7	20.5	18.2	22.7	4.6	2.3	9.1	8.52	10.88	7.04	
Corn	92	22.8	33.7	25.0	9.8	3.3	1.1	4.4	5.95	7.56	4.76	**
Soybeans or other oilseeds	77	26.0	36.4	22.1	11.7	0.0	3.9	0.0	4.90	6.54	3.60	**
Wheat or other small grains	46	32.6	45.7	13.0	4.4	0.0	0.0	4.4	3.86	5.00	2.81	
Hay crops - other than alfalfa	14	50.0	14.3	21.4	7.1	0.0	0.0	7.1	4.82	5.50	4.44	

[a] Means are calculated at the yield midpoint for each yield increase class. If greater than 25%, 27.5% is used in the mean calculation.

* One, two or three asterisks indicates means for the long- and short-term user groups that are different at the 0.10, 0.05, and 0.01 probability levels, respectively.

Table 8. Impact of gypsum usage on fertilizer and lime needs to achieve a given yield.

	Fertilizer use has increased	Fertilizer use has not changed	Fertilizer use decreased 1-5%	Fertilizer use decreased 6-10%	Fertilizer use decreased 11-15%	Fertilizer use decreased 16-20%	Fertilizer use decreased 21-25%	Fertilizer use decreased more than 25%	Mean[a] Full sample	Adoption prior to 2010	Adoption 2010 and later	
Phosphorus	2.9	78.9	4.8	6.7	0.0	2.9	0.0	3.9	1.90	4.20	0.30	**
Potassium	1.9	81.6	1.9	4.9	1.9	3.9	1.0	2.9	2.16	4.80	0.04	***
Nitrogen	2.0	81.4	3.9	6.9	0.0	2.9	0.0	2.9	1.74	4.00	0.20	***
Lime	5.0	75.3	3.0	5.9	1.0	2.0	2.0	5.9	2.57	4.10	1.50	

[a] Means calculated using midpoint values for each fertilizer reduction class. For "fertilizer use has increased, a value of -10% (10% increase) is used. For "fertilizer use decreased more than 25%" a value of 27.5% is used.

* One, two or three asterisks indicates means for the long- and short-term user groups that are different at the 0.10, 0.05, and 0.01 probability levels, respectively.

Table 9. Benefit to cost ratio for gypsum use.[a]

Benefit to cost ratio	Full Sample	Adoption prior to 2010	Adoption 2010 and later
		Percent	
Benefit to cost < 1	33.3	28.1	36.7
Benefit to cost of 1.0 to 2.0	45.7	50.0	42.9
Benefit to cost of 2.01 to 3.0	14.8	9.4	18.4
Benefit to cost of 3.01 to 4.0	3.7	9.4	0.0
Benefit to cost > 4. 0	2.5	3.1	2.0
Median benefit to cost ratio	1.50	1.50	1.50
Mean benefit to cost ratio	1.68	1.76	1.63

[a] The survey asked: *For every dollar spent on gypsum (including hauling and application), how may extra dollars in returns do you estimate that you receive? Example: if you think that a $1,000 investment in gypsum resulted in $2000 in added crop sales and/or reduced fertilizer/input costs, then the benefit cost ratio is $2,000 / 1,000 = 2).*

Table 10. Estimated revenue changes per acre resulting from gypsum application for long-term users.

Crop	Base Yield (per acre)	Yield change[a]	Price per unit ($)	Revenue change ($/ac)	N, P, K Fertilizer savings ($/ac)[a]	Gypsum cost ($/ac)[a]	Partial net benefits ($/ac)	B/C
Alfalfa (Ton/ac)	6	10.88%	225	$ 146.88	9.13	23.65	132.36	6.6
Corn (bu/ac)	170	7.56%	4.4	$ 56.55	6.35	31.65	31.25	2.0
Soybeans (bu/ac)	50	6.54%	12.5	$ 40.88	2.93	31.84	11.96	1.4
Wheat (bu/ac)	65	5.00%	6.9	$ 22.43	5.37	32.72	-4.93	0.8

[a] Yield change percentages, fertilizer cost reduction and Gypsum application rates are based on response from long-term gypsum users.