Accepted for publication 28 September 2011. Published 29 November 2011.

# Using Ground Eggshells as a Liming Material in Corn and Soybean Production

**John D. Holmes,** Extension Field Agronomist, Iowa State University Extension Office, 210 1st St. SW, Clarion, IA 50525;
**John E. Sawyer,** Professor, Department of Agronomy, 2104 Agronomy Hall, Iowa State University, Ames, IA 50011;
**Paul Kassel,** Extension Field Agronomist, Iowa State University Extension Office, 110 W. 4th St., Spencer, IA 51301; and
**Dorivar Ruiz Diaz,** Assistant Professor, Department of Agronomy, Kansas State University, 2711 Throckmorton Hall, Manhattan, KS 66506

Corresponding author: John Sawyer. jsawyer@iastate.edu

Holmes, J. D., Sawyer, J. E., Kassel, P., and Ruiz Diaz, D. 2011. Using ground eggshells as a liming material in corn and soybean production. Online. Crop Management doi:10.1094/CM-2011-1129-01-RS.

## Abstract
Eggshells are a byproduct from egg breaking facilities and potentially useful as an amendment for liming soils. Ground eggshells were evaluated as a liming material at two sites in Iowa with acidic surface soil. The study compared soil pH response and corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] grain yield with multiple rates of agricultural lime (aglime) and ground eggshells (eggshells). Eggshells proved to be an effective liming material and land application for soil pH correction offers a practical use of eggshells. However, the reported effective calcium carbonate equivalent (ECCE) value for the ground eggshells was low as soil pH increase was greater than found with equivalent ECCE rates from aglime. Based on the soil pH responses in this study, it is suggested that ground eggshell ECCE values should be increased 2 to 3 times from reported values. That correction should help avoid over-application and unintended high soil pH levels.

## Introduction
Although the majority of eggs produced in the United States are transported to market as whole eggs, in 2010 32% of all eggs were broken on site, shipped as liquid eggs, and used in manufactured egg products (4). New laying facilities are being built with integration of egg production and on-site breaking. In 1997, more than 50 million cases of eggs (30 dozen eggs per case) were used as processing eggs. These eggs produced approximately 120,000 ton of broken eggshells (2). Egg production has increased over time, and in 2010, 69 million cases of eggs were broken, shipped, and used in processed products (9). This is increasing the local concentration of eggshells needing appropriate use. Disposing of eggshells in landfills has become a serious concern as it is both expensive and uses valuable landfill space (1,11), and potential benefits that could be derived from liming and nutrient application to crop production fields are lost.

Some egg producers take eggshells to landfills; others stockpile and apply to farm fields with poultry manure. Farmers and crop advisers want to know if eggshells have value as a liming source, and if so, at what rate equivalent to quarry limestone should they be applied.

Eggshells are comprised mainly of calcium carbonate (94 to 97%), which should neutralize soil acidity. However, studies with soil application are quite limited. In 1994, Mitchell evaluated the usefulness of ground eggshells as a liming material in a greenhouse study (8). He concluded that finely ground eggshells were an effective liming material but cautioned that coarsely ground eggshells were essentially ineffective. However, eggshells are different than quarry limestone as they are produced by a hen, are of recent origin, and have unique characteristics including an extensive pore structure, membrane layers, and complex mineral formation with a protein matrix foundation (3). These properties could affect the relationship of eggshell particle size on reactivity in soil. Due to lack of research with field application of eggshells in row crop production, questions remain regarding neutralization effectiveness, soil pH change, and crop response.

## Study Goals

This study was designed to evaluate the usefulness of ground eggshells as a liming source in field trials at two sites in Iowa. The study compared soil pH change and crop yield in a corn-soybean rotation with multiple rates of quarry derived agricultural limestone (aglime) and ground eggshells (eggshells). The aglime and eggshell rates were based on reported effective calcium carbonate equivalent (ECCE). Therefore, the applicability of ECCE for use with eggshells was also evaluated.

## Calculation of ECCE

For each site, samples of the aglime and eggshells were collected prior to application and analyzed for ECCE. Table 1 provides the physical and chemical analyses for the materials used at both sites. The ECCE determination is described in the Iowa Agricultural Limestone Act (5), and is determined by multiplying the calcium carbonate equivalent (CCE) by the total fineness efficiency and dry matter percentage. The total fineness efficiency is the sum of the products of a fineness factor multiplied by the percentage of particles passing through 4-mesh, 8-mesh, and 60-mesh screens (Table 1). Fineness factors are 0.1, 0.3, and 0.6 for the 4-, 8-, and 60-mesh screen sizes, respectively.

Table 1. Aglime and eggshell physical and chemical analyses, dry matter basis.

| Property | | Kanawha | | Sutherland | |
|---|---|---|---|---|---|
| | | Aglime | Eggshells | Aglime | Eggshells |
| Moisture (%) | | 1 | 16 | 4 | 17 |
| Particle size (% passing) | sieve no. 4 | 100 | 100 | 100 | 100 |
| | sieve no. 8 | 98 | 55 | 99 | 52 |
| | sieve no. 60 | 67 | 1 | 68 | 2 |
| CCE[x] (%) | | 97 | 74 | 97 | 56 |
| ECCE[y] (lb/ton) | | 1,540 | 400 | 1,570 | 300 |
| N (%) | | BDL[z] | 1.16 | BDL | 7.40 |
| P (%) | | <0.01 | 0.09 | 0.18 | 0.07 |
| K (%) | | <0.01 | 0.10 | 0.02 | 0.08 |
| Ca (%) | | 35.0 | 36.5 | 39.1 | 28.0 |
| Mg (%) | | 0.16 | 0.41 | 0.16 | 0.32 |

[x] CCE = calcium carbonate equivalent.
[y] ECCE = effective calcium carbonate equivalent.
[z] BDL = below detection limit.

Research has shown that more finely ground limestone particles react quicker with soil than more coarsely ground particles (reference 7 as an example). A key research question regarding ground eggshells is will they neutralize soil acidity and increase pH. The eggshells used in the study at each site had high calcium carbonate equivalent, as expected (Table 1). Also, all of the eggshell material used at both sites passed through the 4-mesh sieve, but only 52 to 55% of the passed through the 8-mesh sieve and only 1 to 2% passed the finest 60-mesh sieve (Table 1). Therefore, the ECCE values for the eggshells were considerably lower than the aglime because of the high fraction of coarser particles (Table 1).

## Description of Experimental Sites

The study was conducted at two sites: the Iowa State University Northern Research Farm near Kanawha in north-central Iowa, and at the Iowa State University Northwest Research Farm near Sutherland in northwest Iowa. The soil at the Kanawha site was a Clarion loam that formed in glacial till and has a calcareous subsoil. The soil at the Sutherland site was a Galva silty clay loam that formed in loess and has a neutral to moderately alkaline subsoil. The soil pH in the 0- to 6-inch depth at the beginning of the study at each site was acidic (Table 2) and indicated lime application needed for corn and soybean production (10). A soil pH of 6.5 (0- to 6-inch depth) is considered sufficient for corn and soybean production in Iowa. Based on the initial soil buffer pH at each site (Table 2), the recommended application of pure fine calcium carbonate would be 3,500 lb/acre for the Kanawha site and 5,000 lb/acre for the Sutherland site (10).

Table 2. Initial routine soil tests for each site.

| Test | Kanawha | Sutherland |
|---|---|---|
| pH | 5.7 | 5.4 |
| $pH_b$[x] | 6.4 | 6.2 |
| STP[y] (ppm) | 24 | 27 |
| STK[y] (ppm) | 92 | 200 |
| OM[y] (%) | 4.4 | 4.8 |
| CEC[y] (meq/100 g) | 16 | 21 |

[x] Shoemaker-McLean-Pratt (SMP) buffer pH.

[y] STP = Bray P-1 soil test P; STK = ammonium acetate soil test K; OM = soil organic matter; CEC = estimated cation exchange capacity from extractable K, Ca, Mg, Na, and $pH_b$.

## Testing Ground Eggshells as a Liming Material

Rates of eggshells and aglime were applied at both sites based on the reported material ECCE values; applied at rates of 0, 500, 1,000, 2,000, 4,000, and 8,000 lb ECCE/acre. Application dates were April 2002 at Kanawha, and May 2003 at Sutherland. Since the ECCE values were quite different between the eggshells and aglime, the material dry matter rates varied considerably (Table 3). Treatments were arranged as a complete factorial in a randomized complete block and replicated five times at Kanawha and four times at Sutherland. At both sites, materials were applied to soybean stubble and incorporated prior to planting by disking and field cultivation. Plots were initially planted to corn following the treatment application. Soybean was planted the following year, and a corn-soybean rotation was followed at both sites throughout the experiment (7 crop years at each site). The study areas were chisel plowed to a depth of 8 to 10 inches following corn. No fall tillage was done following soybean. The areas were field cultivated in the spring prior to planting corn and soybean.

Soil samples, 0- to 6-inch depth, were collected from each plot prior to the treatment applications and following harvest annually. Plots were machine harvested and grain yield calculated using 15% moisture for corn and 13% moisture for soybean. Nitrogen (average 155 lb N/acre at Kanawha and 135 lb N/acre at Sutherland), phosphorus, and potassium fertilizers were applied uniformly across the entire study areas before corn to alleviate any potential yield responses from nutrients applied with the treatments or soil test differences.

Table 3. Aglime and eggshell treatment applications, dry matter basis.

| **ECCE rate**[x] (lb/acre) | **Kanawha** | | **Sutherland** | |
|---|---|---|---|---|
| | **Aglime** | **Eggshells** | **Aglime** | **Eggshells** |
| | (lb material/acre) | | | |
| 500 | 650 | 2,500 | 635 | 3,300 |
| 1,000 | 1,300 | 5,000 | 1,270 | 6,600 |
| 2,000 | 2,600 | 10,000 | 2,540 | 13,200 |
| 4,000 | 5,200 | 20,000 | 5,080 | 26,400 |
| 8,000 | 10,400 | 40,000 | 10,160 | 52,800 |

[x] The effective calcium carbonate equivalent, ECCE, of each material was used to determine the treatment application rate. See Table 1 for the aglime and eggshell ECCE values.

PROC GLIMMX, SAS Ver. 9.2 (SAS Institute Inc., Cary, NC) was used to statistically analyze soil pH by site and month after application, and analyze crop yields within site by year and across years. Blocks were considered random, and for crop yield analysis across years, year was considered random in the model. Confidence intervals (95%) for soil pH values were calculated within a sample date to indicate differences between materials. To determine the relative effectiveness of ECCE for eggshells, and to estimate an ECCE correction factor for eggshells based on aglime soil pH response, a linear regression equation was fit to soil pH for the first four ECCE rates for each material at 18, 42, at 78 months after application. Those four rates were used as they provided a linear pH response with both materials, and avoided any plateau response from soil pH approaching neutrality with the highest rates. The ECCE correction factor was then calculated as the ratio of the linear slope for each material at each sampling date and site.

## Soil pH Response to Material Applications

The soil pH was increased by aglime and eggshell application at both sites and all sampling dates (Table 4 and Figs. 1 and 2). At 6 and 18 months after application at Kanawha, and at 6 months at Sutherland, the soil pH was similar with the aglime and eggshells. However, at 18 months for Sutherland and after 18 months for Kanawha, soil pH was increased to a higher level with the eggshells at most ECCE rates. The greater change in soil pH soon after application with aglime relative to eggshells was likely due to fine particles (passing 60 mesh screen) in the aglime reacting quickly, and that were not present in the eggshells, but with more time greater reactivity and pH increase from the eggshells. Based on the reported ECCE value for each material and respective ECCE application rates, eggshells increased pH more than aglime over the 6.5-year period. This is an indication that the calculated ECCE values for the eggshells were low. With the study only conducted for seven crop seasons, it is unknown how long the eggshell or aglime applications would maintain soil pH at a given level. Throughout the study period, each material was relatively effective at maintaining maximum pH correction for the specific application rate.

The soil pH increase plateaued with the highest two eggshell rates due to the pH being near 7.0 (Figs. 1 and 2), therefore limiting further increase as the dissolution of calcium carbonate would decrease and thus slow further pH increase. This pH plateau with high ECCE rates was not found with the aglime as even with the highest rate the pH was less than 7.0 and pH increased across all years and both sites with the highest rate. This is another indication that the reported ECCE value for the eggshells was low. Based on the initial soil pH, buffer pH, and incorporation depth, an aglime rate of approximately 4,000 to 5,000 lb ECCE/acre would be recommended for these soils to correct pH to 6.5 for corn and soybean crops in Iowa (10). At the 4,000 lb ECCE/acre aglime rate, the soil pH was corrected to approximately that level at both sites.

Table 4. Statistical analyses for soil pH by sampling date and site.

| Site | Source of variation | Sample date (month after application) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 6 | 18 | 30 | 42 | 54 | 66 | 78 |
| | | p > F | | | | | | |
| **Kanawha** | Material (M) | 0.055 | 0.612 | <0.001 | <0.001 | 0.005 | <0.001 | <0.001 |
| | Rate (R) | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| | M x R | 0.032 | 0.032 | 0.126 | <0.001 | <0.001 | <0.001 | <0.001 |
| **Suther -land** | Material (M) | 0.893 | 0.008 | <0.001 | <0.001 | 0.005 | <0.001 | <0.001 |
| | Rate (R) | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| | M x R | 0.115 | 0.014 | <0.001 | 0.305 | <0.001 | 0.003 | <0.001 |

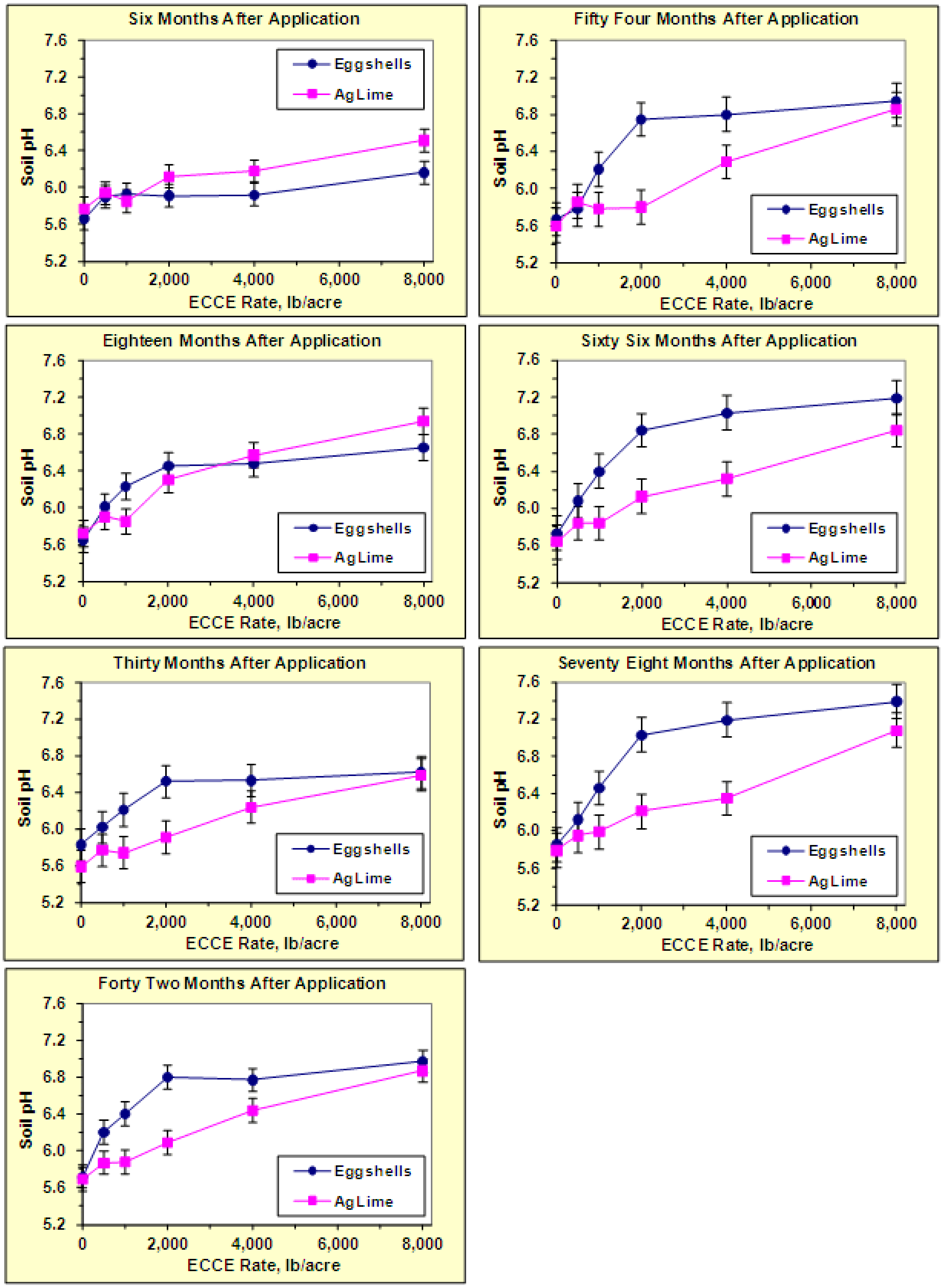


Fig. 1. Soil pH as influenced by liming material and application rate, Kanawha. Bars at each mean represent the confidence interval within a sample date (*P* = 0.05).

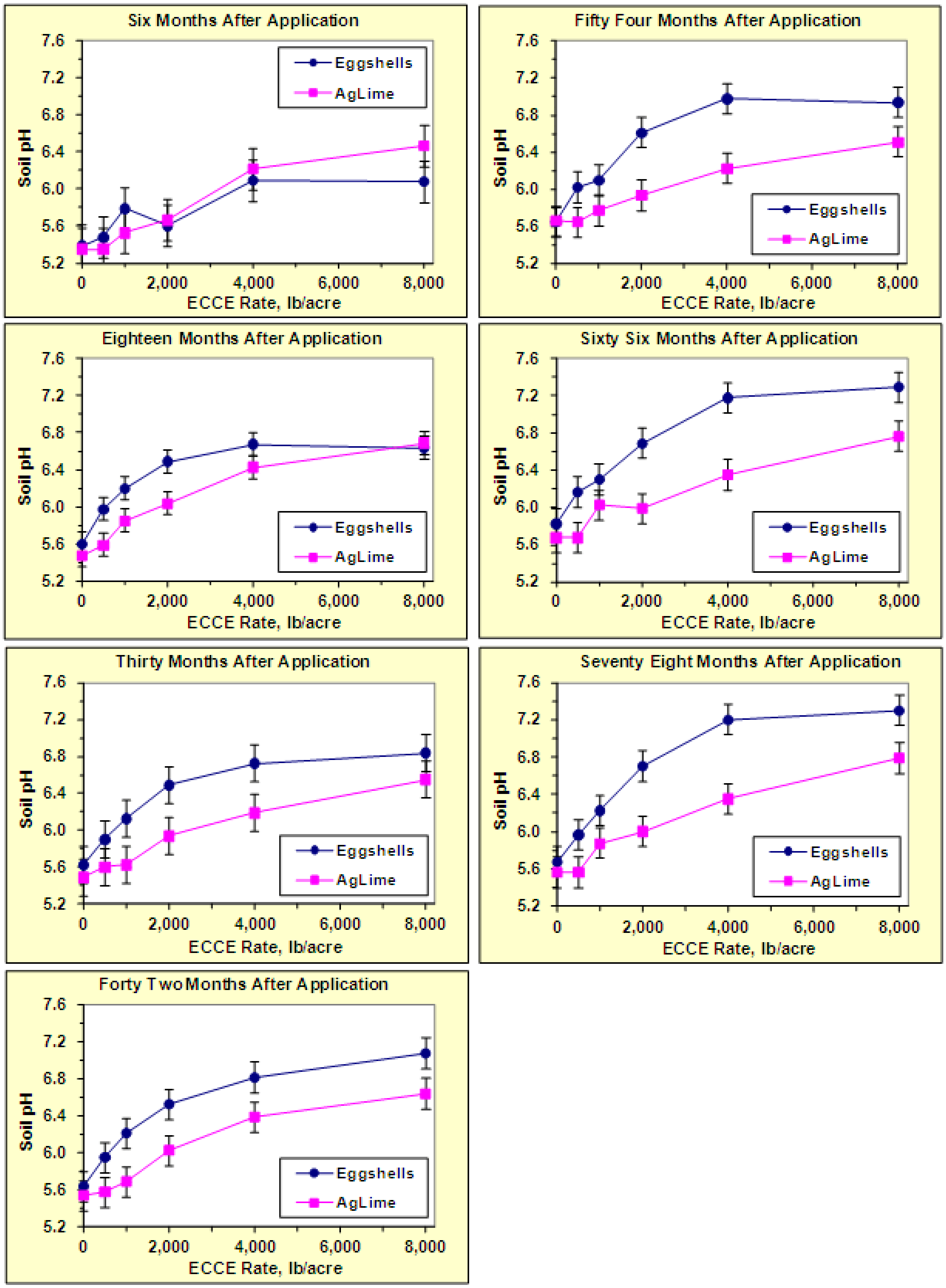


Fig. 2. Soil pH as influenced by liming material and application rate, Sutherland. Bars at each mean represent the confidence interval within a sample date (*P* = 0.05).

## Eggshell ECCE Adjustment

Based on the measured soil pH increases with eggshell and aglime rate applications, the method for calculating ECCE was incorrect for the eggshells. Using the aglime soil pH change as a baseline, an ECCE correction factor was calculated for the eggshells. That calculation was based on the linear slopes of the measured pH for the first four ECCE rates (0, 500, 1000, and 2000 lb ECCE/acre) of each material at 18, 42, and 78 months after application at each location (Table 5). The linear slope for the eggshells was greater than for the aglime. Therefore, the eggshells were increasing soil pH more at each ECCE application rate than the aglime.

Table 5. Linear slope from the equation fit to mean soil pH for the first four ECCE rates (0, 500, 1000, and 2,000 lb ECCE/acre) for each material at 18, 42, and 78 months after application, and the calculated correction factor for the eggshell ECCE.

| **Site** | **Sampling date** (month) | **Material** | **Linear equation** | | | | **ECCE correction factor**[x] |
|---|---|---|---|---|---|---|---|
| | | | **Intercept: pH** | **Slope: ΔpH/ΔECCE** | $R^2$ | $p > F$ | |
| Kanawha | 18 | Aglime | 5.7 | 0.000275 | 0.88 | 0.062 | – |
| | | Eggshells | 5.8 | 0.000383 | 0.92 | 0.042 | 1.4 |
| | 42 | Aglime | 5.7 | 0.000186 | 0.94 | 0.031 | – |
| | | Eggshells | 5.8 | 0.000512 | 0.95 | 0.026 | 2.8 |
| | 78 | Aglime | 5.8 | 0.000200 | 0.97 | 0.013 | – |
| | | Eggshells | 5.8 | 0.000595 | 1.00 | <0.001 | 3.0 |
| Suther-land | 18 | Aglime | 5.5 | 0.000290 | 0.96 | 0.021 | – |
| | | Eggshells | 5.7 | 0.000427 | 0.94 | 0.029 | 1.5 |
| | 42 | Aglime | 5.5 | 0.000254 | 0.95 | 0.027 | – |
| | | Eggshells | 5.7 | 0.000437 | 0.97 | 0.014 | 1.7 |
| | 78 | Aglime | 5.5 | 0.000245 | 0.86 | 0.071 | – |
| | | Eggshells | 5.7 | 0.000508 | 1.00 | 0.001 | 2.1 |

[x] Linear slope for eggshells divided by linear slope for aglime.

Using aglime as the standard, the linear regression equation slopes presented in Table 5 indicate that the calculated ECCE for the eggshells underestimated the actual ECCE. An ECCE correction factor was calculated for each sampling date at each location by dividing the linear slope for the eggshells by the linear slope for the aglime (Table 5). The correction factors were lowest at 18 months and fairly consistent at 42 and 78 months. These timing differences were likely due to continued material dissolution after 18 months. Using the longer sampling periods, an average correction factor for the eggshells at the Kanawha site would be 2.9 and for the Sutherland site 1.9. This means that eggshells, as used in this study, should have the reported ECCE value increased by 2 to 3 times. The need for a correction factor is likely due to several eggshell characteristics, including an extensive pore structure and protein matrix, which increases the reactivity more than expected based solely on the fineness of grind. Using that correction would improve ECCE and ground eggshell application rates to provide expected soil pH correction.

## Corn and Soybean Yield Response to Material Application

At Kanawha, corn yield increased with application rate, and there was no difference in rate response between materials (Tables 6 and 7). The corn yield increase with rate occurred in two years (Table 6) and as an average across years (Table 7). In 2002, the first year of application, mean corn yield was higher with the eggshell application that aglime, although the yield difference was small. At Kanawha, there was a soybean yield decline with application rate in one year (2007) and as an average across years (Tables 6 and 7). It is unknown why that occurred, and the yield decline was the same with both materials. In 2005, the mean soybean yield was higher with aglime application than eggshells, but the difference was only 0.9 bu/acre. No difference between materials was found across years. Based on the initial pH at the Kanawha site, there would be an expectation of yield increase from liming. However, the soil at that site has a high subsoil pH, and the suggested pH level before making a lime application for corn and soybean is less than 6.0 (10). Therefore yield response, if it occurred, would be expected to be low. In addition, soybean grown in the Kanawha area can have issues with iron deficiency chlorosis and soybean cyst nematode (*Heterodera glycines*), both with increased potential at high soil pH. While neither was visually observed with any material rate in the study, high pH with the highest application rates could have resulted in a negative yield influence.

Table 6. Corn and soybean grain yield as influenced by aglime and eggshell application, Kanawha.

| **ECCE rate** (lb/acre) | **Corn** (bu/acre) | | | | **Soybean** (bu/acre) | | |
|---|---|---|---|---|---|---|---|
| | **2002** | **2004** | **2006** | **2008** | **2003** | **2005** | **2007** |
| **Aglime** | | | | | | | |
| 0 | 175 | 194 | 184 | 161 | 38.3 | 55.5 | 62.1 |
| 500 | 174 | 192 | 188 | 166 | 37.3 | 55.9 | 62.9 |
| 1000 | 182 | 198 | 192 | 156 | 38.5 | 54.6 | 64.1 |
| 2000 | 174 | 199 | 186 | 160 | 38.3 | 54.9 | 64.7 |
| 4000 | 175 | 202 | 191 | 157 | 36.9 | 55.6 | 65.0 |
| 8000 | 185 | 197 | 191 | 159 | 36.0 | 55.8 | 59.5 |
| Mean | 178 | 197 | 189 | 160 | 37.6 | 55.4 | 63.1 |
| **Eggshells** | | | | | | | |
| 0 | 173 | 192 | 188 | 164 | 37.4 | 54.9 | 65.5 |
| 500 | 178 | 191 | 190 | 163 | 39.2 | 53.9 | 64.6 |
| 1000 | 181 | 194 | 183 | 165 | 37.9 | 55.5 | 63.7 |
| 2000 | 183 | 204 | 197 | 156 | 36.4 | 55.4 | 60.1 |
| 4000 | 188 | 202 | 192 | 161 | 37.7 | 53.2 | 61.6 |
| 8000 | 185 | 203 | 192 | 167 | 37.4 | 54.2 | 57.8 |
| Mean | 181 | 198 | 190 | 163 | 37.7 | 54.5 | 62.2 |
| **Statistics** | $p > F$ | | | | | | |
| Material (M) | 0.034 | 0.643 | 0.462 | 0.352 | 0.767 | 0.050 | 0.342 |
| Rate (R) | 0.007 | 0.001 | 0.537 | 0.837 | 0.301 | 0.876 | 0.008 |
| M x R | 0.098 | 0.421 | 0.278 | 0.815 | 0.126 | 0.148 | 0.100 |

Table 7. Corn and soybean grain yield across years as influenced by aglime and eggshell application, Kanawha.

| **ECCE rate** (lb/acre) | **Corn** (bu/acre) | | | **Soybean** (bu/acre) | | |
|---|---|---|---|---|---|---|
| | **Aglime** | **Eggshells** | **Mean** | **Aglime** | **Eggshells** | **Mean** |
| 0 | 178 | 179 | 179 | 52.0 | 52.6 | 52.3 |
| 500 | 180 | 181 | 180 | 52.0 | 52.6 | 52.3 |
| 1000 | 182 | 181 | 181 | 52.4 | 52.4 | 52.4 |
| 2000 | 180 | 185 | 182 | 52.7 | 50.7 | 51.7 |
| 4000 | 181 | 186 | 184 | 52.5 | 50.9 | 51.7 |
| 8000 | 183 | 187 | 185 | 50.4 | 49.8 | 50.1 |
| Mean | 181 | 183 | | 52.0 | 51.5 | – |
| **Statistics** | ***p > F*** | | | | | |
| Material (M) | 0.067 | | | 0.268 | | |
| Rate (R) | 0.044 | | | 0.013 | | |
| M x R | 0.504 | | | 0.129 | | |

At Sutherland, there was no effect of aglime or eggshell application on corn yield at any application rate (Tables 8 and 9). Soybean yield increased with increasing application rate for both materials in 2006 and across years. In 2006, the mean eggshell application resulted in a higher soybean yield, but not across years. The crop yield response at Sutherland was opposite that at Kanawha. However, the Sutherland site has a neutral subsoil pH, and an initial lower surface pH than at Kanawha. Prior research at Sutherland has shown the same crop yield response to lime application (6).

Table 8. Corn and soybean grain yield as influenced by aglime and eggshell application, Sutherland.

| ECCE rate (lb/acre) | Corn (bu/acre) | | | | Soybean (bu/acre) | | |
|---|---|---|---|---|---|---|---|
| | **2003** | **2005** | **2007** | **2009** | **2004** | **2006** | **2008** |
| **Aglime** | | | | | | | |
| 0 | 101 | 189 | 177 | 222 | –[x] | 33.9 | 56.4 |
| 500 | 100 | 194 | 177 | 228 | – | 34.5 | 57.9 |
| 1000 | 102 | 193 | 184 | 233 | – | 37.0 | 60.1 |
| 2000 | 100 | 191 | 188 | 232 | – | 37.2 | 62.2 |
| 4000 | 100 | 191 | 187 | 228 | – | 38.3 | 61.5 |
| 8000 | 102 | 192 | 188 | 226 | – | 39.5 | 62.4 |
| Mean | 101 | 192 | 184 | 228 | – | 36.7 | 60.1 |
| **Eggshells** | | | | | | | |
| 0 | 100 | 192 | 184 | 232 | – | 36.6 | 59.5 |
| 500 | 102 | 196 | 182 | 228 | – | 38.5 | 61.2 |
| 1000 | 104 | 194 | 185 | 230 | – | 38.9 | 60.1 |
| 2000 | 102 | 195 | 186 | 236 | – | 39.2 | 64.7 |
| 4000 | 99 | 197 | 181 | 225 | – | 38.0 | 63.6 |
| 8000 | 96 | 194 | 190 | 232 | – | 39.4 | 61.6 |
| Mean | 101 | 195 | 185 | 230 | – | 38.4 | 61.8 |
| **Statistics** | ***p > F*** | | | | | | |
| Material (M) | 0.952 | 0.239 | 0.724 | 0.551 | – | 0.029 | 0.260 |
| Rate (R) | 0.799 | 0.951 | 0.480 | 0.899 | – | 0.041 | 0.285 |
| M x R | 0.695 | 0.994 | 0.780 | 0.916 | – | 0.537 | 0.948 |

[x] No soybean yield in 2004 due to severe hail damage.

Table 9. Corn and soybean grain yield across years as influenced by aglime and eggshell application, Sutherland.

| ECCE rate (lb/acre) | Corn (bu/acre) | | | Soybean (bu/acre) | | |
|---|---|---|---|---|---|---|
| | **Aglime** | **Eggshells** | **Mean** | **Aglime** | **Eggshells** | **Mean** |
| 0 | 172 | 177 | 175 | 45.2 | 48.1 | 46.6 |
| 500 | 174 | 177 | 176 | 46.2 | 49.9 | 48.0 |
| 1000 | 178 | 178 | 178 | 48.6 | 49.5 | 49.1 |
| 2000 | 178 | 180 | 179 | 49.7 | 51.9 | 50.8 |
| 4000 | 177 | 175 | 176 | 49.9 | 50.8 | 50.4 |
| 8000 | 177 | 178 | 177 | 51.0 | 50.5 | 50.7 |
| Mean | 176 | 178 | – | 48.4 | 50.1 | – |
| **Statistics** | ***p > F*** | | | | | |
| Material (M) | 0.400 | | | 0.103 | | |
| Rate (R) | 0.542 | | | 0.024 | | |
| M x R | 0.735 | | | 0.580 | | |

## Conclusions

Ground eggshells proved to be an effective liming material. Land application for soil pH correction offers a practical use of eggshells from egg production facilities and a viable solution for use rather than disposal. However, the reported ECCE value for the ground eggshells was low as the measured soil pH increases were more than those found with equivalent ECCE rates from aglime. Based on the soil pH responses in this study, we suggest that ground eggshell ECCE values that are determined using the Iowa Agricultural Limestone Act be increased 2 to 3 times from reported values. That correction should get eggshell application rates based on ECCE more in line with expected soil pH increases and will help avoid over-application.

## Acknowledgments

We would like to thank Dave Rueber and Ryan Rusk, research farm managers, for their efforts with the research sites. Partial funding for the project was provided by the Iowa Egg Council and Iowa State University Extension.

## Literature Cited

1. Anonymous. 2005. Georgia Tech researchers partner with industry to study alternative uses for eggshell waste. Online. Poultry Tech, vol. 17, no 2. Agric. Tech. Res. Prog., Food Processing Tech. Div., Georgia Tech Res. Inst., Atlanta, GA.
2. Anonymous. 1998. Waste egg shell components recovery. Online. WO/1998/041326 World Intellectual Property Organization, Geneva, Switzerland.
3. Hunton, P. 2005. Research on eggshell structure and quality: An historical overview. Brazilian J. Poultry Sci. 7:67-71.
4. Ibarburu, M., and Bell, D. 2010. U.S. egg industry statistical report. Flock Statistics #10. Online. Egg Industry Center Newsletter, Dep. Animal Science, Iowa State Univ., Ames, IA.
5. Iowa Department of Agriculture and Land Stewardship. 1998. Iowa agricultural limestone act, Chapter 201A, agricultural liming material. State of Iowa, Des Moines, IA.
6. Kassel, P. 2002. Lime and tillage research project, Northwest Research Farm and Allee Demonstration Farm research report SRF02-29, 31. Iowa State Univ., Ames, IA.
7. Meyer, T. A., and Volk, G. W. 1952. Effect of particle size of limestones on soil reaction, exchangeable cations, and plant growth. Soil Sci. 73:37-52.
8. Mitchell, C. C. 1994. Crushed eggshells in the soil, Auburn Univ. Farm Demonstration Report S-01-94. Alabama Coop. Ext. Serv. and Exp. St., Auburn, AL.
9. National Agricultural Statistics Service (NASS). 2011. Egg Products. Online. Jan. 2011. USDA-NASS, Washington, DC.
10. Sawyer, J. E., Mallarino, A. P., Killorn, R., and Barnhart, S. K. 2008. A general guide for crop nutrient and limestone recommendations in Iowa. PM-1688. Rev. ed. Iowa State Univ. Coop. Ext. Serv., Ames, IA.
11. Sonenklar, C. 1999. Famous for egg waste. Online. Research/Penn State, Vol. 20, no. 3. Pennsylvania State Univ., Univ. Park, PA.