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Organic Fertilizer Abrasive Grits Increase Soil Available Nitrogen, Plant Height, and Biomass

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Organic fertilizer abrasive grits increase soil available nitrogen, plant height, and biomass

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Abstract

In organic cropping systems, air-propelled abrasive grits can be used to control in-row weeds. If the applied abrasive grit is an approved organic fertilizer, these applications may serve a dual purpose of weed control and crop fertility. Laboratory soil incubations examined the N mineralization rates of several grit types with differing C/N ratios (Agra Grit [crushed walnut shells, 170:1], corncob grit [91:1], Sustane [composted turkey litter, 5.0:1], Phytaboost Plant Food [crushed and pelletized soybean meal, 5.0:1]). A greenhouse study determined plant wheat (*Triticum aestivum* L.), kale (*Brassica napus pabluaria* DC), and velvetleaf (*Abutilon theophrasti* Medik.) growth response in soils amended with these grits. The N mineralization rates varied by grit type, soil, and application rate. The N mineralized from Phytaboost within 56 d was similar among the amounts of N a whereas the amount of N mineralized from Sustane was inversely related to the amount of N applied. Agra Grit and corncob grit immobilized soil N due to their high C/N ratios. In soils amended with Sustane, plant height and biomass were 15–43% and 34–83% greater than for plants grown in soils with Agra Grit, corncob grit, and the nontreated soil. Applications of organic fertilizer as air-propelled grit may improve crop growth; however, if weed control is imperfect, these grits may increase weed growth. Grits with high C/N ratios may immobilize soil available N but not affect plant growth.

1 | INTRODUCTION

Weeds are difficult to control in organic crops and can cause major yield losses. Most physical weed control methods are for between-row control, although in-row weeds can be problematic (Van Der Weide et al., 2008). Each method has different strengths and weaknesses. Cultivators provide relatively inexpensive and effective between-row weed control. However, cultivators do not provide between-plant or in-row weed control. In-row physical methods, such as harrowing (Kurstjens & Perdok, 2000) or flame weeding (Cisneros & Zandstra, 2008; Knezevic & Ulloa, 2007), may be effective but can result in crop injury. Air-propelled abrasive grit applications are an alternative to control in-row weeds (Braun et al., 2019; Carlson, Forcella, Wortman, & Clay, 2018; Erazo-Barradas,

Abbreviations: DAP, days after planting.

Friedrichsen, Forcella, Humburg, & Clay, 2019; Forcella, 2009a; Wortman, 2015), although between-row weeds are not targeted and may need additional treatment. Advantages of air-propelled abrasive grits are that they cause minimal damage to the crops, they remove weeds that are typically the most problematic to control, and nutrients contained within grits may be available to the crop.

Nutrient availability from grit will differ depending on the grit source. For example, walnut shell grit has low nutrient availability, whereas soybean meal or pelletized poultry litter potentially have high nutrient availability (Carlson et al., 2018; Forcella, 2009a,b). If organic fertilizers are used as the grit source (Braun et al., 2019; Carlson et al., 2018), then the in-row application may simultaneously control weeds and increase soil fertility, especially for N (Forcella, James, & Rahman, 2010; Wortman, 2014). Because N is often the most limiting nutrient in organic cropping systems (Mikkelsen & Hartz, 2008), these types of applications may serve a dual purpose for improving crop health. This is especially true for organic systems that rely on manures for fertility management because manure application rates are based on crop P removal rates than crop N requirement (Wander, 2019).

Developing fertilizer strategies that enhance crop competitive ability and minimize weed interference improves overall crop yields (Blackshaw & Brandt, 2008; Cathcart & Swanton, 2003; DiTommaso, 1995). Understanding the mineralization rates of organic N fertilizers is critical knowledge that can inform producers on optimal timing and rates of supplemental N applications to match crop N needs (Poffenbarger et al., 2015). The amount and timing of N availability from organic grits are dependent on grit application rate, nutrient content, grit mesh size (Flavel & Murphy, 2006), and mineralization rate, which is dependent on soil microbial composition (Cookson, Cornforth, & Rowarth, 2002; Vigil & Kissel, 1995; Whalen, Chang, & Olson, 2001), soil moisture (Brown, Hangs, Schoenau, & Bedard-Haughn, 2017), and temperature (Agehara & Warnacke, 2005; Brown et al., 2017; Gaskell et al., 2006; Hartz & Johnstone, 2006; Miller & Geisseler, 2018).

The in-row placement and timing of abrasive grit applications (i.e., just after abrading weeds) may provide a competitive advantage to crops over weeds. The influence of N from poultry litter, applied as fertilizer source, has been documented to have a positive effect on corn growth and yield (Licht & Al-Kaisi, 2005; Noellsch, Motavalli, Nelson, & Kitchen, 2009; Shapiro & Wortman, 2006; Tremblay et al., 2012), red Russian kale (*Brassica napus pabluaria* Medik.) (Braun, 2017), and velvetleaf (*Abutilon theophrasti* Medik.) growth (Little, Mohler, Ketterings, & DiTommaso, 2015). In addition, weed seed germination and plant biomass response to N is species dependent but generally increases as N increases (Blackshaw et al., 2003; Sweeney, Renner, Laboski, & Davis, 2008). Therefore, weed response to an abrasive grit application also should be considered.

Core Ideas

- Nitrogen mineralization rate varied by grit type, soil, and application rate.
- Organic fertilizer grits increased soil N, whereas high C/N ratio grits immobilized soil N.
- Plant height and biomass were highest in soil amended with Sustane (low C/N).
- High C/N grit amended soils had similar plant height and biomass as the nontreated control.

These studies were initiated to examine the rate of N mineralization from different grits and the influence of grit application on plant growth. The specific research objectives were to determine (a) the N mineralization rates in laboratory incubations of organic amendments used as abrasive grits and (b) the growth response of selected plants in soils amended with these grits in greenhouse conditions. The grit materials (Agra Grit [a walnut shells product], corncob grit, Sustane turkey litter [a composted turkey litter], and Phytaboost Plant Food [crushed and pelletized soybean meal]) included materials derived from plant and animal sources with high and low N contents.

2 | MATERIALS AND METHODS

2.1 | Soils

Two soils were used in laboratory and greenhouse studies (Table 1). A Brandt silty clay loam (fine-silty, mixed, superactive, frigid Calcic Hapludoll) was collected from the 0- to 3-cm depth in the spring from Aurora, SD, before planting. An Egan silty clay loam (fine-silty, mixed, mesic Udic Haplustoll) was collected from the 0- to 3-cm depth before planting from a certified organic field from the Southeast Research Farm in Aurora, SD. After collection, soils were air dried (40 °C) and screened through a 5-mm sieve. Soils were stored in a cooler at 5 °C until study initiation.

2.2 | Abrasive grits

The N mineralization and plant growth response was determined for the following grit types: Agra Grit (Agra Life), a crushed walnut shells product; corncob grit (Green Products Company); Sustane (Sustane Corporation), an aerobically composted and pelletized turkey litter with a

TABLE 1 Locations, soil description, pH content, sand, silty and clay content, organic matter content, previous crop and soil N, NO_3–N, and NH_4–N content of soils used to study N mineralization and plant growth response from air-propelled abrasive grits

Soil	Location	Soil description	Previous	pH	Sand	Silty	Clay	Organic matter	Soil N	NO_3–N	NH_4–N
					g kg^{-1} soil						
Brandt silty clay loam	Aurora, SD	0–1% slope, fine-silty, mixed, superactive, frigid Calcic Hapludoll	conventional corn	6.5	14	59	27	2.7	110	54	58
Egan silty clay laom	Beresford, SD	0–1% slope, fine-silty, mixed, mesic Udic Haplustoll	certified organic corn	5.7	5.4	61	34	3.8	70	56	13

TABLE 2 Description of air-propelled abrasive grits used in both N mineralization studies and plant uptake studies including total N, total C, C/N ratio, and grit size

Grit	Description	Total N	Total C	C/N	Grit size
		mg kg^{-1}			mm
Agra Grit	crushed walnut shells	0.31 (0.03)	51 (1.7)	170 (13)	1.0
Corncob grit	crushed corncobs	0.53 (0.06)	47 (0.2)	91 (11)	2.0
Phytaboost plant food 7–1–2	pelletized soybean meal, a certified organic fertilizer with a 7–1–2 ($N–P_2O_5–K_2O$) rating	9.0 (0.08)	45 (0.04)	5.0 (0.04)	2.0
Sustane 8-2-4	aerobically composted turkey litter, a certified organic slow release fertilizer with an 8–2–4 ($N–P_2O_5–K_2O$) rating	8.0 (0.20)	40 (0.12)	5.0 (0.12)	1.0

Note: Values in parentheses are SE. These grits have previously been reported to control weeds when used in an abrasive grit management system.

fertilizer grade of 8–2–4 (N–P–K); and Phytaboost Plant Food (California Organic Fertilizers Inc.), crushed and pelletized soybean meal with a fertilizer grade of 7–1–2 (N–P–K) (Table 2). The grit applied to soil was passed through a 5-mm sieve to get uniformly sized products.

A subsample of each grit was dried to 60 °C and ground to pass a 1-mm sieve. Four replicate samples of 1 μg were analyzed to quantify total C and N using a Sercon 20-20 continuous flow ratio mass spectrometer (Sercon, Ltd.) (Clay, Clay, Lyon, & Blumenthal, 2005).

2.3 | Nitrogen mineralization in aerobic soil incubations

2.3.1 | Sustane and Brandt soil incubation

Soil incubations were conducted using a method based on Sistani, Sikora, and Rasnake (2008). Air-dried Brandt soil (250 g) was put into 1-L beakers (diameter, 10.8 cm) and covered with parafilm. Nontreated control samples had no added grit. Sustane grit (8–2–4) was mixed into the sample at Day 0 at four rates. The 3.6 g grit kg^{-1} soil was considered a 1X treatment, based on the rate applied for weed control in field applications (800 kg grit ha^{-1}, which would apply 64 kg N ha^{-1}) (Carlson et al., 2018). Additional treatments included 1.2 g (1/3X), 7.2 g (2X), and 14.4 g (4X) grit kg^{-1}, which would apply 22, 128, and 256 kg N ha^{-1}, respectively, for each treatment in a field setting. The 1/3X rate represented 270 kg grit ha^{-1} rate used for weed control in abrasive weeding trials in vegetable crops (Wortman, 2015). The 2X rate was based on two field applications that provided better weed control than a single pass (Erazo-Barradas et al., 2019). The 4X rate was for an extreme comparison and would represent four abrasive grit applications in one season. Treatments were replicated three times. After grit was mixed into the soil, deionized water was added to achieve 30 g water to 100 g soil for a moisture content equivalent to field capacity. The incubation was done at 25° C in a dark room. Every 2 d, parafilm was removed to allow for aeration, and weights were checked with water added as needed to maintain 30% moisture content. The study was terminated after 112 d of incubation.

2.3.2 | Comparison of four grits and rates in the Egan soil

Air-dried Egan soil (250 g) was placed into 1-L plastic bags to allow for gas exchange and to minimize water loss. Nontreated control samples had no added grit. Agra Grit, corncob grit, Sustane, and Phytaboost were mixed into the soil either at 3.6 (1X) or 1.2 (1/3X) g grit kg^{-1} soil on Day 0. After 10 and 20 d of incubation, an additional 3.6 g grit was added to the 1X samples so that the treatments had X+X or X+X+X treatments. These additions mimicked field application timings seen in past field studies of air-propelled abrasive grit management (Erazo-Barradas et al., 2019). The total amount of N added in a field setting from the 1/3X, 1X, X+X, and X+X+X treatments for Agra Grit would be 0.84, 2.5, 5.0, and 10 kg N ha^{-1}, respectively; corncob grit would be 1.4, 4.2, 8.4, and 13 kg N ha^{-1}, respectively; and Phytaboost would be 24, 72, 144, and 246 kg N ha^{-1}, respectively. Moisture content was kept at 30%, and water addition was typically 1 ml wk^{-1}. The soil incubation was kept at 25 °C in a dark room. Incubation was conducted once and terminated 183 d after study initiation.

During each incubation study, soil was sampled six times (0, 7, 14, 28, 56, and 112 d), with two additional samplings at 142 and 183 d in the Egan soil study. At each sampling, 16 g of wet soil were removed, air-dried at 38 °C, and passed through a 2-mm sieve. The inorganic N (NO_3–N and NH_4–N) concentrations of each soil sample were extracted using the method of Kachurina, Zhang, Raun, and Krenzer (2000) with 1 M KCl and analyzed on an Astoria Analyzer 300 (Astoria-Pacific Inc.) by the Cd reduction method (Maynard, & Kalra, 1993).

2.4 | Nitrogen mineralization and response of indicator plants

Greenhouse experiments used indicator plants to examine the potential of different grit types to affect plant growth. The experiment was modified based on Wortman (2015) and repeated three times between December 2016 and April 2017. The day/night greenhouse conditions were 16/8 h and 25/15 °C.

Red Russian kale, velvetleaf, or wheat were planted into individual 8-cm-diameter pots for each treatment. Pots were filled with sand that had been acid washed and rinsed with deionized water until neutral pH to provide a nutrient-poor growth media. A 2-cm-deep layer of Brandt soil amended with 3.6 g kg^{-1} of one of three grits or not treated was placed on top of the sand. The grits used were Agra Grit, corncob grit, and Sustane, which provided 3.4, 5.7, and 86.2 mg N, respectively.

Seeds of wheat (n = 20), red Russian kale (n = 10), and scarified velvetleaf (n = 30) were planted at depths of 0.5, 1, and 1 cm, respectively, 7 d after grit application into separate pots. The hard red spring wheat variety was 'Brick', red Russian kale was a certified organic variety, and velvetleaf originated from a local Brookings County, SD, population. Plants were thinned 2 wk after emergence to five wheat, three kale, or five velvetleaf plants per individual pot.

Plant height measurements began 7 d after planting (DAP), with measurements taken every 2 d. Final measurements were taken 27 DAP because laboratory soil incubations determined that 50% of N mineralization occurred within 30 d after application. All shoots from a pot were harvested together 27 DAP, dried at 60 °C, and weighed.

2.5 | Statistical analysis

2.5.1 | Nitrogen mineralization

Soil incubations were established as a completely randomized repeated-measure design. The amount of grit added to the soil comprised individual treatments in the first study (Brandt soil), which was replicated three times within the experiment and conducted once. In the second study (Egan soil), the main factor was the type of grit applied, and the subfactor was the number of times grit was added. The second study was replicated four times within the experiment and conducted once.

Total inorganic N mineralized from the grits was quantified at each sampling date. The total inorganic N mineralized from the grit over the course of the studies was modeled using the exponential rise to maximum three-parameter model:

$$f = y_0 + N_a\left(1 - e^{-bx}\right) \quad (1)$$

where f is the estimated organic N mineralized at a given sampling time, y_0 is the inorganic N content at the beginning of the study, N_a is the available N in the active pool, b is the mineralization rate constant, and x is the time in days (Poffenbarger et al., 2015). Curve fitting was performed using SigmaPlot 13 (Systat Software Inc.). The RMSEs were calculated following Roman, Murphy, and Swanton (2000) (Equation 2):

$$\mathrm{RMSE} = \left[1/n \sum_{i=1}^{n} (\mathrm{Pi} - \mathrm{Oi})^2\right] \quad (2)$$

where Pi is the predicted value, Oi is the observed value, and n is the total number of comparisons. Goodness of fit was examined. The RMSE values of multiparameter models are commonly used to estimate model quality (Mayer & Butler, 1993; Roman et al., 2000; Sarangi, Irmak, Lindquist, Knezevic, & Jhala, 2016; Werle, Sandell, Buhler, Hartzler, & Lindquist, 2014); lower RMSE values indicate better model fits between observed and predicted values. An ANOVA was used to determine differences among the regression coefficients using the "aov" function in base R (R Core Team, 2017). The two incubation studies were analyzed separately because of differences among soils and treatments.

2.5.2 | Impact of grits on plant growth

This experiment had a factorial arrangement with three factors (plant species) and four levels (grit types). The treatments were replicated four times within an experiment, and experiments were conducted three times from December 2016 through April 2017 (12 replicates total). Response variables were analyzed separately by species, and data were pooled among experiments. An analysis of covariance was performed to examine the plant height response (mm d^{-1}) of each species. The analysis of covariance was analyzed using the "lm" function in base R (R Core Team, 2017). The mean squares for each variable were estimated using an ANOVA to determine if slopes of the growth rates were significant. The ANOVA was completed using the library "agricolae" (de Mendiburu, 2009) in R (R Core Team, 2017).

Relative dry biomass was calculated on a per-plant basis as a fraction of the maximum dry biomass of an individual plant within an experiment and species. Relative dry biomass was used to compare plant responses among all experiments. An ANOVA was used to determine differences among relative dry biomass using the "aov" function in base R (R Core Team, 2017). Mean separations were performed using the "LSD.test" function in the "agricolae" package (de Mendiburu, 2009) in R (R Core Team, 2017) to determine Fisher's LSD.

3 | RESULTS AND DISCUSSION

3.1 | Sustane and Brandt soil incubation

In the Brandt soil, the baseline N at Day 0 (y_0) was similar among all grit treatments and averaged 112 mg N kg^{-1} soil. Total N added from all treatments in the Brandt soil ranged from 0 mg N kg^{-1} soil in the nontreated control to 1,150 mg N kg^{-1} soil in the 4X Sustane treatment (Table 3). The estimated available N (N_a) was similar among the nontreated control, 1/3X, 1X, and 2X treatments (average, 180 mg N kg^{-1} soil), whereas the 4X Sustane treatment had almost twice as much N_a (Table 3). The estimated N mineralization rates (b) of the 1/3X, 1X, and 2X Sustane treatments were similar and averaged 0.13 mg Nk g^{-1} soil d^{-1}. The nontreated control and 4X Sustane treatments had lower estimated N mineralization rates of 0.030 and 0.060 mg N kg^{-1} soil d^{-1}, respectively (Table 3). The percentage of N mineralized from the Sustane treatments within 56 d of application was inversely related to the amount of Sustane added to the soil, ranging from 86% in the 1/3X treatment to 36% in the 4X treatment. Values of percentage of N mineralized were chosen at 56 d of application because of the zero slope of the curve (Figure 1), which indicates that the mineralization process was almost complete (Hartz & Johnstone, 2006).

The differences in N_a among the treatments reflected the amount of N in each treatment. The similar mineralization rates (b) of 0.03, 0.11, 0.16, 0.16, and 0.06 of all treatments after 56 d indicate that the N applied with Sustane had been mineralized and that the soil microbial community was mineralizing soil organic matter. Prior to 56 d the N mineralization rate varied with the amount of Sustane added. Whereas the b value of all Sustane treatments was expected to be the same, the 4X Sustane treatment had a b value 50% lower than other additions before Day 56. The high N addition at one time may have been more than the soil microbial community could have mineralized (Dinnes et al., 2002), thus leading to a slower N mineralization rate during the first 56 d. The percentage of N mineralization during the first 56 d for all Sustane treatments was similar to the amount reported from other organic poultry litters in

TABLE 3 The total N added, estimated available N (N_a), soil N mineralization rate (b), R^2 value, RMSE, and percent N mineralized within the first 56 d of the incubation from each amount of Sustane added and the no-grit control treatment in the Brandt silty clay loam soil

Amount of grit added	Total N added	N_a	*b*	R^{2a}	RMSE	N mineralized in 56 d
g grit kg^{-1} soil	——mg N kg^{-1} soil——		—mg N kg^{-1} soil d^{-1}—			%
0 (control)	0	200 (57)	0.03 (0.02)	.54	68	–
1.2 (1/3X)	96	120 (19)	0.11 (0.04)	.73	29	86 (1.3)
3.6 (1X)	287	170 (29)	0.16 (0.07)	.70	43	72 (2.5)
7.2 (2X)	575	240 (37)	0.16 (0.06)	.74	55	51 (2.2)
14.4 (4X)	1,148	370 (47)	0.06 (0.02)	.80	71	36 (4.1)

Note. The estimated N at time y_0 averaged 112 mg N kg^{-1} soil among all amounts added to the soil. Values in parentheses are SE.
[a]Determined using the equation $f = y_0 + N_a(1 - e^{-bx})$.

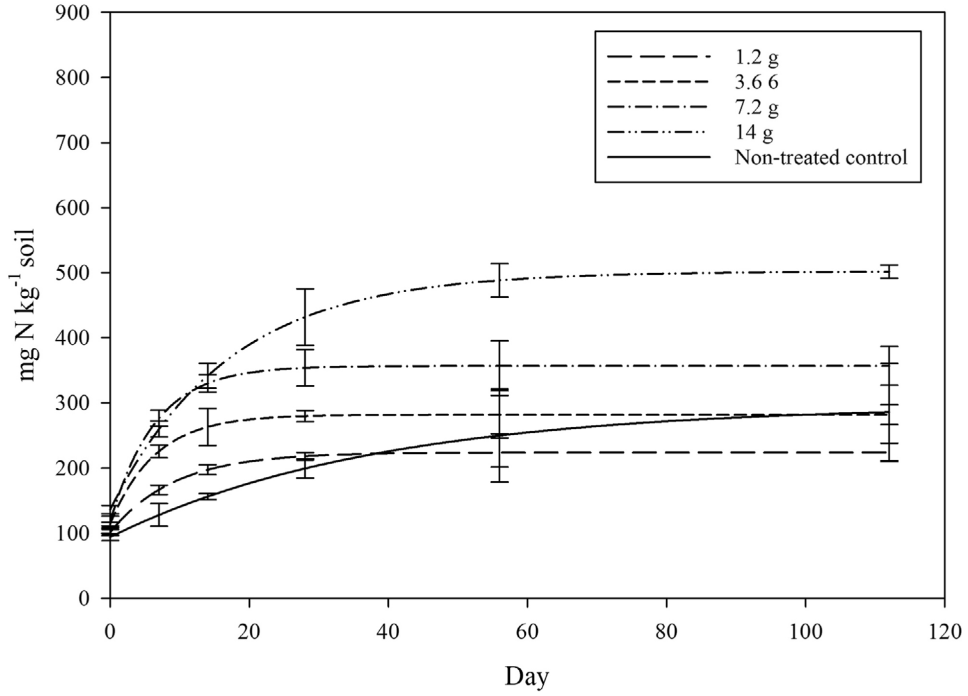

FIGURE 1 Nitrogen mineralization (mg N kg^{-1} soil d^{-1}) estimated using the model $f = y_0 + N_a(1 - e^{-bx})$ of Sustane 8–2–4 from different rates applied to a Brandt silty clay loam soil

aerobic soil incubations (Cabrera, Chiang, Merka, Thompson, & Pancorbo, 1993; Castellanos & Pratt, 1981; Hadas, Baryosef, Davidov, & Sofer, 1983).

3.2 | Comparison of four grits and rates in the Egan soil

Before grits were added to the Egan soil, the baseline N (y_0) averaged 49 mg N kg^{-1} soil, which is lower than in the Brandt soil. Total N added ranged from 4 mg N kg^{-1} soil for the 1/3X Agra Grit treatment to 969 mg N kg^{-1} soil for the X+X+X Phytaboost treatment. The estimated N_a after incubation differed among grits and the amount of grit added to the soil (Table 4). The N_a of the Agra Grit (walnut shells) treatment was inversely related to the amount of Agra Grit added to the Egan soil. This grit had a high C/N ratio, and data indicate that N was immobilized. The corncob grit N_a differed among the total amount of grit added because the 1/3X and 1X were similar and higher than the X+X and X+X+X rates (Table 4). As the amount of Phytaboost and Sustane increased, N_a increased (Table 4). Estimated b values of the Agra Grit, Phytaboost, and Sustane treatments were similar and averaged

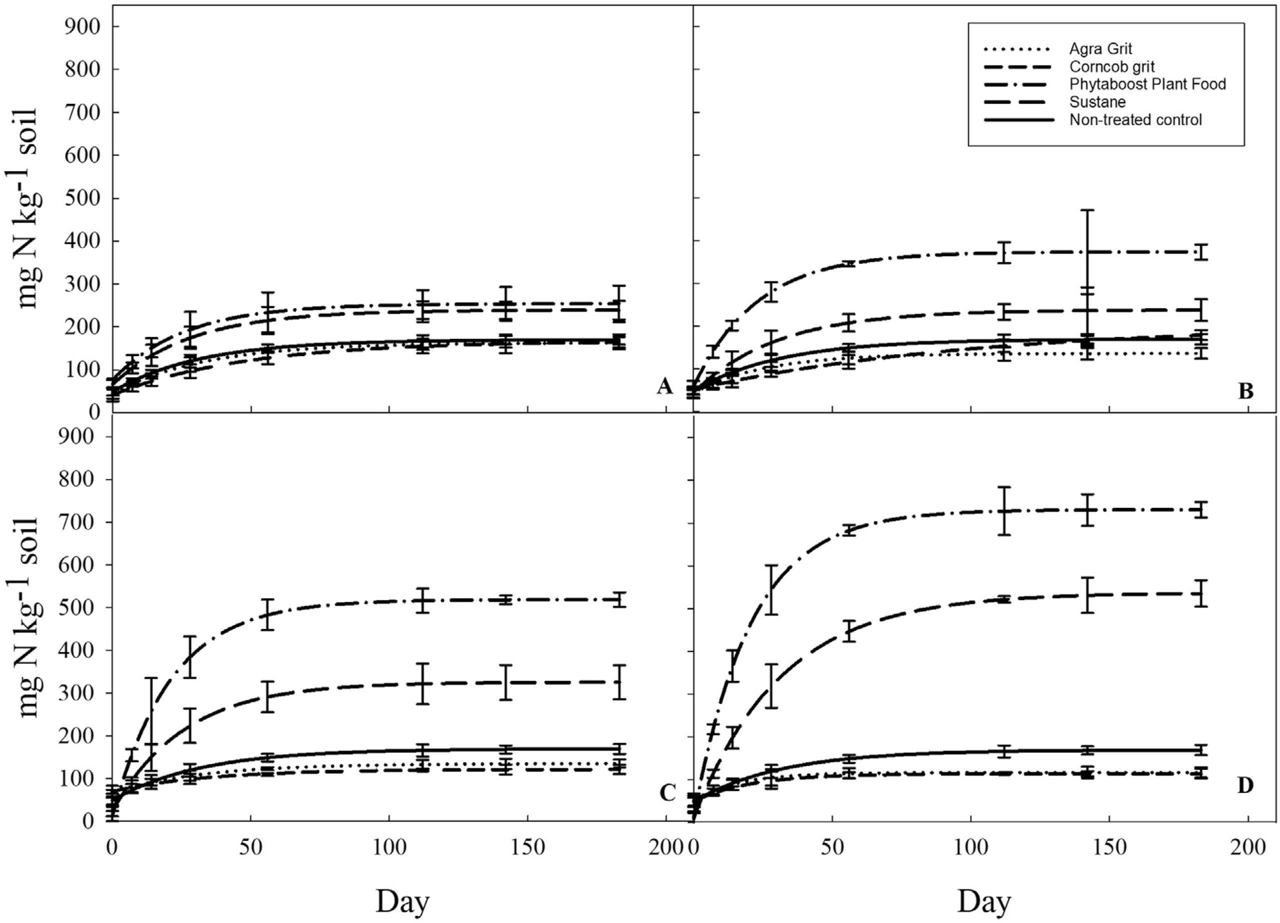

FIGURE 2 Nitrogen mineralization (mg N kg^{-1} soil d^{-1}) estimated using the model $f = y_0 + N_a(1 - e^{-bx})$ of (a) 1.2 (1/3X), (b) 3.6 (1X), (c) 7.2 (X+X), and (d) 10.8 (X+X+X) in an Egan silty clay loam soil

0.38 mg N kg^{-1} soil d^{-1}, which was similar to the 1/3X rate used in the Brandt soil; however, by 56 d the mineralization from Sustane was similar (Figure 2). The *b* value of corncob grit was lower when compared with the *b* value of Agra Grit, Phytaboost, and Sustane treatments. Among the corncob grit treatments, *b* was inversely related to the total amount of corncob grit added to the Egan soil.

In the Egan soil study, differences in the N_a among grits were attributed to total N content and type of grit (Agehara & Warnacke, 2005; Spargo, Cavigelli, Mirsky, Meisinger & Ackroyd, 2016). The lower estimated N_a values for the 1X, X+X, and X+X+X of the Agra Grit treatments and for the X+X and X+X+X of the corncob grit treatments were attributed to the high C/N ratio of each (168:1 and 98:1, respectively) (Flavel & Murphy, 2006; Paul & Clark, 1989). Although screened through a 5-mm sieve, the average particle size of corncob grit was 2 mm, compared with Agra Grit, which was 1 mm. The average grit size may have affected C decomposition and N immobilization (Ambus, Kure, & Jensen, 2002; Angers & Recous, 1997).

The estimated N_a values among the organic fertilizers (Phytaboost and Sustane) were inversely related to the amount of grit and N added to the soil. Phytaboost would have been expected to have a lower N_a value than Sustane because of the lower N fertilizer rating (7% according to the label); however, Phytaboost had a measured N content of about 9% (Table 2). The higher N content of Phytaboost (Table 2) could have increased the amount of N_a in this study compared with the Sustane treatment (measured at 7.98% N) (Table 2). The Sustane treatment is also marketed as a slow-release fertilizer, which could have decreased the N_a because of the formulation of the fertilizer.

The percentage of N mineralized by Day 56 varied by grit type and amount added. The percentages of N mineralized The Agra Grit and corncob grit treatments were compared with the N mineralized in the nontreated control because of the small amount of N added from these grits. The 1/3X Agra Grit treatment mineralized 104% of N in the soil, whereas the 1X, X+X, and X+X+X treatments mineralized an average of 70% of the N in the soil. The percentage of N mineralized from the corncob grit was inversely related to the amount of grit added to the soil. The percentage of N mineralized from the 1/3X and 1X Sustane treatments averaged 72% of the N added, whereas the

TABLE 4 In the Egan silty clay loam soil incubation the timing of grit applied, amount of grit applied, total N added, estimated available N (N_a), soil N mineralization rate (b), R^2 value, RMSE, and percent N mineralized in the first 56 d of the incubation from each grit and amount added

Grit	Timing of grit applied	Amount of grit applied	Total N added	N_a	b	R^2 [a]	RMSE	Percent N mineralized in 56 d [b]
		g grit kg^{-1} soil	——mg N kg soil^{-1}——		µg N g soil d^{-1}			%
Control	–	0	0	120 (12)	0.032 (0.0089)	.77	25	–
Agra Grit	1/3X	1.2	4	120 (14)	0.034 (0.011)	.73	26	100 (5.1)
	1X	3.6	11	92 (14)	0.039 (0.0060)	.60	28	79 (6.8)
	X+X	7.2	22	66 (15)	0.030 (0.019)	.43	30	67 (6.2)
	X+X+X	10.8	34	65 (16)	0.061 (0.038)	.37	32	73 (4.7)
Corncob grit	1/3X	1.2	6	130 (16)	0.021 (0.0087)	.69	32	80 (2.1)
	1X	3.6	19	150 (38)	0.0099 (0.0060)	.74	29	50 (3.1)
	X+X	7.2	38	90[c]	$2.6 \times 10^{-0.5}$ (0.0053)	.75	26	37 (4.7)
	X+X+X	10.8	57	75[c]	$1.0 \times 10^{-0.5}$ (0.0063)	.67	27	13 (1.1)
Phytaboost plant food 7–1–2	1/3X	1.2	110	170 (23)	0.035 (0.012)	.67	46	68 (3.6)
	1X	3.6	320	320 (46)	0.044 (0.016)	.65	54	72 (2.8)
	X+X	7.2	650	510 (42)	0.047 (0.095)	.85	81	81 (1.7)
	X+X+X	10.8	970	720 (68)	0.048 (0.012)	.81	100	71 (2.2)
Sustane 8–1–2	1/3X	1.2	96	180 (35)	0.039 (0.019)	.80	65	76 (5.1)
	1X	3.6	290	190 (26)	0.033 (0.012)	.66	54	67 (6.1)
	X+X	7.2	580	300 (39)	0.039 (0.014)	.69	78	47 (4.1)
	X+X+X	10.8	860	530 (37)	0.032 (0.0061)	.88	75	52 (4.3)

Note. The N estimated at time 0 (y_0) averaged 46 mg N kg^{-1} soil, and b values averaged 0.038 ± 0.002 mg N kg^{-1} soil d^{-1} among all grits and amounts mixed into the soil. Values in parentheses are SE.

[a]Determined using the equation $f = y_0 + N_a(1 - e^{-bx})$. [b]The percent N mineralized from the amounts of Agra Grit and corncob grit mixed in the soil are the percent N mineralized from the soil compared with the total N mineralized from the nontreated control. [c]Based on estimation without the first two samplings because of N immobilization.

X+X and X+X+X mineralized an average of 50% of the N added to the soil, similar to the Sustane treatments in the Brandt soil. Phytaboost mineralized an average of 70% of the N added to the soil from the 1/3X, 1X, and X+X+X treatments, whereas the X+X treatment mineralized 81% of the N added to the soil (Table 4).

The similarity of the estimated mineralization rates (*b*) among the Agra Grit, Phytaboost, Sustane, and nontreated control treatments was attributed to the N mineralizing from the soil organic matter rather than from grit N. Gordillo and Cabrera (1997) reported that the mineralization rate of the slow N pool did not differ among turkey litters, and Hartz and Johnstone (2006) reported that, after 2 wk, N mineralization from organic amendments mimicked the N mineralization from soil organic matter.

The RMSE of the exponential rise to maximum model for N mineralization in both soils varied depending on the type, amount, and timing of grit applied. In the Brandt soil, the RMSE of the Sustane treatments increased with increasing amounts of grit applied to the soil (from 29.0 to 70.5; Table 3). The nontreated control in the Brandt soil study had an RMSE value of 67.5, which was similar to the 4X rate of Sustane. The RMSEs of the Agra Grit and corncob grit treatments were numerically similar among amounts of grit applied to the soil (average, 29.0 and 28.4, respectively). The Agra Grit and corncob grit treatments had similar RMSE as the nontreated control (25.4; Table 4). Both the Phytaboost and Sustane treatments in the Brandt soil had increased RMSE values as the amount of grit applied to the soil increased and were higher than the nontreated control.

The exponential rise to maximum model described the N mineralization for both soils well as the R^2 values were 60% or greater among the different amounts of Agra Grit, Phytaboost, and Sustane (the nontreated control). The R^2 values among the different amounts of corncob grit added were high, although X+X and X+X+X mineralized less than 40% of the N from the soil when compared with the nontreated control (Table 4). The X+X and X+X+X corncob grit treatments could have immobilized the soil N because of the high C/N ratio (Flavel & Murphy, 2006; Paul & Clark, 1989) and because of the higher amount of corncob grit in the soil mixture than in the 1/3X and 1X treatments.

The percentages of N mineralized from Phytaboost and Sustane were similar to values previously reported for soybean meal and poultry litter. Sexton and Jemison (2011) reported that 75% of the N in soybean meal was mineralized into an organic potato field within 3 mo of application. These grits also mineralized similar amounts of N as high-organic-N fertilizers. High-organic-N fertilizers (>10% N), like feather meal and seabird guano, have been reported to mineralize 60–80% of N applied in 4–8 wk (Hadas & Kautsky, 1994; Hartz & Johnstone, 2006).

3.3 | Comparison between the Brandt and Egan soils

Although the Brandt and Egan soil studies were conducted differently, both methods were suitable to maintain aerobic conditions (Compton & Boone, 2000; Contosta, Frey, & Cooper, 2011). In both soils an effort was made to not collect soil with visible grit in the sample; however, grits were small enough in size that this was likely impossible. Errors in the models and N samples could have been affected by the sampling. The estimated N values, y_0, differed between soils. The Brandt soil had 112 mg N kg^{-1} soil, which was more than double the baseline of 49 mg N kg^{-1} soil of the Egan soil. The mode estimated that the total amounts of N mineralized from the soil in the nontreated control treatments in the Brandt and Egan soils were 74 and 50 mg N kg^{-1} soil, respectively. Soil N mineralization differs among soils (Chu & Groga, 2010; Deenik, 2006; Reich, Grigal, Aber, & Gower, 1997; Stanford & Smith, 1972), whereas in the current studies the slow pool N mineralization was similar between both nontreated control treatments.

The estimated *b* and percent N mineralized of the 1/3X and 1X grit of Sustane differed between soils. Percent N mineralized of the Brandt soil (86%) was greater than the Egan soil. The larger percentage of N mineralized in the Brandt soil was attributed to the sand content in the soil (Gordillo & Cabrera, 1997; Sistani et al., 2008). The higher sand content of the Brandt soil may have resulted in higher estimated *b* of the Sustane treatments than in the Egan soil, as Hadas et al. (1983) reported that soils with higher sand contents had higher N mineralization. Gordillo and Cabrera (1997) and Sistani et al. (2008) reported that soils with higher silt and clay content had less available N, which was similar to the Egan soil. In both soils, the percentage of N mineralized from the Sustane treatments decreased as the amount of N added increased.

At 56 d after the addition of grit, the exponential rise to maximum model estimated that the amount of N mineralized from the Sustane 1/3X and 1X treatments were 235 and 280 mg N kg^{-1} soil in the Brandt soil and 202 and 217 mg N kg^{-1} soil in the Egan soil. These values were closely related to the observed values for the 1/3X and 1X Sustane treatments. The exponential rise to maximum model fit the nontreated control in the Egan soil study better because it was 70% lower than the RMSE value in the Brandt soil. The Sustane 1/3X and 1X treatments had lower RMSE values in the Brandt soil when compared with the Egan soil. The RMSE of these models varied by the amount and timing of grit applied: The lower amount of grit applied or application of grits with low N content resulted in lower RMSE values in both soils. The model fit the Sustane 1/3X ($R^2 = .73$) and 1X in the Brandt soil ($R^2 = .70$), and the nontreated control ($R^2 = .77$) and 1/X ($R^2 = .80$) treatment in the Egan soil were fit well by the model. The nontreated control in the Brandt soil and the 1X Sustane treatment in the Egan soil had low R^2 values (.54 and .66, respectively). The R^2 values of the Sustane treatments in the Brandt soil suggest that this model can be used to describe N mineralization from these organic amendments. The R^2 values in the Egan soil were not as consistently high as in the Brandt soil, suggesting that this model explained less of the variability and may not be generalized among soil types.

3.4 | Grit impact on plants: Wheat

The height response of wheat was similar among replications ($p = .24$), whereas the height response differed among grits ($p < .10$). Sustane, which had the faster N mineralization in the laboratory experiments, had the fastest height response (average, 1.3 mm d^{-1}). The Agra Grit, corncob grit, and nontreated control treatments, which had slow N mineralization or immobilization in laboratory studies, had lower height responses (average, 1.1 mm d^{-1}).

The relative dry biomass was similar among repetitions ($p = .32$) but differed among grits ($p < .001$) (Table 5). The relative dry biomass had a similar pattern as the height response, where the Sustane treatment had the highest relative weight (average, 90 kg kg^{-1}). This was 1.5 times more biomass than the Agra Grit, corncob grit, and nontreated control treatments, which all had similar and lower relative dry biomasses (average, 50 kg kg^{-1}).

3.5 | Red Russian kale

The height response of red Russian kale was similar among grits (average, 0.46 mm d^{-1}) (Table 5). In the second experiment, Sustane had the fastest height response (average, 0.411 mm d^{-1}), whereas the Agra Grit corncob grit and nontreated control had similar and lower height responses (average, 0.30 mm d^{-1}).

The relative dry biomass was similar among replications ($p = .24$) and differed among grits ($p < .001$). The Sustane treatment had the highest relative dry biomass and averaged 95 kg kg^{-1} of the peak biomass, almost two times greater than the Agra Grit, corncob, and nontreated control grit treatments, which averaged 52 kg kg^{-1} of the peak biomass.

3.6 | Velvetleaf

All replications and grits had a similar height responses (average, 0.2 mm d^{-1}). The dry biomass of velvetleaf was similar among all experiments ($p = .11$) and differed among grits ($p < .05$) (Table 5). Sustane had the highest dry biomass (average, 0.07 g $plant^{-1}$), almost 20 times larger than the Agra Grit, corncob grit, and nontreated control, which averaged 0.004 g $plant^{-1}$.

A common response of wheat and red Russian kale plants was the increased plant height with Sustane and plant heights that were similar among Agra Grit, corncob grit, and nontreated control treatments. The greater plant height in the soil amended with Sustane was attributed to N mineralization when compared with the other treatments. The N mineralization soil incubations in this study determined that Sustane increased soil available N. Zhao, Reddy, Kakani, and Reddy (2005) reported plants that plants lacking N have slower growth. The increased plant height response in wheat and red Russian kale from Sustane could be beneficial for crop growth if weeds are controlled. However, if weeds are not controlled with air-propelled abrasive Sustane grit, the additional N may increase weed growth, as observed with velvetleaf, and could reduce any yield advantage for the crop. The similar plant height response from Agra Grit, corncob grit, and the nontreated control could mean that if these grits are used to control weeds they may not reduce or improve either crop or weed growth through a fertilizer effect.

The relative dry biomasses of wheat red Russian kale and velvetleaf when amended with Sustan are similar to the strong growth responses of certain weeds to conventional N fertilizer sources (Andreasen, Litz, & Streibig, 2006; Blackshaw & Brandt, 2008; Blackshaw et al., 2003) and differ from the lack of responses to blood meal, an organic fertilizer with high amounts of N in common lambsquarters (*Chenopodium album* L.), Powell amaranth (*Amaranthus powelli* S. Watson), and giant foxtail (*Setaria faberii* Herrm) (Little et al., 2015). The dry biomass of velvetleaf when soil was amended with Sustane was similar to the increased biomass response reported by Little et al. (2015) of organic fertilizer and Bonifas, Walters, Cassman, and Lindquist (2005) of a conventional fertilizer. The increased relative dry biomass suggests that weeds could benefit from grit applications of organic N fertilizers if misapplied or if weed control is poor (Poffenbarger et al., 2015). This could be of greater detriment to the crop if weed growth is increased during the critical weed-free period (Hall, Swanton, & Anderson, 1992; Van Acker, Swanton, & Weise, 1993; Welsh, Bulson, Stopes, Froud-Williams, & Murdoch, 1999).

TABLE 5 The estimated mineralized N from 27 d of experiments, height response, and relative dry biomass of wheat, red Russian kale, and velvetleaf grown in pots with sand and a top layer of Brandt silty clay loam soil

Grit	Estimated N[a]	Wheat		Red Russian kale		Velvetleaf	
		Height response	Relative dry biomass	Height response[b]	Relative dry biomass	Height response	Relative dry biomass
		mm d^{-1}	kg kg^{-1}	mm d^{-1}	kg kg^{-1}	mm d^{-1}	kg kg^{-1}
Agra Grit	170	1.1b	56b	0.29b	54b	0.18	61b
Corncob grit	150	1.0b	49b	0.28b	48b	0.16	50b
Sustane 8–2–4	240	1.3a	89a	0.41a	95a	0.20	77a
Nontreated control	220	1.1b	55b	0.29b	54b	0.18	62b
P value		<.001	1.98×10^{-11}	<.10	.000012	.12	.03

Note. Grits were applied at a rate of 3.6 g grit kg^{-1} soil. *P* values are for within each species. The height response of wheat and velvetleaf were similar among experiments, whereas in the second experiment red Russian kale was higher than the first and third experiments. Relative dry biomass was similar among all experiments within species. Letters denote significant differences at level $\alpha = .05$

[a]Based on 112 d incubation experiments from laboratory data. [b]Height response of red Russian kale from Experiment 2.

4 | CONCLUSIONS

The mineralization of N from organic fertilizers has varied effects on plant growth. The organic fertilizer Phytaboost had the highest N content (9.0 mg N kg^{-1} grit), and at least 68% of the N applied was mineralized within 56 d. In contrast, with Sustane organic fertilizer, which had the second-highest N content (8.0 mg N kg^{-1} grit), mineralization was inversely related to the amount of N applied. Agra Grit and corncob grit immobilized soil N in aerobic soil incubations, whereas when soils were amended with these grits there were no adverse effects on plant growth in comparison to plants grown in nontreated soil. Plants growth in greenhouse settings with high N grits (low C/N) had faster height responses and higher relative dry biomasses when compared with plants grown in soil with high C/N grits. A single application of grit during the growing season may increase crop growth, but if attempts to control weeds are unsuccessful these high-N organic fertilizers may provide additional N to weeds. High-carbon organic grits may not affect weed growth or vigor if misapplied or if weeds are not controlled, and N immobilization in treated soil can occur. Grits used for air-propelled abrasive weed management affect weed growth and have differing rates of N mineralization, which varied between soils and when the amounts and timing of applications differed.

We hypothesize that these results could help producers select a grit type that would match their plant needs. A producer could use either the Sustane or Phytaboost grits to apply supplemental N while controlling weeds with an abrasive grit application, or if interested in weed control alone a producer could use Agra Grit or corncob grit. Research is needed to determine how the exponential rise to maximum model can be used to determine N mineralization of organic amendments in different soils and to determine how these organic fertilizers mineralize N in field studies compared with laboratory studies. Field studies should incorporate growth of both crops and weeds, as well as grit N content, into the study design to determine how grits decompose in a field setting.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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