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# Propelled Abrasive Grit for Weed Control in Organic Silage Corn

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## ABSTRACT

Weed management in organic farming requires many strategies to accomplish acceptable control and maintain crop yields. This 2-yr field study used air propelled abrasive grit for in-row weed control in organically certified silage corn (*Zea mays* L.). Corn cob grit was applied as a single application at corn vegetative growth stages V1 (one true leaf; numbers correspond to number of true leaves at the corn vegetative stage), V3, or V5 (in 2013) and V3, V5, and V7 (in 2014) and in double and triple combinations at these stages. Between-row weed control was accomplished by flaming or cultivation after the last grit application. Grit effects on weed efficacy and silage yield were quantified and compared with hand-weeded and season-long weedy treatments. Grit applications decreased in-row weed biomass by >80% and increased yield up to 250% when compared with the weedy check. Single early applications (V1 and V3) increased yield, with additional treatments decreasing end-of-season weed density and biomass. Single late grit applications (V5 and V7) also decreased weed biomass, but silage yields were reduced compared with hand-weeded and early treatments. Early grit applications may have value for growers to control in-row annual weeds in organic silage corn without soil disturbance.

## Core Ideas

- Air-propelled corn cob grit can control in-row weeds in corn through abrasion
- A single grit application applied at V1 or V3 of corn increased silage yield.
- A single grit application applied at V5 or V7 suppressed weeds, but had lower silage yield.

**W**EEDS ARE responsible for severe reductions in organic crop yield quantity and quality (Stopes and Millington, 1991; Posner et al., 2008; Liebman and Davis, 2009). Accordingly, weed control typically ranks as the primary research priority among organic producers (Baker and Smith, 1987; Walz, 1999, 2004). It also is a key limiting factor for farmers wishing to transition to organic production (Bond and Grundy, 2001; Walz, 2004).

Successful weed control in organic fields is challenging, in part, because it requires the use of strategies involving multiple techniques to achieve economically acceptable results (Cloutier et al., 2007; Kruidhof et al., 2008; Liebman and Davis, 2009; USDA, 2014; Van Der Weide et al., 2008; Walz, 1999). Weed control in organic crops often is accomplished by hand-weeding and mechanical methods, such as tillage. These methods often are considered the foundations of weed control in organic systems (Radosevich et al., 1997; McErlich and Boydston, 2013). However, high labor costs are associated with hand-weeding, and repeated soil tillage destroys soil quality, may promote emergence of new flushes of weeds, and increases the chance of soil erosion (Harper, 2015).

The use of herbicides derived from natural products as soil treatments (e.g., corn gluten meal) or foliar sprays (e.g., clove [*Syzygium aromaticum* (L.) Merr. and L.M. Perry] oil) do not always control weeds adequately (Johnson et al., 2013). Although other techniques in organic systems such as steaming, flaming, and microwaving soil to destroy seeds and other propagules (Radosevich et al., 1997) may be successful, they also can be impractical because of costs and/or energy requirements, or they may be suitable primarily for control of between-row weeds. Consequently, weeds near or in the crop row remain persistent problems in organic systems. Thus, development is needed for alternative control methods that can be used close to or within crop rows, but do not depend on soil disturbance.

Previous research suggested that abrasive grits may be used to control weeds (Nørremark et al., 2006), and greenhouse and field studies have demonstrated that granulated walnut shells and corn cob grits can be used to control small weed seedlings (Forcella, 2009a, 2009b, 2012). One split-second blast of corn cob grit delivered from a sand blaster at a 500 kPa pressure was

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**Abbreviations:** V1, V3, V5, V7, number of true leaves at the corn vegetative stage.

enough to achieve 85% weed mortality (Forcella, 2009a). Field studies demonstrated that two applications using hand-held equipment to propel corncob grit, combined with inter-row cultivation, successfully reduced weeds in corn and increased grain yield (Forcella, 2012). Additional research in organic vegetables showed that organic fertilizers, including corn gluten meal, greensand (glaucanite; potassium fertilizer), soybean [*Glycine max* (L.) Merr.] meal, and bone meal, applied as air-propelled grits, provided control of broadleaf and grass weed seedlings (Wortman, 2014). The use of organic fertilizers in organic transplanted tomato (*Lycopersicon esculentum* Mill.) trials reduced weed biomass near the plants from 69 to 97% and increased yield by about 44% compared with plants from untreated areas (Wortman, 2015). All of the above experiments with abrasive grits were performed with commercially available hand-held equipment, but these implements were appropriate only for one crop row at a time, not multiple rows simultaneously.

To further mechanize the grit application technique, a tractor-mounted abrasive grit sprayer that can treat four crop rows simultaneously was constructed by agricultural engineers at South Dakota State University (Lanoue, 2012), however its effectiveness was unknown. Consequently, the objectives of this 2-yr field experiment in organic silage corn were (i) to test the new sprayer and assess the efficacy of the propelled abrasive grit management system at multiple timings and frequencies for post-emergence in-row weed control combined with a single between-row weed control operation (either by flame-weeding or cultivation); and (ii) to quantify silage corn yields in these treatments compared with yields from untreated and hand-weeded treatments.

## MATERIALS AND METHODS

### Experimental Site and Design

The specific fields (known as E16E, 14 ha, 2013; and Sommer South, 15 ha, 2014) used for this study have been certified for organic production and are located at the West Central Research and Outreach Center (WCROC) of the University of Minnesota, Morris, MN (Erazo-Barradas, 2016). The soil types (Lewis et al., 1971) were a McIntosh silt loam (fine-silty, mixed, superactive, frigid aquic calciudoll) in 2013 and a McIntosh/Tara (fine-silty, mixed, superactive, frigid aquic hapludoll) silt loam complex in 2014. The previous crop in E16E (2012) was sorghum–sudangrass (*Sorghum × drummondii* [Nees ex. Steud.] Millsp. & Chase), whereas winter wheat (*Triticum aestivum* L.) was in Sommer South (2013). Fields were tilled prior to corn planting and liquid swine manure was applied in 2013 at 55,000 L ha<sup>-1</sup> (estimated available N ~ 324 kg ha<sup>-1</sup>) (Loria et al., 2007) and composted dairy manure was applied in 2014 at 74 Mg ha<sup>-1</sup> (estimated available N ~ 61 kg ha<sup>-1</sup>) (Livestock Wastes Subcommittee, 1993). These amounts were based on N recommendations for silage yield goal (~14,000 kg ha<sup>-1</sup>), soil sample results, and previous manure applications (Brown et al., 2010).

The entire fields were planted with organic corn varieties; Viking 79–96N (relative maturity 96 d) was planted on 26 May 2013 at 95,600 plants ha<sup>-1</sup>, and Blue River 33L90 (relative maturity 93 d) was planted on 21 May 2014 at 73,000 plants ha<sup>-1</sup>. Row spacing was 76 cm each year. Varieties and seeding rates were chosen by the farm manager and based on seed availability. The effect of seeding rate on silage yield was examined using the equation:

$$\text{Expected yield} = 9.91[1 - \exp(-0.362x)] \text{ Mg ha}^{-1}$$

where  $x$  is the plant population in plants m<sup>-2</sup> (Overman and Scholtz, 2011).

Growing degree days (base 10°C) from May (planting) through late-August totaled about 2360 each year, about 12% less than the 25-yr average (1986–2011). Rainfall for this same period was 111 mm in 2013 and 117 mm in 2014, about 25% greater than the 25-yr average. These data indicate that both growing seasons were cooler and wetter than the 25-yr average.

The study consisted of three single-grit applications, two double-grit applications, and a single triple-grit application to the crop rows. Timing of applications was based on corn growth stages (Table 1), as defined by Ritchie et al. (1997). All grit application treatments were coupled with a single between-row treatment of either flaming or cultivation at the V5 (five true leaves; numbers correspond to number of true leaves at the corn vegetative stage) (2013) or V7 (2014) corn growth stages. Each year, four grit-free treatments also were established. These were (i) season-long weedy control, (ii) hand-weeded control, (iii) cultivation only and (iv) flaming only. The latter two treatments occurred once at V5 (2013) or V7 (2014). Grit applications at V3 and V5 corn growth stages were common treatments in both years. The first grit application in 2013 occurred at V1 (13 June), whereas in 2014, the first application occurred at V3 (4 June), due to wet soil conditions during V1–V2 stages. The last grit application was at V5 (27 June) in 2013 and at V7 (23 June) in 2014.

Single, double, or triple applications of corncob grit (particle size 0.5 mm) (Green Products Company, Conrad, IA) were applied each year using a four-row grit applicator (Fig. 1) as described by Lanoue (2012). The applicator was mounted on the three-point hitch of a John Deere 7610 tractor that traveled at 2.5 km h<sup>-1</sup>. The applicator had four pairs of nozzles. The nozzles in each pair were aimed at each side of a corn row so that grit was applied within 15- to 20-cm from the base of corn plants and at a 30° angle from the horizontal soil surface and a 60° angle from the vertical (upright corn plants). Grit was passed by gravity from two holding tanks to the nozzles wherein compressed air (690 kPa) entrained the grit and expelled it at an aggregate rate of 480 kg ha<sup>-1</sup>.

Annual broadleaf species were the predominant weeds both years. At the early application dates, redroot pigweed (*Amaranthus retroflexus* L.) at the 2-leaf stage comprised 85% of the weed population, with the remainder being common lambsquarters (*Chenopodium album* L.) at the 3-leaf stage. Pennsylvania smartweed (*Polygonum pennsylvanicum* L.) was present at later applications, comprising up to 20% of the weed population with plants at the 3-leaf to 5-leaf stages of growth. Grasses were observed infrequently during grit applications both years.

Between-row weed control was performed with either cultivation or flaming about a week after the last grit application (2 July 2013 and 7 July 2014). Flaming was accomplished using a custom-built, single-wheeled, hand-pushed flame weeder that had five burners mounted 15-cm apart. Burners were positioned 18-cm above soil surface beneath a hood over the row middle and angled back at 30° to the soil. This treatment was performed at a speed of 3.1 km h<sup>-1</sup> and delivered a propane dose of 50 kg ha<sup>-1</sup>. Cultivation was accomplished using a tractor-mounted John Deere 886 cultivator driven at 5 km h<sup>-1</sup>.

Table 1. Grit applications timings and frequencies based on corn growth stage (see Ritchie et al., 1997) at Morris, MN, in 2013 and 2014. A season-long weedy control, hand-weeded control (weeding occurring at each time of grit application, and whenever needed), and a single cultivation between-row, and single flaming between-row also were included in the treatments.

Grit application timings			
2013		2014	
Growth stage	Date	Growth stage	Date
V1†	13 June	V3 <sup>1</sup>	4 June
V3	19 June	V5	13 June
V5	27 June	V7	23 July
V1+V3	13 June + 19 June	V3+V5	4 June + 13 June
V1 + V5	13 June + 27 June	V3+V7	4 June + 23 June
V3 + V5	19 June + 27 June	V5 + V7	13 June + 23 June
V1+V3+V5	13 June + 19 June + 27 June	V3+V5+V7	4 June + 13 June + 23 June

† For each grit treatment, a between-row flaming or cultivation was performed about 1 wk after the V5 (2 July 2013) and V7 (7 July 2014) grit applications. In addition, the single flaming or cultivation treatments with no grit application were established at this same time.

Aboveground weed biomass was collected just prior to silage corn harvesting at the R5 corn growth stage (20 Aug. 2013 and 15 Sept. 2014). For in-row weeds, 15 × 40 cm quadrats were centered lengthwise on the crop row; whereas for between-row weeds, quadrats were placed centrally between two corn rows. Weeds within these quadrats were clipped at ground level, sorted and counted by species, dried at 40°C until constant weight, and weighed.

The heights of three randomly selected corn plants from the two central rows of each plot were measured from soil surface to the node of the last emerging leaf just prior to harvest. Plants from two 1-m long central rows of each plot were cut at the soil surface, dried at 40°C until constant weight, and weighed. Yields were calculated based on dry crop biomass.

### Statistical Analysis

Treatments were established in a randomized complete block design with four replications (Steel and Torrie, 1996) in plots measuring 3 × 3 m and consisting of four corn rows. Due to differences in fertility regimes, plant population, and timing of grit and between-row applications, data were not combined but analyzed by year. Treatments were considered the fixed effects, whereas block was considered a random effect. Mixed effects ANOVA models using the library *agricolae* (de Mendiburu, 2014) in R (R Core Team, 2014) were used to test the effects of grit timing frequency combined with cultivation or flaming on total weed biomass, in-row and between-row weed biomass, silage corn yield, and plant height. Maximum potential yield without weed competition for each site-year environment were estimated from the weed free plots, whereas season-long weedy plot values were used as a basis to assess weed control and yield without weed control.

## RESULTS AND DISCUSSION

### Weed Control

Weed biomass (dry weight) was quantified just prior to silage harvest. In the season-long weedy plots, total weed biomass (combined in-row plus between-row) averaged about 5500 kg ha<sup>-1</sup> in 2013 and 5000 kg ha<sup>-1</sup> in 2014 (Table 2). The broadleaf species that were most prevalent were redroot pigweed, common lambsquarters, and Pennsylvania smartweed. Grass species, yellow and green foxtail (*Setaria pumila* [Poir.] Roem. & Schult. and *S. viridis* [L.] P.Beauv., respectively) also were observed in all plots at harvest, but their densities were too low for



Fig. 1. In-row grit applicator constructed by Lanoue (2012) and used for applications in Morris, MN, in 2013 and 2014 (Photograph courtesy of Dean Peterson).

meaningful analyses. Between-row weed biomass in the season-long weedy treatment accounted for 78% of the total biomass in 2013 and 70% of the total biomass in 2014. Cultivation and flaming were similar in their effectiveness and reduced weed biomass by 83% in 2013 and 60% in 2014 ( $p < 0.001$  each year) (Table 2). The lesser control for the between-row treatments in 2014 may have been due to the later timing (V7 vs. V5), such that the weeds were larger and more difficult to control.

In-row weed biomass in the season-long weedy treatment accounted for 1200 kg ha<sup>-1</sup> (about 22% of total biomass) in 2013 and 1500 kg ha<sup>-1</sup> (30% of total) in 2014. All grit applications reduced in-row weed biomass compared with the season-long weedy treatment, however effectiveness varied with the timing (growth stage of corn) and frequency (single, double, or triple) of grit application. In 2013, the applications at V1, V5, V1 + V3, and V1 + V5 resulted in 73 to 88% reduction in weed biomass compared with the season-long weedy treatment. In 2014, all treatments, except the single application at V3 (54% control), had 64 to 100% less biomass than the season-long weedy treatment and, due to variability, were statistically similar in weed biomass to the hand-weeded control. Single application treatments at V1 and V5 in 2013 resulted in 80 and 75% in-row biomass reduction, respectively, whereas, in 2014, single treatments at V5 and V7 resulted in 73 and 93% in-row biomass reduction, respectively.

The double and triple combination frequencies of grit application had in-row biomass reductions that were similar to some of the single applications. For example, in 2013, only the double application at V1 + V5 resulted in enhanced biomass

Table 2. Weed biomass, percent control based on season-long weedy treatment, and silage corn yield at Morris, MN, 2013 and 2014, with differing in-row and between-row weed control treatments.

In row treatment	2013			Treatment	2014		
	Weed biomass†	Control	Silage yield†		Weed biomass†	Control	Silage yield†
	kg ha <sup>-1</sup>	%	kg ha <sup>-1</sup>		kg ha <sup>-1</sup>	%	kg ha <sup>-1</sup>
Season long weedy	1177		6008	Season long weedy	1501		8970
V1	231	80	16960	V3	688	54	9890
V3	370	69	15840	V5	402	73	8650
V5	290	75	13200	V7	111	93	7600
V1+V3	320	73	17870	V3+V5	215	86	10120
V1+V5	146	88	13260	V3+V7	5	99	9735
V3+V5	415	65	12300	V5+V7	547	64	9140
V1+V3+V5	370	69	13241	V3+V5+V7	248	83	9750
Hand weed control	5	99	14970	Hand weeded control	5	99	11350
LSD‡(0.05)	225		4249	LSD‡(0.05)	580		2000
Between row		2013				2014	
Season long weedy	4287		6008		3515		8971
Flaming	830	81	14485		1647	53	9395
Cultivation	668	84	14870		1115	68	9165
Handweeded control	5	99	14970		5	99	11347
LSD‡(0.05)	170		4660		1751		1900

† Values for weeds and corn are oven-dry weights.

‡ LSD is least significant difference based on ANOVA.

reduction (88%) compared to the V1 or V5 single application (80 and 75% weed biomass reduction, respectively). In 2014, only the double application at V3 + V7 resulted in the numerically greatest biomass reduction (>99%), but statistically was similar to the single application at V5 (73% reduction) and V7 (93% reduction).

### Corn Silage Yield

Because the corn was taken for silage, plant height was measured just prior to harvest as a possible indicator of sensitivity to treatments or to weed competition. Exposure to grit in combination with either cultivation or flaming did not influence plant height. In 2014, even though cultivation and flaming were performed after the V7 corn growth stage, final plant height was not affected by treatment.

Corn silage yield in the hand-weeded controls differed between years. Yields (dry weights) averaged close to 15,000 kg ha<sup>-1</sup> in 2013, and 11,300 kg ha<sup>-1</sup> in 2014, a 24% yield difference. Based on the equation reported by Overman and Scholtz (2011), silage yield in the higher population, weed-free treatments in 2013 would be expected to be about 4% greater than those in 2014. Differences in corn variety between years also may have influenced final yields. For example, in Minnesota silage variety trials (2014 Corn Silage Field Crop Trials Results, <https://www.maes.umn.edu/sites/maes.umn.edu/files/2014%20Corn%20Silage%20Final.pdf>; accessed Nov. 2017) 93 d relative maturity varieties (such as the one used in 2014) tended to yield about 5% less compared with 96 d relative maturity varieties (such as the one used in 2013). Fertility differences, with much more available N from swine manure in 2013, also may have increased silage yield in weed-free treatments, although both manures were applied at rates appropriate for the expected yield goals.

The between-row treatments of cultivation and flaming had similar yields within a year, when grit was not applied. In 2013, silage yields based on between-row treatments were similar to the hand-weeded control and about 2.5 times greater than yield

of the season-long weedy treatment. In 2014, the between-row treatment silage yields were similar to the weedy treatment and about 20% less than the hand-weeded control. The yield reduction in 2014 was most likely due to longer weed interference duration (beyond V7, 2014 compared with treatment soon after V5, 2013), poorer weed control due to larger weeds present, and overall lower yield potential when compared with yields of 2013.

Silage yield differed by grit application timing and frequency, averaged over between-row treatments ( $p < 0.001$ , 2013;  $p = 0.04$ , 2014). Whether cultivation or flaming was used, the yields within the same grit timing and frequency treatments were similar (<5% difference) and, therefore, they were averaged over between-row treatments. In 2013, silage yields in all grit treatments were greater than those of the season-long weedy check and did not differ from the hand-weeded control (Table 2). Otherwise, the only significant differences in yield among grit treatments were between the V1+V3 treatment (highest yield) and V5, V1+V5, and V1+V3+V5 (lower yields). Yield reduction in the V5 treatment may have been due to longer duration of weed interference, as weed control after treatment at this stage was very good. In 2014, yield was similar to the hand-weeded control when grit treatments were applied at V3, V3+V5, V3+V7. The V5, V7, and V5+V7 treatments, while having good weed control, resulted in yields equivalent to the season-long weed check, which likely occurred due to longer duration of weed competition in these treatments.

These data reinforce the concept that weed control needs to be undertaken early, just before or at the start of the critical weed-free period (Zimdahl, 2008), even if greater weed control (as measured by biomass) can be achieved by later applications. Complete season-long weed control is not necessary to achieve maximum yield, which agrees with studies reporting that weeds emerging after the critical weed-free period do not reduce yield (Cardina et al., 1995; Knake and Slife 1965; Oliver 1988; Radosevich et al., 1997).

One of the concerns about abrasive grit applications aimed at the corn row is damage to corn plants by the grit, similar to

the damage inflicted on weeds. Indeed, pitting was observed on the corn leaves due to grit abrasion after applications. However, at early stages of corn development, the plants overcame any damage and had higher yields, probably because ear and tassel tissues were not differentiated until after the V3 stage, and the growing point still was below the soil surface and so was not injured (McWilliams et al., 1999). In addition, corn plants can withstand brief grit applications (Forcella, 2009a, 2009b, 2012) and broadcast flaming (Knezevic et al., 2009, 2012) after the V5 corn growth stage with no effect on plant height and yield.

Another concern is that abrasion by grit might lead to greater disease incidence due to the open wounds in leaf and stem tissue. In this study, both years were cool and wet and no diseases were observed on the plants throughout the season. In fact, the greatest problems for the crop may have been (i) soil compaction due to the multiple tractor passes with double- and triple-grit applications, and (ii) driver error as there was little space between the tractor tires and the corn rows. These issues may be minimized if the crop is planted and treatments are applied with an auto-steer system, and if the grit applicator is commercialized and enlarged, a greater number of rows treated simultaneously to have fewer tire-tracked interrows.

Finally, measurements of energy consumption were neither intended nor made in these experiments. However, coarse estimates of energy use were derived using values for a John Deere 7610 tractor from the Nebraska Tractor Test Laboratory website (<http://tractortestlab.unl.edu/testreports>). Diesel fuel consumption was estimated at 35 L ha<sup>-1</sup> (1600 MJ ha<sup>-1</sup>) for each grit application. This compares to about 60 L propane ha<sup>-1</sup> (3100 MJ ha<sup>-1</sup>) for one pass of a flame weeder (Ascard, 1998). For comparison, farms with conventional corn–soybean rotations (and use herbicides) expended 800 to 1400 MJ ha<sup>-1</sup> for weed control (Clements et al., 1995). Thus, in terms of energy, grit application likely is within the norms for organic management, although higher than that of ‘conventional’ management with herbicides.

In conclusion, application of abrasive grit to control in-row weeds was an effective approach to manage weeds and maintain organic silage corn yields without in-row soil disturbance. The application of grit decreased in-row weed biomass up to 90% at the end of the season. Depending on timing, crop yields also increased. A single late application of grit (at V5 or V7) reduced weed biomass, but due to the length of weed interference with the crop, also reduced yields. These results show the importance of early grit applications, such as at the V1 and V3 stages of corn, on final yield. Increasing grit application frequency from a single application may help with controlling later emerging weeds and, thereby, reduce the potential of increasing the soil weed seed bank (Clay et al., 2005), but more frequent grit applications did not necessarily increase crop yields. Lastly, for organic production of agronomic crops in expansive fields, larger and more sophisticated grit applicators may increase efficiency and decrease energy usage with this new weed control technique.

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