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Air-Propelled Abrasive Grit for Postemergence In-Row Weed Control in Field Corn

Frank Forcella*

Organic growers need additional tools for weed control. A new technique using abrasive grit propelled by compressed air was tested in field plots. Grit derived from corncobs was directed at seedlings of summer annual weeds growing at the bases of corn plants when the corn was at differing early stages of leaf development. Season-long, in-row weed control exceeded 90% when two or three abrasion events were coupled with between-row cultivation. Timing of weed abrasion was critical, with highest levels of control corresponding to the one- and five-leaf stages or the one-, three-, and five-leaf stages of corn development. Corn yields associated with these treatments were equivalent to those of hand-weeded controls in which no abrasive grit was applied. Thus, air-propelled abrasive grit applications at the one-, three-, and five-leaf stages of corn controlled weeds sufficiently to prevent weed-induced reductions in corn grain. Additionally, these applications were not harmful to corn plants. This new concept for weed control may be of interest to organic crop managers.

Nomenclature: Corn, *Zea mays* L. 'Croplan 294RR' and '3114RR'.
Key words: Abrasion, alternative weed management, corncob, nonchemical, organic, sandblasting.

Los agricultores de productos orgánicos necesitan de herramientas adicionales para el control de la maleza. Una nueva técnica que usa un polvo abrasivo propulsado por aire comprimido fue probada en parcelas en el campo. Un polvo derivado de mazorcas de maíz fue dirigido a plántulas de maleza anual de verano que crecían al pie de las plantas de maíz, cuando este cultivo se encontraba en diferentes etapas tempranas del desarrollo de las hojas. A lo largo de la estación, dentro de hileras, el control de maleza excedió 90% cuando dos o tres aplicaciones de la abrasión se asociaron con paso de cultivadora entre hileras. El tiempo de abrasión para la maleza fue crítico, con los más altos niveles de control correspondiente a las etapas de 1 y 5 hojas o en las etapas de desarrollo del cultivo de 1, 3 y 5 hojas. Los rendimientos de maíz asociados con estos tratamientos fueron equivalentes a aquellos con controles de deshierbe manual, en los cuales no se aplicaron los polvos abrasivos. Por lo tanto, las aplicaciones de los polvos propulsados con aire comprimido en las etapas de 1, 3 y 5 hojas de maíz, controlaron la maleza lo suficiente para prevenir reducciones en el rendimiento del grano causadas por éstas. Adicionalmente, estas aplicaciones no fueron perjudiciales a las plantas de maíz. Este nuevo concepto para el control de maleza podría ser de interés para los productores de cultivos orgánicos.

Abrasive grits propelled by compressed air are used to rejuvenate painted, rusted, or greased surfaces. These grits typically are associated with the term "sandblasting." Many types of abrasive grits exist, but for purposes of sandblasting they fall under two general categories: hard and soft grits. Soft grits include materials processed from common agricultural residues, notably corncobs, nut shells, and seed coats of stone fruits. Discovery of additional uses for these residues may enhance their values as well as those of their parent crops. One additional use of these materials possibly could be the POST abrasion and control of weed seedlings.

Soft grits were tested in greenhouse and nursery experiments for their ability to abrade and control broadleaf and grass weeds. A single brief exposure ($\leq$ 1 s) to abrasive grits, which were propelled at air pressures of about 500 kPa, typically killed small broadleaf weed seedlings (Forcella 2009a) and severely abraded grass seedlings (Forcella et al. 2011). When these weeds were growing near the bases of corn seedlings, and grits were aimed at the weeds and not at the whorl of the corn plant, the weeds were controlled and the crops unaffected (Forcella 2009b, Forcella et al. 2011). Results from these "concept-testing" experiments were promising and justified adapting the idea to field settings.

The objective of this study was to determine whether (1) selective in-row weed control could be achieved from applications of corncob grit in field corn and (2) the necessary number and timing of those applications to achieve season-long weed control. If successful, the technique may have value in row crop production on organic farms where new and effective methods for controlling weeds without soil tillage are needed (Moncada and Sheaffer 2010, Moynihan 2010, Walz 2004).

Materials and Methods

Field corn was sown at about 82,000 seeds ha^{-1} in rows spaced 76 cm apart at the Swan Lake Research Farm (45.60°N, 95.91°W), Stevens County, Minnesota. Corn hybrids were 'Cropland 294RR' in 2009 and '3114RR' in 2010. The soil was a Barnes loam (Udic Haploboroll, fine, loamy, mixed) with 5% organic matter, which had been chiseled, spread with 140–60–60 kg ha^{-1} of N–P–K, and field-cultivated prior to planting. Three planting dates occurred each year: early, middle, and late, which corresponded to May 9, June 18, and July 1, 2009; and April 27, May 18, and June 2, 2010. Each planting date was a separate experiment.

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* Research Agronomist, North Central Soil Conservation Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, 803 Iowa Avenue, Morris, MN 56267. Corresponding author's E-mail: frank.forcella@ars.usda.gov

Table 1. End-of-season weed control as a percentage of total aboveground weed dry weight in nontreated check plots (last column) as influenced by timing of abrasive grit application. Application timing was based on development stages of corn: e.g., "3, 5" represents two applications, the first at the three-leaf stage and the second at the five-leaf stage of corn. Early, middle, and late represent three corn planting dates.[a]

Year / date	Corn leaf stages at time(s) abrasive grit was applied											Weed dry weight
	1	2	3	5	1, 2	1, 3	1, 5	2, 4	3, 5	4, 6	1, 3, 5	
	(% ± SE)											(g m^{-1} row ± SE)
2009												
Early	41 ± 15.6	25 ± 14.7	49 ± 22.4		61 ± 8.6	41 ± 5.5						85 ± 14.0
Middle						60 ± 24.1*			42 ± 19.0			17 ± 7.7
Late								42 ± 17.3		48 ± 21.1*		22 ± 5.9
2010												
Early	64 ± 6.1		62 ± 21.4	75 ± 8.1*		72 ± 16.1*	93 ± 2.7*		53 ± 20.3		82 ± 3.4*	162 ± 44.6
Middle	26 ± 24.5		76 ± 10.6*	85 ± 9.2*		94 ± 1.8*	86 ± 9.7*		74 ± 17.0*		93 ± 2.9*	25 ± 10.0
Late	84 ± 13.1*		59 ± 6.8	64 ± 17.0		80 ± 15.2*	96 ± 2.8*		89 ± 6.2*		98 ± 1.4*	50 ± 6.2
Average	54	25	62	75	61	69	92	42	65	48	91	

[a] Hand-weeded treatments were free of weeds except for the middle and late planting dates in 2010, which had 0.3 ± 0.26 and 2.8 ± 0.80 g m^{-1} row, respectively.

* Values did not differ ($P < 0.05$) from hand-weeded treatments.

Weed control treatments consisted of abrading weeds (described below) when corn reached specific leaf stages (Table 1). Because the corn leaf stage at which abrasion would reduce weeds most effectively was unknown beforehand, a range between the one-leaf and five-leaf stages of corn was chosen for initial abrasion events. Second and third abrasion events followed initial events as part of some treatments. Experiences during 2009 were used to adjust and refine treatments in 2010. Each experiment also consisted of weedy and hand-weeded control treatments. The latter were kept weed-free throughout the growing season. Randomized complete block designs with four replications were used. Treated plots were two rows wide and 6 m long in 2009, and two rows wide and 3 m long in 2010. Plots were separated from one another by two rows of hand-weeded corn.

Abrasion of weeds was performed using grit derived from corncobs. Particle size of the grit was the commercial standard of 20–40 mesh, or approximately 0.5 mm diameter. Grit was placed in a tank pressurized from 550 to 700 kPa (80 to 100 psi) with compressed air. A high-strength hose connected the tank to a single porcelain nozzle. The nozzle emitted grit in a full-cone pattern at a rate that was pressure-dependent. Maintenance of a steady pressure was not possible with the equipment available for these concept-testing experiments. Consequently, the tank was repressurized to 700 kPa once pressure dropped to 550 kPa. (Emission rates ± SE were 35 ± 0.7, 39 ± 0.9, and 42 ± 0.8 g s^{-1} at 550, 625, and 700 kPa, respectively.)

The nozzle was regulated by hand so that its tip was within 60 to 100 cm from the bases of corn plants and at an angle of about 30° from the horizontal (soil surface) and 60° from the vertical (upright corn plants). These distances and angles were altered through trial and error in the in 2009 experiments and fixed in the 2010 experiments. The person operating the nozzle walked at 0.9 ± 0.01 m s^{-1} (3.1 ± 0.03 km h^{-1}) behind a small off-road vehicle that held the grit tank and air compressor. The nozzle was aimed at the bases of corn plants within each row. This procedure dispersed grit in a 10-cm-wide band from the corn row toward the middle of the interrow area, but only on one side of each corn row. Consequently, the vehicle and operator turned at the end of each treated plot and repeated the procedure on the opposite side of the corn row. After the final treatment in each experiment, the between-row areas of all plots were cultivated with a shielded cultivator. Shields were set to provide a 15-cm-wide band centered on the corn row of protected soil and plants.

Corn stands were determined by counting all corn plants within 2-m lengths of each row in each plot in late August. Aboveground portions of weeds were clipped in these same areas, sorted by species, dried at 40 C for 2 wk, and weighed. Weeds were primarily redroot pigweed (*Amaranthus retroflexus* L.) and common lambsquarters (*Chenopodium album* L.), and some green and yellow foxtail [*Setaria viridis* (L.) Beauv. and *S. pumila* Poir.]. Weed control was calculated as the percentage of reduction in total weed dry weight in each plot compared to the plot with the highest total dry weight in each block, which typically occurred in the weedy check plot. Corn ears were counted and hand-harvested in October, dried at 40 C for 2 wk, and shelled; the grain was weighed, adjusted to 15.5% seed moisture, and yields were calculated. Effects of treatments on weed control and corn yields within each experiment were analyzed through ANOVA, whereas associations between weed control and corn yield were examined through simple correlation (Anonymous 2008).

Results and Discussion

Weed Control. Single applications of abrasive grit at the one-, two-, or three-leaf stages of corn occurred nine times during the six experiments over the course of 2 yr. In seven of these instances weed control was lower ($P < 0.05$) than that in hand-weeded check treatments (Table 1) and would be unacceptable for practical weed control. In most of these cases, season-long control of annual weeds was < 65%, which typically would not be sufficient to prevent yield losses in corn. In contrast, a single application of grit at the five-leaf stage of corn occurred in three experiments, and it provided

Table 2. Corn grain yield as influenced by timing of abrasive grit application. Application timing was based on development stages of corn; e.g., "3, 5" represents two applications, the first at the three-leaf stage and the second at the five-leaf stage of corn. Weedy represents weedy check treatments, and weed-free represents hand-weeded treatments. Early, middle, and late represent three corn planting dates.

	Corn leaf stages at time(s) abrasive grit was applied												
Year	1	2	3	5	1, 2	1, 3	1, 5	2, 4	3,5	4,6	1,3,5	Weedy	Weed-free
	Mg ha^{-1} ± SE												
2009													
Early	8.4 ± 0.18	8.4 ± 0.65	8.5 ± 0.45		9.0 ± 0.28	9.0 ± 0.40						8.1 ± 0.13	9.5 ± 0.86*
Middle						5.1 ± 0.75			5.0 ± 0.69			6.1 ± 0.44	6.6 ± 0.98
Late								1.7 ± 0.42		2.1 ± 0.13		2.3 ± 0.55	1.9 ± 0.18
2010													
Early	10.1 ± 0.58		9.4 ± 1.27	10.5 ± 0.39*		10.9 ± 0.27*	10.5 ± 0.71*		11.3 ± 0.70*		10.8 ± 0.28*	9.0 ± 0.36	11.2 ± 0.34*
Middle	11.2 ± 0.59		10.9 ± 0.56	11.6 ± 0.15		10.9 ± 0.38	10.7 ± 0.30		11.0 ± 0.33		11.2 ± 0.38	10.9 ± 0.28	10.7 ± 0.90
Late	9.1 ± 0.39		8.2 ± 1.18*	9.7 ± 0.44		10.5 ± 0.55	9.9 ± 0.59		9.6 ± 0.32		9.5 ± 0.19	9.9 ± 0.21	10.0 ± 0.91

* Values differed ($P < 0.05$) from the weedy treatment.

season-long control between 64 and 85%, suggesting that abrasion events at or near the five-leaf stage of corn may be more critical for reducing weed dry weights than earlier events.

Two applications of abrasive grit achieved high levels of weed control, especially when the grit was applied when corn was at the one- and three-leaf stages or the one- and five-leaf stages. Under these circumstances, season-long control was as high as 96%. However, two applications, at the one- and two-leaf stages, two- and four-leaf stages, or four- and six-leaf stages of corn, resulted in season-long control of only 42 to 61%. Two applications, at the three- and five-leaf stages of corn, achieved intermediate levels of control, ranging from 42 to 89%.

Three applications of abrasive grit (at the one-, three-, and five-leaf stages of corn) achieved season-long weed control between 82 and 98%, and averaged 91%. This level of weed control likely was sufficient to minimize corn yield loss due to weed competition. Nevertheless, three grit applications did not improve control beyond that achieved with two applications at the one- and three-leaf and one- and five-leaf stages of corn.

The relatively low levels of control achieved in 2009 compared to 2010 probably reflected differences in nozzle angles and distances of the grit-emitting nozzle relative to the corn row. In 2009, the research team learned by trial and error how to position the nozzle to enhance its effects, and these improvements were implemented in 2010.

Lastly, of the total weed biomass in 2009 and 2010, 19 and 7% comprised grasses (primarily foxtail); 30 and 59%, common lambsquarters; and 51 and 32%, redroot pigweed, respectively. Broadleaf weed biomass was correlated well with total weed biomass ($r^2 = 0.97$ in 2009 and 0.99 in 2010), which indicated that broadleaf weeds generally reacted similarly to treatments. Grass weeds were too sparse for an analogous assessment.

Corn Yields. Abrasion treatments never affected corn stands ($P > 0.20$) or ear densities ($P > 0.42$) in any experiment in either year. Weed-free corn yields reflected planting date effects in 2009 (Table 2), dropping from 9.5 Mg ha^{-1} with early planting to 6.6 and 1.9 Mg ha^{-1} with middle and late plantings (Lauer et al. 1999). The low yields with the late planting date (July 1) were exacerbated by dry conditions throughout the growing season, but especially in July. (Rainfall in May, June, July, and August was 11, 41, 20, and 70 mm, respectively.) Consequently, weed control had no detectable influence on yields for the middle and late planting date experiments in 2009. Only in the early planting date experiment was corn yield significantly higher in the weed-free treatment than in the weedy check treatment. Although yields of grit-treated corn did not differ from those of the weedy check treatment, they also did not differ from the hand-weeded check, which indicated that even two abrasive grit treatments did not injure corn sufficiently to lower yields.

The 2010 growing season was ideal for corn, and yields often exceeded 10 Mg ha^{-1}, even in the late planting date experiment. (Rainfall in May, June, July, and August was 37, 87, 57, and 164 mm, respectively.) In the early planting date experiment, weeds were sufficiently abundant to lower corn yields significantly in the weedy check and the one- and three-leaf grit abrasion treatments. Weeds apparently also lowered corn yields in the three-leaf treatment of the late planting date experiment. Otherwise, all other yields were equivalent to the hand-weeded check treatments. Even with three sequential grit abrasion events at the one-, three-, and five-leaf stages of corn, injury to corn plants was insignificant in terms of grain yield losses.

Corn grain yield was correlated, albeit poorly, with weed control only in the early planting date experiments of both years ($r = 0.55$ and $P = 0.002$ in 2009; $r = 0.62$ and $P < 0.001$ in 2010). In the middle and late planting date experiments, correlation coefficients were low (0.04 to 0.23) and never significant ($P = 0.38$ to 0.89). Lack of correlation with the latter two planting dates reflected low weed dry weights, even in the weedy plots (Table 1), probably because late seedbed preparation often reduces populations of summer annual weeds substantially and increases the competitive advantage of corn (Gunsolus 1990).

Mechanical damage to corn plants early in the season possibly can affect disease incidence (Draper 2004). Although slight leaf pitting due to grit abrasion occurred on treated corn seedlings, no diseases were observed subsequently in these experiments.

Grit Application Rate and Tentative Cost. Approximately 1,140 kg ha^{-1} of grit would have been applied per treatment given the following assumptions: (1) an average emission rate of 39 g grit s^{-1} from a single nozzle, (2) grit applications to both sides of a corn row by two nozzles (one nozzle per side of a crop row), (3) 76-cm corn row spacing, and (4) a ground speed of 0.9 m s^{-1}. Commercially available corn cob grit in 2011 could be purchased in 908-kg (2,000-pound) bags for about $270 (approximately $0.30 kg^{-1}) (e.g., Green Products Company, Conrad, IA), which would result in a product cost for weed control of $340 ha^{-1} per pass. Coupled with the additional costs of hauling and applying such a large quantity of material, this expenditure is too great to be a realistic option for managing weeds in a commodity crop like field corn, although the value may be within reason for high-value horticultural crops, such as orchards and vineyards.

Even for field corn, however, possibilities exist for reducing these costs if grit were to be used for weed control. For example, on-farm collection and milling of corn cobs would lower the high cost of grit. Fresh weight of a cob at harvest in 2010 was 37 ± 0.5 g, and cob moisture content at that time typically is 50% (Shinners et al. 2003). With a 2010 corn population of 83,000 ± 600 ear-bearing plants ha^{-1}, approximately 1,500 kg ha^{-1} of dry cob material would have been produced, which is more than sufficient for a single-pass grit application. Additionally, use of more-efficient nozzles, higher ground speeds, etc., likely would reduce application rates and costs. An extreme case of reducing the cost of grit would be to use only compressed air and no grit. The Pneumat system for POST control of weed seedlings uses only compressed air (Lütkemeyer 2000, as reported in van der Weide et al. 2008). Forcella et al. (2010) noted that compressed air alone did damage weeds, but efficacy was enhanced greatly with the addition of grit into the airstream.

Corncob grit was used in the experiments described above primarily to test the concept of employing abrasive materials for weed control in field situations. However, other types of grit, which may be cheaper or have greater utility, could substantially lower the effective cost of abrading weeds. For instance, some organic growers apply various N-rich seed meals (e.g., corn gluten meal; Forcella et al. 2010) or crushed limestone to meet the fertility needs of their crops. Such organically approved fertilizers also could substitute as abrasive grits to control weeds and, thereby help resolve two important issues simultaneously (weed control and crop fertility) and reduce associated costs accordingly.

In summary, relatively high levels of season-long and in-row weed control can be achieved with air-propelled abrasive grit if it is applied two or three times in field corn. These times correspond to the one- and five-leaf and one-, three-, and five-leaf stages of corn. Single applications or multiple applications at other times are not conducive to consistently high levels of weed control by this method. Provided that the abrasive grit is aimed at the bases of the corn plants, crop injury is negligible and corn yields are as high as those in hand-weeded controls. Appropriateness of this technique in herbaceous crops other than corn is not known. However, preliminary field observations in 2011 suggest that soybean treated from emergence through the third trifoliate stages of growth is not damaged significantly by grit applications.

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