Renewable Agriculture and Food Systems

cambridge.org/raf

Research Paper

Cite this article: Forcella F, Dalman N, Poppe S, Hoover E (2023). Grit effects on grass weeds and grit-weeding in aronia berry (*Aronia melanocarpa*). *Renewable Agriculture and Food Systems* **38**, e50, 1–7. https://doi.org/10.1017/S1742170523000431

Received: 1 February 2023
Revised: 5 September 2023
Accepted: 25 October 2023

Keywords:
bone meal; eggshell; hazelnut shell; non-chemical control; sugar beet pulp

Corresponding author:
Frank Forcella;
Email: forcellafrank@gmail.com

Grit effects on grass weeds and grit-weeding in aronia berry (*Aronia melanocarpa*)

Frank Forcella[1], Nathan Dalman[2], Steve Poppe[3] and Emily Hoover[4]

[1]Department of Agronomy and Plant Genetics, University of Minnesota, St Paul, MN, USA; [2]West Central Research & Outreach Center, University of Minnesota, Morris, MN, USA; [3]West Central Research & Outreach Center, University of Minnesota, Morris, MN, USA and [4]Department of Horticultural Science, University of Minnesota, St Paul, MN, USA

Abstract

Two sequential experiments examined the effects of abrasive grit on seedlings of grass weeds and young shoots of perennial weeds. First, four types of grit derived from agricultural residues (bone meal, eggshell, hazelnut shell, and sugar beet pulp) were tested under high air pressure in a controlled environment for their abilities to abrade seedlings of an annual grass, *Setaria faberi* Herrm., and the perennials *Festuca arundinacea* Schreb., *Poa pratensis* L., and *Elymus repens* (L.) Gould. Differing grit particle sizes and amounts, as well as weed seedling stages, were examined for efficacy after abrasion by each type of grit. Second, hazelnut shell grit was used to control *P. pratensis* and *Taraxicum officinale* Weber in field trials with aronia (*Aronia melanocarpa* [Michx.] Elliott), which is a new, shrubby, berry crop in the midwestern USA. Grit weeding was compared to two other treatments: manual weeding (hand-hoeing + hand-pulling) and no weed control (weedy check) over two years. In the grit comparison experiment, control of *S. faberi* was highest for egg-shell grit (63–100% across grit particle sizes, rates, and seedling stages) and least for sugar beet pulp (17–97%). The former grit had the highest bulk density of all grits, and the latter had the lowest bulk density. For damage to perennial weeds, egg-shell grit performed best (17–80% control) and bone meal least (10–47% control). *Elymus repens* was controlled better than other perennial grasses, especially by eggshell grit (up to 73% control) and hazelnut shell grit (up to 67% control) with particle sizes of 1–2 mm. In the aronia experiment, both grit abrasion and manual weeding achieved comparable levels of weed suppression (≥87%) and required similar amounts of cumulative seasonal time spent weeding (3–4 min per shrub). Thus, applications of abrasive grit derived from agricultural residues are potential alternatives for non-chemical management of weeds in aronia and, perhaps, in other high-value perennial crops.

Nomenclature

Aronia melanocarpa cv. 'Viking', aronia berry or black chokeberry; *Corylus avellana × americana*, hybrid hazelnut; *Elymus repens*, quackgrass; *Festuca arundinacea*, tall fescue; *Poa pratensis*, Kentucky bluegrass; *Setaria faberi*, giant foxtail; *Taraxicum officinale*, common dandelion.

Introduction

Aronia berries (also known as black chokeberries) are produced by *Aronia melanocarpa* (Michx.) Elliott, a multi-branched shrub in the rose family (Rosaceae) native to the northeastern and midwestern USA (Hardin, 1973). Aronia has been domesticated for its fruit, which are dark purple to black berries with very high concentrations of anthocyanins (Scott and Skirvin, 2007). This latter trait has been the stimulus for aronia propagation, with the fruit being used as a food coloring agent, as well as being processed into juices, syrups, and liqueurs (Kulling and Rawel, 2008). The antioxidant capacity of fresh aronia fruit was higher than that of any of 18 common fruits examined (Kulling and Rawel, 2008).

When grown as a horticultural crop, aronia has few pest problems, but weeds can interfere with plant growth as well as crop management (McKay, 2001). Although black plastic mulches or landscape fabrics are recommended for weed control (Bussieres et al., 2008), weeds still can cause problems if they establish in transplant openings in such mulches (Fig. 1). Furthermore, because aronia fruit and fruit products are considered by many as health foods with medicinal properties, controlling weeds in aronia plantings without the use of synthetic herbicides is appealing to some growers and consumers.

Weed management without the use of synthetic herbicides often is more costly, more time-consuming, and less effective than weed control with synthetic herbicides (Coleman et al., 2019; Domenghini, 2020). However, to meet the needs of some growers and consumers who desire food products, especially fruits and vegetables (Pearson, Henryks and Jones,

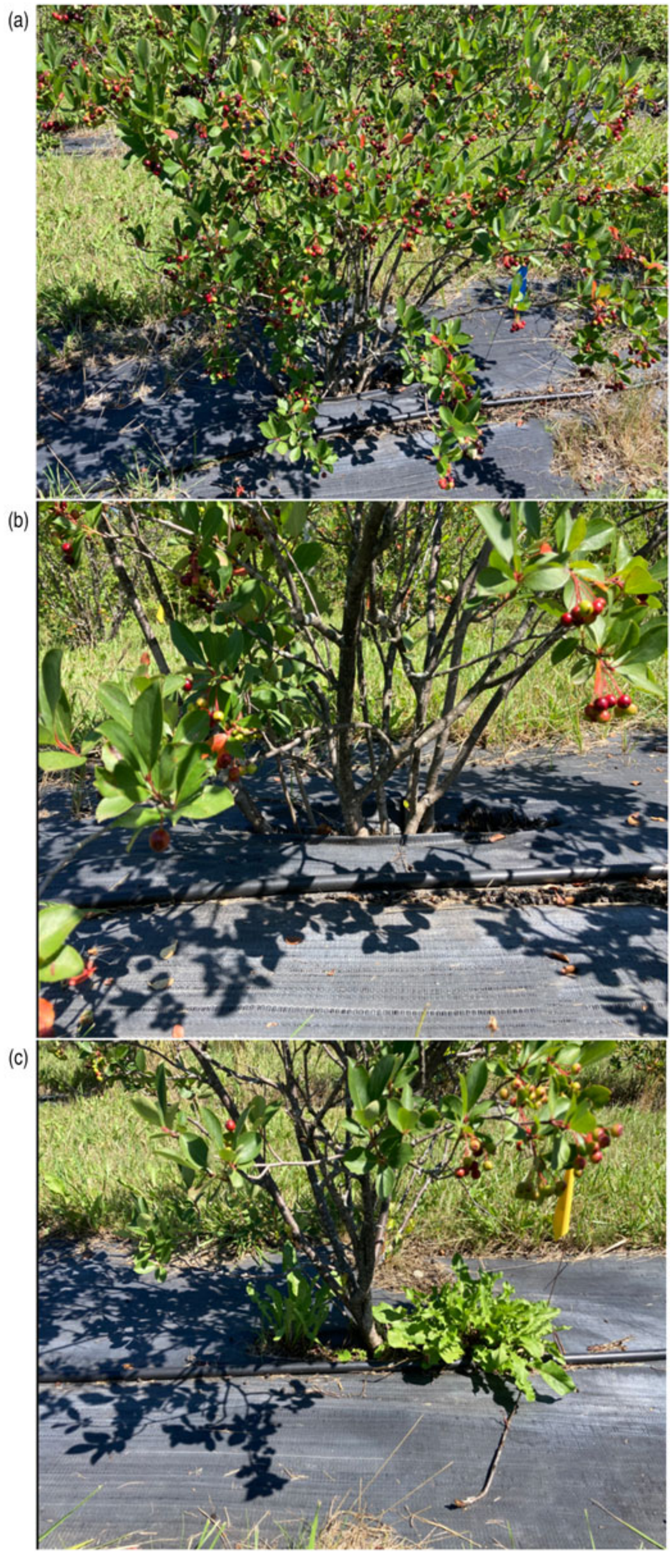

Figure. 1. (A) Ten-year old aronia berry (chokeberry) shrub that previously had been transplanted into 40 cm slits in woven landscape fabric. (B) Close-up view of base of aronia berry shrub with multiple stems and excellent weed control. (C) *Taraxicum officinale* emerging through transplant slit in woven landscape fabric.

2011), that are grown free of herbicides, new methods of weed control must be conceived and tested for their efficacy and reliability. Abrasive grit application is one example of a new method of weed control. In addition to the absence of synthetic herbicides, grit weeding has an additional benefit in that it also makes use of agricultural residues that typically represent disposal problems and economic burdens for growers or processors.

Grit-weeding uses abrasive grit, typically 1–2 mm in diameter, emitted under high air pressure from nozzles that are aimed at weeds (Forcella et al., 2020). If the weeds are small seedlings or young shoots at the time of grit application, the entire aboveground portions of the plants can be eliminated in less than a second, whereas larger weeds require longer periods of abrasion. Thus, efficiency is achieved with this method if weed seedlings (annuals) or shoots (perennials) are ≤ 5 cm tall (Forcella et al., 2018).

Many types of abrasive grit exist, and several are derived from agricultural or horticultural residues (Perez-Ruiz et al., 2018). Some of these residues represent disposal problems for growers and processors. The most common among these is grit derived from the cobs of corn (*Zea mays* L.). The use of corn cob grit to manage weeds has at least three attributes: (a) corn cobs are an abundant commodity, (b) their use represents increased economic value for a plant product that typically is returned to the field as a degradable agricultural residue, and (c) abrasive weeding with corn cob grit does not include the use of herbicides. These attributes are especially valuable in the Midwestern USA where corn is the dominant crop. However, corn cob grit is considered a soft grit, which often is used for 'blasting' to remove excess grease, rust, etc. from metal surfaces, refurbish wood siding on homes and other buildings, and so forth. It is an effective replacement for hard grits (e.g., silicon carbide, aluminum oxide, etc.) that might damage sensitive surfaces (Hansink, 2000).

Small annual broadleaf weed seedlings can be controlled effectively with pressurized corn cob grit (Erazo-Barradas et al., 2018; Forcella et al., 2020), but management of perennial weeds, especially grasses, is more difficult (Forcella et al., 2018). With corn cob grit, the amount of grit needed and the time required to abrade perennial weeds to eliminate their influences on perennial crops is too high to be practical for even high-value horticultural crops (Forcella, Poppe and Hoover, 2023).

Grits harder than those from corn cobs may be more useful for abrading and controlling tenacious perennial weeds. Candidate grits derived from plentiful Midwestern agricultural residues include bone meal, eggshells, nut shells and, possibly, pulp from sugar beet (*Beta vulgaris* L.). Grit from shells of walnut (*Juglans regia* L.) grown in California and Oregon already is marketed as a blasting medium, but to our knowledge the other three potential grit sources have not been examined previously as abrasive grits. An objective of our research was to test these agricultural residues for their effectiveness in abrading hard-to-control weeds, such as annual and perennial grasses. Grit from walnut shells, however, was replaced by that from hazelnut shells, as shrub-like hybrid hazelnut (*Corylus avellana* L. × C. *americana* Marshall) is a new commercial crop in Minnesota and Wisconsin (Braun et al., 2019). Once the harvested nuts of this plant are processed, abundant woody shells remain as a waste product and disposal issue. Thus, we also explored the use of hazelnut shell grit as an abrasive agent for damaging grass weeds and controlling perennial weeds in aronia berry.

Materials and methods

Grit testing on annual and perennial grasses

We examined grits derived from (a) bovine bone meal, (b) chicken eggshells, (c) hazelnut shells, and (d) sugar beet pulp.

https://doi.org/10.1017/S1742170523000431 Published online by Cambridge University Press

Sources of all of these livestock- and crop-derived materials were from commercial industries in Minnesota and Wisconsin. All grits were processed and provided by the Agricultural Utilization Research Institute, Waseca, Minnesota. Each of the raw materials was converted into grits of four different sizes; i.e., grits were able to pass through sieves with openings of (a) 0.5 mm, (b) 0.7 mm, (c) 1.0 mm, and (d) 2.0 mm. The latter category excluded grit < 1.0 mm diameter.

Annual grass weed experiments

Seeds of *Setaria faberi* Herrm. (giant foxtail) were collected in western Minnesota, stored at room temperature until dormancy was lost, sown in 8.5-cm diameter pots filled with loam potting mix, and grown in a heated greenhouse (23°/18° day/night) during January through March 2021 at the West Central Research and Outreach Center, Morris, Minnesota, USA. Pots were thinned to one seedling. Four nearly identical experiments were performed on separate sets of seedlings of *S. faberi*, with three replications (seedlings) per treatment. The four experiments were as follows:

Experiments 1 and 2. When seedlings were 5–7.5 cm tall, they were subjected to a single abrasion event (see below for abrasion details) by 7.5 ml (Expt 1) or 15 ml (Expt 2) of grit in one of each of 13 different treatments using differing types of grit (Table 1). These grit types were bone meal, eggshell, hazelnut shell, and sugar beet pulp, each with three different particle size classes (0.5, 0.7, and 1.0 mm). Corn cob grit (1–2 mm) also was included for comparison because of its use in prior experiments (e.g., Forcella et al., 2020).

Experiments 3 and 4. When seedlings were 10–15 cm tall, they were subjected to a single abrasion event by 15 ml (Expt 3) or 30 ml (Expt 4) of grit in one of each of 16 different treatments using differing types of grit (Table 1). These grit types were bone meal, eggshell, hazelnut shell, and sugar beet pulp. There were four particle sizes for each type of grit: 0.5, 0.7, 1.0, and 1.0–2.0 mm. Corn cob grit was not included for comparison in these experiments.

Immediately after abrasion, each seedling was visually assessed for damage with a score of 0–10, with 0 indicating no damage by abrasion and 10 indicating complete removal of the aboveground portion of the plant through abrasion. Pots were reset on greenhouse benches in a randomized manner and surviving seedlings were allowed to regrow for two weeks, at which time the maximum height of each seedling was measured to the nearest cm.

Perennial grass weed experiment

For experiments on perennial grasses, sod plugs (2 cm diameter, 7.5 cm deep) of *Festuca arundinacea* Schreb. (tall fescue) and *Poa pratensis* L. (Kentucky bluegrass), as well as 5-cm rhizome segments of *Elymus repens* (L.) Gould (quackgrass), were collected from field sites in Morris, MN, and grown as above. When plants were 5–7.5 cm tall they were abraded once by 30 ml of the grits derived from bone meal, eggshell, and hazelnut shell. Four grit sizes (described above) were used for each grit type. Each treatment was replicated three times. Damage to shoots was assessed immediately after abrasion treatments on a scale of 0–10 (described above). Each perennial grass species was considered a separate experiment. Neither *F. arundinacea* nor *P. pratensis* normally are considered weeds; indeed, both species often are planted in alleyways in orchards and berry farms. However, over time both species can invade crop rows either through seed dispersal or by creeping rhizomes; thus, they were candidates for weed control experiments.

Abrasion was accomplished through a trigger-operated sandblasting nozzle as pictured in Forcella (2009). The nozzle was connected to an air compressor that generated 820 kPa of air pressure. A 100-ml funnel served as a grit reservoir, which was connected to the sand blaster *via* a short and flexible nylon tube. Depending upon specific experiments, volumes of grit used per abrasion event were either 7.5, 15, or 30 ml. Delivery rates were >7.5 ml s^{-1} (Forcella, James and Rahman, 2010), but when applying grit the trigger was held for 5 s to insure complete depletion of the volume of grit in the funnel. The nozzle of the sand blaster was positioned approximately 30 cm from the target seedlings and at an angle of about 45°. Distances and angles varied slightly to accommodate targeted seedlings of different sizes.

Lastly, bulk densities of each type of grit in the 1.0 mm particle size class were estimated by weighing three 150 ml volumes of dry grit and calculating weight per volume (g cm^{-3}).

Analysis of variance and Fischer's LSD were used to assess each experiment and determine differences among treatment means ($P = 0.05$).

Aronia berry field trial

The study site was at Country Blossom Farm, Douglas County, Minnesota (4 117 5.87°, −95.47°), and consisted of 9–10-yr-old multi-stemmed shrubs of aronia (cv. 'Viking') that previously had been transplanted into 40 cm slit-like openings in woven landscape fabric. Shrubs were spaced at approximately 2 m within rows and 3 m between rows (Knudson, 2008). Twelve uniform shrubs, each about 1.2 m tall (S.E. = 0.07), were chosen for study. Four blocks (replications) were established. Each block was comprised of three adjacent shrubs within the same row, and each block was in a different row. One of the following three treatments was assigned randomly to one plant in each block: (a) weeds controlled through abrasion by grit, (b) weeds controlled manually by hoeing with a hand-held hoe as well as by hand-pulling, and (c) weeds not controlled. The site was surveyed once weekly beginning on April 30, 2021 and again on May 5, 2022, and during each survey a visual determination was made regarding the need for weed control each week in the grit and hand-hoeing treatments. Weekly surveys ended in July each year.

Grit-weeding was accomplished by abrasion of weedy plants through the application of hazelnut shell grit (ca. 1–2 mm diameter) at high pressure (ca. 600–700 kPa). Grit was emitted through a single nozzle applicator connected to a grit reservoir and an air compressor all mounted on a portable hand-pulled wagon (Forcella et al., 2020). During application of grit, the nozzle typically was held 15–30 cm from small seedlings of annual weeds or small shoots of perennial weeds, as abrasion of older plants is not effective. The volume of grit used and time spent grit-weeding was recorded during each weeding session.

Hand-hoeing was performed with a beet hoe (1.25 m pole tipped with a small triangular steel tine), which allowed easier access within slits in the landscape fabric than other types of implements. Hand-pulling also was implemented as needed, especially for aronia shrubs with clustered stems that impeded hoeing (e.g., Fig. 1B). Times spent hoeing and hand-pulling were recorded.

Weed management continued until July 2, 2021 and July 7, 2022, by which times emergence of most annual weeds had ceased. Subsequently, remaining weeds were allowed to grow for an additional week and were then clipped at ground level within the entire 40 cm-long fabric slit on July 9, 2021 and July 13, 2022,

https://doi.org/10.1017/S1742170523000431 Published online by Cambridge University Press

Table 1. Visually assessed control scores (10 = complete control) of seedlings of the grass weed, *Setaria faberi*, immediately after high-pressure (820 kPa) abrasion by differing types of grit, sizes of grit, and volumes of grit

		Expt 1	Expt 2	Expt 3	Expt 4
	Grit size	Grit volume applied			
Grit type	(mm)	7.5 ml	15 ml	15 ml	30 ml
----------------	------------	-------------	------------	------------	------------
Bone meal	0.5	8.0	8.7	1.0	5.0
	0.7	**9.0**	**9.7**	1.7	**8.7**
	1.0	7.7	**9.3**	2.3	**8.3**
	1.0–2.0			**7.3**	**9.3**
Eggshell	0.5	**9.3**	**9.3**	**8.3**	6.3
	0.7	**9.0**	9.0	**7.3**	**9.3**
	1.0	**9.0**	**10.0**	**8.0**	**9.3**
	1.0–2.0			**8.0**	**10.0**
Hazelnut shell	0.5	6.7	7.0	1.3	4.7
	0.7	7.3	8.7	5.0	7.3
	1.0	**8.3**	**10.0**	5.0	7.7
	1.0–2.0			**8.0**	**10.0**
Sugar beet pulp	0.5	5.7	8.7	1.7	2.0
	0.7	7.0	8.7	3.0	3.0
	1.0	7.7	8.7	5.0	7.3
	1.0–2.0			3.7	**9.7**
Corn cob	1.0–2.0	7.3	7.7		
LSD (0.05)		1.1	0.8	2.5	2.2

Experiments assessed two size ranges of giant foxtail seedlings: 5–7.5 cm tall (Expts 1 and 2) and 10–15 cm tall (Expts 3 and 4) at time of treatment. LSD = Fischer's least-significant difference at $P = 0.05$. Values in bold do not differ from maximum control value within columns.

stored in paper bags on a greenhouse bench and air-dried until reaching a constant weight Dry weights were recorded to the nearest gram. Identities of most of the weed samples were noted.

After aronia shoot growth ceased in late autumn, five leader shoots of each shrub were selected randomly and annual growth (shoot elongation) in 2021 and 2022 was measured to the nearest mm. Average annual shoot elongation was calculated for each shrub.

Analyses of variance (ANOVA) were performed for weed weights, weed control percentages, times spent weeding, and annual average aronia leader shoot growth using the Data Analysis package in MicroSoft Excel. LSDs among treatment means were calculated using a statistical probability level of 0.05. Data for each year were analyzed separately using single-factor ANOVA, whereas two-factor ANOVA was employed when experimental years were compared. Some comparisons required the use of Student's *t*-tests ($P = 0.05$).

Results and discussion

Grit testing on annual and perennial grasses

Annual grass weed experiments

In Experiment 1 the highest average value for visually assessed control of small *Setaria faberi* seedlings was 9.3 for small-diameter eggshell grit (Table 1). However, none of the other eggshell grits, nor the bone meal (0.7 mm) or hazelnut (1.0 mm) grits differed significantly from this maximum control value. Only very small amounts of grit (7.5 ml) were used in this experiment. Larger volumes of grit (15 ml) were used in Experiment 2, and damage to small *S. faberi* seedlings was higher (>8.0) for nearly all treatments. In both of these experiments, the scores for corn cob grit were <8.0 and significantly less than maximum values for other treatments, which indicated that the 'soft' nature of corn cob grit is less effective than harder grits for damaging grass weeds. Grits derived from eggshells tended to have the highest scores, and those derived from sugar beet pulp (another soft grit) had the lowest scores (Table 1).

In Experiments 3 and 4, seedling sizes (10–15 cm) were larger than in the two prior experiments and, therefore, were more difficult to control. In Experiment 3, eggshell grit again tended to have the highest scores (≥7.3) (Table 1), but bone meal (1–2 mm) and hazelnut (1–2 mm) also damaged *S. faberi* seedlings significantly (scores up to 7.3 and 8.0, respectively). With large volumes (30 ml) of grit applied in Experiment 4, eggshell and bone meal grits achieved the highest scores, as did hazelnut shell grit (1–2 mm) and sugar beet pulp (1–2 mm), with scores as high as 10.0, 9.3, 10.0, and 9.7, respectively (Table 1).

Bulk densities in g cm^{-3} of eggshell, hazelnut shell, bone meal, corn cob, and sugar beet pulp were 0.96, 0.59, 0.50, 0.43, and 0.21, respectively (all S.E. < 0.02). When averaged across grit particle sizes, the densest grit, eggshell, abraded *S. faberi* better than other grits. Sugar beet pulp, the least dense grit, had the lowest average abrasion scores. However, all grit types sometimes abraded *S. faberi* seedlings well, with scores of ≥9.7 (Table 1).

Regrowth of weeds in Experiments 1–4 is shown in Figure 2. Basically, if initial visual scores (assessments of control) of *S. faberi* seedlings were >8, regrowth of those seedlings was minimal. In contrast, regrowth could be substantial if initial control values were scored as <8. Larger *S. faberi* seedlings resisted abrasion more than smaller seedlings, and their regrowth was greater as well despite being abraded by larger volumes of grit.

Perennial grass weed experiments

Damage scores to small shoots of perennial grasses by the various types of grits ranged from 1.0 to 8.0 (Table 2). For each type of grit the lowest values tended to occur for the smallest particles sizes, and the highest damage scores occurred with the two larger particles sizes. These damage assessments for the perennial grasses were noticeably lower for all grit types compared to those seen for *S. faberi* (Table 1).

For both *Festuca arundinacea* and *Poa pratensis*, relatively high scores (5.7–8.0) for immediate damage by abrasive grits occurred only for eggshell grit. Bone meal and hazelnut shell grits did not appear to be effective in appreciably damaging these two perennial grasses, with damage scores ranging from 1.0 to 4.7 and 1.0 to 5.0, respectively. *Elymus repens* also was damaged appreciably by eggshell grit (score as high as 7.3), and also significantly affected by hazelnut shell grit (5.0–6.7), especially with the larger grit sizes (1.0 mm and 1.0–2.0 mm).

Aronia berry field trial

The primary weeds found in the landscape fabric openings were the perennials, *Taraxicum officinale* Weber (common dandelion), and *Poa pratensis*. The former weed likely infested the openings through its wind-dispersed seeds, whereas the latter had been sown in the alleyways between the rows of aronia, and its seeds likely dispersed to the openings after inter-row mowing operations.

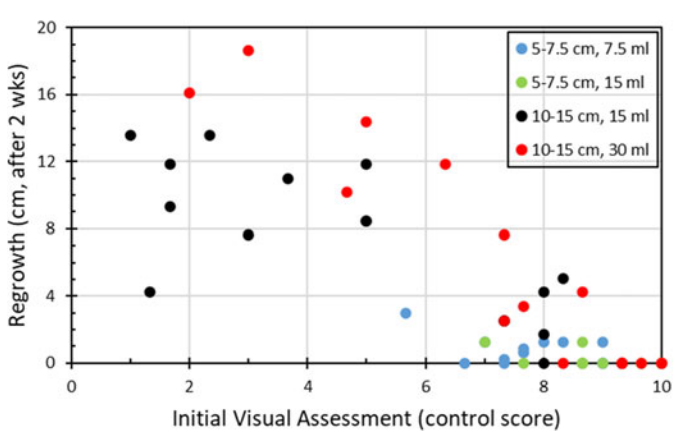

Figure. 2. Regrowth (cm) of *Setaria faberi* seedlings two weeks after abrasion by various volumes and types of grit in four different experiments. Initial seedling sizes ranged from 5 to 15 cm, and applied grit volumes ranged from 7.5 to 30 ml. Note that when initial control ratings were ≥8, regrowth was limited appreciably regardless of grit type, grit volume, or initial seedling size.

By mid-July dry weights of weeds (±S.E.) per linear meter of opening in landscape fabric averaged 88 g ± 32 across years in the absence of control treatments (Fig. 3). (Neither year nor the interaction of year and treatment was significant, $P > 0.28$ and 0.17, respectively.) This value was significantly greater than those for grit-weeding and hand-hoeing ($7 \pm 4.1\ g\ m^{-1}$ and $2 \pm 0.3\ g\ m^{-1}$, respectively, $P < 0.01$); values for the latter two treatments did not differ significantly from one another. Average weed control affected by grit-weeding was 87% ± 5.6, and that for hand-hoeing was 95% ± 1.7 ($LSD_{0.05} = 14$). There was no effect of year or an interaction of year by treatment on control percentages.

Weed growth affecting aronia shrubs was assessed visually 10 times each year (2021 and 2022), but weeding operations were deemed necessary only 6 and 7 times in those same years. Average cumulative times spent grit-weeding and hand-hoeing were 3.9 ± 1.11 and 2.8 ± 0.34 min per shrub per season, respectively, which did not differ significantly ($P = 0.39$). Neither year ($P = 0.27$) nor the interaction of year × treatment ($P = 0.91$) were significant.

The cumulative total volume of hazelnut grit applied per shrub averaged 1.4 ± 0.41 liters, with no difference between years (*t*-test, $P = 0.34$). The grit applicator applied grit at approximately $0.35\ L\ min^{-1}$, and the volumes applied reflected the times spent on applications each year which, in turn, were associated with weed abundances each year.

Aronia leader shoot growth did not differ among treatments ($P > 0.80$) in either year, with rates being 26, 29, and 28 mm per shoot in 2021, and 59, 50, and 46 mm per shoot in 2022 for manually weeded, grit-weeded, and weedy check treatments, respectively. However, the difference in growth between years was highly significant ($P < 0.01$), with elongation rates averaging 28 mm per shoot in 2021 and 52 mm per shoot in 2022. Greater growth of aronia shoots in 2022 than in 2021 likely reflected May through July rainfall. The long-term average rainfall for this period is 261 mm at the nearby Chandler Field Airport (Alexandria, Minnesota), but comparable rainfall in 2021 was only 96 mm (37% of average) but 320 mm in 2022 (123% of average). Air temperatures during this same period average 17.8°, but were 19.8° in 2021 and 18.8° in 2022. Thus, the main portion of the growing season for aronia was much dryer and somewhat hotter in 2021 than in 2022.

Grit-weeding around the bases of aronia shrubs did not injure the bark or stems of the shrubs, and we observed no damage to the landscape fabric through which the shrubs were growing. Although we did not test young aronia transplants, which likely have thinner and more sensitive barks than established shrubs, we previously have applied grit at high air pressures around the bases of young canes of newly transplanted raspberry (*Rubus idaeus* L.) and saw no damage to the crop (Forcella et al., 2020). Woody stems probably are naturally resistant to abrasion by grit. Another potential concern is accumulation of grit on the mulch or in crop rows after repetitive applications. Rain appears to wash grit from the mulch surface to adjacent alleys, and when in contact with soil or sod, the grit disappears within one year, possibly through rapid decomposition because of its very small particle size.

The hybrid hazelnuts used as a shell source were grown and processed in Minnesota and Wisconsin. The bone meal, eggshells, and sugar beet pulp also originated in Minnesota. Many other types of agricultural residues, from a wide variety of sources and agricultural regions, also can be used as sources

https://doi.org/10.1017/S1742170523000431 Published online by Cambridge University Press

Table 2. Visually assessed control scores (10 = complete control) of seedlings of three perennial grass species (*Festuca arundinacea*, *Poa pratensis*, and *Elymus repens*) immediately after high-pressure (820 kPa) abrasion by 30 ml of three different types of grit and four sizes of grit

Grit type	Grit size (mm)	Perennial grasses		
		Festuca	*Poa*	*Elymus*
----------------	------------	-------------	------------	------------
Bone meal	0.5	1.3	2.3	1.3
	0.7	1.0	1.0	1.7
	1.0	3.0	1.3	1.7
	1.0–2.0	4.7	1.7	4.3
Eggshell	0.5	3.0	2.3	1.7
	0.7	**8.0**	**4.0**	3.3
	1.0	4.0	2.3	**6.7**
	1.0–2.0	**5.7**	**5.7**	**7.3**
Hazelnut shell	0.5	1.0	1.3	1.7
	0.7	2.0	2.0	1.7
	1.0	2.0	2.0	**5.0**
	1.0–2.0	5.0	3.3	**6.7**
LSD (0.05)		2.6	1.7	2.6

Seedlings were 5–7.5 cm tall at time of abrasion with grit. LSD = Fischer's least significant difference at $P = 0.05$. Highlighted values do not differ from maximum control value in each column.

of grit. These include grits derived from those mentioned above as well as corn cobs, grape pomace, pelleted organic fertilizers, spent coffee grounds, and walnut shells (Forcella, James and Rahman, 2010; Forcella, 2017; Perez-Ruiz et al., 2018; Carlson et al., 2020). Use of such agricultural residues as weed-stunting abrasive grits converts burdens into value-added products and economic opportunities. However, this conversion can be successful only if applications of abrasive grits actually control weeds with reasonable efficacies and costs for labor and materials. Although grit-weeding may be economically favorable in some high-value organic horticultural crops (Wortman et al., 2020), our work with aronia berries transplanted into landscape fabric can address only some of these issues. Hazelnut shell grit did control weeds with efficacies and time allotments similar to those of manual weeding (i.e., hand-hoeing), of which the latter would be a form of weed control prevalent on organic farms. At this point, we cannot address the issue of material and application costs, as products such as hazelnut shell grit and abrasive grit applicators do not have, as yet, assigned monetary values. However, Oregon-grown hazelnut shells are sold in bulk for as little as \$40 per cubic yard (\$0.05 L^{-1}). At that price, the cost per aronia shrub for grit in the current experiment would have been \$0.07, and that for the entire 0.1 ha orchard would be \$12. Labor costs (\$20 h^{-1}) solely for time spent applying grit to all shrubs in the orchard would have been \$217. Naturally, many additional expenditures need to be included to fully account for total costs of grit weeding, but too little information exists to do so. Despite these shortcomings, practical and economically viable application of abrasive grit in organic horticultural settings, such as aronia berries, seems possible.

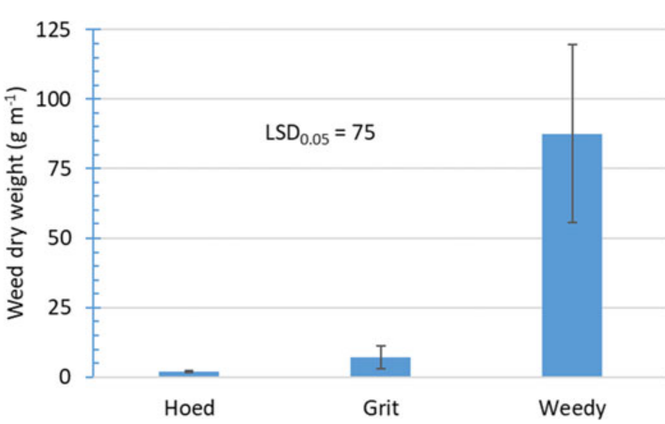

Figure. 3. Weed dry weights per linear meter of landscape fabric openings (slits) for aronia berry (chokeberry) shrubs in response to three treatments: hand-hoeing, grit weeding, and weedy check. Means are combined values for 2021 and 2022, as ANOVA indicated no effect of year ($P = 0.17$), but a highly significant effect of treatment ($P < 0.01$). Vertical bars are standard errors. LSD calculated for a probability level of 0.05.

Acknowledgments. The authors thank the American Hazelnut Company and Agricultural Utilization Research Institute for providing hazelnut shells and grit, Country Blossom Farm for providing access to its land and plants, the Minnesota Department of Agriculture and U.S. Department of Agriculture for providing funds through the Specialty Crop Block Grant program, and summer students, Sofia Sparby and Hayden Michaelson, for their cheerful demeanors and tireless work ethics.

Funding statement. This research was supported by a Specialty Crop Block Grant through the Minnesota Department of Agriculture.

Competing interests. No conflicts of interest are declared.

References

Braun, L.C., Demchik, M.C., Fishbach, J.A., Turnquist, K. and Kern, A. (2019) 'Yield, quality, and genetic diversity of hybrid hazelnut selections in the Upper Midwest of the USA', *Agroforestry Systems*, **93**, pp. 1081–91.

Bussieres, J., Boudreau, S., Clement-Mathieu, G., Dansereau, B. and Rochefort, L. (2008) 'Growing black chokeberry (*Aronia melanocarpa*) in cutover peatlands', *HortScience*, **43**, pp. 494–99.

Carlson, M., Forcella, F., Wortman, S., Clay, D. and Clay, S.A. (2020) 'Organic fertilizer abrasive grits increase soil available nitrogen, plant height, and biomass', *Agrosystems, Geosciences & Environment*, **3**, p. e20091. https://wileyonlinelibrary.253com/journal/agg21of14; https://doi.org/10.1002/agg2.20091

Coleman, G.R.Y., Stead, A., Rigter, M.P., Xu, Z., Johnson, D., Brooker, G.M., Sukarieh, S. and Walsh, M.J. (2019) 'Using energy requirements to compare the suitability of alternative methods for broadcast and site-specific weed control', *Weed Technology*, **33**, pp. 633–50.

Domenghini, J.C. (2020) 'Comparison of acetic acid to glyphosate for weed suppression in the garden', *HortTechnology*, **30**, pp. 82–87.

Erazo-Barradas, M., Forcella, F., Humberg, D. and Clay, S. (2018) 'Air-propelled abrasive grit for weed control in organic silage corn', *Agronomy Journal*, **110**, pp. 632–37.

Forcella, F. (2009) 'Potential for air-propelled abrasives for selective weed control', *Weed Technology*, **23**, pp. 317–20.

Forcella, F. (2017) 'Spent coffee grounds as air-propelled abrasive grit for weed control in organic production', *Weed Technology*, **31**, pp. 769–72.

Forcella, F., Humburg, D., Wortman, S. and Clay, S. (2018) 'Air-propelled abrasive grit can damage the perennial weed, quackgrass', *Canadian Journal of Plant Science*, **98**, pp. 963–66.

Forcella, F., James, T. and Rahman, A. (2010) 'Post-emergence weed control through abrasion with an approved organic fertilizer', *Renewable Agriculture and Food Systems*, **26**, pp. 31–37.

Forcella, F., Poppe, S. and Hoover, E. (2023) 'Grit-weeding in apple', *Technology in Agronomy*, **3**, pp. 1–3.

Forcella, F., Poppe, S., Tepe, E. and Hoover, E. (2020) 'Broadleaf weed control with abrasive grit during raspberry establishment', *Weed Technology*, **34**, pp. 830–33.

Hansink, J.D. (2000) 'An introduction to abrasives for protective coating removal operations', *Journal of Protective Coatings and Linings*, **17**, pp. 66–73.

Hardin, J.W. (1973) 'The enigmatic chokeberries (*Aronia*, Rosaceae)', *Torryea*, **100**, pp. 178–84.

Knudson, M. (2008) 'USDA-NRCS plant guide: black chokeberry (*Aronia melanocarpa* (Michx.) Ell.)'. USDA-Natural Resources Conservation Service, Bismark Plant Materials Center. Available at: www.plant-materials.nrcs.usda.gov/pubs/ndpmcpg6028.pdf

Kulling, S.E. and Rawel, H.A. (2008) 'Chokeberry (*Aronia melanocarpa*)—A review on the characteristic components and potential health effects', *Planta Medica*, **74**, pp. 1625–34.

McKay, S.A. (2001) 'Demand increasing for aronia and elderberry in North America', *New York Fruit Quarterly*, **9**, pp. 2–3.

Pearson, D., Henryks, J. and Jones, H. (2011) 'Organic food: what we know (and do not know) about consumers', *Renewable Agriculture & Food Systems*, **26**, pp. 171–77.

Perez-Ruiz, M., Brenes, R., Urbano, J.M., Slaughter, D.C., Forcella, F. and Rodríguez-Lizana, A. (2018) 'Agricultural residues are efficient abrasive tools for weed control', *Agronomy for Sustainable Development*, **38**, pp. 18. https://doi.org/10.1007/s13593-018-0494-6

Scott, R.W. and Skirvin, R.M. (2007) 'Black chokeberry (*Aronia melanocarpa* Michx.): a semi-edible fruit with no pests', *Journal of the American Pomological Society*, **61**, pp. 135–37.

Wortman, S.E., Forcella, F., Lambe, D., Clay, S.A. and Humburg, D. (2020) 'Profitability of abrasive weeding in organic grain and vegetable crops', *Renewable Agriculture & Food Systems*, **35**, pp. 215–20.