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Renewal Pruning Alone or in Combination with Thinning Pruning Affects Growth, Fruit Yield and Fruit Quality of Aroniaberry

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Abstract. **Aroniaberry (*Aronia mitschurinii*) produces small pome fruits that possess health promoting compounds. Management practices for orchards are lacking, since aroniaberry is a relatively new crop. Pruning is an important cultural practice to optimize fruit yield in orchards. The response of an established aroniaberry orchard to pruning was evaluated over three years (2020 to 2022). Pruning treatments were as follows: 1) renewal pruning (removal of shoots to the base) only in year 1; 2) renewal pruning in year 1 + thinning to 18 shoots in year 2; 3) renewal pruning in year 1 + thinning to 9 shoots in year 2; and 4) no-pruning (control). In response to renewal pruning, plants grew uniformly and vigorously, producing 28 new vegetative primary shoots with an average length of 66 cm by the end of the first growing season. Limited flowering and fruiting occurred in the second season for plants receiving pruning treatments. Fruit yield on pruned plants was significantly less than for unpruned controls. In season 2, increased thinning of renewal-pruned plants negatively affected the number of inflorescences per plant, but positively affected individual fruit fresh weight and fruit °Brix:titratable acidity ratios. Fruits from all treatments had similar monomeric anthocyanins, total phenolics and mineral content. In season 3, flower production and predicted fruit yield from pruned plants and unpruned controls were similar, even though pruned plants were substantially smaller. In the third season, there were no longer any differences between renewed + thinned plants and those that received only renewal pruning, making shoot thinning an unnecessary practice. The results of this study demonstrate that renewal pruning can be an effective way to manage and rejuvenate an aging aroniaberry orchard.**

Black chokeberry [*Aronia melanocarpa* (Michx.) Elliot] is a North American native shrub that reaches 2 to 2.5 m tall, with a multistemmed habit, five-petaled white flowers in cymes, and pome fruits that are black (Brand 1992; Dirr 2009). Aroniaberry (*A. mitschurinii* A.K. Skvortsov and Maitul) originated in cultivation and is used for fruit production purposes in Europe, Russia and North America (Bolling et al. 2015; Mahoney et al. 2019). The species resulted from crossing ×*Sorbaronia fallax* 'Ivan's Beauty' with black chokeberry (Brand et al. 2017; Taheri et al. 2013). Aroniaberry is primarily distinguished from black chokeberry by its larger stems, leaves, inflorescences, and fruits, and non-rhizomatous crown (Brand et al. 2017, 2022; Leonard et al. 2013).

Interest in aroniaberry as a fruit crop is driven by the potential health benefits and nutraceutical properties of the fruit (Brand 2009; Leonard et al. 2013; Mahoney et al. 2019; McKay 2001). The fruits produce high levels of anthocyanins and polyphenols comparable to other fruit crops grown for their health benefits (Kulling and Rawel 2008; Oszmianski and Wojdylo 2005). These phytochemicals have high antioxidant, anti-inflammatory, antimutagenic, and antidiabetic capacities (Bolling et al. 2015; Bussières et al. 2008; Kulling and Rawel 2008; Ristvey and Mathew 2011; Taheri et al. 2013). Reported health benefits include reduced hypertension, cardiovascular disease, and cancer cell proliferation, and improved urinary and gastrointestinal health (Bolling et al. 2015; Brand et al. 2017; Kulling and Rawel 2008; Oszmianski and Wojdylo 2005; Ristvey and Mathew 2011; Taheri et al. 2013).

Aroniaberry exhibits high pest resistance, requires few grower inputs and is amenable to mechanical harvesting (Brand 2009; Bussières et al. 2008; Kulling and Rawel 2008; McKay 2001; Ristvey and Mathew 2011). Despite the high potential of aroniaberry as a fruit crop, limited research has been conducted on cultural and production requirements. Pruning is an important cultural practice for commercial fruit production operations; however, practices vary by crop (Kovaleski et al. 2015). The benefits of pruning include increased fruit yield and quality, reduced incidence of diseases, and easier harvest. Pruning recommendations for aroniaberry are limited and there exist few published scientific reports on the subject. Trinklein (2007) and McKay (2001) recommend pruning five years after installation to maintain open plant centers. Kask (1987) reports Russian research that found optimal production is achieved when plants are pruned to 1 m in height every 4 to 5 years once they reach 8 to 10 years of age. Hannan (2015) recommends regular pruning to remove five-year-old canes and maintain manageable size to sustain fruit productivity. Hannan (2015) also suggests that plants may be renewed by cutting the plant all the way back to the ground every 10 years.

The objective of this study was to evaluate the impacts of renewal pruning, where all stems were removed to the ground, and thinning, where the number of stems was reduced the following year, on plant re-growth, time to resumption of fruit production, and fruit quality and yield. Plants growing in an established, ten-year-old orchard of aroniaberry that had not previously been pruned were used for this research.

Materials and Methods

Plant material and experimental design. In 2010 an orchard of aroniaberry (*A. mitschurinii* 'Viking') was installed at the University of Connecticut Plant Science Research and Education Facility in Storrs, CT (lat. 41.79544°N, long. −72.22836°W). Plants were installed in 1 m wide clean cultivated rows with 4.6 m spacing on center between rows and 0.91 m spacing on center within rows. Seven rows each containing 100 plants were installed. The field soil was a Paxton and Montauk fine sandy loam. In 2020, soil tests indicated 6.7% organic matter and pH of 5.4 at the site. This study, conducted over 3 years from 2020 to 2022, had four experimental treatments as follows: 1) no-pruning control, 2) renewal pruning only, 3) renewal pruning and thinning pruning to 18 shoots remaining per plant, and 4) renewal pruning and thinning pruning to 9 shoots remaining per plant. The experimental unit consisted of five adjacent plants within a row. Units were arranged in a randomized complete block design with eight replications. The outermost upper (western) and lower (eastern) planting rows were excluded from the study to prevent edge effects from confounding results. In early Apr 2020, 2021, and 2022, 10 $g \cdot m^{-2}$ of granular fertilizer was applied within the planting rows (All Purpose 15N–6.5P–12.5K; Greenview, Lebanon, PA, USA), and 18.7 $mL \cdot m^{-2}$ of a diluted solution (25.1 $mL \cdot L^{-1}$) of pre-emergent herbicide (Surflan A.S.; United Phosphorous Inc., King of Prussia, PA, USA) was applied within the planting rows.

In Mar 2020, all experimental plants, except for those designated as no-pruning control plants, received a renewal pruning, where all shoots per plant were pruned back to ∼10 cm in height (Fig. 1A–B). Renewal

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Fig. 1. Renewal pruning and shoot regrowth for renewal-pruned aroniaberry (*Aronia mitschurinii*). (**A**) Plants after renewal pruning and before brush removal in Mar 2020. (**B**) Pruned crown in Mar 2020. (**C**) Initial shoot emergence in May 2020 from a renewal-pruned crown. (**D**) Shoot regrowth in Jul 2020. (**E**) Shoot regrowth in Sep 2020. (**F**) Shoot regrowth in Mar 2021 showing original stem stubs and new annual shoot production.

pruning was accomplished using a brush-cutter and clearing saw (FS 460; Stihl, Waiblingen, Germany) with a 22.6 cm chisel-tooth circular saw blade (Stihl). Plants were allowed to regenerate shoots for the remainder of the 2020 growing season (Fig. 1C–E). In Nov 2020, the number of primary shoots per plant and the length of each shoot per plant was measured. Total shoot length per plant was calculated by summing the lengths of each shoot per plant. For renewal-pruned plants, primary shoots were those originating from the remaining portion of stem following the renewal pruning (Fig. 1E). For no-pruning control plants, primary shoots consisted of main shoots arising from the crown. Total shoot length was summed per plant. In Mar 2021, thinning pruning was performed using bypass hand pruners. Plants that had received renewal pruning were thinned to 18 shoots remaining, 9 shoots remaining, or had no shoots removed (Fig. 2). In May 2021, the number of inflorescences per plant was quantified. For renewal-pruned and thinned plants, the number of inflorescences per stem per plant were counted and total number of inflorescences were summed for each plant. For renewal pruning only and no-pruning control plants, the number of inflorescences per shoot was counted for two 25% quadrants of the plant, selected at random, summed and multiplied by two. In Nov 2021, the number of primary shoots were counted, and the length of each shoot was recorded. In May 2022, the number of inflorescences was quantified as described for 2021. In Nov 2022, plant height and width were measured, the number of primary shoots and lateral shoots (shoots originating from a primary shoot) per plant were counted, and the length of primary and lateral shoots were recorded.

Fruit production and analysis. In mid-Aug 2021 all fruits per plant were harvested and the total fruit weight per plant was determined in the field using a hanging scale (Detecto HSDC; Cardinal, Webb City, MO, USA). Fruit weight per plant was averaged for the five plants per experimental unit, and fruits were combined to form a homogenous sample per unit. Average fruit weight was determined by taking the weight of 100 fruits, selected at random, and dividing by 100. These 100 fruits were then dried at 60 °C for 7 d and then weighed. Water content was determined by subtracting the dry weight from the fresh weight. The dried fruit was ground into a fine powder using a coffee grinder and mineral content was analyzed by the University of Connecticut Soil Nutrient Analysis Laboratory (Storrs, CT, USA). An organic elemental analyzer (Vario Macro Cube; Elementar, Langenselbold, Germany) was used to measure total nitrogen. All other macro and micronutrients were prepared using the dry ash method (Miller 1998) and analyzed using a spectrometer (Genesis ICP-OES; Spectro, Kleve, Germany).

Sugar content (°Brix) was measured for juice pressed from three fruits using a refractometer (PAL-1 Pocket; Atago, Tokyo, Japan). For each experimental unit, three refractometer measurements were taken and averaged. Titratable acidity was measured using 5 mL of pressed juice and a minititrator and pH meter (HI 84532; Hanna Instruments, Woonsocket, RI, USA) with low range titrant, and expressed as malic acid equivalents. For analysis of monomeric anthocyanins and total phenolics, fruits were frozen in liquid nitrogen, pulverized in a blender (Magic Bullet; Homeland Housewares, Los Angeles, CA, USA), and 1 g of pulverized tissue was added to 10 mL of 80% (w/v) acetone. The sample was then vortexed for 20 s, sonicated for 5 m, and centrifuged at 3000 rpm for 5 m. This process was repeated three times and then samples were incubated for 24 h in the dark in a refrigerator. The supernatant was used for analysis of monomeric anthocyanins and total phenolics. Monomeric anthocyanins were measured using the AOAC pH differential method of Lee et al. (2005). In a 96-well plate, two dilutions (40:1) were prepared. One dilution was adjusted to pH 1 using 0.025M potassium chloride and the other to pH 4.5 using 0.4 M sodium acetate. Using a microplate reader (Synergy 2 Multi-Mode; Agilent BioTek Instruments Inc., Winooski, VT, USA) and analysis software (Gen5; Agilent BioTek Instruments Inc.), absorbance at 520 nm and 700 nm was measured. The original supernatant sample was analyzed three times and averaged. Results were reported as cyanidin-3-glucoside equivalents. Total phenolics were evaluated using the Folin-Ciocalteau method of Singleton et al. (1999). Using a 96-well plate, 10 µL of sample was combined with 790 µL deionized water and 50 µL of Folin-Ciocalteau reagent. Samples were left to sit for 5 min at room temperature. Then 150 µL of saturated sodium carbonate solution was added and the sample left to sit at room temperature for 2 h. Absorbance was measured at 765 nm using the microplate reader. Total phenolics were calculated using a gallic acid standard solution calibration curve. Samples were run three times and averaged.

Statistical analysis. Data were subjected to ANOVA (PROC GLIMMIX) and mean separation by Tukey's honestly significant difference test ($P \leq 0.05$) using statistical software (SAS ver. 9.4; SAS Institute, Cary, NC, USA). Using 2021 total inflorescences

Fig. 2. Representative aroniaberry (*Aronia mitschurinii*) plants in Mar 2021. (**A**) Plant that had received renewal pruning and thinning to 9 shoots. (**B**) Plant that had received renewal pruning and thinning to 18 shoots. (**C**) Plant that had received renewal pruning only.

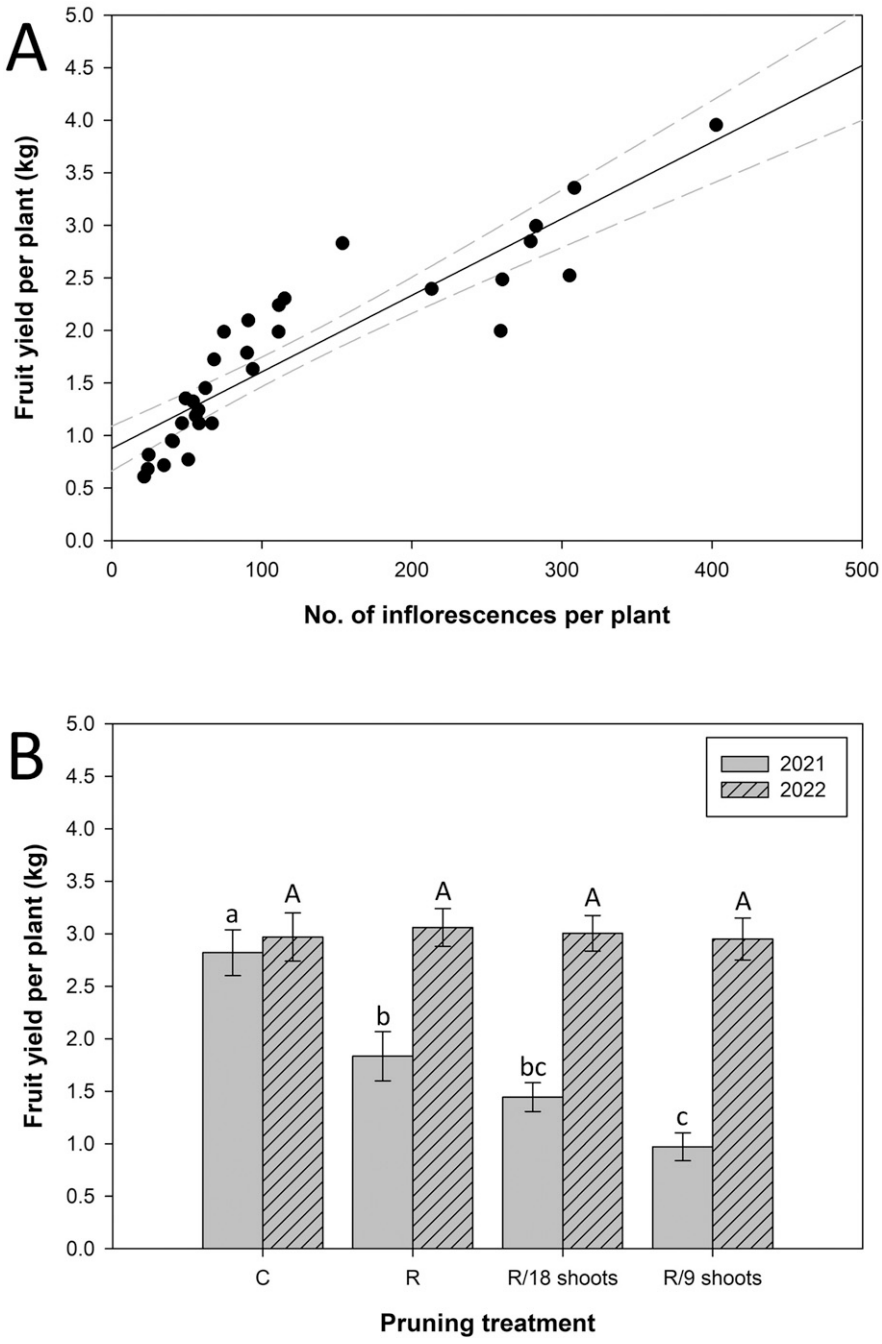

Fig. 3. Regression analysis of total inflorescences and fruit yield for aroniaberry (*Aronia mitschurinii*) in 2021 (**A**), and predicted 2022 fruit yield for plants that received renewal pruning (**B**). Mean separation within year indicated by different letters (lowercase for 2021, and uppercase for 2022) using Tukey's honestly significant difference test at $P \leq 0.05$. Error bars represent standard error. C = no-pruning (control); R = renewal pruning only; R/18 shoots = renewal pruning + thinning to 18 shoots; R/9 shoots = renewal pruning + thinning to 9 shoots.

and fruit yield data, regression analysis (PROC REG) was performed to develop a predictive equation [yield = 0.0073(total inflorescences) + 0.8760; R^2 = 0.8066] for predicting 2022 fruit yield (Fig. 3A).

Results

After three growing seasons, plants that had received renewal pruning in 2020 had grown to reach 63% of the height and 51% of the width of unpruned control plants (Table 1). Plants that received renewal pruning possessed more primary shoots (27.8) in Nov 2020 than control plants that were not pruned (20.9). In Nov 2021, renewal-pruned plants had more primary shoots than control plants and plants that had renewal pruning and thinning to 18 or 9 shoots. Total primary shoot length was greater for renewal-pruned plants than plants that had renewal pruning and thinning; however, average primary shoot length did not vary. Control plants produced more inflorescences per stem and total inflorescences than plants receiving renewal pruning and renewal pruning and thinning to 18 or 9 shoots. Plants that received renewal pruning and thinning to 9 shoots produced fewer total inflorescences than plants that received no-pruning or renewal pruning only. In Nov 2022, the number of primary shoots was equivalent for all experimental treatments. Renewal-pruned plants were similar to plants that had renewal pruning and thinning to 18 or 9 shoots for all primary and lateral shoot measures and total inflorescences. More inflorescences per shoot were produced by plants that had renewal pruning and thinning to 18 or 9 shoots than from those that had renewal pruning only, which in turn produced more than the unpruned control plants.

In Aug 2021, fruit yield was greatest from unpruned plants (Fig. 3B). Renewal pruning only plants yielded more fruit than those receiving renewal pruning and thinning to 9 shoots. Fruit yield from renewal pruning and thinning to 18 shoots was similar to renewal pruning only and renewal pruning and thinning to 9 shoots. Individual fruit fresh weight was greater from plants receiving renewal pruning and thinning to 9 shoots than from those receiving renewal pruning only or no-pruning; there was no difference between plants receiving renewal pruning and thinning to 9 or 18 shoots (Table 2). Individual fruit dry weight was greater from plants receiving renewal pruning and thinning to 9 shoots than from the no-pruning control, but similar from plants receiving renewal pruning only and renewal pruning and thinning to 18 shoots. Titratable acidity was greater from the no-pruning control than from renewal pruning and thinning to 18 or 9 shoots, but similar from the no-pruning control and renewal pruning only. Sugar content, monomeric anthocyanins and total phenolics did not vary among the experimental treatments. Sugar content:TA was greater from renewal pruning and thinning to 9 shoots than from renewal pruning only, but was similar from renewal pruning and thinning to 18 shoots and renewal pruning only. The no-pruning control had the lowest sugar content:TA.

Fruits from the no-pruning control had more calcium and less nitrogen and phosphorous than fruits from the other pruning treatments (Table 3). The no-pruning control had greater magnesium than the renewal pruning and thinning to 9 shoots treatment, but neither were different from the other two pruning treatments. Renewal pruning only had greater iron than renewal pruning and thinning to 18 or 9 shoots, which did not differ from the no-pruning control. Renewal pruning and thinning to 9 shoots had greater zinc than the no-pruning control and renewal pruning only, but did not differ from renewal pruning and thinning to 18 shoots. All pruning treatments produced similar fruit potassium content.

Discussion

Fruit production of aroniaberry orchards has been observed to reach a plateau by years 8 to 10 and then decline (Hannan 2015). The study orchard produced large crops in years

Table 1. Plant height and width and production of primary shoots, lateral shoots, and inflorescences for aroniaberry (*Aronia mitschurinii*) plants that received no-pruning (control), renewal pruning only, renewal pruning and thinning to 18 shoots, or renewal pruning and thinning to 9 shoots in years 2020–22.

Pruning Treatment	Plant ht (cm)	Plant width (cm)	No. primary shoots	Total primary shoot length (cm)	Avg primary shoot length (cm)	No. lateral shoots	Total lateral shoot length (cm)	Avg lateral shoot length (cm)	No. inflorescences per shoot	Total no. inflorescences
2020										
No-pruning (control)	-	-	20.9 b[i]	-	-	-	-	-	-	-
Renewal pruning only	-	-	27.8 a	1833.1	66.1	-	-	-	-	-
2021										
No-pruning (control)	-	-	20.9 b	-	-	-	-	-	14.8 a	288.9 a
Renewal pruning only	-	-	28.9 a	1934.5 a	66.9 a	-	-	-	2.9 b	99.2 b
Renewal pruning + thinning to 18 shoots	-	-	18.0 b	1183.1 b	65.7 a	-	-	-	3.6 b	62.0 bc
Renewal pruning + thinning to 9 shoots	-	-	9.0 c	590.4 c	65.6 a	-	-	-	4.3 b	38.5 c
2022										
No-pruning (control)	278.9 a	288.0 a	20.9 a	-	-	-	-	-	13.9 c	286.9 a
Renewal pruning only	174.5 b	147.1 b	25.9 a	5048.4 a	92.8 a	111.7 a	2627.2 a	22.5 a	38.9 b	299.5 a
Renewal pruning + thinning to 18 shoots	-	-	22.8 a	4868.7 a	98.5 a	108.4 a	2660.3 a	24.5 a	62.2 a	291.8 a
Renewal pruning + thinning to 9 shoots	-	-	20.0 a	4072.8 a	90.5 a	87.0 a	2293.5 a	25.7 a	60.5 a	284.4 a

[i] Mean separation, indicated by different letters, within column within year by Tukey's honestly significant difference test at $P \leq 0.05$ ($n = 5$).

Table 2. Individual fruit fresh and dry weights, sugar content, titratable acidity (TA), total monomeric anthocyanins (ACY), and total phenolic (TP) for plants of aroniaberry (*Aronia mitschurinii*) that received no-pruning (control), renewal pruning only, renewal pruning and thinning to 18 shoots, or renewal pruning and thinning to 9 shoots in 2021.

Pruning treatment	Individual fruit fresh wt (g)	Individual fruit dry wt (g)	Sugar content (°Brix)	TA	Sugar content:TA	ACY[i]	TP[ii]
No-pruning control	1.04 b[iii]	0.190 b	13.6 a	1.08 a	12.71 c	3.26 a	16.9 a
Renewal pruning only	1.05 b	0.197 ab	13.9 a	0.99 ab	13.97 b	3.59 a	17.8 a
Renewal pruning + thinning to 18 shoots	1.09 ab	0.203 ab	14.0 a	0.94 b	14.86 ab	3.42 a	16.2 a
Renewal pruning + thinning to 9 shoots	1.14 a	0.214 a	14.5 a	0.96 b	15.15 a	3.57 a	18.0 a

[i] ACY was expressed as cyanidin-3-glucoside. Units were $mg \cdot g^{-1}$ of fresh fruit.
[ii] TP was expressed as gallic acid equivalents. Units were $mg \cdot g^{-1}$ of fresh fruit.
[iii] Mean separation, indicated by different letters, within column within year by Tukey's honestly significant difference test at $P \leq 0.05$ ($n = 5$).

4 to 7 (2013 to 2016) with yields stagnating and decreasing after that. Pruning by selective removal of unproductive shoots or periodic renewal, the removal of all stems to the base, is typically recommended to sustain fruit productivity in the long term. This work demonstrated that aroniaberry plants respond positively to renewal pruning. New primary shoot growth in 2020 on renewal-pruned plants was highly uniform (Fig. 1D–F) with ~29 shoots per plant and shoots were ~67 cm in length (Table 1). In the second season (2021) following renewal pruning, plants saw a return of flowering. The act of thinning plants in year two (2021) decreased the number inflorescences produced per plant, since thinned plants had fewer shoots.

In the second season following renewal pruning, control plants produced more fruits than plants that had received renewal pruning or renewal pruning and thinning, because control plants had more flowers. Individual fruits were larger from plants that had renewal pruning and thinning to 9 shoots than from control plants, since pruned and thinned plants had fewer fruits among which to allocate

Table 3. Fruit nutrient content for plants of aroniaberry (*Aronia mitschurinii*) that received no-pruning (control), renewal pruning only, renewal pruning and thinning to 18 shoots, or renewal pruning and thinning to 9 shoots in 2021.

Pruning treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)	Magnesium (%)	Iron (mg/kg)	Zinc (mg/kg)
No-pruning control	0.515 b[i]	0.150 b	1.094 a	0.223 a	0.113 a	14.14 ab	5.00 b
Renewal pruning only	0.630 a	0.171 a	1.089 a	0.169 b	0.108 ab	15.91 a	5.11 b
Renewal pruning + thinning to 18 shoots	0.671 a	0.183 a	1.081 a	0.169 b	0.105 ab	13.05 b	6.41 ab
Renewal pruning + thinning to 9 shoots	0.666 a	0.185 a	1.066 a	0.159 b	0.099 b	13.40 b	7.74 a

[i] Mean separation, indicated by different letters, within column within year by Tukey's honestly significant difference test at $P \leq 0.05$ ($n = 5$).

Fig. 4. Aroniaberry (*Aronia mitschurinii*) fruits in Aug 2021. (**A**) Ripe fruit clusters on a renewal-pruned plant. (**B**) Ripe infructescence from renewal-pruned plant. (**C**) Ripe infructescence from no-pruning control plant.

photosynthates (Table 2; Fig. 4). Similar findings have been reported for other crops where plants with fewer fruits develop larger fruits due to the compensatory relationship between available photosynthetic tissue, or source organs, and the fruit, or sink organs (Schupp et al. 2017; Strik et al. 2003; Strik and Poole

Fig. 5. Orchard plants of aroniaberry (*Aronia mitschurinii*) in May 2012 in third growing season following installation (**A**), and renewal-pruned plants in May 2021 in third growing season following renewal pruning (**B**).

1991). Fruits produced on plants that had renewal pruning or renewal pruning and thinning had equivalent and occasionally superior biochemical or nutrient content compared with fruits on control plants. Pruning has been shown to increase anthocyanin content in cranberry and sugar content (°Brix) in apple and blueberry (Kovaleski et al. 2015; Schupp et al. 2017; Strik and Poole 1991).

In the third season following renewal pruning (2022), flower production and predicted fruit yields were equivalent for all treatments, even though renewal-pruned plants were significantly smaller than control plants (Tables 1 and 2; Fig. 3B). There was little difference between plants that had received renewal pruning and thinning and renewal pruning only in 2021, although thinned plants possessed slightly higher quality fruits. Therefore, we do not recommend thinning pruning following renewal pruning, since the benefits of thinning do not outweigh the added pruning labor expense, which is one of the costliest components of fruit production (Lorenzo et al. 2022; Strik et al. 2003; Zahid et al. 2022). The size, appearance and fruit production capacity displayed by renewal-pruned plants in 2022 was analogous to three-year-old plants established in a new orchard in 2012 (Fig. 5A–B). Pruned plants in this study will continue to increase in size and fruit production output to exceed control plants as they grow over the next 1 to 3 years.

Following renewal pruning, growers can expect a loss of fruit production for only two seasons, with a return to modest fruit production levels in year three (Fig. 4A). It is expected that rejuvenated aroniaberry orchards will produce large amounts of fruit in years four, five and six following renewal pruning, equivalent to a newly installed orchard in the same time frame. Thinning of shoots on renewal-pruned plants provides little or no benefit to the orchard rejuvenation process and should not be conducted to avoid additional labor inputs. In conclusion, renewal pruning is an effective way to bring an aroniaberry orchard back to greater fruit production levels.

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