Girdling Treatment to Reduce Vigor and Increase Production of High-quality Yellow-skinned ‘Koukou’ Apples

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The production of yellow-skinned apples has increased in recent years; however, they are less acceptable to consumers than red-skinned apples. Therefore, the production of high-quality fruit is essential. In the present study, we applied a girdling treatment at 1) different times (June or August), and 2) different widths (2 cm, 5 cm, and 8 cm). We compared the effect on tree growth, flower bud formation and fruit quality over a 4-year field trial using vigorous yellow-skinned ‘Koukou’ apple trees. The August girdling reduced the shoot growth by about 6 to 10 cm per shoot and this reduction also restricted secondary extension of the shoots. The August treatment improved the fruit quality parameters, including the soluble solids content and skin color index, more effectively than the June treatment. Compared with the girdling timing, the effect of girdling widths in August was less obvious, but even the 2 cm treatment in August was enough to reduce tree vigor and improve fruit quality. Apical flower bud formation was accelerated by the August girdling in both the treatment year and the following year. Regardless of the girdling width, the August girdling improved the fruit quality parameters: e.g. flesh firmness, soluble solids content, and skin color index. The August girdling fruit also had higher sorbitol and sucrose concentrations than the control. Moreover, both the girdling treatments accelerated the incidence of watercore, which is a preferred condition for the Asian market. In conclusion, we found that all widths of girdling in August improved the harvested fruit qualities, including the sugar (sucrose) content, as well as watercore development in the treatment year and effectively controlled tree vigor, increased flower bud formation and increased yields.

Key Words: flower bud formation, Malus × domestica Borkh, skin coloration, sugar composition, tree vigor.

Introduction

In recent years, several yellow-skinned apples (Malus × domestica Borkh.) have become popular in Japan following the release of new cultivars such as ‘Shinano-Gold’ and ‘Morinokagayaki’ (Igarashi et al., 2016). As warmer temperatures suppress anthocyanin synthesis in the skin of red-skinned apple fruit, there are increasing concerns that global warming may be detrimental to fruit pigmentation (Honda and Moriya, 2018). Yellow-skinned apples do not require some of the detailed horticultural care that is needed for skin coloration in red-skinned apples such as leaf-picking, fruit-rotation and silver-sheet mulching. Therefore, the dissemination of yellow-skinned apples is being promoted among leading fruit growers due to the recent global warming conditions (Fukuda, 2006). However, the acceptability of yellow-skinned apples such as ‘Koukou’ to consumers is still lower than that of red-skinned apples (Cliff et al., 2002; Jahangir et al., 2019).

The ‘Koukou’ apple, which has a high sugar content and low acidity, was released in Japan in 1999 (Shiozaki and Shinoda, 1998). These features of ‘Koukou’ apples are attractive to consumers and high grade fruits are supplied to the gift market (Matsumoto et al., 2016). In Asian markets, the acceptability of apples to consumers is increased by a high sugar concentration. Recently released apples which have received a high taste evaluation contain a high sucrose content (Matsumoto et al., 2018; Watanabe et al., 2011). In addition to these sugar-related factors, a particular trend for the Asian market that is not seen in the European and the American markets, is for watercored apples. These apples have a special value because the consumer
can confirm the full maturation of the apples visually and the fruit gives off a very pleasant scent (Tanaka et al., 2016). In European and American countries, watercored apples are recognized as physiologically disordered because the condition can induce browning during the storage period (Fukuda, 1984). However, watercore apples are often preferable in the Asian market, although the sugar content of this portion is not necessarily higher than the other parts. They are separated from normal apples and sold as “honey ("Mitsu" in Japanese) apples”, because they look as if they have been filled with honey (Tanaka et al., 2016).

It is not easy to harvest fruit which have favorable traits in terms of a high sugar (sucrose) content and watercore development. The ‘Koukou’ apple also has very vigorous tree growth and it is difficult to maintain sufficient flower bud formation and achieve good fruit qualities (Shiozaki and Shinoda, 1998). Growers have applied many horticultural methods to address these issues. For example, using a dwarfing rootstock sometimes reduces tree vigor and improves fruit productivity and soluble solids content (Soejima et al., 2010). However, because of some of the genetic features of scion apples, yellow-skinned apples such as ‘Kiou’, ‘Toki’, ‘Shinano-Gold’, and ‘Koukou’ frequently show vigorous tree traits even if dwarfing rootstock is used, and still have reduced flower bud formation and yield (Enseikai, 2014).

In some yellow-skinned apples, the postharvest storage stage can effectively ameliorate the fruit quality and a reduction in the titratable acidity is observed in ‘Shinano-Gold’ apples (Enseikai, 2014). In addition, the generation of a yellower skin color is observed in ‘Golden Delicious’ apples during postharvest storage (Rizzolo et al., 2006). However, ‘Koukou’ apples do not show these postharvest ripening traits; the sugar (sucrose) content and watercore index do not increase with postharvest storage (Matsumoto et al., unpublished).

It is important to find suitable cultivation techniques to improve ‘Koukou’ apple tree growth and fruit quality because the existing planting and storing techniques are inadequate. Therefore, we tested the application of a girdling treatment to ‘Koukou’ trees to see whether this treatment was effective in reducing tree vigor and improving fruit qualities. Girdling is one of the most widely used horticultural practices to control tree vigor and improve fruit quality and has been used for thousands of years with fruit crops such as grapes, citrus, peaches, and apples (Goren et al., 2004). For apples, girdling treatment has been applied to improve productivity (Greene and Lord, 1983) and skin blush (Wargo et al., 2004). Arakawa et al. (1998) reported that trunk girdling (90% of a 5 cm bark ring was removed) in June for red-skinned ‘Megumi’ apples increase the flower bud formation, soluble solids content, and sucrose content. However, not only the cultivars, but also the girdling timing, methods, and intensities differed among these studies. Moreover, there are no reports which focus on yellow skin coloration, the sugar composition (especially sucrose content), and watercore development and intensity.

In the present study, we carried out a 4-year field trial to investigate the appropriate timing and intensity of girdling, and the effect in the following year on fruit quality parameters, shoot development, and flower bud formation.

**Materials and Methods**

**Plant materials**

Experiments were conducted in the 2014, 2015, 2017, and 2018 seasons using four ‘Koukou’ apple trees (aged 20, 21, 23, and 24 years in each year, respectively) grafted on M. prunifolia grown at the experimental farm of Hirosaki University (Fujisaki Farm, 40°39'25" N, 140°29'9" E). Trees were trained to a flat, open-center form (7.0 m × 7.0 m planting) with four primary scaffolds. Within the 4-primary scaffolds, only three scaffolds were used for the experiment in 2014 and 2015. The experimental design was a randomized complete block with two (2014, 2015) or three (2017, 2018) treatments and four primary scaffold replications. For the experiments in 2014, 2015, and 2017, different tree sets were used. In the 2018 season, the same tree set was used as in 2017 to assess the effect of the girdling treatment over two years. Except for the girdling treatment, conventional horticultural practices were applied to all trees.

**Girdling treatments**

For the experiments in 2014 and 2015, 5 cm girdling treatments were applied to the base of each primary scaffold on June 4 (June treatment), or August 4 (August treatment). For the experiment in 2017, three different girdling treatment widths (2 cm, 5 cm, or 8 cm, respectively) were applied to the base of each primary scaffold on August 9. In the 2018 season, girdling treatment was not applied to any trees. The girdling was done using a grafting knife, and the decorticated portion was covered with a plastic film until it grew its own callus. In the control treatment, no girdling was applied to the base of the primary scaffold.

**Shoot length and quality analysis**

In the 2014 and 2015 seasons, 40 shoots per primary scaffold per tree (160 shoots in total) were randomly selected after shoot growth had stopped (October 16, 2014; December 1, 2015) and the shoot length was measured. The percentage of secondary extension shoots was calculated as: number of shoots for which secondary extension had developed/total shoot number × 100.
Bearing shoot length, bourse length, bourse shoot length, and apical flowering bud rate measurement

In the 2017 and 2018 seasons, 40 bourses, bourse shoots, and bearing shoots per primary scaffold per tree were randomly selected after fruit harvest (November 18, 2017; November 26, 2018) and the length of each was measured (160 portions in total). Ninety shoots (up to 20 cm long) per primary scaffold per tree were randomly selected after leaf fall (March 20, 2018; March 5, 2019) and the apical flowering bud rate was calculated (360 apical buds in total) in the 2017 and 2018 seasons. A flowering bud was defined as an apical bud which was more than 5 mm in diameter after destructive investigation.

Fruit quality analysis

Thirty fruit per primary scaffold per tree were randomly harvested on November 4, 2014 or November 6, 2015. The fruit harvested from four trees from each treatment were mixed (120 fruit in total). All harvested fruit were measured as follows. The fruit fresh weight was measured using a digital scale (EB-3200D; Shimadzu, Kyoto, Japan). Fruit length and diameter were measured using digital calipers (DIGIPA; Mitutoyo, Kawasaki, Japan) and the Length/Diameter (L/D) ratio was calculated. The skin color index was scored on a scale of 1–6 with 1 = green yellow to 6 = orange yellow according to the Aomori standard color chart for harvesting of new yellow apple cultivars (Fukazawa-Akada et al., 2010). Destructive measurements were conducted using 20 fruit per primary scaffold per tree (80 fruit in total). Flesh firmness was measured at two points on the equator of the fruit after removing the skin with an 11.1-mm tip penetrometer (FT327; Facchini srl, Alfonsine, Italy). The soluble solids content of the juice was determined using a digital refractometer (N-1; Atago, Tokyo, Japan). Total titratable acidity was measured by titration with 0.1N NaOH up to pH 8.3 and calculated as malic acid. As reported by Enseikai (2014), the incidence of watercore was scored on a scale of 0–4 with 0 = no incidence, 1 = very little, occurring only in vascular bundles, 2 = little, occurring around vascular bundles, 3 = medium, covering 20% of the equatorial transverse section, and 4 = high, covering 50% of the equatorial transverse section.

In 2017 and 2018, 10 fruit per primary scaffold per tree were randomly harvested on November 6 (40 fruit in total) and all harvested fruit qualities were measured as described above. The sugar composition was measured as follows. The juice collected from 10 fruit was passed through a membrane filter (0.45 μm, Centricut MF; Kurabo, Osaka, Japan). Then, a 5-μL aliquot of filtrate was injected into a high-performance liquid chromatography system (PU2089 Plus; JASCO, Tokyo, Japan) equipped with a differential refractive index detector (RI2031 Plus; JASCO). Sugars were separated using an SC1011 column (Shodex, Tokyo, Japan) with water as the solvent maintained at 85°C and a flow rate of 0.6 mL·min⁻¹. Fructose, glucose, sorbitol, and sucrose were identified and quantified by comparing the peaks produced with a known standard sugar solution with a reporting integrator (807IT; JASCO).

Fruit yield

In the 2018 season, we recorded the fruit yield (t/10 a) from each treatment tree which had the girdling treatments applied in 2017. The fruit numbers of each primary scaffold were counted and average fruit fresh weight was calculated using 10 randomly selected fruit. These values showed the fruit yield per primary scaffold. Trees were planted in 7.0 m × 7.0 m with four primary scaffolds. Thus, the yields per 10 ares were calculated as follows: 1000 × fruit yield per primary scaffold/12.25.

Statistical analysis

Data were analyzed using the Tukey–Kramer honestly significant difference (HSD) test, the Pearson’s Chi-squared test, or the Steel-Dwass test using JMP 14 software (SAS Institute, Cary, NC, USA), and significant differences among the treatments were determined. Unless otherwise stated, differences were considered significant at P < 0.05.

Results

Effects of girdling timing on shoot growth

According to the duplicated girdling experiments using different tree sets in the 2014 and 2015 seasons, the girdling timing affected the tree growth parameters differently (Table 1). The August treatment reduced the shoot growth in both years, although the June treatment reduced it only in 2014. A similar tendency was observed in the number of secondary extension shoots, for which only the August treatment noticeably reduced the secondary extension of the shoots in the two years. (Table 1).

| Year | Girdling treatments | Shoot length (cm) | Incidence of secondary extension shoot (%) |
|------|---------------------|-------------------|------------------------------------------|
| 2014 | Control             | 33.1 a’          | 44.4 a                                   |
|      | June                | 26.8 b           | 13.8 b                                   |
|      | August              | 23.3 c           | 18.1 b                                   |
| 2015 | Control             | 23.0 a           | 10.6 a                                   |
|      | June                | 21.0 a           | 6.9 a                                    |
|      | August              | 16.7 b           | 1.9 b                                    |

Different letters within the same column and year show a significant difference by Tukey-Kramer’s HSD tests (shoot length) and Pearson’s Chi-squared test (Incidence of secondary extension shoots) at the 5% level (n=160).
Effects of girdling timing on fruit quality parameters

The fresh weight did not change with the girdling treatments in 2014, but in 2015 the June treatment resulted in heavier fruit (Table 2). The L/D ratio showed no treatment effect in either year. In 2014, the flesh firmness of the August treatment was harder than with the other treatments, although the flesh firmness decreased only with the June treatment in 2015. The soluble solids content and the titratable acidity were increased by the August treatment in both years. Both treatments showed a higher skin color index than the control, and the index in the August treatment was higher than the June treatment. In 2015, the watercore index in August was higher than in June and in the control, although there was no difference among the treatments in 2014 (Table 2). Collectively, the fruit quality of August girdling was better than the June girdling.

Effects of girdling width in August on the tree quality parameters in the treatment year and the following year

In the treated year (2017), different girdling widths in the August treatment did not significantly impact on the bearing shoot length, bourse shoot length, or bourse shoot length, although the bourse shoot length with the 2 cm treatment was shorter than with the other treatments (Table 3). The apical flowering bud rate was accelerated with the 2 cm and 8 cm treatments compared with the control.

When we monitored the impact of girdling on the shoot growth in the year following the treatment, the bearing shoot length and bourse shoot length at the end of the 2018 season had decreased because of the girdling treatments in 2017, regardless of the girdling width (Table 3). The bourse length with the 2 cm and 5 cm treatments decreased in 2018, although there was no difference with the 8 cm treatment. The apical flowering bud rate increased significantly with all the treatment widths, with the highest percentage increase in 2018 with the 8 cm treatment.

Table 2. Effect of girdling treatments on fruit quality parameters of ‘Koukou’ apples.

| Year | Girdling treatments | Fresh weight (g) | L/D ratio | Flesh firmness (N) | Soluble solids content (°Brix) | Titratable acidity (mg/100 mL) | Skin color index | Water core index |
|------|---------------------|------------------|-----------|-------------------|------------------------------|-------------------------------|----------------|----------------|
| 2014 | Control             | 351.8 a          | 0.85 a    | 65.2 b            | 14.1 b                       | 0.35 b                        | 3.3 c           | 1.7 a          |
|      | June                | 355.1 a          | 0.85 a    | 66.0 b            | 14.1 b                       | 0.36 b                        | 3.7 b           | 1.6 a          |
|      | August              | 355.5 a          | 0.85 a    | 69.3 a            | 15.1 a                       | 0.40 a                        | 4.5 a           | 1.9 a          |
| 2015 | Control             | 373.7 b          | 0.86 a    | 71.5 a            | 14.6 b                       | 0.31 b                        | 2.7 c           | 1.6 b          |
|      | June                | 398.6 a          | 0.86 a    | 67.7 b            | 14.9 b                       | 0.31 b                        | 3.4 b           | 1.8 ab         |
|      | August              | 387.7 ab         | 0.86 a    | 72.1 a            | 15.3 a                       | 0.34 a                        | 3.9 a           | 2.2 a          |

* Length/Diameter ratio.

Table 3. Effect of girdling treatment width on the morphology of branches and the apical flowering bud rate of ‘Koukou’ apples at the end of the treatment season (2017) and the end of the year after the treatment season (2018).

| Girdling treatments in 2017* | Bearing shoot length (cm) | Bourse length (cm) | Bourse shoot length (cm) | Apical flowering bud rate (%) |
|-----------------------------|---------------------------|--------------------|--------------------------|------------------------------|
| Treated year (2017)         |                           |                    |                          |                              |
| Control                     | 12.2 a                    | 1.9 a              | 18.7 a                   | 39.8 b                       |
| 2 cm                        | 10.4 a                    | 1.7 a              | 14.6 b                   | 48.8 a                       |
| 5 cm                        | 11.1 a                    | 1.8 a              | 17.9 a                   | 44.8 ab                      |
| 8 cm                        | 10.3 a                    | 1.9 a              | 17.5 ab                  | 47.3 a                       |
| Next year of the treatment (2018) |                    |                    |                          |                              |
| Control                     | 14.0 a                    | 1.8 a              | 18.9 a                   | 33.9 c                       |
| 2 cm                        | 10.6 b                    | 1.4 b              | 10.4 b                   | 43.8 ab                      |
| 5 cm                        | 10.7 b                    | 1.5 b              | 11.4 b                   | 39.3 b                       |
| 8 cm                        | 10.1 b                    | 1.6 ab             | 9.9 b                    | 51.1 a                       |

* Girdling treatments were conducted on August 9, 2017.

Effects of girdling width in August on the fruit quality parameters in the treated year and the year following treatment

In the treated year (2017), regardless of the girdling width in August, the flesh firmness, soluble solids content, titratable acidity, skin color index and watercore index all significantly increased (Table 4). The fresh weight also increased with the 2 cm and 8 cm treatments, but the L/D ratio did not change with any width treatments. An increase in the sucrose and sorbitol contents was recorded regardless of the treatment width, while fructose contents did not change with any width treatment (Table 4).

To monitor whether there were any negative effects from girdling in the year following treatment, we investigated the fruit quality in 2018. Results showed that the effect of girdling treatment in 2017 did not influence the fruit quality in 2018, except for the fresh weight (Table 4). The fresh weight in the 5 cm and 8 cm treat-
ments was lower than the control. However, regardless of the girdling width, the fruit yield in the year after treatment (2018) was increased by the treatments in 2017. The sugar compositions of 2018 were not influenced by the 2017 treatments (Table 4).

**Discussion**

When girdling is used as a practical horticultural tool, it is important to decide the appropriate timing and the intensity because these two factors affect tree vigor and fruit quality characteristics differently (Goren et al., 2004). We examined the best timing based on duplicated girdling experiments using different tree sets in the 2014 and 2015 seasons and found that the August treatment was more effective at reducing tree vigor compared with the June treatment (Table 1). The August treatment reduced the shoot growth about 6 to 10 cm per shoot and this reduction may have been mainly due to restriction of secondary shoot extension (Table 1). That is, the August girdling treatment increased the number of short branches that are suitable for fruit bearing (Matsumoto and Shiozaki, 2012).

In the present study, we also found that the August treatment improved the fruit quality parameters, including the soluble solids content and the skin color index, more effectively than the June treatment (Table 2). Wargo et al. (2004) pointed out that in apples, the girdling treatment affected the fruit quality, tree growth and/or flower bud formation differently, based on the treatment timing. Generally, it has been reported that using a girdling treatment in the early growth season (May to June) accelerated the flower bud formation with a consequent reduction in terminal growth (Dennis and Edgerton, 1966; Li et al., 1996), whereas treatment in a later growth season (August to September) increased fruit firmness, sugar content, and skin blush (Elfving et al., 1991; Wargo et al., 2004). However, in the present study, the August treatment showed both a reduction in shoot growth and an improvement in the fruit quality parameters compared with the June treatment.

The limited effect of the June treatment may have been because the girdling wound was gradually mitigated, and phloem transport recovered before the fruit maturation season. Generally, the sugar content increases with fruit development because fruit are strong sink organs (Beruter et al., 1997). If girdling can restrict sugar transport to sink organs other than fruit, the assimilated sugars will be preferentially distributed in the fruit. However, the June treatment may enable translocation of photoassimilated sugars to other sink organs (e.g., the trunk and roots) in addition to fruit, possibly due to the early recovery of phloem transport. Therefore, the June treatment did not show an increase in the sugar content of the fruit (Table 2).

For yellow-skinned cultivars, little attention has been paid to the improvement of the skin coloration to date. However, Wargo et al. (2004) reported that August girdling increased the production of well-blushed ‘Jonagold’ apples, concomitant with an advanced yellow background color. This finding shows that the skin coloration of yellow-skinned apples is also ameliorated by girdling treatment, as indicated in the present experiment (Table 2). A possible reason why the August treatment showed a higher skin color index than the June treatment may be accelerated maturation. In peach and nectarine fruit, girdling induces high ACC (1-aminocyclopropane-1-carboxylate) content, ACC ox-
The weight of each fruit decreased (Table 4). Consequently, fruit maturation is accelerated and this improves the skin coloration (Agusti et al., 1998). However, in our study, the flesh firmness of the August treatment was firmer than the June treatment; thus, the August treatment did not accelerate maturation (Table 2). This may be because the ethylene evolution of ‘Koukou’ apples is normally very low due to the low expression level of *Md-ACS1*, which encodes 1-aminocyclopropane-1-carboxylate synthase (ACS) (Sunako et al., 1999; Wang et al., 2009). Further research is needed to clarify the mechanisms of skin color improvement because of girdling in yellow-skinned apples.

Compared with the timing of girdling, the effect of the girdling width in August was not so obvious and even the 2 cm treatment in August showed a reduction in tree vigor and an improvement in fruit quality (Tables 3 and 4). The bearing shoot length and bourse length did not change with the treatment in the treatment year (2017) because these parameters affected the bearing position of the latest fruit; thus, the growth increment during the fruit development duration was limited (Table 3). On the other hand, the bourse shoot length, which indicates the latest shoot growth, was reduced with the 2 cm treatment and the apical flowering bud rate was increased with both the 2 cm and 8 cm treatments in the treatment year (Table 3). These results also showed that the August treatments effectively reduced tree vigor independent of the girdling width. The increase in the apical flowering bud rate may be induced by the reduction in the number of secondary extension shoots (Table 1). In general, maturation of the apical flowering bud on the secondary extended shoot is less than the primary extended shoot because a faster cessation of the shoot growth gives more time and energy for the flower buds to mature (Shiozaki, 2012). These mechanisms explain why the August treatment may accelerate flower bud formation even in vigorous ‘Koukou’ apples.

The impact of the previous year’s girdling treatment on the tree growth parameters were carried over to the year following the girdling (Table 3). The apical flower bud formation was enhanced by more than 10% (Table 3). The shortened bearing shoots and bourses of the treated trees indicated that the fruit were being borne on short and weak branches that are more suitable for high-quality fruit production (Shiozaki, 2012). Moreover, the bourse shoot length also remained shorter (Table 3). Normally, ‘Koukou’ apples tend to grow strongly and producing enough flower buds is difficult. However, the August girdling improved the quality of the branches and accelerated flower bud formation in the year following girdling. As a result, fruit yield increased in the year following girdling, although the weight of each fruit decreased (Table 4).

With any girdling width, the August girdling improved the fruit quality parameters: e.g. flesh firmness, soluble solids content, and skin color index (Table 4), as also shown in 2014 and 2015 (Table 2). The girdling treatment affects the sink/source balance of fruit trees. If there is no strong sink organ above the girdling portion, the source activity—leaf photosynthetic activity—decreases dramatically. However, if there are fruit above the girdling portion, then the decline in the leaf photosynthetic activity is mitigated (Poirier-Pocovi et al., 2018; Schechter et al., 1994a, b). Plants of the *Rosaceae* family, including apples, translocate the photoassimilate produced by leaf photosynthesis as sorbitol and sucrose (Yamaki, 2010). In the present study, the August girdling fruit showed higher sorbitol and sucrose concentrations than the control, and they showed a higher watercore index (Table 4). This indicated that the fruit above the girdling portion continuously as a strong sink organ and stored additional photoassimilate. Watanabe et al. (2011) reported that apples that had a high sugar content, especially sucrose, had high sorbitol and sucrose contents in the peduncle. This indicates that fruit can preferentially translocate large amounts of sorbitol and sucrose, thereby increasing their sugar content. This suggests that the change in sink activity due to the girdling treatment will enhance not only the sugar content, but also the sugar composition.

It is worth noting that the girdling treatment accelerated the incidence of watercore regardless of the timing (Table 2) or the width of treatments (Table 4). Shiratake (2007) noted that watercore was induced by imported sorbitol that could not be unloaded into the flesh cells and remained in the apoplastic intercellular spaces. This water-soaked situation induces an anaerobic condition in the fruit and accelerates the production of ethyl and methyl esters. These fragrances improve the acceptability of watercore apples among Asian customers (Tanaka et al., 2016). The present experiment is the first to report that August girdling can accelerate watercored apple production. According to the present results using ‘Koukou’ apples, watercore apples, which sell for a high price as gifts and are normally produced using only special cultivars like ‘Koutoku’ which have unusual characteristics, could be produced intentionally using the girdling technique.

In conclusion, we revealed that girdling of 2–8 cm in August improved the harvested fruit qualities, sugar (sucrose) content and watercore development in the treatment year. It was also effective at controlling tree vigor, and increasing flower bud formation and yield of ‘Koukou’ apple trees. Considering the year variations in the treatment effects, more research is needed on the treatment frequency because yearly treatment may weaken tree vigor too much (Goren et al., 2004). It may be that the girdling treatment should be applied to only one primary scaffold among two to four primary scaffolds that are usually present on commercial apple trees, and this treatment could be rotated through the
primary scaffolds year by year.

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