INCREASING CHINESE CHESTNUT PRIMARY NUT WEIGHT AND BUR PRODUCTION BY HAND REMOVAL OF SECONDARY BURS

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The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled.

INCREASING CHINESE CHESTNUT PRIMARY NUT WEIGHT AND BUR PRODUCTION BY HAND REMOVAL OF SECONDARY BURS

Presented by Darin Enderton

A candidate for the degree of Master of Science

And hereby certify that in their opinion it is worthy of acceptance.

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DEDICATION

Soli Deo gloria

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ABSTRACT

Three treatments were imposed on shoots of ‘Orrin’ and ‘Willamette’ Chinese chestnut (*Castanea mollissima* Bl.) trees to characterize vegetative characteristics of bearing branches and to determine the effect of secondary (2^o) bur removal on primary (1^o) nut weight and 1^o bur production in the subsequent year. Treatments imposed upon trees in 2006 included hand removal of 2^o burs on shoots bearing 1^o and 2^o burs (R), 2^o burs not removed on shoots bearing 1^o and 2^o burs (N), and labeling of shoots bearing 1^o burs only (PO). Treatments were imposed on shoots with equal numbers of 1^o burs to ensure a similar crop load of 1^o nuts. In 2006, R and N treatments had greater shoot diameters, lengths, and numbers of leaves than those of PO treatments. R treatments on ‘Orrin’ trees had greater 1^o nut weight per shoot than the other two treatments. Results for ‘Willamette’ trees were generally similar to those of ‘Orrin’ trees. Average 1^o nut weight of R-treated shoots was greater than that of PO-treated shoots. In 2007, R treatments on ‘Orrin’ produced a greater number of bearing shoots, which generally had more 1^o burs per shoot than the other treatments. When the same treatments were repeated on 2007 shoots that were produced from the 2006 treated branches on ‘Orrin’ trees, R treatments had greater 1^o nut weight per shoot than N treatments. Following an unprecedented April 2007 freeze, ‘Willamette’ trees produced 1^o burs on only 19% of the branches treated in 2006. However, these trees produced a saleable crop of 2^o nuts, whereas 2^o nuts produced in 2006 on N-treated shoots were of insufficient size to be marketable. Thus, results from this study demonstrated that removal of 2^{o} burs enhanced 1^{o} nut weight per shoot at harvest and the number of shoots bearing 1^{o} burs in the subsequent growing season on ‘Orrin’ trees. Additionally, a reduced crop of 1^{o} burs in early spring on ‘Willamette’ trees resulted in a marketable 2^{o} nut crop.

Chapter 1

INTRODUCTION

Demand for chestnuts in the United States is currently being filled almost entirely by imported nuts (FAO Statistics, 2007). From 2000 to 2005, an average of 4500 metric tonnes (t) of chestnuts were imported into the United States (FAO Statistics, 2007), and these nuts have historically come from Italy and China (Stebbins, 1990). Although most chestnuts are imported into the U.S., trees have recently been planted in the Midwest as a relatively new crop (Hunt et al., 2005). Gold et al. (2006) reported unmet demand for Chinese chestnuts in many parts of the U.S., which is expected to increase in the next five years.

There are currently some limitations to growing chestnuts in Missouri. For example, grafted trees of improved cultivars are not always readily available (Gold et al., 2006) and delayed graft incompatibilities that occur three to four years after planting can be problematic (Huang et al., 1994). European (*Castanea sativa*) and Japanese (*C. crenata*) chestnuts are susceptible to low temperature injury during the winter and to chestnut blight [*Cryphonectria parasitica* (Murr.)]. In Missouri, Chinese chestnut (*Castanea mollissima* Bl.) is recommended due to its ability to withstand -30^{o}C temperatures when fully dormant and its adequate chestnut blight tolerance (Miller, 2003). In spite of these attributes, nut size of Chinese chestnut trees is relatively small compared to that of European or Japanese chestnut (Miller, 2003). Currently, there are six grades of chestnuts based on nut diameter, including small (<25 mm), medium (25-29 mm), standard (29-31 mm), large (32-35 mm), extra large (35-38 mm) and special (>38 mm) (Hunt et al., 2004). In Missouri, nuts with ≥30 mm diameter are recommended for direct marketing (Hunt et al., 2004). Some chestnut cultivars currently grown in Missouri, such as ‘Qing’ and ‘Eaton’, can produce small-sized nuts. Thus, management of crop load to produce larger diameter nuts is often necessary. Moreover, many of the Chinese chestnut cultivars produce burs late in the growing season which contain small, unmarketable nuts. Because these secondary (2˚) nuts likely compete with primary (1^{o}) nuts for plant nutrients, nut size may be increased by removing 2^{o} burs. Additionally, early removal of 2^{o} burs in August may increase the number of 1^{o} burs in the following growing season. Because of the paucity of information on managing the crop load of Chinese chestnut trees, a study was conducted to characterize vegetative characteristics of bearing branches and to determine the effect of 2^{o} bur removal on 1^{o} nut weight and subsequent 1^{o} bur production in the following year.

Chapter 2

LITERATURE REVIEW

European chestnut trees grow as tall as 30 m and have been cultivated in the moist temperate regions of southern Europe and Asia Minor since the time of the Roman Empire. While European chestnut trees have been propagated in the United States since the late 1700’s, they lack sufficient hardiness to be grown in many parts of the United States. These trees are also susceptible to chestnut blight and ink disease, caused by *Phytophthora cambivora* and *P. cinnamoni*, respectively (Miller, 2003).

The Japanese chestnut is native to Japan and the southern half of the Korean peninsula, and it has been cultivated in these regions for thousands of years. Japanese chestnut trees were first imported into the U.S. in 1876. Trees grow to a maximum height of 10 to 15 m, but generally lack the cold hardiness of American or Chinese chestnuts. Japanese chestnut trees show resistance to chestnut blight, but are generally considered less resistant than Chinese chestnut trees (Miller, 2003). ‘Colossal’, which is believed to be a European x Japanese chestnut hybrid (Miller, 2003), is currently grown in parts of California and Michigan.

Chinese chestnut is adapted to climatic and edaphic conditions in the Midwest. Some cultivars grow in the same climate as peach (*Prunus persica),* tolerating -30 ^{o}C temperatures when fully dormant. Trees tolerate a wide range of soils, but grow best in well-drained soils of pH 5.5 to 6.0 (Miller, 2003). Chinese chestnuts are produced inside spiny burs. There are generally three nuts per bur, with the middle nut (i.e., wafer nut) much smaller and thinner than the outer nuts. Thus, the wafer generally has no commercial value in the fresh market.

Chinese chestnut flowers are differentiated in the season previous to fruiting. In Missouri, the first flowering generally occurs in June. Bisexual catkins emerge on the proximal part of the current season's shoot, and unisexual male catkins develop toward the distal portion of the shoot. Shi and Stösser (2005) found that Chinese chestnut trees produce 4 to 5 male catkins for every mixed catkin. Female flowers require cross-pollination and are predominantly wind-pollinated, with insects playing a minor role of spreading pollen to different trees. For Japanese chestnuts, the time of pollination affects the number of nuts produced per bur (Shimura et al., 1971). Pistillate flowers were most receptive to pollen 14 to 20 days after the appearance of the first stigma. Controlled pollinations up to 8 days after the appearance of the first stigma generally resulted in only one nut per bur, while later pollinations produced additional nuts per bur (Shimura et al., 1971). Soltész et al. (2003) reported an inverse relationship between bur number per branch and nut size in *C. sativa*. Shoots with greater than three burs produced small nuts of commercially insufficient size.

Ichii (1960) found that Japanese chestnut fruit development goes through two cycles. During the first cycle (from June to late August), burs accumulate 70% of their final dry weight. However, in the second cycle, resources are diverted to the nuts and they gain 85% of their final dry weight. Nut dry weight does not exceed bur dry weight until slightly more than a week before harvest.

In Missouri, Chinese chestnut trees not only produce 1^{o} burs in June, but also produce flowers on catkins in August after a second flush of vegetative growth (Warmund et al., 2005). Following pollination, chestnuts are produced within these late-season burs (i.e., 2^{o} burs). These 2^{o} nuts do not attain sufficient size for harvest, presumably due to the short growing season.

Various cultural practices have been used to improve nut size and alter crop load. Araki (1982) increased the number of pistillate flowers by pruning to enhance light interception. In a summary of Araki's research, Hall (1998) reported that chestnut trees required 35% relative solar radiation to bear fruit. In contrast, apple trees require 30% light interception to produce commercially acceptable fruit (Lakso, 1980; Jackson, 1970). Also, various chemical growth regulators have been used to increase Chinese chestnut bur production. Chen (2002) increased bur number and fruit yield of *C. henryi* by applying TDS (chemical structure unknown) growth regulator solution to chestnut trees before emergence of male flowers in the spring. Su et al. (1998) reported similar results when this solution was applied after emergence of male Chinese chestnut flowers. Zhou et al. (2000) found a combination of brassinosteroids, gibberellic acid (GA_3), paclobutrazol, KH_2PO_4, and boric acid applied to Chinese chestnut trees increased the number of fruit-bearing shoots and the number of pistillate flowers per fruit-bearing shoot. Qiguang et al. (1985) applied GA_3 at 50, 100, 250 or 500 $mg \cdot l^{-1}$, which decreased the number of male inflorescences and increased the number of female flowers. In the same study, urea increased female flowering and decreased male flowers.

Thinning studies have been conducted on other nut trees, such as pecan, to decrease the number of nuts per tree and thereby enhance nut size and return bloom. Smith and Gallott (1990) used a mechanical shaker to reduce pecan crop load on ‘Mohawk’ and ‘Shoshoni’ cultivars, resulting in greater percent kernel when compared to that of unthinned trees. Return bloom of ‘Shoshoni’ trees was also enhanced after the shaker was used. Dodge (1944) applied separate solutions of a sodium salt of dinitro-cresol (Elgetol) and a Bordeaux mixture to pistillate flowers of different pecan trees to reduce nut set. Ethephon (2-chloroethylphosphonic acid) has also been applied to pecan trees to reduce the crop load (Hinrichs et al., 1971; Wood, 1985). However, none of these chemicals have been registered for use on pecans as a thinning treatment.

Chapter 3

MATERIALS AND METHODS

Three, 10-year-old 'Orrin' and four, 5-year-old 'Willamette' Chinese chestnut (*Castanea mollissima*) trees growing at the Horticulture and Agroforestry Research Center near New Franklin, MO were used for this experiment. 'Orrin' scions had been grafted onto Chinese chestnut seedlings and were located within a repository planting in which trees were spaced at 9 m x 9 m. 'Willamette'/Miller 72-66 trees were located in a different orchard at the Research Center where tree spacing was 4 m x 8 m. Fertilizer (34N-0P-0K) was applied to trees on 27 Mar., 23 May and 26 Oct. 2006 at 75, 30 and 45 $kg \cdot ha^{-1}$, respectively. In addition to other dates, both cultivars were fertilized 26 June 2007 at 75 $kg \cdot ha^{-1}$. Trees were drip-irrigated as needed throughout the growing season.

The following three treatments were imposed on shoots of chestnut trees: 1) hand removal of 2^o burs from shoots bearing both 1^o and 2^o burs; 2) 2^o burs not removed on shoots bearing 1^o and 2^o burs; and 3) labeling shoots bearing 1^o burs but no 2^o burs. Each treatment was imposed on 31 shoots on 3 'Orrin' trees and 18 shoots on 4 'Willamette' trees. Secondary burs were removed from R treatment shoots as soon as they were observed from 21 to 28 July 2006 on 'Orrin' trees and 4 to 9 Aug. 2006 on 'Willamette' trees. Remaining burs on trees were wrapped with plastic netting (Bird-X, Inc.; Chicago, Ill.) during the growing season to prevent nut loss at harvest. Nuts from 1^o burs were harvested 9 to 20 Sept. 2006, while those from 2^o burs were harvested 6 to 25 Oct. 2006. Numbers of 1^{o} and 2^{o} burs and numbers and weights of 1^{o} and 2^{o} nuts per bur were recorded at nut harvest. Aborted or unfilled nuts were discarded and excluded from nut weight measurements. Shoot diameter and length were measured at the proximal end of the current season's shoot on 21 July and 16 Nov. 2006 and number of leaves produced on the current season's shoot was counted on 21 July.

On 2 Aug. 2007, N and R treatments were imposed on current season's growth produced on shoots evaluated in 2006. Thus, 2^{o} burs were removed from current season's shoots originating from 2006 R treatments, while N treatments were repeated on current season's shoots originating from 2006 N treatments. The number of 1^{o} burs per shoot was recorded. Secondary burs developing after 2 Aug. were removed bi-weekly until the end of the growing season. Because effect of hand removal of 2˚ burs was of primary interest, PO treatments were excluded from the study in 2007. Primary burs of 'Orrin' shoots were harvested from 13 to 30 Sept. 2007. 'Orrin' 2° burs were harvested 23 Oct. and 1 Nov. 2007. Similar bur and nut data were recorded in 2006 and 2007. Shoot diameters were measured at the proximal end of current season's growth on 2 Aug. 2007.

In 2006, data from each cultivar were analyzed separately with trees arranged in a randomized complete block design. Average number of 1^{o} burs was the same for each treatment in a replicate, and an equal number of branches were used for each treatment within a cultivar (Fig. 1). Data were subjected to an analysis of variance (ANOVA) using the PROC MIXED procedure of SAS (Version 9.1; SAS Institute; Cary, N.C.). Means were separated by Fisher's protected least significant difference (LSD) test, $P \leq 0.05$.

In 2007, nut data from all 'Orrin' shoots originating from 2006 N and R treatments were analyzed as previously described with equal number of 1^{o} burs on the current season's growth (Fig. 2). Another analysis was performed including 2007 nut data from all 'Orrin' shoots originating from branches treated in 2006. However, in this analysis, data from all 2007 treated shoots were used (Fig. 3). Thus, current season's shoots in this analysis had unequal numbers of 1^{o} burs. The PROC GLM procedure of SAS was used for this analysis, and means were separated by Fisher's protected least significant difference (LSD) test, $P \leq 0.05$. A final analysis was conducted on 2007 nut data to evaluate the effect of 2^{o} bur removal over a two-year period on the basis of the 2006 treatments with equal numbers of 1^{o} burs (Fig. 4). Only data from current season's shoots that received the same treatment in 2006 and 2007 were included in this analysis. Data from shoots that did not receive the same treatment in both years were excluded from the analysis. The number of 1° burs per shoot in the 2007 data was unequal in this analysis.

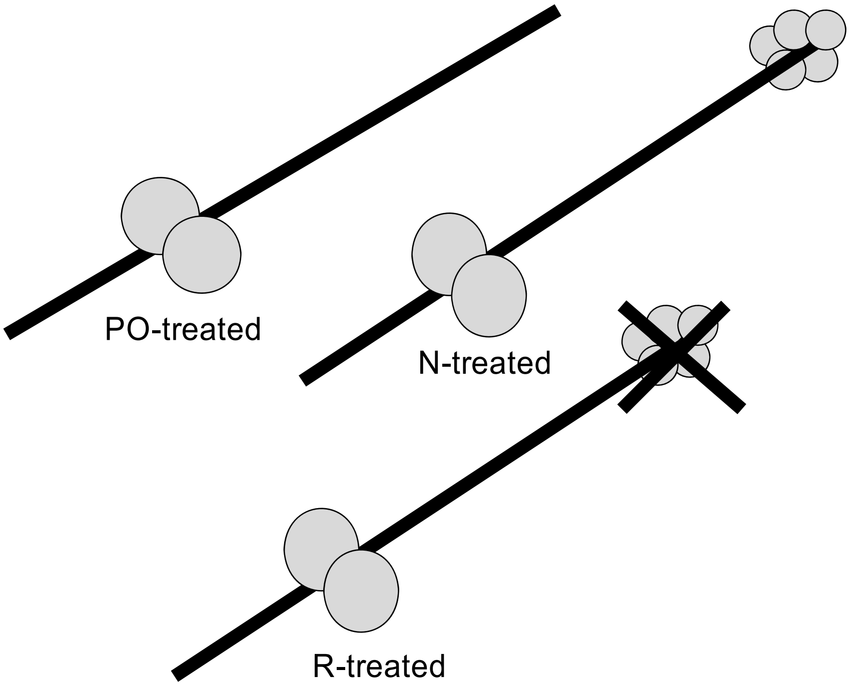

Fig. 1. Illustration of chestnut shoots used in the data analysis presented in Table 1. In this analysis, the average number of 1˚ burs was equal for each treatment in a replicate in 2006, and an equal number of branches were used for each treatment within a cultivar.

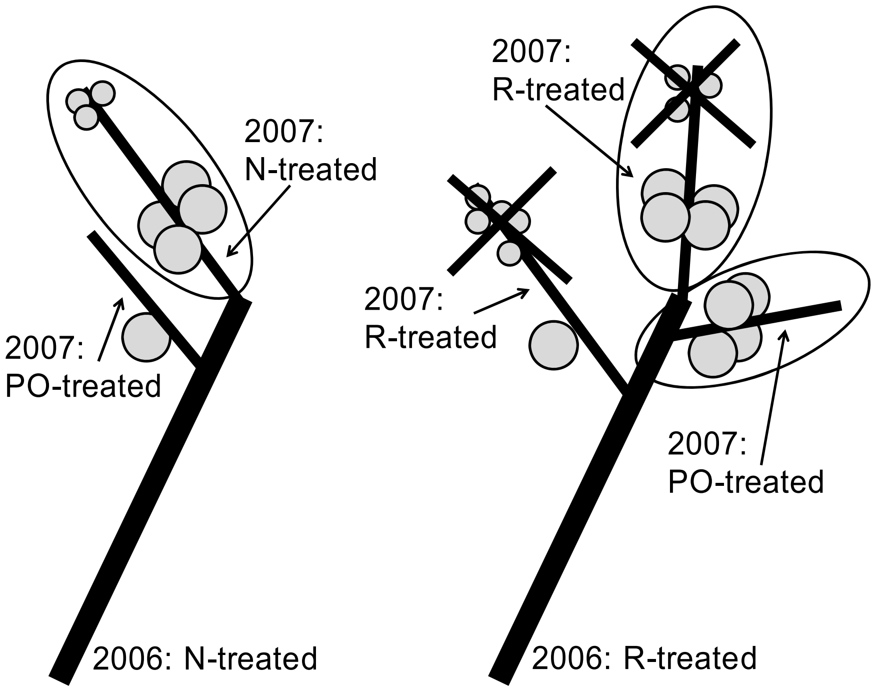

Fig. 2. Illustration of chestnut shoots used in the data analysis presented in Table 2. In this analysis, each treatment averaged four 1˚ burs per shoot for each replication.

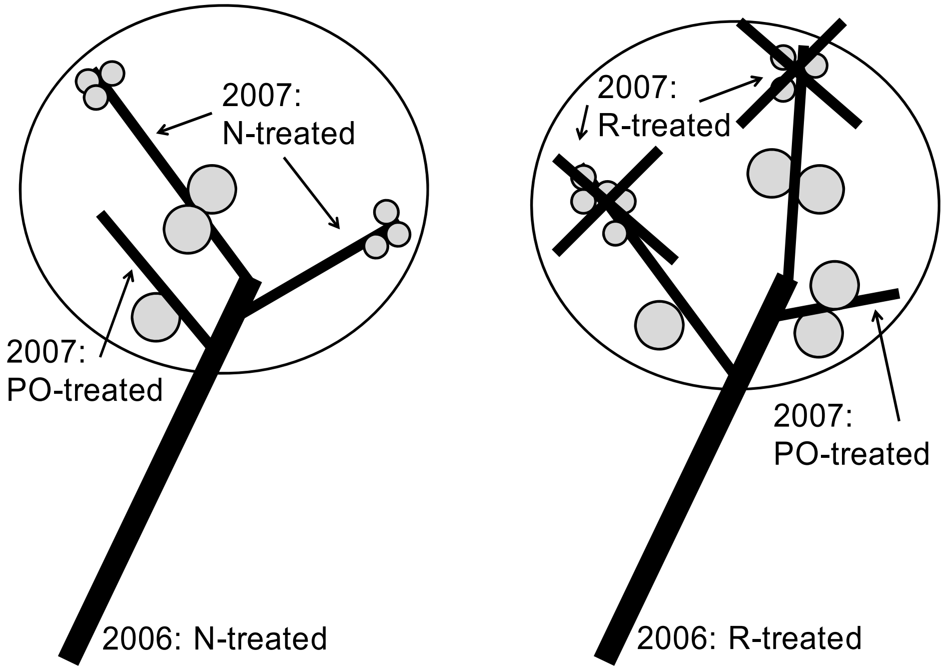

Fig. 3. Illustration of chestnut shoots used in the data analysis presented in Table 3. In this analysis, data were included from all 2007 shoots originating from ‘Orrin’ branches treated in 2006. There was an unequal number of 1˚ burs per shoot in the 2007 data.

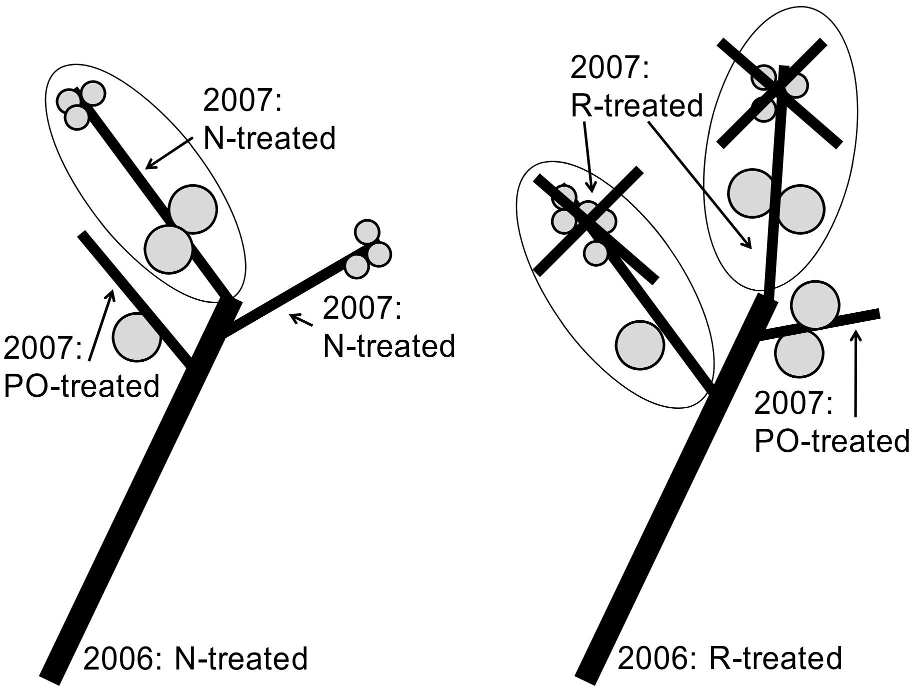

Fig. 4. Illustration of chestnut shoots used in the data analysis presented in Table 4. This analysis included 1˚ nut data from shoots which produced 1˚ and 2˚ burs in 2007 and received the same treatment in 2006 and 2007. All 2007 shoots originated from branches that had been grouped to have average equal numbers of 1˚ burs per shoot in 2006. Data from shoots that did not receive the same treatment in both years or that did not produce 1˚ burs in 2007 were excluded from the analysis. The number of 1˚ burs per shoot in the 2007 data was unequal.

Chapter 4

RESULTS

In 2006, ‘Orrin’ and ‘Willamette’ shoots that averaged two and three 1^{o} burs, respectively, were selected for this study to ensure equal crop load among treatments. The average number of 2^{o} burs removed from R treatments of ‘Orrin’ and ‘Willamette’ shoots was 8.9 and 6.8, respectively. For each cultivar, N and R shoots had similar shoot diameter, length, and leaf number (Table 1). In contrast, PO shoots of each cultivar had smaller diameter, shorter length, and fewer leaves than the other two treatments.

Mean 1^{o} nut weight per shoot of ‘Orrin’ R treatments was greater than that of other treatments, while PO and N shoots produced similar 1^{o} nut weights (Table 1). Average 1^{o} nut weights of N- and R- treated shoots were 0.4 g and 1.3 g more than that of PO shoots, respectively. For ‘Orrin’ trees, mean 2^{o} nut weight per shoot of N treatments was 66.3 g. While ‘Willamette’ R- treated shoots did not have significantly greater 1˚ nuts per shoot or 1˚ nut weight per shoot, they had relatively greater 1^{o} nut weight per shoot than the other treatments. Average 1^{o} nut weights of ‘Willamette’ N- and R-treated shoots averaged ≥2.4 g more than that of PO-treated shoots. Mean 2^{o} nut weight per shoot of N treatments on ‘Willamette’ trees was 15.7 g. Average 2^{o} nut weight was 5.8 g (data not shown).

In 2007, an unprecedented low temperature event occurred from 4 to 10 Apr. After the third-warmest March in 118 years, -8 ^{o}C was recorded at the Research Center on 9 Apr. At the time of the freeze event, bud break had occurred on ‘Willamette’ trees, and new shoot growth was injured. By 26 June 2007, only 19% of the 2006 N- or R-treated shoots on ‘Willamette’ trees had produced 1^{o} burs. Because ‘Willamette’ trees had few 1^{o} burs, 2° bur removal treatments were not imposed on this cultivar in 2007. By 2 Aug., ‘Willamette’ trees averaged 9.4 secondary burs per shoot and had a mean 2^{o} nut weight per shoot of 87.5 g. Average 2^{o} nut weight from 63 shoots was 9.5 g.

In contrast, ‘Orrin’ trees did not exhibit symptoms of injury. When data from 2007 branches with equal numbers of 1^{o} burs (an average of 4 primary burs per shoot) were analyzed, results were generally similar to those obtained in 2006 (Table 2). Although there were no statistical differences among treatments, R treatments in 2007 produced 1^{o} nuts that weighed 11.9 g more per shoot than those of N treatments (Table 2). Additionally, average 1^{o} nut weight of R treatments was ≥1.1 g more than that of other treatments.

By 26 June 2007, PO-, N-, and R-treated branches had produced an average of 2.1, 4.1, and 4.7 new shoots, respectively. When data from all 2007 shoots were analyzed, 2006 R-treated branches produced a greater number of new shoots bearing 1^{o} burs than the other treatments (Table 3). PO treatments had fewer 1^{o} burs per shoot than those of R treatments. Because the effect of hand removal of 2^{o} burs was of primary interest, the N and R treatments were repeated on shoots originating from similar treatments in 2006, while 1^{o} nut data were not obtained from PO shoots at harvest. R treatments averaged 3 more 1^{o} nuts per shoot than N-treated shoots (Table 3). Also, R treatments had greater 1^{o} nut weight per shoot than that of N treatments. Although 1° nut weight was not statistically significant, it was generally greater for R-treated shoots than for N-treated shoots (Table 3). By Aug. 2007, N and R treatments produced an average of ten 2^o burs per shoot.

When nut data from 2007 branches that received the same treatment for two years were analyzed, there were 12 shoots that received the N treatment in 2007 and 22 shoots that received the R treatment. In 2007, an average of 14.3 and 11.3 secondary burs per shoot were recorded on the date of first treatment on N and R treatments, respectively. Although there were no statistical differences in nut characteristics among treatments, 2007 R-treated shoots that originated from 2006 R treatments had fewer 1^o burs and fewer 1^o nuts per shoot than those of 2007 N treatments originating from 2006 N-treated branches (Table 4). However, average 1^o nut weight of shoots receiving R treatments in 2007 was greater than that of N treatments.

Table 1. Annual vegetative and reproductive characteristics of 'Orrin' and 'Willamette' chestnut shoots that had PO, N, or R treatments in 2006.[z]

		Vegetative characteristics			Reproductive characteristics		
Cultivar	Treatment	Shoot diameter[y] (mm)	Shoot length[x] (cm)	Leaf no./ shoot	No. of 1^{o} nuts/ shoot	1^{o} nut wt./ shoot (g)	Avg. 1^{o} nut wt. (g)
'Orrin'	PO	6.3 a[v]	16.5 a	13.7 a	6.6 a	67.4 a	10.6 a
'Orrin'	N	8.0 b	36.4 b	23.2 b	6.7 a	71.0 a	11.0 ab
'Orrin'	R	7.9 b	37.1 b	22.5 b	6.6 a	78.3 b	11.9 b
'Willamette'	PO	8.2 a	26.6 a	14.3 a	8.3 a	112.2 a	14.0 a
'Willamette'	N	10.0 b	51.8 b	23.7 b	7.8 a	122.9 a	16.4 b
'Willamette'	R	9.9 b	53.7 b	23.9 b	8.2 a	131.5 a	16.5 b

[z] Data from treated shoots with equal numbers of 1^{o} burs were included in this analysis (n=31 for 'Orrin' treatments and n=18 for 'Willamette' treatments). ‘Orrin’ and ‘Willamette’ shoots averaged two and three 1° burs per shoot, respectively, for each replication.

[y] Diameter measured at proximal end of current season's growth in Nov. 2006.

[x] Shoot length of current season's growth recorded in Nov. 2006.

[v] Means within each column followed by different letters are significantly different by LSD (*P*≤0.05).

Table 2. Annual reproductive characteristics of treated 'Orrin' shoots with an equal number of 1^{o} burs in 2007.[z]

2007 Treatment	No. of 1^{o} nuts/ shoot	1^{o} nut wt./ shoot (g)	Avg. 1^{o} nut wt. (g)
PO	9.4	76.9	8.5
N	8.7	75.6	8.9
R	9.0	87.5	10.0

[z] Each treatment averaged four 1˚ burs per shoot for each replication (n=8 for each treatment). Treatment means were not statistically different for nut characteristics by LSD ($P \leq 0.05$).

Table 3. Reproductive characteristics in 2007 of all 'Orrin' shoots originating from branches treated in 2006.[z]

2006 Treatment	No. of bearing shoots	No. of 1^{o} burs/ shoot	No. of 1^{o} nuts/ shoot	1^{o} nut wt./ shoot (g)	Avg. 1^{o} nut wt. (g)
PO	0.6 a	2.2 a	--[y]	--	--
N	1.0 a	3.6 ab	8.3 a	79.1 a	9.4 a
R	1.6 b	5.2 b	11.3 a	112.0 b	9.9 a

[z] N and R treatments were repeated in 2007 on branches receiving similar treatments in 2006. There was an unequal number of 1˚ burs per shoot in the 2007 data. Means within each column followed by different letters are significantly different by LSD ($P \leq 0.05$).

[y] Data not recorded in 2007.

Table 4. Reproductive characteristics of 2007 'Orrin' shoots that received the same treatment in 2006.[z]

2006 and 2007 Treatment	No. of 1° burs/ shoot	No. of 1° nuts/ shoot	1° nut wt./ shoot (g)	Avg. 1° nut wt. (g)
N	4.7	10.8	102.0	9.2
R	3.8	9.1	94.5	10.3

[z] All 2007 shoots included in this analysis originated from branches that had equal numbers of 1˚ burs per shoot in 2006 (n=12 for N treatment, n=22 for R treatment). Data from shoots that did not receive the same treatment in both years were excluded from the analysis. The number of 1˚ burs per shoot in the 2007 data was unequal. Treatment means were not statistically different at LSD ($P \leq 0.05$).

DISCUSSION

In 2006, PO-treated shoots were less vigorous than those of other treatments (Table 1). Also, vigorous shoots that received the R treatment had greater 1^o nut weight per shoot than those that had the PO treatment. While light measurements were not recorded in this study, these results support those of Araki (Hall, 1998) in which sun-exposed shoots with large diameters produced greater nut yield than weaker, shaded shoots. Hand removal of 2^o burs also resulted in greater 1^o nut weight per shoot than when 2^o burs were left on ‘Orrin’ trees (Table 1). The reason for the increased 1^o nut weight on R-treated shoots may be that assimilate normally allocated to 2^o nuts was instead distributed to 1^o nuts. Other nut crops, such as pecan, have exhibited a similar response to a reduction in crop load. Smith and Gallott (1990) reported greater percent kernel of harvested pecan nuts when the number of fruits was reduced by a mechanical shaker as compared to that of nuts that did not receive the thinning treatment. Many researchers have shown that manual or chemical thinning of fruit results in larger diameter apples at harvest and greater return bloom the following season (Dennis, 2000).

R-treated ‘Orrin’ shoots in 2007 tended to produce greater 1^o nut weight per shoot than N treatments (Table 2). The lack of statistical significance may be attributed to the few numbers of treated shoots in 2006 that produced at least one shoot with 1^o and 2^o burs which could receive the same treatment in 2007. Thus, there were few degrees of freedom for treatments that had equal numbers of 1^o burs when data were analyzed in this manner.

Results from this study also indicated that ‘Willamette’ trees generally showed a response to the removal of 2^{o} burs that was similar to ‘Orrin’ trees (Table 1). Although results were not statistically significant, 1^{o} nut weight per shoot of R treatments was relatively more than that of N and PO treatments. The reason for the lack of significance may be that the variability in 1^{o} nut weight per shoot was large within treatments on ‘Willamette’ trees. Also, ‘Willamette’ trees were younger than ‘Orrin’ trees in this study, possibly resulting in greater variability in reproductive characteristics.

Hand removal of 2^{o} burs on ‘Orrin’ trees in 2006 resulted in greater numbers of total shoots and nut-bearing shoots in 2007 than those receiving the N treatment in 2006 (Table 3). Thus, shoots that grew vigorously in 2006 had a greater capacity to produce more 1^{o} nut weight than the weaker PO-treated shoots (Table 3). When data from shoots that received similar treatments for two consecutive years were analyzed, 1^{o} nut weight per shoot of R-treated shoots was slightly less (although not significantly) than that of N-treated shoots (Table 4). However, the average 1^{o} nut weight of R-treated shoots was greater than that of the N treatments. Thus, other shoots originating from the previous year’s R treatment compensated for the reduced 1^{o} nut weight per shoot on 2007 R-treated shoots (Table 3).

Results from the current study differed slightly from a study conducted by Warmund et al. (2005). In the earlier study, 2^{o} burs on eight-year-old ‘Orrin’, ‘Willamette’, and ‘Armstrong’ trees received N and R treatments as described in the present study. However, data from all shoots with varying numbers of 1^{o} burs were analyzed in the earlier study, while data from shoots with equal numbers of 1^{o} burs were compared in the present study. In the earlier study, removal of 2^o burs did not affect the 1^o nut weight per shoot at harvest, but mean 1^o nut weight was greater for R-treated shoots than for N-treated shoots. In the following year, R-treated shoots produced relatively more 1^o burs than N-treated shoots. Thus, the different methods of data analysis (i.e., inclusion of data with unequal numbers of 1^o burs per shoot) may have affected the results. However, both of these studies demonstrated that removal of 2^o burs affected the 1^o nut crop either by increasing nut weight per shoot or by increasing average nut weight. Additionally, the removal of 2^o burs generally increases the number of 1^o burs per shoot in the following year.

Although the freeze event of April 2007 resulted in loss of a second year of data collection on effect of consecutive years of 2^o bur removal on ‘Willamette’ trees, important information was gained regarding their low temperature susceptibility. ‘Willamette’ trees had relatively more crop loss than ‘Orrin’ trees when temperatures dropped to -8 ^oC, with only 19% of the treated shoots producing 1^o burs. Although 1^o bur numbers were reduced by the cold temperatures, a substantial number of 2^o burs were produced later in the growing season. In fact, ‘Willamette’ branches treated in 2006 averaged 9.4 secondary burs per shoot in 2007 after the freeze event, whereas treated shoots averaged 6.8 secondary burs in 2006. Secondary nut weight per shoot and average 2^o nut weight was also greater in 2007 than in 2006. Thus, ‘Willamette’ trees had the capacity to produce a crop of 2^o chestnuts that were marketable for processing purposes.

Results from this study show the complex relationship between the varying numbers of 1^{o} and 2^{o} burs and differing numbers of nuts per bur that contribute to total yield per tree and average nut weight. When the number of 1^{o} burs was reduced on ‘Willamette’ trees by a freeze event, the number of 2^{o} burs produced that season increased. For ‘Orrin’ trees, 2^{o} bur removal generally resulted in greater 1^{o} nut weight per shoot at harvest and an increased number of 1^{o} burs per shoot in the subsequent growing season (Tables 1, 2, 3). Average 1^{o} nut weight was influenced by 1^{o} nut weight per shoot and the number of 1^{o} nuts per bur (Table 4). However, in spite of these complex relationships, the removal of 2^{o} burs generally enhanced 1^{o} nut weight at harvest and the number of shoots bearing 1^{o} burs in the following growing season. While hand removal of 2^{o} burs on large Chinese chestnut trees may not be practical due to high labor costs, the use of hormones or other chemical treatments for 2^{o} bur removal may be economically feasible in the future. Alternatively, Chinese chestnut trees that produce few 2^{o} burs could be grown. Preliminary assessments in 2006 and 2007 have shown that cultivars such as ‘Peach’ and ‘Qing’ produce a low percentage of 2^{o} burs late in the growing season (K. Hunt, unpublished data). However, long-term evaluation of 2^{o} bur production has not been reported.

Chapter 5

SUMMARY AND CONCLUSIONS

N- and R- treated shoots of ‘Orrin’ and ‘Willamette’ trees had similar shoot diameters, shoot lengths, and numbers of leaves per shoot in 2006. However, R treatments on ‘Orrin’ trees had greater 1^{o} nut weight per shoot than that of N treatments (Table 1). Secondary bur removal on ‘Willamette’ trees also resulted in enhanced 1^{o} nut weight per shoot, although this increase was not statistically significant. Additionally, ‘Orrin’ R-treated shoots generally had greater average 1^{o} nut weight than that of N-treated shoots, although differences were not statistically significant. When R treatments were continued in 2007 on ‘Orrin’ shoots of the same treatment, similar results were obtained with generally greater 1^{o} nut weight per shoot and greater average 1^{o} nut weight than those of N-treated shoots (Table 2).

R-treated branches from 2006 produced greater numbers of bearing shoots with relatively more 1^{o} burs in June 2007 (Table 3). In Oct. 2007, current season’s shoots originating from 2006 R treatments tended to produce a greater number of 1^{o} nuts per shoot with greater nut weight per shoot than those originating from 2006 N-treated shoots (Table 3). When 2^{o} bur removal was continued over a two-year period, untreated (i.e., PO) current season’s shoots compensated for the reduced number of 1^{o} nuts per shoot and 1^{o} nut weight per R-treated shoot (Table 3, 4).

While the 1^{o} nut crop of ‘Willamette’ trees was greatly reduced by an April 2007 freeze event, a large number of 2^{o} burs were produced later in the growing season which produced marketable 2° nuts for processing purposes. Thus, results obtained from 'Orrin' and 'Willamette' trees demonstrated the complex relationship among yield components. For example, the early removal of 2° burs generally resulted in greater 1° nut weight per shoot when the number of 1° burs and nuts were similar (Table 1). Average nut weight of 'Orrin' trees was generally increased by the removal of 2° burs (Tables 1, 2, 3). Following 2° bur removal, a greater number of new shoots produced 1° burs with generally more 1° burs and nuts per shoot in the subsequent growing season (Table 3). In contrast, when 1° burs were eliminated by freezing temperatures in early spring, trees produced a marketable crop of 2° nuts. Thus, this study demonstrated that 1° nut weight per shoot and average 1° nut weight at harvest, as well as 1° bur set in the subsequent growing season, were generally enhanced by 2° bur removal. While hand removal of 2° burs is currently cost-prohibitive, the use of chemical thinners in the future may be feasible to enhance 1° nut yield and nut weight.

LITERATURE CITED

Araki, H. 1982. Effects of severity of renovation pruning on tree growth and nut yield and size in chestnut trees (*Castanea crenata*). J. Jpn. Soc. Hort. Sci. 51(3): 278-285.

Chen, L. Y. 2002. Application of TDS plant growth regulator on chinquapin trees. Forest Res., Beijing. 15(5):604-608.

Dennis, Jr., F.G. 2000. The history of fruit thinning. Plant Growth Regulat. 31:1-16.

Dodge, F.N. 1944. Reducing the set of pecan nuts by spraying in flower with phytotoxicants. Proc. Amer. Soc. Hort. Sci. 45:59-62.

FAO Statistics Division. 2007. Core Trade Data. Food and Agriculture Organization of the United Nations. 11 September 2007. <http://faostat.fao.org/site/343/DesktopDefault.aspx?PageID=343>.

Gold, M. A., Cernusca, M. M. and L. D. Godsey. 2006. Competitive market analysis: chestnut producers. HortTechnology. 16(2):360-369.

Hall, P. 1998. Physiological and ecological characteristics of chestnuts. Proc. Chestnut Pruning and Grafting Conf., Wkshp. and Farm Walk. Beechworth, Victoria, Australia, 29-30 Aug. 1998. Premium Chestnuts Australia.

Hinrichs, H.A., D.W. Ramming and D.A. Hopfer. 1971. Effects of ethephon on thinning nuts and loosening shucks of pecan. Annu. Rpt. Northern Nut Growers Assn. 62:105-108.

Huang, H., J.D. Norton, G.E. Boyhan, and B.R. Abrahams. 1994. Graft compatibility among chestnut (*Castanea*) species. J. Amer. Soc. Hort. Sci. 119(6):1127-1132.

Hunt, K., M. Gold, and W. Reid. 2004. Growing Chinese chestnuts in Missouri. Univ. Mo. Ctr. Agrofor. Columbia, Mo.

Hunt, K., M. Gold, W. Reid, and M. Warmund. 2005. Growing Chinese chestnuts in Missouri. Univ. Mo. Ctr. Agrofor. Columbia, Mo.

Ichii, T. 1960. Growth studies of chestnut fruits. I. Developmental changes in the chemical composition of chestnut fruits. J. Jpn. Soc. Hort. Sci. 29:281-286.

Jackson, J.E. 1970. Aspects of light climate within apple orchards. J. Appl. Ecol. 7:207-16.

Lakso, A.N. 1980. Correlations of fisheye photography to canopy structure, light climate, and biological responses to light in apple trees. J. Amer. Soc. Hort. Sci. 105(1):43-46.

Miller, G. 2003. Chestnuts, p. 167-181. In: Fulbright, D.W. (ed.). A guide to nut tree culture in North America, Vol. 1. Published by Northern Nut Growers Assn. Printed by McNaughton and Gunn, Inc., Saline, Mich.

Qiguang, Y., Lizhong, R. and D. Guohua. 1985. Effects of ethephon, GA_3 and nutrient elements on sex expression of Chinese chestnut. Scientia Hortic. 26:209-215.

Shi, Z. and R. Stösser, R. 2005. Reproductive biology of Chinese chestnut (*Castanea mollissima* Blume). European J. Hort. Sci. 70(2):96-103.

Shimura, I., Yasuno, M. and C. Otomo. 1971. Studies on the genetics and breeding of chestnut in respect of various economic characters. II. The effect of pollination time on the number of nuts in the cupule. Jpn. J. Breeding. 21(2):77-80.

Smith, M.W., and J.C. Gallott. 1990. Mechanical thinning of pecan fruit. HortScience. 25(4):414-416.

Soltész, M., J. Nyéki and Z. Szabó. 2003. Chestnut (*Castanea sativa* Mill.), p. 467-497. In: Kozma, P., J. Nyéki, M. Soltész and Z Szabó (eds.). Floral biology, pollination and fertilization in temperate zone fruit species and grape. Akadémiai Kiadó.

Stebbins, R.L. 1990. Requirements for a United States chestnut industry, p. 324-327. In: J. Janick and J.E. Simon (eds.). Advances in new crops. Timber Press, Portland, OR.

Su, M.Y., Zhou, G.Z., Ying, T.L., Hu, X.M., Jin, Z.F. and KeQin Shen. 1998. Techniques on using TDS growth regulator to increase fruit bearing in Chinese chestnut. Forest Res. 11(3):319-324.

Warmund, M.R., K.L. Hunt, and M.A. Gold. 2005. Removal of secondary burs increases average nut weight from primary burs of ‘Armstrong’, ‘Orrin’ and ‘Willamette’ Chinese chestnuts. Acta Hort. (ISHS) 693:149-152.

Wood, B.W. 1985. Effect of ethephon on IAA transport, IAA conjugation, and antidotal action of NAA in relation to leaf abscission of pecan. J. Amer. Soc. Hort. Sci. 110(3):340-343.

Zhou, Z.X., Xu, Y.R., Wang, P.C., Xu, X.Y, and C.J. Wang. 2000. Effects of several chemical regulators and their combinations on female flower number and fruit bearing in Chinese chestnut. Forest Res., Beijing. 13(2):153-159