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Bur and Nut Production on Three Chestnut Cultivars

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Abstract

Studies were conducted to characterize bur and nut development on shoots of young chestnut (*Castanea* sp.) trees over a two year period and to determine the effect of secondary (2º) bur removal on subsequent bur and nut production. Terminal shoots of 'Peach' trees with primary (1º) and 2º burs (PS) grew longer and had greater stem diameter than those shoots with 1º burs only (PO), 2º burs only (SO), or with no burs (VO). PS shoots of 'Peach' had greater 1º nut weight per shoot than the other types of shoots in 2006. PS shoots also produced 2º nuts with as much or more weight per shoot than SO shoots. For 'Peach' trees, 2005 fruiting or vegetative shoots were most likely to develop a VO shoot in 2006. PS shoots of 'Willamette' trees typically produced more 1º nut weight per shoot than the other types of shoots. However, 2º nut weights per shoot were similar for PS and SO shoots on 'Willamette' trees. The odds of 2005 fruiting or vegetative 'Willamette' shoots developing into PO shoots the following year were ≥ 50%. When 2º burs were removed from shoots of 'Orrin' trees in late July (R treatment), 1º nut weight per shoot at harvest and the number of 1º bur-bearing shoots in the following year were greater than that on shoots where 2º burs were not removed (N treatment). Thus, 1º nut weights were enhanced by 2º bur removal, as well as subsequent 1º bur production. For 'Willamette' trees, R-treated trees also had relatively more 1º nut weight per shoot than N-treated shoots at harvest in the year the treatment was imposed, but most 1º flowers were killed by an early April freeze event the following year. In spite of this loss, a marketable crop of 2º nuts was produced.

Demand for chestnuts in the United States is currently being satisfied primarily by imported nuts (9). From 2000 to 2005, an average of 4500 MT of chestnuts were imported into the United States (9), and these nuts have historically come from Italy and China (7). However, in recent years, several different chestnut species and their hybrids have been planted and their nuts are also marketed in the United States (10). Many of the chestnut trees grown in the Pacific Northwest are considered hybrids of European (*C. sativa* Mill.) and Japanese (*C. crenata* Sieb. & Zucc.) species ('Colossal', 'Bouche de Betizac', 'Yolo Grande', and 'Marsol') (11). Because these trees lack winter cold hardiness, Chinese chestnut (*C. mollissima* Bl.) cultivars such as 'Peach' and 'Orrin' or hybrids including 'Willamette' [Chinese x American (*C. mollissima* x *C. dentata* Borkh.)] and 'Eaton' [*C. mollissima* x (*C. crenata* x *C. dentata*)] are grown in the Midwestern USA (1,3). While Chinese chestnut trees and their hybrids generally tolerate -30ºC during mid-winter, buds on terminal shoots of trees are sometimes susceptible to spring frost injury (5).

Chinese chestnut flowers are differentiated in the summer previous to fruiting (5). In Missouri, the first flowering generally occurs in June. Bisexual catkins are produced distally on the current season's shoot and unisexual male catkins develop proximally on the same shoot. Bisexual catkins produce pistillate flowers proximally which develop into primary (1º) burs (12). There are generally three nuts per bur with the middle nut (i.e., wafer nut) being smaller and thinner than the outer nuts. Because wafer nuts do not always fill, they generally have little commercial value in the fresh market.

A second flowering period occurs in late July or early August after a second flush of vegetative growth (12). Following pollination, nuts are also produced within these late-season secondary (2º) burs. However, 2º nuts do not often attain sufficient size for the retail

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market by the end of the growing season.

Currently, there are six grades of chestnuts based on nut diameter, ranging from small (<25 mm) to special (>38 mm) (3). Some chestnut cultivars currently grown in North America, such as 'Qing' and 'Eaton', produce a high percentage of small-sized nuts. It is unknown if removal of 2° burs would result in larger 1° nuts at harvest and increase 1° bur production in the subsequent growing season. Because of the paucity of information on early bearing and crop load management of young Chinese chestnut trees, studies were conducted to characterize bur and nut development on various shoot types over a two year period and to determine the effect of 2° bur removal on 1° nut weight at harvest and subsequent 1° bur production in the following year.

Materials and Methods

Characterization of early fruiting. Five 4-year-old 'Peach' and five 4-year-old 'Willamette' Chinese chestnut trees growing in a deep, upland Menfro silt loam soil (fine-silty, mixed, superactive, mesic typic hapludalfs) at the Horticulture and Agroforestry Research Center (HARC) near New Franklin, MO were used for this study. Cultivars had been grafted onto Miller 72-138 seedling rootstock and were spaced 4 x 8 m apart and were arranged in a randomized complete block design. Trees were maintained in their natural form with little pruning. Drip-irrigation scheduling and pest and fertility management followed local recommendations (3). Fertilizer (34N-0P-0K) was applied underneath the trees to the dripline of the canopy annually on 27 Mar., 23 May, and 26 Oct. at 75, 30 and 45 kg·ha-1, respectively.

All terminal shoots on each tree were identified and labeled on 10 Aug. 2005 as those with 1° and 2° burs (PS), those bearing 1° burs only (PO), those with 2° burs only (SO), or vegetative (VO) shoots with no burs. Data recorded in 2005 included stem diameter measured at the proximal end of the current season's growth and total shoot length measured 11 Nov., the number of 1° and 2° burs, the number of 1° and 2° nuts per bur, and 1° and 2° nut weights per shoot. Burs were wrapped with netting (Bird-X, Inc.; Chicago, Ill.) on 1 Sept. to prevent nut loss at harvest. Nuts from 1° burs were harvested on 15 Sept., while those from 2° burs were harvested 28 Oct. Non-filled nuts in a bur were discarded. All bur and nut measurements were repeated in 2006 on the same shoots that were previously labeled in 2005.

Data were analyzed by cultivar as a randomized complete block design using individual trees as blocks. Vegetative growth of terminal shoots and fruiting data were subjected to an analysis of variance (ANOVA) using the PROC MIXED procedure of SAS (Version 9.1; SAS Institute; Cary, N.C.) and means were separated by Fisher's protected least significant difference (LSD) test, $P \leq 0.05$.

Because of unequal numbers of shoot types in 2006, odds were calculated to estimate the probability that a 2005-labeled shoot type would become a PS, PO, SO, or VO shoot the following year. Data for each branch type within a cultivar were analyzed separately and each tree was considered a block. Data were subjected to the GENMOD procedure of SAS with a logit link function for a binomial distribution. Odds were back-transformed [% shoot type = odds / (1 + odds)] to estimate percentage of each shoot type in 2006.

Hand removal of 2° burs. Three 10-year-old 'Orrin' and four 5-year-old 'Willamette' chestnut trees growing at HARC 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 72-138 trees, fertilization, and irrigation schedules were similar to those described above.

Bur and nut production were evaluated on shoots that produced 1° burs. Shoots with either two or three 1° burs with and without 2° burs were identified and labeled for this study. Treatments included removal of 2° burs from shoots by hand in late July or early August (R), 2° burs not removed (N), and shoots bearing 1° burs only (PO). A total of 31 shoots on 'Orrin' trees and 18 shoots on 'Willamette' trees were used for this study. For 'Orrin', only shoots that had two 1° burs were included in the study to ensure equal crop load among treatments. For 'Willamette', only shoots that had three 1° burs were included. Secondary burs were removed from R 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 to prevent nut loss at harvest. Nuts from 1° burs were harvested 15 Sept. 2006, while those from 2° burs were harvested 25 Oct. 2006. Numbers of 1° and 2° burs and numbers and weights of 1° and 2° nuts per bur were recorded at harvest. Shoot diameter and length were measured as previously described, and the number of leaves on current season's growth was recorded on 16 Nov. 2006.

In 2007, a freeze event during 4 to 10 Apr. killed many 1° flowers on 'Willamette' shoots so data were not obtained for these trees. Because 'Orrin' trees flowered later, bur and nut data were obtained for this cultivar. On 2 Aug. 2007, PO shoots were labeled and N and R treatments were repeated in 2007 on current season's shoots that had 1° and 2° burs. Only 2007 shoots receiving similar treatments in 2006 were included in the data. The number of 1° burs per shoot was also recorded. Secondary burs developing after 2 Aug. were removed two times per week until the end of the growing season. Because the effect of hand removal of 2° burs was of primary interest, 1° nut data were not obtained from PO shoots in 2007. Primary and 2° nuts from 'Orrin' shoots were harvested on 20 Sept. and 1 Nov. 2007, respectively.

For the bur removal experiment, data were analyzed by cultivar as a randomized complete block design using individual trees as blocks. In 2006, the average number of 1° burs was the same for each treatment in a replicate, and an equal number of branches was used for each treatment within a cultivar. In 2007, data were analyzed from current season's growth from shoots treated similarly for two years. Data were subjected to ANOVA using the PROC MIXED procedure of SAS and means were separated by Fisher's protected LSD test, $P \leq 0.05$.

Results

Characterization of early fruiting. The total numbers of PS, PO, SO, and VO 'Peach' shoots labeled in 2005 were 12, 27, 5, and 32, respectively. Thus, 16, 35, and 7% of all terminal shoots were PS, PO, and SO shoots, respectively. The greatest percentage of terminal shoots (42%) did not produce burs in 2005.

PS shoots of 'Peach' were the most vigorous (in length and diameter), PO and SO shoots were intermediate, and VO shoots were the weakest in 2005 (Table 1). Vegetative shoots were most often located in the lower portion of the tree canopy, while bur-bearing shoots were in the upper, sun-exposed portion of the tree. PS and PO shoots of 'Peach' trees produced similar numbers of 1° burs, nuts, and nut weight per shoot in 2005 (Table 1). Also, PS and SO shoots produced similar numbers of 2° burs and nuts per shoot, but PS shoots had greater 2° nut weight per shoot than that of SO shoots.

In 2006, PS shoots of 'Peach' trees labeled in 2005 had relatively more 1° bur-bearing shoots, burs, and nuts than PO and SO shoots, but these differences were not statistically significant (Table 2). However, PS shoots had greater 1° nut weight per shoot than PO and SO shoots at harvest. All four types of shoots had similar numbers of 2° bur-bearing shoots, burs, and nuts in 2006. However, PS shoots had greater 2° nut weight per shoot than PO and V shoots.

When odds of 2005-labeled shoots of 'Peach' trees becoming other shoot types in 2006 were calculated, 2005-labeled PS shoots were about equally as likely to pro-

Table 1. Vegetative and fruiting characteristics of terminal shoots of 'Peach' Chinese chestnut trees in 2005.

Type of shoot in 2005[z]	Shoot length (cm)[y]	Shoot diameter (mm)[y]	No. of 1° burs/ shoot[w]	No. of 1° nuts/ shoot	1° nut wt./ shoot (g)	No. of 2° burs/ shoot[v]	No. of 2° nuts/ shoot	2° nut wt./ shoot (g)
PS	92.7 a[xv]	13.4 a	1.3 a	3.2 a	64.0 a	3.6 a	6.4 a	56.2 a
PO	78.6 b	11.8 b	1.4 a	3.3 a	58.8 a	--	--	--
SO	81.3 b	12.2 b	--	--	--	2.8 a	4.6 a	41.7 b
VO	46.4 c	8.8 c	--	--	--	--	--	--

[z] PS = shoots with 1° (primary) and 2° (secondary) burs, PO = shoots with 1° burs only, SO = shoots with 2° burs only, VO = vegetative shoots. Total numbers of PS, PO, SO, and VO shoots labeled on chestnut trees in 2005 were 12, 27, 5, and 32, respectively.
[y] Shoot lengths and diameters were measured on 11 Nov. 2005.
[x] Means within each column followed by different letters are significantly different ($P \leq 0.05$).
[w] Burs were harvested on 15 Sept. 2005.
[v] Burs were harvested on 28 Oct. 2005.

duce 1° burs (odds of PS + PO shoots) or become vegetative shoots in 2006 (Table 3). In contrast, 2005 PO- and VO-labeled shoots had the highest odds of being VO shoots and the lowest odds for becoming PO or SO shoots in 2006. For 2005 SO-labeled shoots, only a total of 12 shoots of any type were produced on all five 'Peach' trees in 2006 and 7 of these shoots were vegetative.

For 'Willamette' trees, the total numbers of PS, PO, SO, and VO shoots labeled in 2005 were 26, 35, 15, and 74, respectively. Thus, 17, 23, and 10% of all terminal shoots were PS, PO, and SO shoots, respectively. In contrast, 49% of the terminal shoots were vegetative in 2005. PS and SO shoots of 'Willamette' trees were the longest, PO shoots were intermediate, and VO shoots were the shortest (Table 4). PS shoots had greatest diameter, followed by SO shoots, then PO shoots,

Table 2. Fruiting characteristics of terminal shoots of 'Peach' Chinese chestnut trees in 2006.

Type of shoot in 2005[z]	No. of 1° bur-bearing shoots	No. of 1° burs/ shoot[y]	No. of 1° nuts/ shoot	1° nut wt./ shoot (g)	No. of 2° bur-bearing shoots	No. of 2° burs/ shoot[x]	No. of 2° nuts/ shoots	2° nut wt./ shoot (g)
PS	1.2 a[w]	2.2 a	5.7 a	90.5 a	0.3 a	0.9 a	1.3 a	13.6 a
PO	0.6 ab	0.9 ab	2.2 ab	37.0 b	0.1 a	0.1 a	0.1 a	1.1 c
SO	0.8 ab	1.0 ab	2.6 ab	51.0 b	0.2 a	0.6 a	1.0 a	9.6 ab
VO	0.3 b	0.3 b	1.0 b	16.8 c	0.2 a	0.5 a	0.8 a	4.8 bc

[z] Shoot types were labeled in 2005. Data were recorded in 2006 from terminal shoots originating from 2005 shoot types. PS = shoots with 1° (primary) and 2° (secondary) burs, PO = shoots with 1° burs only, SO = shoots with 2° burs only, VO = vegetative shoots. Total numbers of PS, PO, SO, and VO shoots in 2006 were 6, 36, 21, and 132, respectively.
[y] Burs were harvested on 15 Sept. 2006.
[x] Burs were harvested on 28 Oct. 2006.
[w] Means within each column followed by different letters are significantly different ($P \leq 0.05$).

Table 3. Odds and percent of 2005-labeled shoot types that were PS, PO, SO, or VO shoots in 2006 on 'Peach' and 'Willamette' chestnut trees.[z]

Type of shoot in 2005[y]	Type of shoot in 2006	'Peach' shoot types		'Willamette' shoot types	
		Odds	%	Odds	%
PS	PS	0.12	10	0.22	18
PS	PO	0.65	39	1.51	60
PS	SO	0.19	16	0.07	7
PS	VO	0.87	47	0.45	31
PO	PS	0.10	9	0.15	13
PO	PO	0.29	22	1.75	64
PO	SO	0.05	5	0.07	6
PO	VO	3.12	76	0.37	27
SO	PS	---[x]	---	0.14	12
SO	PO	---	---	1.00	50
SO	SO	---	---	0.12	10
SO	VO	---	---	0.61	38
VO	PS	0.07	6	0.07	7
VO	PO	0.15	13	1.24	55
VO	SO	0.08	7	0.04	4
VO	VO	4.83	83	0.69	41

[z] PS = shoots with 1° (primary) and 2° (secondary) burs, PO = shoots with 1° burs only, SO = shoots with 2° burs only, VO= vegetative shoots only.

[y] The total number of PS, PO, SO, and VO shoots labeled on 'Peach' chestnut trees in 2005 were 12, 27, 5, and 32, respectively. The total number of PS, PO, SO, and VO shoots labeled on 'Willamette' chestnut trees in 2005 were 26, 35, 15, and 74, respectively.

[x] For 2005 SO-labeled shoots, only 0, 4, 1, and 7 were PS, PO, SO, and VO shoots, respectively, in 2006. Because of the low numbers of 2006 shoot types, odds were not calculated.

and VO shoots had the smallest diameter at the end of the growing season (Table 4). PS shoots also had more 1° burs and nuts, and greater nut weight per shoot than those of PO shoots (Table 4). SO shoots had more 2° burs per shoot than PS shoots but the number of 2° nuts and nut weights were similar for these shoot types.

In 2006, VO shoots of 'Willamette' trees labeled in 2005 had the fewest 1° bur-bearing shoots, burs, number of nuts, and the smallest nut weight per shoot as compared to the other shoot types (Table 5). PS shoots produced more 1° and 2° bur-bearing shoots, burs and nuts with greater nut weights than PO shoots. However, PS and SO shoots were similar for these fruiting characteristics in 2006.

For 'Willamette' trees, all four types of 2005-labeled shoots generally had the highest odds of becoming a PO shoot in 2006 and the lowest odds of becoming a SO shoot (Table 3). Also, odds of all 2005-labeled shoots becoming a PS shoot in 2006 were relatively low.

Hand removal of 2° burs. For each cultivar, N and R shoots had similar shoot diameter, length, and leaf number in 2006 (Table 6). PO shoots of each cultivar were less vigorous and had fewer leaves than shoots of the other two treatments. Because shoots were selected with a similar number of 1° burs per shoot, the number of 1° nuts per shoot

Table 4. Vegetative and fruiting characteristics of terminal shoots of 'Willamette' Chinese chestnut trees in 2005.

Type of shoot in 2005[z]	Shoot length (cm)[y]	Shoot diameter (mm)[y]	No. of 1° burs/ shoot[w]	No. of 1° nuts/ shoot	1° nut wt./ shoot (g)	No. of 2° burs/ shoot[v]	No. of 2° nuts/ shoot	2° nut wt./ shoot (g)
PS	74.9 a[x]	11.3 a	2.9 a	7.0 a	110.3 a	5.6 b	6.2 a	40.1 a
PO	43.7 b	8.7 c	2.5 b	6.2 b	85.9 b	--	--	--
SO	70.1 a	10.1 b	--	--	--	7.0 a	5.0 a	43.9 a
VO	34.1 c	6.8 d	--	--	--	--	--	--

[z] PS = shoots with 1° (primary) and 2° (secondary) burs, PO = shoots with 1° burs only, SO = shoots with 2° burs only, VO= vegetative shoots. Total numbers of PS, PO, SO, and VO shoots labeled on chestnut trees in 2005 were 26, 35, 15, and 74, respectively.
[y] Shoot lengths and diameters were measured on 11 Nov. 2005.
[x] Means within each column followed by different letters are significantly different ($P \le 0.05$).
[w] Burs were harvested on 15 Sept. 2005.
[v] Burs were harvested on 28 Oct. 2005.

Table 5. Fruiting characteristics of terminal shoots of 'Willamette' Chinese chestnut trees in 2006.

Type of shoot in 2005[z]	No. of 1° bur-bearing shoots	No. of 1° burs/ shoot[y]	No. of 1° nuts/ shoot	1° nut wt./ shoot (g)	No. of 2° bur-bearing shoots	No. of 2° burs/ shoot[x]	No. of 2° nuts/ shoots	2° nut wt./ shoot (g)
PS	1.7 a[w]	4.5 a	11.6 a	140.9 a	0.6 a	2.4 a	2.4 a	13.5 a
PO	1.2 b	2.7 b	6.8 b	82.9 b	0.2 b	0.7 c	0.7 c	5.2 c
SO	1.3 ab	3.0 ab	7.8 ab	104.3 ab	0.4 ab	1.5 ab	1.9 ab	11.1 ab
VO	0.5 c	1.2 c	2.9 c	34.4 c	0.2 b	0.5 c	0.7 c	4.5 c

[z] Shoot types were labeled in 2005. Data were recorded in 2006 from terminal shoots originating from 2005 shoot types. PS = shoots with 1° (primary) and 2° (secondary) burs, PO = shoots with 1° burs only, SO = shoots with 2° burs only, VO= vegetative shoots. Total numbers of PS, PO, SO, and VO shoots in 2006 were 29, 200, 10, and 117, respectively.
[y] Burs were harvested on 15 Sept. 2006.
[x] Burs were harvested on 28 Oct. 2006.
[w] Means within each column followed by different letters are significantly different ($P \le 0.05$).

for each treatment was similar. Primary nut weight per shoot of 'Orrin' R treatments was greater than that of other treatments. Also, average 1° nut weight for R-treated shoots was greater than that PO-treated shoots. For 'Orrin' trees, mean 2° nut weight per shoot of N treatments was 66.3 g and average 2° nut weight was 5.3 g (data not shown).

For 'Willamette', 1° nut weight per shoot was 8.6 g more for R-treated shoots than for N-treated shoots, although this difference was not statistically significant (Table 5). PO shoots had less 1° nut weight per shoot than the other treatments. Average 1° nut weights of 'Willamette' N- and R-treated shoots were similar and they averaged ≥ 2.4 g more than that of PO shoots. Mean 2° nut weight per shoot of N treatments on 'Willamette' trees was 15.7 g and average 2° nut weight was 5.8 g (data not shown).

Table 6. Vegetative and fruiting characteristics of 'Orrin' and 'Willamette' chestnut shoots that had PO, PS, or R treatments in 2006.[z]

Cultivar	Treatment[y]	Shoot diameter (mm)[x]	Shoot length (cm)[x]	Leaf no./ shoot[x]	No. of 1° nuts/ shoot	1° nut wt./ shoot (g)	Ave. 1° nut wt. (g)
Orrin	R	7.9 a[v]	37.1 a	22.5 a	6.6 a	78.3 a	11.9 a
Orrin	N	8.0 a	36.4 a	23.2 a	6.7 a	71.0 b	11.0 ab
Orrin	PO	6.3 b	16.5 b	13.7 b	6.6 a	67.4 b	10.6 b
Willamette	R	9.9 a	53.7 a	23.9 a	8.2 a	131.5 a	16.5 a
Willamette	N	10.0 a	51.8 a	23.7 a	7.8 a	122.9 a	16.4 a
Willamette	PO	8.2 b	26.7 b	14.3 b	8.3 a	112.2 b	14.0 b

[z] Data from treated shoots with equal numbers of 1o burs were included in this analysis. Each treatment was imposed on 31 shoots on three 'Orrin' trees and 18 shoots on four 'Willamette' trees). 'Orrin' and 'Willamette' shoots had two and three 1° burs per shoot, respectively, for each replication.

[y] R = 2° burs removed from shoots in late July or early Aug., N= 2° burs not removed, and PO = shoots with 1° burs only (no 2° burs produced).

[x] Shoot diameter measured at proximal end of current season's growth and shoot length of current season's growth and the number of leaves on these shoots were recorded on 16 Nov. 2006.

[v] Means within each column followed by different letters are significantly different by LSD ($P \leq .05$).

In 2007, an unprecedented low temperature event occurred from 4 to 10 Apr. (11). After the third warmest March in 118 years, -8 °C was recorded at HARC on 9 Apr. At the time of the freeze event, budbreak had occurred on 'Willamette' trees, and new shoot growth was injured. By 26 June, only 19% of the 2006 N- or R- treated shoots on 'Willamette' trees had produced 1° burs. Because of the small number of 1° burs, 2° bur removal treatments were not imposed on this cultivar in 2007. By 2 Aug. 2007, 'Willamette' trees averaged 9.4 secondary burs per shoot and had a mean 2° nut weight per shoot of 87.5 g. Average 2° nut weight from 63 shoots was 9.5 g.

In contrast, 'Orrin' trees did not exhibit symptoms of low temperature injury. By 26 June 2007, the 2006 R, N-, and PO-treated branches produced an average of 4.7, 4.1, and 2.1 new shoots, respectively, of which 1.6, 1.0, and 0.6 were 1° bur-bearing, respectively (Table 7). When data from all 2007 shoots were analyzed, 2006 R-treated branches produced a greater number of new shoots bearing 1° burs than the other treatments (Table 7). PO treatments had fewer 1° burs per shoot than those of R treatments. R treatments produced 3 more 1° nuts per shoot and also had greater 1° nut weight per shoot than N treatments (Table 7). Although average 1° nut weight was not statistically different, 1° nuts from R-treated shoots averaged 0.5 g more than those from N-treated shoots (Table 7). By Oct. 2007, N treatments produced an average of ten 2° burs per shoot (data not shown).

Discussion

'Peach' trees averaged 15 terminal branches per tree and 'Willamette' trees averaged 30 terminal shoots during their first year of production (2005) (Tables 1, 4). Also, 'Willamette' trees were precocious with 61 and 229, 1° bur-bearing shoots in 2005 and 2006, respectively. Peach' trees had only 39 and 42, 1° bur-bearing shoots in 2005 and 2006, respectively (Tables 1, 2, 4, 5). After the first year of nut production, most of the 2005-labeled terminal 'Peach' shoots had the highest odds of producing non-bearing shoots the following year (Table 3). In contrast to 'Peach' trees, ≥ 62% of the 2006 shoots on 'Willamette' trees produced 1° burs (PS + PO

Table 7. Fruiting characteristics in 2007 of 'Orrin' shoots originating from branches treated in 2006.[z]

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

[z] R = 2° burs removed from shoots on 2 Aug., N = 2° burs not removed, and PO = shoots with 1° burs only (2° burs not removed). N and R treatments were repeated in 2007 on branches receiving similar treatments in 2006. There were 12 N-treated and 22 R-treated shoots in 2007. Means within each column followed by different letters are significantly different by LSD ($P \leq 0.05$).

[y] Data not recorded in 2007.

shoots) from 2005-labeled shoots types, including VO shoots (Table 3).

Shoots that produced 1° and 2° burs (PS, N, and R shoots) were generally more vigorous than those that had 1° burs only, 2° burs only, or did not produce any burs (Tables 1, 4, 6). Also, PS shoots of young (4 year-old) 'Peach' and 'Willamette' trees produced relatively more 1° nut weight per shoot than less vigorous shoots in the growing season that shoots were identified and in the following year (Tables 1, 2, 4, 5). This result was more evident for 'Willamette' trees than for lower-yielding 'Peach' trees.

Also, bur-bearing shoots were most often found in the upper portion of the canopy while VO shoots were most often located in the lower, shaded portion of the canopy. While light measurements were not recorded in this study, these observations support the report that buds most likely to contain flower primordia are those at or near the tips of vigorous branches in well-lit parts of the tree canopy (5). *Castanea crenata* trees purportedly require more than 35% interception of full sunlight to bear fruit in Japan (H. Araki, Agricultural Institute, Kasai, Japan, personal comm.).

Secondary burs were produced on vigorous PS shoots, as well as weaker SO shoots of 'Peach' and 'Willamette' trees (Tables 1, 2, 4, 5). Interestingly, terminal shoots that did not produce 1° burs in June had the capacity to produce 2° burs with nuts later in the growing season (SO shoots). The reason for this is unclear. Cultivar differences in 2° nut weights were also observed. In 2005, PS shoots on 'Peach' trees produced greater 2° nut weight per shoot than SO shoots (Table 1). In contrast, 2° nut weight per shoot was similar for PS and SO shoots of 'Willamette' trees (Table 4). Similar 2° nut weights from PS and PO shoots for 'Willamette' trees may have been due to competition for plant assimilates from the 1° burs and nuts on PS shoots later in the growing season. The lighter 1° nut crop on 'Peach' may have resulted in less competition for assimilates as 2° nuts filled on PS and SO shoots (Table 1).

The second study demonstrated that 1° nut weight per shoot and average 1° nut weight of 'Orrin' trees was generally greater when 2° burs were removed (Table 6). In the year after treatments were imposed, the number of 1° bur-bearing shoots and the 1° nut weight per shoot were greater on R-treated shoots as compared to N-treated shoots (Table 7). For 'Willamette' trees, R-treated shoots had relatively more 1° nut weight per shoot than N-treated shoots in 2006, but the response was not statistically significant (Table 6). Also, the average 1° nut weights were similar for these two treatments. This contrast in cultivar response may be attributed to differences in crop load. 'Orrin' shoots used in this study had two 1° burs per shoot, while 'Willamette' shoots had three 1° burs per shoot. Thus, the effect of 2° bur removal may not have been as pronounced for 'Willamette' as for 'Orrin' because of competition for assimilates among the developing nuts in the three burs per shoot.

Results from the current study differed slightly from those of a preliminary study conducted by Warmund et al. (12). In the earlier study, 2° burs on eight-year-old 'Orrin', 'Willamette', and 'Armstrong' trees received N and R treatments as described in the present study. However, shoots with varying numbers of 1° burs were used in the earlier study, while data from shoots with equal numbers of 1° burs were compared in the present study. In the earlier study, removal of 2° burs did not affect the 1° nut weight per shoot at harvest, but mean 1° nut weight was greater for R-treated shoots than for N-treated shoots. In the following year, R-treated shoots produced relatively more 1° burs than N-treated shoots. Thus, the different methods (i.e., use of shoots with unequal versus equal numbers of 1° burs per shoot) most likely affected the results. However, both of these studies demonstrated that removal of 2° burs affected the 1° nut crop either by increasing nut weight per shoot or by increasing average nut weight. Additionally, the removal of 2° burs generally increases the number of 1° burs per shoot in the following year.

Although the freeze event of April 2007 resulted in loss of a second year's data on the effect of 2° bur removal on 'Willamette' trees, new information was gained regarding their low temperature susceptibility. 'Willamette' trees had substantially more 1° flower and bur loss than 'Orrin' trees when temperatures dropped to -8°C in early April, with only 19% of the treated 'Willamette' shoots producing 1° burs. Although 1° bur numbers were reduced by spring cold temperatures, a substantial number of 2° burs were produced on 'Willamette' trees later in the growing season. After the 2007 freeze event, current season's shoots from N-treated branches in 2006 averaged 9.4 secondary burs per shoot, whereas N-treated shoots averaged 6.8 secondary burs in 2006 (data not shown). Secondary nut weight per shoot was also greater in 2007 (87.5 g) than in 2006 (15.7 g), as well as average 2° nut weight (5.8 g in 2006 vs. 9.5 g in 2007). Thus, 'Willamette' trees had the capacity to produce a marketable crop of 2° chestnuts after a late freeze.

Results from this study elucidated the complex relationship between the varying numbers of 1° and 2° burs and differing numbers of nuts per bur that contribute to tree yield and average nut weight. When the number of 1° burs was reduced on 'Willamette' trees by an April freeze event, the number of 2° burs produced that season increased. For 'Orrin' trees, 2° bur removal resulted in greater 1° nut weight per shoot at harvest and relatively more 1° burs per shoot in the subsequent growing season (Tables 6, 7). Average 1° nut weight was influenced by 1° nut weight per shoot and the number of 1° nuts per bur (Table 4). However, in spite of these complex relationships, the removal of 2° burs generally enhanced 1° nut weight per shoot at harvest and the number of shoots bearing 1° burs in the following growing season (Tables 6, 7). While hand removal of 2° burs on large Chinese chestnut trees may not be practical due to high labor costs, the use of growth regulators or other chemical treatments for 2° bur removal may be economically feasible in the future.

Various chemical growth regulators have been evaluated for increased Chinese chestnut bur production (6, 8,14). While 2° flowering was not specifically addressed in these reports, these studies tested the effect of growth regulators applied to chestnut trees in the spring on 1° flowers, burs, and nuts. Su et al. (8) increased bur number and nut yield by applying a growth regulator solution to chestnut trees before catkin emergence in the spring. Zhou et al. (14) found that a combination of brassinosteroids, gibberellic acid (GA_3), paclobutrazol [(2RS, 3RS)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl-) pentan-3-ol)], potassium dihydrogen phosphate (KH_2PO_4), and boric acid (H_3BO_3) applied to Chinese chestnut trees in the spring increased the number of bur-bearing shoots and the number of pistillate flowers on treated shoots and decreased the percentage of non-filled chestnuts in burs. Qiguang et al. (6) reported that GA_3 applied during the onset of floral differentiation decreased the number of unisexual catkins and increased pistillate flowers. Other researchers reported increased yields when catkins were thinned, presumably due to decreased competition for plant nutrients (2, 4, 13). These reports demonstrate that thinning or removal of secondary catkins in the spring is a strategy that can be used to enhance total 1° nut weight, average 1° nut weight at harvest, and the production of 1° burs in the following season. Alternatively, results from our study demonstrated that the 1° nut crop and 1° bur production in the subsequent season can also be altered by removal of 2° burs in late July or early August (Tables 6, 7).

While thinning treatments could be applied to produce large 1° nuts, Chinese chestnut cultivars that produce large 1° nuts with few 2° burs and nuts could be selected and grown. Preliminary assessments in 2006, 2007, and 2008 have shown that cultivars such as 'Peach', 'Qing', 'Simpson', 'Carr', 'Auburn Homestead', and 'Gideon' produce few 2° burs from late July through early November (K. Hunt, unpublished data). In contrast, 'Armstrong', 'AU-Cropper', 'Carolina', 'Crane', 'Eaton', 'Ford's Tall', 'Jersey Gem', 'Orrin', 'Mossbarger', 'Revival', and 'Willamette' produce many 2° burs. However, long-term records of 1° and 2° nuts production for Chinese chestnut cultivars are not yet available.

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