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Effects of Early Cropping on Growth and Yield of Southern Highbush Blueberry Cultivars (*Vaccinium corymbosum* L. Interspecific Hybrids)

Marcela P. Borda[1,2], Maria A. Pescie[1], and Norberto F. Gariglio[3]

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Abstract

Early cropping, no removal of fruit buds for the first 2 years after planting, allows blueberry growers to gain early partial recovery of orchard establishment costs and to avoid additional costs associated with flower bud thinning. However, as with most young fruiting plants, the presence of fruit affects root and vegetative growth. The effects of early cropping on growth and yield of two 1-year-old southern highbush blueberry cultivars were evaluated using potted plants. Experiments with 'Star' (high vigor) and 'O'Neal' (medium to low vigor) were conducted over the course of 3 consecutive years. The four treatments were a control (T0), or 100% flower bud (FB) removal during the first 2 years after potting; 100% and 50% FB removal at year 1 and year 2, respectively (T1); 50% and 0% FB removal at year 1 and year 2, respectively (T2); and no removal of flower buds during the first 2 years after planting (T3). In the third year of growth, flowers were not removed for any of the treatments. Three vegetative variables (number of shoots, number of leaves, and total leaf area per plant) and four reproductive variables (number of flower buds, number of fruits, annual fruit yield per plant, and cumulative fruit yield per plant) were measured annually. Fruit yield was quantified as number and weight of fruit at harvest. At the end of the third growing season, each plant was destructively harvested to obtain dry weight of its organs. In both cultivars, high early cropping fruit yields did not negatively affect vegetative or reproductive plant growth, nor did early cropping affect root crown or canes dry weight accumulation. High crop load during the first year did not reduce fruit yield the second year; however, high crop load during the second year reduced fruit yield the third year. Early cropping was a feasible practice for 'Star' and 'O'Neal' cultivars of southern highbush blueberry grown in warm–temperate areas of Argentina. Cultivar vigor did not clearly influence the response of plants to early cropping.

The blueberry bush is native to North America, and the United States is the main producer, consumer and exporter of its berries (Villata, 2012). In Argentina, blueberry cultivation has spread widely during the last two decades because of the commercial advantages in off-season production when exporting to the Northern hemisphere (Gordó, 2008). Southern highbush blueberry hybrids can be obtained by performing interspecific crosses and backcrosses among *Vaccinium corymbosum, V. virgatum*, and *V. darrowii* cultivars (Trehane, 2004). These hybrids are the most widely cultivated in Argentina today (Rivadeneira & Kirschbaum, 2011) because of their low chilling requirements (200–600 winter chill h) (Ehlenfeldt et al., 1995), harvest precocity during the growing season (Lyrene & Ballington, 2006), and superior adaptation to the agro-ecological con-

[1] Facultad de Ciencias Agarias, Universidad Nacional de Lomas de Zamora, Ruta Provincial Nº4 Km 2 Llavallol (1836), Buenos Aires, Argentina.

[2] Corresponding author: marcelaborda25@yahoo.com.ar

[3] Facultad de Ciencias Agrarias, Universidad Nacional del Litoral, Kreder 2806 (3080),Esperanza, Santa Fe, Argentina.

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ditions of the Buenos Aires Province.

America's blueberry growers remove reproductive buds by pruning at planting to prevent production in the first few years, a practice said to improve root and vegetative growth (Bañados, 2005; Dodge, 1981; Gough, 1994; Lockwood, 1999; Pritts, 2004, 2006; Pritts & Hancock, 1992; Williamson et. al., 2004; Yarborough, 2006). It is well known that early cropping in the first 2 years reduces fruit yield in the third year in northern highbush blueberry (*Vaccinium corymbosum* L.) cultivars (Strik & Buller, 2005). Furthermore, early cropping reduces cumulative fruit yield in late-season cultivars, but cumulative fruit yield is not affected by early cropping in early-season cultivars (Strik & Buller, 2005). In addition, vegetative development is promoted by flower bud (FB) thinning of southern highbush blueberries (Maust et al., 1999a; 1999b; 2000).

Crop load changes the pattern of carbon partitioning in fruit trees (Cannell, 1985). In apples (*Malus domestica* B.) and persimmons (*Diospyros kaki*), high crop load improves total dry matter (DM), as compared with deblossomed plants, by stimulating photosynthetic leaf activity (Avery, 1970; Choi et al., 2010; Lenz, 2009; Palmer, 1992; Park, 2011). Despite this positive effect, increasing crop load reduces dry matter partitioning to the roots because of strong fruit-sink activity (Choi et al., 2010; Lenz, 2009; Palmer, 1992; Park, 2011; Park & Kim, 2011). Early cropping also reduces DM partitioning to roots of the northern highbush blueberry (Strik & Buller, 2004; 2005), whereas the effects of this cultural practice on the growth of southern highbush blueberries appear to be cultivar specific. In 'Misty', a low-vigor southern highbush cultivar, FB thinning increases root and total dry matter accumulation, whereas no increased growth responses have been observed in higher-vigor cultivars such as 'Santa Fe' (Williamson & NeSmith, 2007).

In Argentina, 'Star' cultivar cultivation has increased in the recent years (Rivadeneira & Kirschbaum, 2011) because of its high vigor and superlative reproductive behavior as compared with the 'O'Neal' cultivar. Although both cultivars are widespread in the warm–temperate regions of Argentina (Rivadeneira & Kirschbaum, 2011), little is known about the effects of early cropping on either cultivar's vegetative and reproductive traits. Cultural practices used by Argentinian growers of the southern highbush blueberry are based upon knowledge obtained from cultivating other blueberry groups, such as northern highbush blueberries, which require different agro-ecological conditions to develop and to produce fruit. Consequently, it is necessary to acquire information about how this relatively new crop performs in warm–temperate climates in order to establish adequate cultural practices. Therefore, the objective of this study was to determine the effects of early cropping on vegetative growth, dry matter partitioning, and fruit yield in the two southern highbush blueberry cultivars most widely grown in the warm–temperate areas of Argentina, one high vigor ('Star') and the other medium to low vigor ('O'Neal').

Materials and Methods

The current research was conducted in La Unión town (34°53'S; 58°34'W, 12 m above sea level [ASL]), in the warm–temperate Buenos Aires Province, Argentina, over the course of 3 consecutive years (2009–2012). Exactly 20 one-year-old plants each of two low-chill (~ 400 h) southern highbush cultivars, 'Star' and 'O'Neal' (*Vaccinium corymbosum* L. interspecific hybrids) (Lyrene & Sherman, 2000), were planted outdoors into 30 L containers in June 2009, with complementary drip irrigation. Total count was 40 plants. The growing medium was a ratio of 1 part peat, 1.76 parts local loamy clay soil, and 1.24 parts *Pinus elliotis* wood chips (V/V). The initial potting mix pH was 4.87, and pH was maintained throughout the experimental period within the range of 4.2–5.2 (Williamson et al., 2007) by the addition of iron sulfate. Fertilization was calculated to adequately support potential plant demand in four experimental treatments (Ts). Each treatment was replicated five times. Treatments were based on the removal of FBs during the first 2 years after transplanting: a control treatment (T0) involving 100% FB removal each year in the first 2 years; 100% and 50% FB removal at year 1 and year 2, respectively (T1); 50% and 0% FB removal at year 1 and year 2, respectively (T2); and no removal of FBs during the first 2 years after transplanting into pots (T3).

In year 1, FBs were removed by cutting with pruning shears at planting time, whereas in subsequent years, buds were removed by hand according to treatment specifications. All FBs were retained during year 3 on all plants undergoing all four treatments. Three vegetative variables, shoot number, leaf number, and total leaf area per plant, were recorded. These variables were measured quantitatively after spring and summer flush growth of the shoots was complete (Pescie et al., 2011). Leaves and shoots per plant were counted, and plant leaf area was estimated using NeSmith's (1991) equation:

$$\text{Leaf area} = 0.31 + 0.62\ (\text{leaf length} \times \text{leaf width}). \quad \text{(Equation 1)}$$

Total leaf area per plant was calculated by summing individual leaf areas. Reproductive variables included the number of FBs per plant, counted during dormancy both before and after bud thinning. Fruits were harvested weekly by hand at full blue stage, and fruit number per plant was recorded. Annual fruit yield (fresh fruit weight) per plant was calculated by summing fruit weight of each partial harvest. After harvest, berries were oven-dried at 60°C to a constant weight, when fruit weights no longer decreased, and fruit DW (g) was recorded. Cumulative 3-year fruit fresh weight was calculated per plant and per treatment. All plants were destructively harvested at the end of the third growing season. Each plant was divided into root crown and canes; each organ was oven-dried at 60ºC to a constant weight, and DW was recorded. Total DW per plant was calculated by summing the DWs of each of the three organs, root crowns, canes, and fruit.

The experimental was a 2 x 4 factorial in a completely randomized design, with two cultivars and four FB thinning treatments. Data were analyzed using SAS/STAT® software, version 13.1 (SAS Institute Inc., Cary, NC, 2012) using the PROC MIXED procedure. Variables with significant interaction were analyzed as treatments within cultivars, and the Tukey adjustment for multiple comparisons was applied. Number of shoots, number of leaves and leaf area per plant data were analyzed using the repeated measures procedure and the Tukey–Kramer adjustment for multiple comparisons.

Results and Discussion

Dry Weight Accumulation and Partitioning. Our results showed significant interaction between cultivar and treatment ($p < 0.0001$); consequently, cultivars were analysed separately. 'Star' root crown DWs were not affected by the treatments at the end of year 3. 'Star' T1 and T3 plants had the highest cumulative fruit DWs, whereas T1, T2, and T3 plants had highest total DW per plant as compared with T0 (Figure 1a). In 'O'Neal' plants, early cropping did not suppress root crown DW, and cumulative fruit and total DW per plant were highest for plants undergoing the T2 treatment, whereas T0 plants had the lowest DW value in all tissues weighed except canes (Figure 1b). Total DW for 'Star' plants was nearly twice as high as for 'O'Neal'. Overall, the highest fruit load treatments (T2 and T3) did not reduce DWs of root crown and canes of either cultivar (Figure 1).

Fruit load improved leaf photosynthetic rate due to its carbon sink activity, and high fruit load had a positive effect on total plant and fruit DW values (Avery, 1970; Choi et al., 2010; Lenz, 2009; Palmer, 1992; Park, 2011). Young persimmon fruit DW can account for up to 94% of the total plant DW (Park & Kim, 2011). According to our re-

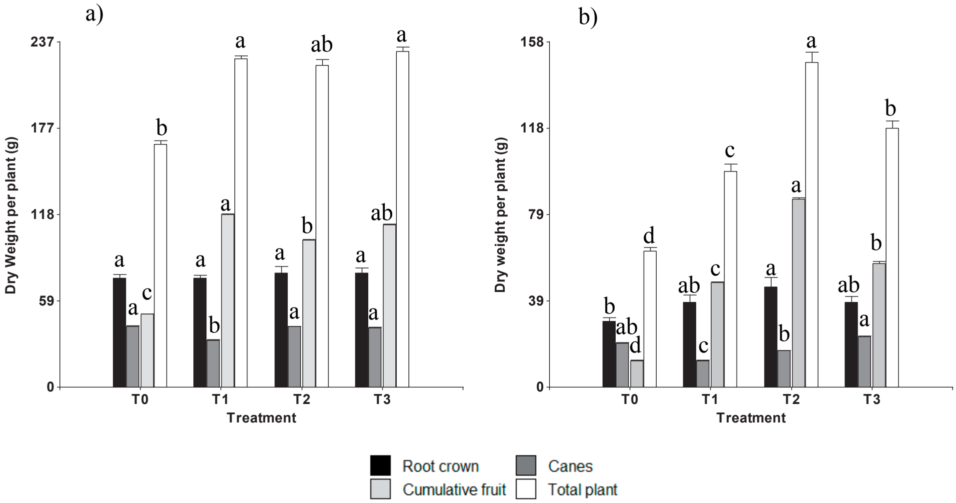

Figure 1. Effect of early cropping on dry weight (DW) accumulation and partitioning at the end of the third growing season in a) 'Star', and b) 'O'Neal' southern highbush blueberry cultivars subjected to different flower bud (FB) thinning treatments (Ts). Bars denote ± SE of the mean. Means within plant organ followed by common letters do not differ at the 5% level of significance. Treatments included T0, control treatment, 100% FB removal during the first 2 years; T1, 100% and 50% FB removal at year 1 and year 2, respectively; T2, 50% and 0% FB removal at year 1 and year 2, respectively; T3, no FB removal during the first 2 years after potting.

sults, however, blueberry fruits did not act as a strong sink organ, and accounted for only 1% and 2% of the total DW accumulation for 'O'Neal' and 'Star', respectively. In contrast, root crowns were the most competitive sink, accounting for 64% and 66% of the total DW in 'Star' and 'O'Neal', respectively. These results support those of Pritts and Hancock (1985), and Throop and Hanson (1997), where fruits were considered to be a weak sink in young blueberry plants. In fact, in our research, the canes represented a more competitive sink than fruits, accounting for 33% of the total DW for 'Star' and 31% of the total DW for 'O'Neal'. In contrast, leaves accounted for just 1% and 2% of the total cumulative DW for 'Star' and 'O'Neal', respectively.

In northern highbush blueberries, other researchers have reported that early cropping reduces root DW by 42% compared with controls (Strik & Buller, 2004; 2005). These results have proved to be non-repeatable for southern highbush blueberry cultivars harvested in late spring–early summer (mid-December) (Pescie & Lovisolo, 2005). Northern highbush blueberry plants, especially late cultivars, have a short growing season after harvest, especially in regions where harvest extends to the beginning of autumn (Strik & Buller, 2004; 2005). At northern latitudes, late-fruiting plants' growth after harvest is limited to a short period, especially when very unfavorable temperatures predominate (Lyrene, 2006). Conversely, most southern highbush blueberry cultivars growing in warm–temperate climates, such as the Buenos Aires Province in Argentina, have at least a 4-month growing period after harvest, with an average temperature of about 23.6°C (Instituto Nacional de Tecnología Agropecuaria [INTA], 2017) that allows the continued growth of stems and the accumulation of significant root and crown DM reserves. In contrast, in the Southeastern United States, the effects of early cropping on growth appear to be cultivar specific. In the United States, growth of high-vigor cultivars, such as 'Santa Fe', is not affected by early cropping, whereas for the low-vigor 'Misty' cultivar, DW accumulation in different plant organs, mainly the roots and crown, is significantly reduced by early cropping (Williamson & NeSmith, 2007).

Vegetative Development. Our results showed a significant interaction between year and treatment variables ($p < 0.0001$); therefore, we analyzed our treatments separately by year. In year 1, the lighter crop-load treatments (T0 and T1) grew the fewest leaves and shoots, and had the lowest total leaf area per plant (Table 1). In year 2, T1 'Star' plants produced the most shoots and leaves, whereas T0 'Star' plants had the fewest shoots and leaves. Year 2 'O'Neal' T2 plants grew the most shoots and leaves, followed by T1, T3, and T0, in decreasing order. During the third growing season (year 3), vegetative parameters were not correlated with crop load treatments (data not shown).

Previously published research has shown that, in southern highbush blueberries, total leaf area per plant can be reduced by increasing crop load (Maust et al., 1999a; 1999b; 2000). However, in our experiment, total leaf area was not affected by higher crop load. This was particularly noticeable in the high-vigor 'Star' cultivar (Table 1). In contrast, vegetative growth was reduced in intensive FB thinning treatments (T0 and T1) for both 'Star' and 'O'Neal' (Table 1). This physiological response can be explained because all FBs were eliminated in these treatments (T0 and T1) by pruning at planting,

Table 1. Effect of early cropping on number of shoots and leaves, and total leaf area per plant in 'Star' and 'O'Neal' Southern highbush blueberry plants subjected to flower bud (FB) thinning treatments.

Cultivar	Treatment	Shoots per plant (No)	Leaves per plant (No)	Total leaf area (cm2)
		Year 1		
Star	T0	12 b[z]	168 b	1,762 b
	T1	14 b	189 b	1,806 b
	T2	19 a	212 a	2,150 a
	T3	23 a	227 a	2,319 a
O'Neal	T0	11 b	138 b	1,621 c
	T1	12 b	142 b	2,018 b
	T2	20 a	235 a	2,199 b
	T3	25 a	269 a	2,476 a
		Year 2		
Star	T0	70 c	511 c	4,173 b
	T1	94 a	547 a	4,617 a
	T2	82 b	526 b	4,592 a
	T3	86 ab	538 ab	4,597 a
O'Neal	T0	22 d	279 d	2,255 d
	T1	52 b	510 b	2,819 b
	T2	72 a	581 a	3,172 a
	T3	36 c	388 c	2,493 c

[z] Treatment × year, $p < 0.0001$. Means within column, cultivar and year followed by common letters do not differ at the 5% level of significance. Treatments include T0, control treatment, 100% FB removal during the first 2 years; T1, 100% and 50% FB removal at year 1 and year 2, respectively; T2, 50% and 0% FB removal at year 1 and year 2, respectively; T3, no FB removal during the first 2 years after planting.

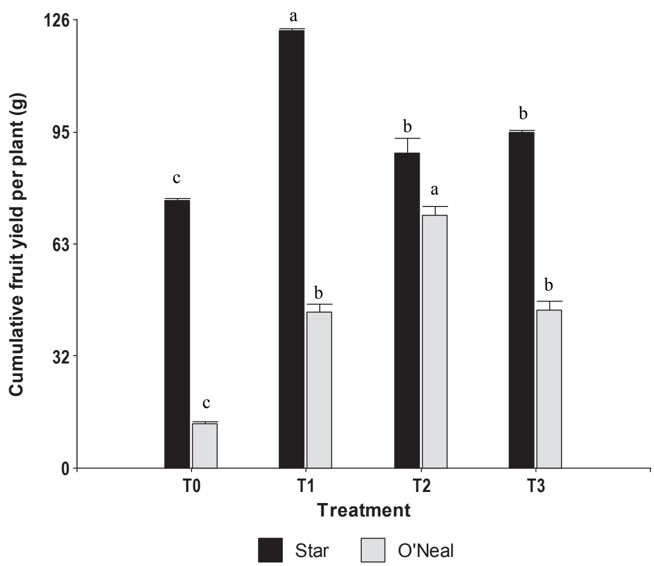

Figure 2. Effect of early cropping on the cumulative fruit yield in 'Star' and 'O'Neal' southern highbush blueberry cultivars subjected to different flower bud (FB) thinning treatments (Ts). Error bars denote ± SE of the mean. Means within cultivars followed by common letters do not differ at the 5% level of significance. Treatments included T0, control treatment, 100% FB removal during the first 2 years; T1, 100% and 50% FB removal at year 1 and year 2, respectively; T2, 50% and 0% FB removal at year 1 and year 2, respectively; T3, no FB removal during the first 2 years after potting.

which reduced the number of vegetative buds. As a consequence, the number of subsequent shoots per plant was reduced from 48% to 39% in 'Star', and from 56% to 52% for 'O'Neal' plants (Table 1). As blueberry plants typically display strong apical dominance (Darnell, 2006), the reduction in shoot count also caused a reduction in the number of leaves and in a reduced leaf area per plant (Table 1), unlike peach tree response to summer pruning after harvest (Weber et al., 2011). Thus, our results indicated that the elimination of all FBs by pruning at planting time (as in the T0 and T1 treatments) did not improve vegetative growth of potted southern highbush blueberries cultivated in warm–temperate climates. In addition, reduced vegetative growth caused by pruning at planting continued through year 2 in the T0-treated plants of both cultivars (Table 1). On the other hand, high crop load (as in the T3 treatment) caused shoot suppression and reduced leaf count and leaf area by the end of year 2 in the lower-vigor 'O'Neal' cultivar (Table 1), probably because of increased competition for photoassimilates between growing organs.

Fruit Yield. Our results showed a significant interaction between cultivar and treatment variables ($p < 0.0001$); consequently, we analyzed cultivars separately. Cumulative 3-year fruit yield per plant was higher for 'Star' (+45%) than for the low-vigor 'O'Neal' variety. In both cultivars, T0-treated plants produced the lowest yields. Interestingly, the most productive treatments depended on cultivar; 'Star' plants undergoing the T1 treatment were most productive, but 'O'Neal' fruit yield was highest in plants undergoing the T2 treatment (Figure 2).

Previous research has shown that early cropping does not affect cumulative yield in early fruiting northern highbush blueberries cultivars such as 'Duke' and 'Bluecrop';

however, better yields were achieved by removing fruit from late-fruiting cultivars such as 'Elliott' (Strik & Buller, 2005). In our trials, FB removal in early-fruiting cultivars 'Star' and 'O'Neal' during the first 2 years after planting (the T0 treatment) caused a reduction in the cumulative fruit yield in comparison with early cropping treatments.

Annual fruit yield progression showed that the presence of fruit during the first year (as in the T2 and T3 treatments) did not affect fruit yield in year 2. In fact, both 'Star' and 'O'Neal' plants undergoing the T2 and T3 treatments produced the most fruit (Figure 3a, 3c). In contrast, fruit load during year 2 strongly affected fruit yield in year 3, with year 3 yields for both cultivars severely reduced in T2 and T3 plants with high crop load treatments (Figure 3b, 3d). Year 2, T1 crop load seemed to be appropriate for 'Star' because relative fruit yields were only slightly lower than in year 3 T0 plants (– 8%) (Fig-

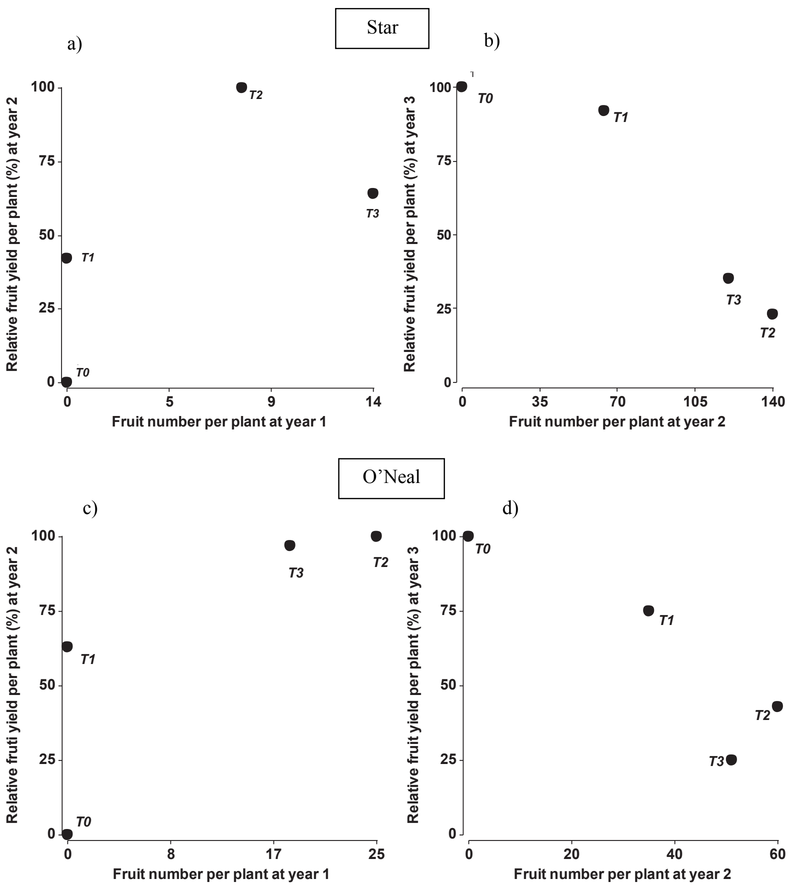

Figure 3. Relationship between the number of fruits per plant and relative fruit yield the following year for 'Star' and 'O'Neal' Southern highbush blueberry cultivars subjected to different flower bud (FB) thinning treatments. Treatments included T0, control treatment, 100% FB removal during the first 2 years; T1, 100% and 50% FB removal at year 1 and year 2, respectively; T2, 50% and 0% FB removal at year 1 and year 2, respectively; T3, no FB removal during the first 2 years after planting.

ure 3b). In contrast, relative fruit yield of T1-treated 'O'Neal' plants was 25% lower than the T0 controls, indicating that fruit load in year 2 was somewhat excessive (Figure 3d).

Although blueberries are not considered to be a biennial (or alternate) bearing species (Monselise & Goldschmidt, 1982), Strik and Buller (2004) have shown that early cropping during the first year reduces the number of FBs in the second year. This effect was also observed in our experiments. The T2 and T3 plants with high crop loads in year 2 produced only low numbers of FBs in year 3 (data not shown). Although the most appropriate treatment for obtaining the highest cumulative fruit yield for 3 consecutive years was differed by cultivar (Figure 2), this apparent difference disappeared when the evolution of fruit yield per year was analyzed (Figure 3). Both, T2 and T3 treatments were appropriate cultural practices in year 1 and the T1 treatment was the most appropriate cultural practice in year 2 because of its positive effects on year 3 fruit yield. Consequently, both blueberry cultivars could reach maximum cumulative fruit yield for 3 consecutive years with a similar flower bud thinning treatment during the first 2 years.

In conclusion, early cropping was a feasible cultural practice for potted plants; it did not negatively affect vegetative and reproductive growth of early-season southern highbush blueberry cultivars 'Star' and 'O'Neal' when they were grown in pots in the warm–temperate climate of Buenos Aires, Argentina. Although relative fruit yield of plants with their FBs removed in earlier years was the highest during year 3, their cumulative fruit yield was lower in comparison with early cropping treatments. The thinning of FBs during year 1 did not show favorable effects on plant growth. On the other hand, fruit load adjustment during year 2 was crucial to the successful implementation of this cultural practice. Cultivar vigor did not show a clear influence on the response of plants to early cropping.

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