Pruning and pollination studies on southern highbush blueberries (*V. corymbosum* L. interspecific hybrids)

By

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Summary

Commercial production of the southern highbush blueberries (SHB) 'Jewel', 'Emerald', 'Star', 'Snowchaser' and 'Bluecrisp' started recently in the Western Cape. In South Africa, no research has been conducted on pruning and pollination of SHB, and various questions regarding these practices have arisen.

Six experiments were conducted to evaluate the self-compatibility and the effect of cross-pollination on berry characteristics of 'Star', 'Emerald', 'Jewel', 'Bluecrisp' and 'Snowchaser'. The effect of cross-pollination on fruit set, berry weight, berry diameter and fruit development period is cultivar dependant. 'Bluecrisp' appears self-incompatible and 'Misty' or 'Emerald' can be recommended as cross-pollinators. 'Snowchaser' seems self-compatible and solid block plantings can be recommended. 'Misty' and 'Emerald' would be recommended as cross-pollinators for 'Star' and 'Jewel' respectively, even though these cultivars will set an adequate crop when self-pollinated. Although 'Emerald' seem self-compatible, the fruit set tends to vary greatly and cross-pollination with 'Jewel', 'Misty' and 'Bluecrisp' is recommended to obtain early maturing berries of the required size. Another season's data is required before final conclusions can be drawn.

In order to establish sustainable summer pruning strategies for South African growing conditions that will maximise yield and berry quality for SHB, two pruning trials were conducted.

In the first trial, the severity of pruning of 'Star', 'Emerald' and 'Jewel' was evaluated. We established that summer pruning is a compromise between total yield and desired berry size. All the pruning treatments reduced total vegetative growth and shoot number, but increased individual shoot length. Summer pruning increased berry weight and diameter by reducing total yield, but also by developing better quality bearing wood. Vigorous laterals stimulated by pruning seize growth later thereby delaying reproductive bud initiation and harvest. An increase in the severity of pruning increased the level to which the plants responded. No pruning and 'light pruning' gave the highest yields, but one more season's data will clarify whether successive light pruning is sustainable. "Standard pruning" resulted in a well-balanced plant with an intermediate yield and berry size. Heading of one-year-shoots as part of the pruning strategy is not recommended for any of the cultivars. "Severe pruning" will only be recommended for young, newly established plantings where vegetative growth is the main objective.

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A second trial was conducted to study the effect of time of summer pruning. At Teeland, delaying pruning resulted in a decrease in total new growth and shoot number thereby reducing yield. This was probably due to progressively more buds that became endodormant. For all three cultivars, pruning as soon as possible after harvest would therefore be recommended. At Lushof, the effect of time of summer pruning was not significant. This could be due to the fact that plants were younger and more vigorous or because the area is warmer and growth continued for longer. One more season's data is needed before any final conclusions are drawn.

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Opsomming

Kommersiële verbouing van die “southern highbush” bloubessies (SHB) ‘Jewel’, ‘Emerald’, ‘Star’, ‘Snowchaser’ en ‘Bluecrisp’ is ’n nuwe ontwikkeling in die Wes-Kaap. In Suid-Afrika is nog geen navorsing oor die snoei en bestuiwing van SHB onderneem nie, en verskeie vrae het oor hierdie praktyke ontstaan.

Ses eksperimente is gedoen om die self-verenigbaarheid, sowel as die effek van kruisbestuiwing op bessie-eienskappe van ‘Star’, ‘Emerald’, ‘Jewel’, ‘Bluecrisp’ en ‘Snowchaser’ te evalueer. Die effek van kruisbestuiwing op vrugset, bessiegewig, bessiedeursnee en vrugontwikkelingsperiode is kultivar spesifiek. ‘Bluecrisp’ blyk self-onverenigbaar te wees en kruisbestuiwing met ‘Misty’ of ‘Emerald’ word aanbeveel. ‘Snowchaser’ blyk self-verenigbaar te wees en suiwer blok aanplantings kan dus aanbeveel word. ‘Misty’ en ‘Emerald’ word onderskeidelik as kruisbestuiwers vir ‘Star’ en ‘Jewel’ aanbeveel, alhoewel beide kultivars ‘n goeie oes sonder kruisbestuiwing kan lewer. Vir ‘Emerald sal kruisbestuiwing met ‘Jewel’, ‘Misty’ of ‘Bluecrisp’ aanbeveel word, indien vroeë, groot bessies belangrik is. ’n Tweede seisoen se data word benodig om bogenoemde te bevestig voor finale aanbevelings gemaak kan word.

Twee snoeiproewe is uitgevoer om volhoubare somersnoei-strategieë te ontwikkel wat die opbrengs en kwaliteit van bessies onder Suid-Afrikaanse groeitoestande sal maksimeer.

In die eerste snoeiproef is die intensiteit van snoeisnitte vir ‘Star’, ‘Emerald’ en ‘Jewel’ ondersoek. Daar is vasgestel dat totale opbrengs en bessiegrootte teen mekaar opgeweeg moet word wanneer strafheid van snoei ge-evalueer word. Somersnoei verminder totale vegetatiewe groei en aantal nuwe lote, maar vermeerder lootlengte en bessiegrootte. Somersnoei het ‘n toename in bessiegrootte tot gevolg deur dat die totale opbrengs verminder, maar ook deur die kwaliteit van draende lote te verbeter. Meer groeikragtige lote gestimuleer deur somersnoei, staak verlengingsgroei later in die seisoen wat dan lei tot later bloknopinisiasie en oes. Geen snoei, sowel as “ligte snoei” het gelei tot die grootste opbrengs na die afloop van een seisoen, maar nog ‘n seisoen se data word benodig om vas te stel of dit volhoubaar is. “Standaard snoei’” lei tot ‘n goed gebalanseerde plant met ‘n gemiddelde opbrengs en bessiegrootte. “Harde snoei” sal slegs aanbeveel word vir nuwe aanplantings waar vegetatiewe groei die hoof prioriteit is.

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Om die tydsbereking van somersnoei aan te spreek, is ‘n tweede snoeiproef uitgevoer. Op Teeland, het ‘n uitstel van somersnoei gelei tot ‘n afname in vegetatiewe groei en aantal lote en dit het dan gelei tot ‘n afname in opbrengs. Hierdie was moontlik die gevolg van meer knoppe wat mettertyd in endodormansie ingegaan het. Op Lushof het die tydsberekening van somersnoei geen betekenisvolle effek gehad nie. Dit kan moontlik toegeskryf word aan die jonger, groeikragtige plante, of aan die langer groeiseisoen weens die warmer klimaat in die area. Nog ‘n seisoen se data word egter benodig voor enige finale gevolgtrekkings gemaak kan word.

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General introduction

The South African blueberry industry is focused on export and supplies the northern hemisphere in their off-season (Greeff and Greeff, 2006). The highest income is obtained from mid September until the end of November, spring in the southern hemisphere. Under South African growing conditions, northern highbush and rabbiteye blueberries ripen too late to serve this early market. Growing conditions in the Western Cape are ideal to cultivate the southern highbush blueberry (SHB) (*Vaccinium corymbosum* interspecific hybrids) cultivars Star, Jewel, Snowchaser, Bluecrisp and Emerald to serve this particular market window (personal communication McKenzie, 2010). 'Star', 'Jewel', 'Snowchaser', 'Bluecrisp' and 'Emerald' were bred at the University in Florida, and are characterised by high yields, early ripening and superior quality fruit. These cultivars were recently introduced to the Western Cape and new orchards are currently being planted. Orchard practices need to be established for local growing conditions to increase the profitability of these cultivars. In order to implement the correct pruning and pollination practices, the flower morphology and growth habit of these cultivars need to be understood under local conditions.

Firstly, a literature review was conducted on the flowering and pollination biology of blueberries with the emphasis on the effect of cross-pollination. The growth habit of blueberries was reviewed whereafter different pruning techniques were evaluated with the focus on the time and severity of pruning.

The genome of southern highbush blueberries is complex and very little is known about the gynoecious interaction and pollen compatibility of SHB (Lang and Parrie, 1992; Gupton and Spiers, 1994). Tests on pollen sources are necessary for each cultivar before any recommendations can be made regarding the need for cross-pollination (Danka *et al*., 1993). We therefore wanted to evaluate the self-compatibility and the effect of cross-pollination on fruit characteristics for the cultivars Star, Emerald, Jewel, Snowchaser and Bluecrisp.

The second aim of this study was to develop a sustainable summer pruning strategy that maximizes yield and fruit quality on 'Star', 'Emerald' and 'Jewel'. The severity and time of pruning are two factors that influence the response of deciduous fruit crops to pruning (Wertheim, 2005). The first trial evaluated the effect of the severity of summer pruning after harvest on vegetative growth, yield, berry quality and the time of harvest. Further, the effect of the time of summer pruning was studied to

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determine until how late in the season pruning can be performed before a reduction in yield occurs the following season.

Literature cited

Danka, G.D., G.A. Lang and C.L. Gupton. 1993. Honey bee (Hymenoptera : Apidae) visits and pollen source effects on fruiting of 'Gulfcoast' southern highbush blueberry. J. Econ. Entomol. 86(1):131-136.

Greeff, M.P. and P.F. Greeff. 2006. Blueberries in South Africa, p.255-256. In: N.F. Childers and P.M. Lyrene (eds.), Blueberries for growers, gardeners, promoters. Horticultural Publications. Gainesville. Florida.

Gupton, C.L. and J.M. Spiers. 1994. Interspecific and intraspecific pollination effects in rabbiteye and southern highbush blueberries. HortScience 29:324-326.

Lang, G.A. and E.J. Parrie. 1992**.** Pollen viability and vigor in hybrid southern highbush blueberries (Vaccinium corymbosum L. x spp.). HortScience 27:425-427.

Wertheim, S.J. 2005. Pruning, p.176-189. In: Tromp, J., A.D. Webster and S.J. Wertheim (eds.), Fundamentals of temperate zone tree fruit production. Backhuys Publishers. Leiden. The Netherlands.

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Literature review: Pruning and pollination of southern highbush blueberries (*V. corymbosum* L. interspecific hybrids)

1. Introduction

1.1 Southern highbush blueberries (*Vaccinium corymbosum* interspecific hybrids)

Blueberries belong to the family Ericaceae, genus *Vaccinium* and the section Cyanococcus. Blueberries are native to various countries, 40% to Southeast Asia, 25% to North America and 10% to Central and South America (Darnell, 2006). Although there are 400 *Vaccinium* species, only four are of major commercial value, viz. rabbiteye (*V. ashei* R.), lowbush (*V. angustifolium* Ait), northern highbush (*V. corymbosum* L.), and southern highbush blueberries (*V. corymbosum* interspecific hybrids) (Darnell, 2006).

Wild *V. corymbosum* plants occur from north-eastern Florida to Quebec. *V. corymbosum* produce typically large canes from the ground, are crown forming and grow between 3 and 5 m high. They are naturally found in sandy soils high in organic matter with shallow water tables. The chilling requirement of wild highbush blueberries vary from 0 to 1000 chilling hours below 7 ^{0}C (Lyrene and Ballington, 2006).

Wild highbush blueberries are diploid or tetraploid. The tetraploid species, however, do not occur naturally south of Gainesville in the north-central part of the Florida peninsula. All northern highbush cultivars are derived from tetraploid forms of *V. corymbosum* (Lyrene and Ballington, 2006). The breeding of northern highbush blueberries started with a number of wild *V. corymbosum* L. plants of which most were from New Jersey and New Hampshire. These crosses resulted in cultivars that were released by the U.S. Department of Agriculture in 1912 and have a chill requirement of over 1000 chill units (hours below 7°C). This germplasm was utilised to breed the next generation of cultivars of northern highbush cultivars with a high chill requirement. Thus northern highbush cultivars cannot be cultivated in the warmer regions of Florida. Only some rabbiteye cultivars (*V. ashei* Reade) with lower chill requirements can be grown in warmer production areas. The rabbiteye blueberries have a long fruit developmental period and ripen later than the highbush blueberries of northern Carolina, and thus do not obtain such high prices as those obtained on the early fresh produce market. The Florida growers therefore needed low chill, early maturing blueberries (Lyrene and Ballington, 2006).

In 1948, the first survey of blueberries with a lower chilling requirement than the rabbiteye blueberries was done (Sharp and Sherman, 1971). Native to Florida, 5 tetraploid species, 2 hexaploid

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species and 5 diploid species with potential were selected. From these, *V. darrowi* C. (diploid), an evergreen native to Winter Haven, Florida (≈200 hours below 7°C) wa s chosen as primary parent. This species was crossed with the tetraploid *V. corymbosum* L. and hexaploid *V. ashei* R. Breeding continued from these initial hybrids at the tetraploid level. Other species including *V. tenellum* Ait., a diploid, and *V. angustifolium* Ait., a tetraploid were also later added to the breeding program. In 1970, the various selections were narrowed down to 7 tetraploid highbush type blueberries that ripened from April to May in the northern hemisphere (Sharp and Sherman, 1971). The first three cultivars released by the University of Florida in 1976 were Sharpblue, Florablue and Avonblue. These cultivars provide fresh blueberries from late April to early May (northern hemisphere) (Eck 1988a). Since 1976, numerous new southern highbush cultivars have been released with better fruit quality characteristics. These include the cultivars Abundance, Arlen, Biloxi, Bladen, Blueridge, Emerald, Jewel, Legacy, Lenoir, Misty, O'Neal, Pamlico, Reveille, Sampson, Southern Belle, Springhigh and Star (Lyrene and Ballington, 2006).

1.2 South African blueberry industry

The first South-African blueberries were planted 1970's in the Lydenburg district in Mpumalanga (Greeff and Greeff, 2006). The goal of the industry is to supply the northern hemisphere with blueberries in their off-season. In 1987, blueberries were introduced to other production regions including George, Knysna and Stellenbosch. Primarily rabbiteye cultivars Beckyblue, Aliceblue, Delite, Tifblue, and Climax were planted. However, southern highbush cultivars including O'Neal, Misty, and Sharpblue were introduced soon thereafter to some of the regions. These southern highbush cultivars are harvested as early as October (southern hemisphere (SH)). At some of the colder sites, late ripening northern highbush cultivars were also introduced. Midseason cultivars ripening in December/January (SH) include Premier, Tifblue, Climax, Duke, Bluecrop, Jubilee, Toro and Legacy. The late season cultivar Elliot ripens in February/March (SH) (Greeff and Greeff, 2006)

There is one excellent market window for South African blueberries in the UK, viz. mid September until end of November (personal communication McKenzie, 2011). Southern highbush cultivars Misty, Sharpblue and O'Neal are not early enough and in addition have production and postharvest problems. In order to supply the early market, Eurafruit Variety Group (EVG) imported new southern highbush cultivars from Fall Creek Nursery in the US. These new cultivars were bred at the University of Florida by Dr. Paul Lyrene and include 'Star', 'Emerald', 'Jewel', 'Bluecrisp' and 'Snowchaser'. Currently the industry covers approximately 380 hectares with the large majority of the new planting from 'Star', 'Emerald', 'Jewel', 'Snowchaser' and 'Bluecrisp'. In the 2010/2011

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season, over 700 tonnes of blueberries were exported to the UK (personal communication McKenzie, 2011).

Locally, the majority of blueberries are supplied by Eurafruit Local (subsidiary of Eurafruit) to the Woolworths, Pick and Pay and Spar supermarket groups. In the 2010/2011 season, 250 tonnes of blueberries were sold locally. The volumes will increase in the next five seasons as many orchards are not in full production yet, and new orchards are still being established (personal communication McKenzie, 2011).

1.3 Cultivars newly introduced into the Western Cape.

Star, Emerald, Jewel, Bluecrisp and Snowchaser are five southern highbush blueberry cultivars that were recently introduced into the Western Cape, South Africa. These cultivars were released by the University of Florida and have relatively low chill requirements, are harvested early and have superior quality fruit.

'Star' was introduce in 1996 and has a chill requirement of 400 hours below 7^{o}C (Lyrene and Ballington, 2006). According to Lyrene and Ballington (2006), 'Star' displays medium to high vigour. 'Star' reaches full bloom ±25 February and 25% of the fruit can be picked by ±25April (Gainesville) (NH) (Lyrene and Sherman, 2000). 'Star' is known for a condense crop and most of the harvest can be completed within three weeks (Lyrene and Ballington, 2006). Although 'Star' benefits from cross-pollination, it will yield a partial crop when self-pollinated (Lyrene and Sherman, 2000). On average fruit weight is 1.6 g and fruit size is constant over the harvest period.

The cultivar Jewel has a chill requirement of 200 to 300 hours below 7^{o}C and was released in 1999 (Lyrene and Ballington, 2006). According to Lyrene (2001), 'Jewel' has an upright, somewhat spreading growth habit with medium vigour. On average full bloom in Gainesville is reached by 10 February (NH). Flowers are partially self-compatible but require cross-pollination to increase fruit size and number. 'Jewel' is high yielding with an average berry weight for the first berries that ripen of 1.7 to 2.5 g. Fruit is firm, has a good picking scar with a tart to sweet flavour (Lyrene, 2001a). The first picking date for 'Jewel' in Gainesville is around 15 April with the peak harvest around 25 April (Lyrene, 2001).

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The cultivar Emerald was released in 2001 and has a chill requirement of 200 to 300 hours below 7^{o}C (Lyrene, 2001b). 'Emerald' is an upright to semi-spreading plant with high vigour. From personal observation 'Emerald' is more spreading than upright under South African growing conditions especially compared to 'Jewel' and 'Snowchaser (Figure 1). 50 % full bloom in Gainesville (NH) is reach around 15 February and flowers are partially self-compatible. Self-pollination will only yield half the crop compared to when flowers are cross-pollinated (Lyrene, 2001b). 'Emerald' is known for its ability to set heavy crops while still obtaining excellent fruit size (Lyrene, 2008b). On average the first berries weigh 2.9 g. Fruit is large, firm, have good flavour with a good picking scar. In Gainesville, 80% of the crop is harvested between ±15 April and ±10 May (Lyrene, 2001b).

The cultivar Bluecrisp has a chill requirement of around 400-600 hours below 7^{o}C. 'Bluecrisp' produces a semi upright and vigorous plant (Lyrene, 1999). The flowering period for 'Bluecrisp' is from middle February to middle March in northern-central Florida (NH). Though the flowers are partially self-compatible, cross-pollination is needed for full productivity (Lyrene, 1999). The berries are large and on average weigh 2.2 g. Fruit has a distinct crisp texture and are of good firmness and flavour. In an average year in Gainesville (NH) 80% of the crop is picked between ±20 April and ±15 May (Lyrene, 1999).

The cultivar Snowchaser has a very low chill requirement of 100 to 200 hours below 7^{o}C (Lyrene, 2008a). 'Snowchaser' displays high vigour and a between upright and spreading growth habit (Lyrene, 2008a). 50% full bloom is reached by ±15 February (Windsor, Fla) on average 15 days before 'Star'. Flowers have a medium to low self-fruitfulness and cross-pollination with other southern highbush blueberries is recommended. Up to 25% of berries can be harvested before ±5 April, this is on average 18 days before 'Star'. On average berries weigh 1.7 g per berry and have good flavour (Lyrene, 2008a).

2. Pollination of southern highbush blueberries

The quantity and the quality of pollen produced differ among cultivars and are two of the factors that influence fruit set in blueberries (Eck, 1988c). The effect of the quality and quantity of pollen produced, as well as the possible effect of cross-pollination between cultivars, e.g. Star, Jewel, Snowchaser, Bluecrisp and Emerald, has not been studied under South African conditions.

Figure 1. Southern highbush blueberry 'Emerald' (displaying spreading growth habit under South African growing conditions).

2.1 Blueberry flower anatomy

Reproductive (R) and vegetative (V) buds develop in leaf axils (Eck, 1988b). Flower bud differentiation takes place after shoot cessation end of summer (Bañados and Strik, 2006). The first indication of differentiation of the R-buds can be seen mid to late summer by the flattening of the apical meristem and the appearance of sepal primordia (Gough 1994a). The R-buds differentiate basipetally along the shoot over a period of a few weeks on current season growth. Blueberries do not form R-buds on older wood and will only bear fruit on one-year-old wood. The R-buds are ovoid structures approximately 3.5 to 7 mm long (Eck, 1988b). Within each individual bud, the apex forms the peduncle of the future racemose inflorescence (Gough *et al.*, 1978). The apex initiates axillary meristems as it develops; each of these axillary meristems is linked to the peduncle by its own pedicel. The meristem differentiation proceeds acropetally until it ends with abortion of the apex known as black tip formation. Anything between 8 and 16 florets develop per inflorescence (Darnell, 2006). Multiple inflorescences are not common in blueberries, and although it sometimes occurs on medium to thick shoots, most of the time only a single inflorescence will develop in a leaf axil (Eck, 1988b). Terminal racemes on shoots tend to open first, followed by racemes lower down. Racemes on thinner shoots open earlier than on thicker shoots. Within the raceme, basal florets open first, followed by florets on the middle section and last those at the distal end. Despite the opening

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sequence of the florets within the raceme, distal fruit mature first followed by the fruit from the middle of the cluster (Eck, 1988b).

The blueberry inflorescence is entomophilous, thus designed for insect pollination (Eck, 1988d). The blueberry floret consists of a single style, eight to ten stamens, a calyx formed by five fused sepals and five fused petals all which are fused into an inferior ovary (Figure 2) (Gough, 1994a). Each stamen consists of a micro pore, anther tube and anther which are supported by a hairy, flattened filament. The pistil consists of a stigma, style and the ovary. The stigma and style are connected to the ovary that contains ten locules connected to the placental tissue resting against the central ovarian pillar. The central lobe canal of the style is lined with dark staining celled stigmoidal tissue where pollen tube growth takes place (Gough, 1994a). The five bundles of the central pillar are fused at the style and branch to each of the five placentas. The placenta comprises of simple parenchyma cells. Up to 100 ovules develop on the five placentas. During excellent pollination and fertilisation conditions, a maximum of 65 seeds were found in most cultivars (Gough, 1994a). Seeds in blueberry are strong sinks and therefore responsible to draw resources from the plant that result in bigger fruit (Yarborough, 2006).

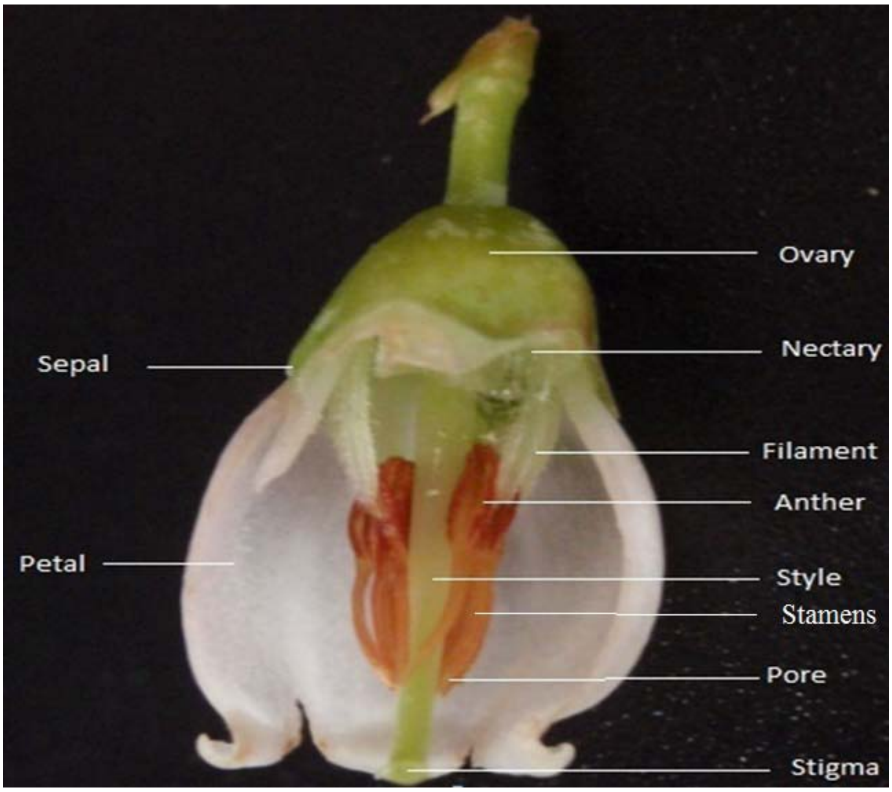

Figure 2. Longitudinal section through southern highbush blueberry.

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By the end of autumn all the flower parts are differentiated. The individual pollen grains appear a few weeks prior to bloom. The pollen is shed as tetrahedral tetrads during full bloom when stigma receptivity is optimal (Figure 3). Pollen from the same flower is unlikely to fall on the stigma as the stigma is flared outwards (Gough, 1994a). Pollination is highly dependent on pollinators like honey bees (*Apis mellifera*) (Mackenzie, 2009). The nectary at the base of the corolla excretes nectar to attract pollinating insects (Gough, 1994a). Bees can only reach the nectar by pushing through the clustered stamens. Pollen is shed on the bees and carried to the next florets they visit. The stigma, positioned in the centre of the stamens, excretes a sticky liquid. The stigma is receptive to pollen for four to six days, depending on the cultivar and environmental conditions (Eck, 1988b).

Once viable pollen is transferred onto the stigma (pollination), the pollen will germinate and the pollen tube will grow down the stylar canal, into the ovarian ovule and into the embryo sac where the generative nucleus are injected (Gough, 1994a). The pollen tube growth is guided by the vegetative nucleus in the tube which is influenced by chemicals released by the stigmoidal tissue in the canal (Gough, 1994a). The generative nucleus divides into two sperm nuclei which enter the egg sack. One sperm nucleus fuses with the diploid polar nucleus to form the endosperm while the other fuses with the egg to form the zygote (fertilization). The zygote becomes the embryo that is nourished by the endosperm and eventually forms a seed (Gough, 1994a).

Figure 3. Tetrad pollen of the cultivar Emerald (displaying three out of the four pollen tubes germinating)

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2.2 Pollen source and fruit characteristics

Various studies showed that cross-pollination has an effect on fruit size, fruit set, fruit development period, seed number, sugar accumulation and overall berry quality of *V. corymbosum* L. and *V. corymbosum* interspecific hybrids (Gupton, 1984; Lyrene, 1989; Lang and Danka, 1991; Lang and Parrie, 1992; Gupton and Spiers, 1994; Huang *et al.*, 1997). The question of whether cross-pollination is necessary for all southern highbush blueberry cultivars is still in dispute.

The number and quality of seeds formed by a plant is directly correlated to the reproductive fitness of the plant (Gough, 1994a). Given that a mature blueberry contains approximately 65 seeds, and that each egg cell must be fertilised by a separate pollen grain, multiple tetrad pollen must be deposited onto the stigma for optimum fruit development (Gough, 1994a). Not every pollen grain is capable of fertilising an ovule, thus the number of pollen grains needed for optimal fertilisation exceeds the number of ovules. Reasons for this include physical blockage, ovule abortion, tube attrition and other factors like timing of pollination (Dogterom *et al.*, 2000).

According to Gupton (1984), cross-pollination with outcross pollen in northern highbush hybrids resulted in significantly more viable seeds and increased berry weight compared to self and half-sibling crosses. However, fruit set for self-pollination was equal to or better than out-crossing for all but one hybrid. Therefore, if cross-pollination does not occur in these hybrids, there is a possibility that many small berries develop. According to Gupton (1984), the sterility and incompatibility patterns of these hybrids are complex. From his research, he observed two patterns of incompatibility in addition to one case of sterility. The first pattern reduced fruit set with cross-pollination, but the seed number and berry size increased. The second pattern increased fruit set, but reduced seed number and fruit size with cross-pollination. He concluded that the genetic base of this low chill highbush material is quite narrow and that most of the low-chilling cultivars and clones share some common germplasm. This could be a problem for evaluating low chill highbush blueberries in the breeding nursery, in that their potential yield could be underestimated. Therefore, there is a need for new parents with different genes to increase outcross-pollination in low chill highbush blueberries (Gupton, 1984).

Lyrene (1989) studied the effect of self-pollination, cross-pollination and mixed pollination on the southern highbush cultivar Sharpblue. He used pollen from ‘O’Neal’ and ‘FL 2-1’. He found an increase in fruit set from 37% when self-pollinated, to 84% and 91% when cross-pollinated with ‘O’Neal’ and ‘FL 2-1’, respectively. The average number of mature seeds increased from 3.5 for self,

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to 13 for mixed and 24.4 for cross-pollination. Cross-pollinated fruit were harvested 13 days before mixed pollinated fruit and 20 days before self-pollinated fruit. Within each pollination treatment, fruit with more seeds ripened earlier and were heavier, suggesting that cross- and mixed pollination affected fruit size and fruit development period through the direct effect of seed number on fruit size and the fruit development period. Seed number per berry accounted for 65% to 82% of all the variation in fruit development period and 45% to 84% in berry weight. This is especially the case when only a few seeds are present. Thus, the beneficial effect of having 15 seeds per berry instead of 10 was much smaller than having 10 seeds instead of 5. According to Lyrene (1989), two trends are clear from the literature: a) the relative number of seeds produced after cross-pollination and self-pollination vary between *Vaccinium* spp. and also within clones of the same species. The number of seeds per berry increase with cross-pollination compared to self-pollination in most, if not in all clones. The extent to which the seed number increased with cross-pollination varies, but is generally less for highbush cultivars compared to lowbush and rabbiteye blueberries. b) The extent to which fruit will set, size, and ripen in normal time with fewer seeds vary between cultivated *Vaccinium* spp. and clones within the species. According to Lyrene (1989), the fact that mixed pollen (outcross and self-pollen) produced fewer seeds than cross-pollination can be due to two factors: a) Fewer foreign pollen grains were put on each stigma and there was not enough outcross pollen for optimum seed numbers. b) Self pollen grains interfered with the process by which foreign pollen grains resulted in more viable seeds. In commercial plantings, 100% cross-pollination can never be obtained and therefore the mix pollen treatment is a better representative of what is happening in the orchard. Lyrene (1989) concluded that grower observations and greenhouse pollinations studies indicate that self-pollination of ‘Sharpblue’ results in smaller, later maturing berries with smaller seeds. Thus interplanting of a compatible cross-pollinator would be beneficial.

In contrast to Lyrene (1989), Lang and Danka (1991) did not find an increase in fruit set when honey-bee-mediated cross-pollination with ‘Gulfcoast’ was used on ‘Sharpblue’. According to Lang and Danka (1991), one of the reasons for this was that the pollination technique used differed. Lyrene (1989) used a single pollen application, while Lang and Danka (1991) used bees which might have visited a flower several times thereby increasing the fruit set. Although cross-pollination had no effect on fruit set, the fruit size was increased by 13.6% with cross-pollination compared to self-pollination. A difference in seed number was also observed; self-pollinated fruit had 27.5% fewer seeds than cross-pollinated fruit. Another interesting observation made by Lang and Danka (1991) was that seed number declined through time (from the first to the last harvest) without affecting fruit size. This indicates that fruit size is affected by factors in addition to seed number. Cross-pollination also hastened the fruit development period and thus the time until harvest. Self-pollination resulted in significantly fewer early ripening fruit (14.2%) compared to cross-pollination (34.1%). Since the

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percentage mid–harvested fruit was the same, late harvest fruit was 30.9% in the case of self-pollination and only 9.5% for cross-pollinated fruit. Lang and Danka (1991) also observed that cross-pollination resulted in an overall 13% increase in premium marketable fruit. In this trial, the fruit size was not as highly related to seed number in self-pollinated fruit compared to cross-pollinated fruit. According to Lang and Danka (1991), these trends indicate that seeds of different genetic derivation might differ in their influence on fruit growth although the seeds are equally well developed. In addition, they concluded that the influence that seed number has on fruit size may diminished above a certain minimum seed number.

Danka *et al.* (1993) could not find a significant difference in fruit characteristics when the southern highbush cultivar Gulfcoast was cross-pollinated with southern highbush cultivars, Blue Ridge, Cape Fear, Cooper, Avonblue, O'Neal and Georgiagem. This is in contrast to the positive effect on the fruiting characteristics found by Lyrene (1989) and Lang and Danka (1991) when the southern highbush 'Sharpblue' was cross-pollinated. Danka *et al.* (1993) explained this on the basis that 'Sharpblue' contains only 56% of the self-fertile *V. corymbosum* in its genome compared to the 75% of 'Gulfcoast'. They concluded that the influence of pollen sources on southern highbush cultivars differ amongst cultivars and that further pollen source tests are necessarily before recommendations can be made.

Gupton and Spiers (1994) reported that fruit set remained the same for self- and cross-pollination for seven southern highbush cultivars. Although the set remained the same, the number of seeds per berry and berry weight were higher and the fruit development period shorter when outcross pollen was used. The mixed pollen used was from 43% mixed donors of the same species, 7% self and 50% from six donors of a different species. Gupton and Spiers (1994) reported that as the number of pollen donor's increase, the effect on seed set becomes cumulative. Thus inter-planting several cultivars may overcome the effect of selfing.

Parrie and Lang (1992) studied the effect of self- and crosspollination of southern highbush cultivars O'Neal, Gulfcoast and Georgiagem by looking at the number of tetrad pollen needed for stigmatic saturation. They found that 'Georgiagem' needed 14% to 18% and 'O'Neal' and 'Gulfcoast' 16 to 18% more self-pollen than cross-pollen to achieve stigmatic saturation. There are various hypotheses to explain why the blueberry flower stays receptive for pollen longer when self-pollinated than when cross-pollinated. The first is that the hydration of self-pollen, via a glycoprotein receptor/recognition event between the stigmatic exudates and the pollen exine, is only partial in blueberry, resulting in a prolonged availability of exudates. The second is a prolonged production of exudates when self-

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pollen is recognized and therefore the stigma remains receptive for longer (Parrie and Lang, 1992). Parrie and Lang (1992) concluded that further studies on the effect of the genetic source and amount of applied pollen tetrads on seed number and fruit size of southern highbush blueberries are important.

Huang *et al.* (1997) investigated the effect of cross-pollination on fruit growth and ovule abortion of southern highbush blueberries. They established that ovule abortion in the cultivar Sharpblue (cross and self-pollinated) takes place 5 to 10 days after pollination. Ovule abortion was the lowest (22%) when pollen of 'O'Neal' was used, second when pollen of 'Gulfcoast' (29%) was used and the highest when self-pollinated (35%). Furthermore the number of weakly developed ovules was the lowest when out-crossed with 'O'Neal' (33.6%) followed by out-crossing with 'Gulfcoast' (50.8%), and then the greatest when self-pollinated (88.1%). Regardless of pollination treatment, the increase in ovule area was exponentially correlated with fruit growth during early developmental stages. Cross-pollination resulted in significantly greater ovule area, fruit weight and shorter stage III development than self-pollination. Well-developed ovules (seeds) are more effective stimulants than poorly developed ovules. The effect that seeds have on fruit size is believed to be under hormonal control and a large number of mature seeds may be a greater source of endogenous plant hormones and therefore the berry becomes a stronger sink (Huang *et al*. 1997). Huang *et al*. (1997) concluded that southern highbush blueberry fruit growth and development is intimately associated with ovule development and growth, which is affected by pollen sources.

According to Mackenzie (1997), commercial blueberry orchard designs must be cultivar-specific because of the differences in pollination requirements between cultivars (*V. corymbosum* L.). Of the three highbush cultivars he examined, he found that cross-pollination was beneficial for Patriot and possibly Northland, but not for Bluecrop. He also found that the degree of parthenocarpic fruit set differed among the cultivars. 'Patriot' had the highest parthenocarpic fruit set compared to 'Northland' where almost no parthenocarpic fruit set occurred. According to Mackenzie (1997), more research needs to be done on identifying cultivars that flower concurrently and are good cross-pollination sources.

Dogterom *et al.* (2000) used different pollen loads and pollen sources to investigate the pollen requirements for the cultivar Bluecrop. They found that both the pollen load and the source of the pollen had a major influence on the seed number and fruit size. Three different pollen sources were used, viz. self, outcross pollen ('Patriot') and mixed (50% 'Patriot' and 50% 'Bluecrop'). An increase in the seed number was observed when increasing the number of outcross pollen from 10, 25, 125 to 300. Although the seed number still increased when more than 125 pollen tetrads where used, the

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fruit size did not increase any further. Technically, 25 tetrad pollen grains should be able to fertilise 100 ovules, but this is not the case in practise. Dogterom *et al*. (2000) found that maximum seed numbers and fruit size were obtained when 125 tetrad pollen grains were deposited on the stigma. When comparing self, mixed and cross pollen loads, they found that the most seeds, highest fruit set and the best berry size were obtained when 125 pollen tetrads of mixed or outcross pollen was used.

Kobashi *et al.* (2002) found an increase not only in total seed number, but also in the number of brown (viable) seeds on the highbush blueberry 'Weymouth' when hand cross-pollinated with 'Northland' pollen. Self-pollinated and cross-pollinated fruit had an average of 54.5 and 66 seeds, respectively. The average brown seed number was respectively 6.5 and 28.8 for self and cross-pollinated fruit. Cross-pollinated fruit were larger and had higher sugar levels at maturity. They concluded that the sugar content was increased with cross-pollination and that the effect of seed number on abscisic acid and acid invertase activity may be involved in the mechanism.

Chavez and Lyrene (2009) studied the self-compatibility of various *Vaccinium* species, including *V. corymbosum* L. interspecific hybrids. They found average fruit set of 39.4% for self-pollination compared to an average of 82.8% when cross-pollinated. These results on fruit set are in line with Lyrene (1989), but in contrast to the results obtained by Lang and Danka (1991). Chavez and Lyrene (2009) found an increase in the average number of large seed (fully developed brown seeds) from 7.7 when self-pollinated to 31.7 when cross-pollinated. In contrast to other studies (Gupton and Spiers, 1994; Huang *et al.*, 1997; Dogterom *et al.*, 2000; Kobashi *et al.*, 2002), the self-pollinated fruit were on average larger than cross-pollinated berries, 1.69 g and 1.53 g, respectively. This is interesting because most studies show that berry size is positively correlated to seed number (Gupton and Spiers, 1994; Huang *et al.*, 1997; Dogterom *et al.*, 2000; Kobashi *et al*., 2002). According to Chavez and Lyrene (2009), the phenotypic variation between the plants used as female parents may be the reason for these differences. Chavez and Lyrene (2009) used a self-compatibility index where 1 is compatible and 0 is self-incompatible. They scored the southern highbush selections in this study at 0.38, therefore incompletely self-compatible. Even though that was the case, one of the hybrids gave fruit set of 70% when self-pollinated. According to Chavez and Lyrene (2009), this is an indication that low-chill highbush cultivars for solid block plantings can be developed.

In order to answer the question whether small berry size is related to poor pollination, Ehlenfeldt and Martin (2009) evaluated yield and berry weights for three or more harvests each season over ten years for highbush (*V. corymbosum* L.) cultivars Duke and Bluecrop. They could not find a significant correlation between yield and berry weight for either of the cultivars. However, they did find

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indications of a relationship between total yield and seed number. In 'Bluecrop', seed number and berry weight decreased linearly between the first and the third harvest. Between years, berries with similar seed numbers varied in weight as much as 39% for 'Bluecrop' and 86% for 'Duke'. The authors concluded that pollination is an important factor in berry weight, but for equally well-pollinated flowers, other factors like limiting plant resources and over cropping also reduce berry weight and yield.

2.3 Pollen tetrad viability

The ability of tetrad pollen to germinate is referred to as the tetrad viability. Lang and Parrie (1992) found no major difference in the tetrad viability of different southern highbush cultivars (Table 1). They concluded that pollen was viable when at least a single pollen tube developed from a pollen tetrad. Out of the six cultivars they examined, Avonblue had the lowest pollen tetrad viability (79.5%) and Georgiagem the highest (94.3%). Dogterom *et al.* (2000) reported that the pollen tetrad viability for 'Bluecrop' was 93.2% and for 'Patriot' 88.8%. Thus tetrad viability does not differ enough between cultivars to be major factor in fertilisation.

Table 1. The mean of in vitro pollen tube growth rates and percentage tetrad germination (Lang and Parrie, 1992).

Cultivar	Tetrad germination %	Pollen tube growth rate ($\mu m\ h^{-1}$)
Avonblue	79.5 b	30 ab
Floridablue	94.8 a	30 ab
Georgiagem	96.3 a	28 b
Gulfcoast	93.8 a	38 ab
O'Neal	90.5 a	40 a
Sharpblue	94.3 a	26 b

2.3 Pollen tube growth rate

Up to eight days after anthesis, the stigma is still receptive (northern highbush and rabbiteye), although it has been found that seed set decreases after three days (Eck, 1988c). Pollen tube growth rate can determine whether the tube reaches the ovule in time for fertilisation. Lang and Parrie (1992) in an in vitro study found that pollen tube growth rates differed significantly and ranged from 26 $\mu m\ h^{-1}$ to 40 $\mu m\ h^{-1}$ for different highbush cultivars (Table 1). In vitro studies of pollen tube growth rate are, however, not directly representative of in vivo pollen tube growth rates because of the influences associated with the stylar tissue. Still it is a good indication of the inherent pollen vigour. Because of

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the big differences among cultivars, the pollen tube growth rate must be taken into account when testing the viability of blueberry pollen.

2.4 Germination of multiple pollen tubes

As mentioned earlier, tetrad pollen consists out of four pollen grains. Each pollen grain has the ability to germinate and form a viable pollen tube (Lang and Parrie, 1992). Of the six highbush blueberry cultivars Lang and Parrie (1992) studied, all showed substantial multiple pollen tube germination (Table 2). In 'Floridablue', about the same number of multiple and single tubes germinated. For 'Gulfcoast' and 'Sharpblue', 100% of the tetrad pollen showed multiple tube germination and for 'Avonblue', 'O'Neal' and 'Georgiagem' 75% of the tetrads showed multiple pollen tube germination. For the 100 tetrads that germinated in each cultivar the two extremes were 'Floridablue' with 157 pollen tubes and 'Sharpblue' with 324 pollen tubes. Thus, according to Lang and Parrie (1992), the major factor that influences the viability and the capability of tetrads to fertilise flowers can be attributed to pollen tube growth rate and pollen grain viability.

Table 2. Number of pollen tubes germinated from tetrad pollen in different southern highbush cultivars (Lang and Parrie, 1992).

Cultivar	Number of pollen tubes germinated out of 100 tetrad pollens			Total	Pollen grain germination (%)
	2	3	4		
Avonblue	50	25	2	77 c	40.9
Floridablue	43	10	1	54 d	39.3
Georgiagem	35	29	29	93 b	67.4
Gulfcoast	17	53	30	100 a	73.4
O'Neal	29	32	24	85 b	60.0
Sharpblue	9	38	53	100 a	81.1

2.6 Conclusion

Blueberry flowers are entomophilous and require pollinators like bees. Pollination of blueberries is one of the major aspects determining fruit set, quality and the time of harvest. There are various pollination aspects that must be taken into account before commercial orchards are established. Self-compatibility differs between southern highbush cultivars and cross-pollination can be beneficial for some cultivars. Characteristics like fruit set, seed number, fruit weight, fruit diameter and fruit development period can be positively influenced by cross-pollination for some cultivars. Pollen quality between cultivars also varies especially in pollen tetrad viability. Pollen source is important and research for each cultivar is important before recommendations can be made for commercial

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orchards. For the South-African industry where early berries of high quality are important, the effect of cross-pollination on the cultivars introduced to the industry need to be tested.

3. Pruning blueberries

3.1 Blueberry growth habit

In order to prune blueberries correctly, it is important to understand their growth and fruiting habit (Shutak and Muracci, 1966; Yarborough, 2006). Blueberry is a semi-deciduous shrub that reiterates from shoots that arise from buds located on the crown, i.e., the transitional area between the morphologically distinct vascular systems of the shoots and the roots. In warmer production areas, southern highbush blueberries retain their leaves through the winter and never go completely endodormant (Yarborough, 2006). Shoots develop from V-buds on the upper side of the crown that were either dormant for a long period or initiated the previous season. Shoots also develop from V-buds that developed on older wood (adventitious buds). Adventitious buds develop from the cambium, pericycle, endodermis or wound callus. After the second season of shoot growth, the shoot thickens, becomes woody and is called a cane. Canes also develop from adventitious buds on the roots and are then called suckers (Gough, 1994a). A few weeks prior to bloom during spring, V-buds start to swell and will sprout soon after flowering. Stem elongation proceeds at different rates on different shoots. As the shoot extends, the shoot apex continues to produce axillary buds. Shoot growth is sympodial and episodic and flushes terminate growth by apical abortion (Gough, 1994a). The process of apical abortion includes the necrosis of the apex and often the bud beneath (black tip formation). When growing conditions are favourable, the axillary bud near the apex (which is now released from para- and eco-dormancy) will sprout to continue shoot extension growth (the next flush). The number of flushes is cultivar-dependent, but environmental factors can result in big differences within the same cultivar. After black tip formation, a shoot can either remain un-branched (only one bud is released from dormancy), or become branched (two or more buds are released from dormancy). The axillary buds near the base of each shoot usually remain dormant. These buds however will break when the plant is under severe stress, for example, after heavy pruning. Distal buds on the shoot will differentiate into R-buds. The most distal V-buds produce the most vigorous shoots (Gough, 1994a). Each succeeding season, shoots produce laterals, and these laterals produce more laterals. Laterals of subsequent flushes decrease in diameter and become progressively thinner. Thick, vigorous laterals bear better quality berries (larger) than thin laterals (Shutak and Muracci, 1966; Gough, 1994b). Canes older than six years are less productive than young canes (Shutak and Muracci, 1966; Yarborough, 2006). According to Hancock and Nelson (1985), pruning is an

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important factor influencing yield and berry quality. Although highbush blueberry plants increase in size as they get older, beyond a certain point their yield will decrease.

3.2 Different pruning cuts used for blueberries.

Generally the norm is that no cane should be older than six years (Shutak and Muracci, 1966; Gough, 1994b; Yarborough, 2006). The reason for this is that canes 1 to 2.5 cm in diameter are most productive, and without pruning too few new canes develop to replace the old, less productive ones (Hancock and Nelson, 1985). Therefore it is important to remove old canes in order to stimulate new shoots from the crown to rejuvenate the plant (Shutak and Muracci. 1966; Gough, 1994b; Yarborough, 2006). The best way to remove old canes is either by a heading cut to a vigorous lateral (cutting back), or if there is no such lateral, the cane must be removed as close to the soil surface as possible by a thinning cut (removal cut). For northern highbush, some growers prefer to leave a small stub from which new shoots can develop. These shoots are not as vigorous as shoots developing from the crown. Twiggy, bushy growth often occurs at the distal end of canes where reproductive growth occurred the previous season. This growth is not productive anymore and should be removed by a heading cut. This type of cut will probably remove some strong shoots that may have developed between the bushy, short laterals, but this will not be important as long as there are enough strong fruiting laterals lower down on the cane (Shutak and Muracci, 1966). In cultivars that bear high yields, heading shoot tips (tipping) is frequently practiced in winter. By heading back the tips of some of the reproductive laterals, the number of R-buds is drastically reduced thereby decreasing yield, but increasing fruit size. Severity of the tipping depends on cultivar and the number of R-buds. Tipping should be done as late in the winter as possible just before bud swell (Shutak and Muracci. 1966). Another important practise is the removal of new growth that did not harden-off at the end of autumn. The new growth is too short to produce fruit for the next season, will probably be killed during winter (in cold climates) and is susceptible to fungal diseases.

3.3 Expected results from pruning

It is important to note that the effects of the time and severity of winter pruning on northern highbush and rabbiteye blueberries are well documented (Gough, 1983; Siefker and Hanock, 1987; Jansen, 1997; Strik *et al.*, 2003; Krewer *et al.*, 2004). On the other hand, little research has been done on summer pruning of southern highbush blueberries (Bañados *et al.*, 2009). Therefore the expected results from pruning listed below are for winter pruning of northern highbush blueberries unless stated otherwise.

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If pruning is done correctly, a blueberry orchard can consistently produce good yields of high berry quality (Gough, 1994b). Pruning maintains the vegetative and reproductive balance in the plant and therefore lengthens the life of the plant and results in commercial crops. The improvement in light penetration after pruning increases flower bud initiation. Pruning will increase air circulation within the plant and therefore reduces disease pressure (Gough, 1994b). Winter pruning of northern highbush blueberries in general reduces plant size and therefore the total yield the following season (Gough, 1994b; Yarborough, 2006). Even though pruning reduces total vegetative growth, the individual shoot length, leaf size and new cane development are increased. However, if pruning is too severe, especially for consecutive seasons, root growth can be reduced (Gough, 1994b). A decrease in the number of R-buds after pruning results in larger individual berries. Pruning for an increase in berry size is a compromise between total yield and desired berry size (Yarborough, 2006). In general, winter pruning results in a more condense and earlier crop. The smaller, early crop resulting from heavy pruning that benefits from the high prizes of early marketing is often preferred over the larger, but later crop after light pruning (Yarborough, 2006). Thinning cuts will stimulate new cane development from the crown while heading cuts stimulate lateral shoot development at the pruning wound (Gough, 1994b). The degree to which winter pruning reduces total vegetative growth and yield, but increases shoot length, leaf size, fruit size, concentrates and moves the harvest earlier are related to the severity of winter pruning (Shutak and Muracci, 1966; Gough, 1994b; Yarborough, 2006).

3.4 Pruning of young plants

Pruning strategy depends on the phase of orchard development which can be divided as follows: the establishment of new orchards (year one to four), and pruning mature orchards (Shutak and Muracci, 1966; Eck, 1988c; Yarborough, 2006).

The main goal when pruning newly established orchards is to stimulate vegetative growth, eliminate reproductive growth and to form an open, upright, vase shaped plant (Shutak and Muracci, 1966; Eck, 1988c; Gough, 1994b; Yarborough, 2006). For southern highbush blueberries especially during the first year, pruning can be quite severe and up to one half of the plant can be removed. Pruning of weak plants can be even more severe to obtain the optimal plant shape. Though winter is the best time to prune southern highbush blueberries, pruning can be done any time of the year (Yarborough, 2006). The reason for severe pruning during the first season for southern, as well as northern highbush, is to stimulate strong vegetative growth and to bring the top growth in balance with the root system (Gough, 1994b; Yarborough, 2006). Only two to four thick canes are left after pruning and all spindly laterals and low-growing branches and canes going through the middle of the plant are

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removed. According to Gough (1994b), a heading cut should be made on the canes to leave a stub with two to three V-buds. A second light pruning can follow the first pruning to remove all the branches where fruit developed (Yarborough, 2006). It is important that berries must be removed for the first two growing seasons to ensure strong root and shoot growth. In the third year after planting, sufficient fruiting wood can be left to produce 0.5 kg of fruit per plant (Eck, 1988c).

The response to R-bud removal in young southern highbush orchards is cultivar dependent (Williamson and NeSmith, 2007). 'Misty' showed an increase in total dry weight in response to R-bud removal treatments the first few years after planting. In contrast, 'Sante Fe' did not show any increase in plant dry weight. Nevertheless, in order to stimulate vegetative growth, removal of R-buds the first two years after planting is recommended (Shutak and Muracci, 1966; Eck, 1988c; Gough, 1994b; Yarborough, 2006).

3.5 Pruning mature plants

The main objective of pruning a mature blueberry plant is to maintain a good balance between yield and vigorous new growth (Shutak and Muracci, 1966; Eck, 1988c; Gough, 1994b; Yarborough, 2006).

There are three important points to consider when pruning a mature northern highbush plant (Gough, 1994b). Pruning needs to be light enough to ensure a heavy crop for the current season, but must be severe enough to increase berry size. Pruning also needs to be severe enough to balance crop and plant vigour to ensure enough new growth for the following season's crop. Thinning can be very important in certain cultivars and is a compromise between total yield and fruit size. Starting in year four to five, the older canes must be completely removed to stimulate new shoot growth from the crown. The reason for this is that an older cane becomes increasingly branched over time and thinner laterals are less productive than new vigorous, thicker shoots (Yarborough, 2006). Adequate pruning will ensure enough sunlight penetration in the canopy, optimising photosynthesis and R-bud initiation. By opening up the canopy of the plant, the air circulation is increased and this decreases the incidence of disease and improves fruit quality (Gough, 1994b).

Independent of the time of pruning, the following steps should be followed to prune a mature blueberry plant (Shutak and Muracci, 1966). Firstly, all the diseased or injured canes should be removed. Secondly, some of the oldest, least vigorous canes should be cut back to vigorous laterals if these exist, otherwise remove the cane by means of a thinning cut. Remove all low growing branches

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and laterals and finally if necessarily thin out some of the bearing laterals. For some heavy bearing cultivars tipping can be done to remove some fruiting wood.

3.6 Time of summer pruning blueberries

The degenerative effect of aging on vigour due to a lack of pruning is one of the main production problems of blueberries in Chile (Bañados *et al*., 2009). The lack of vigour is evident in short laterals and an absence of new cane development from the crown. Different pruning techniques are currently used by growers to solve this problem. In colder production regions, where plants go endodormant, winter is the most common time to prune. However, in the warmer production regions where the plants never completely lose their leaves or go endodormant, summer pruning is also performed to complement, or replace winter pruning (Bañados *et al*., 2009). Summer pruning is performed after harvest during the phase of active shoot growth and therefore is more devitalizing in the short term than winter pruning (Wertheim, 2005). One of the objectives of summer pruning is to stimulate lateral branching by cutting back vigorous shoots (Bañados *et al*., 2009).

Bañados *et al*. (2009) studied the effect of time of summer pruning on lateral shoot growth, R-bud induction and fruit quality for ‘Star’ (southern highbush), ‘O’Neal’ (southern highbush) and ‘Elliott’ (northern highbush). Pruning was done in monthly intervals from December to March (southern hemisphere). The time of summer pruning had a significant effect on the number and length of lateral development (Bañados *et al*., 2009). Bañados *et al.* (2009) reported that over 90% of the shoots pruned in December for all three cultivars produced laterals. For all three cultivars, the capacity to produce laterals decreased from the first to the last pruning treatment. Earlier pruning resulted in more and longer laterals for all three cultivars studied. The reason for the decrease in number and length of laterals produced as pruning was done progressively later is probably due to an increase in the stage of dormancy of the buds (Bañados *et al.*, 2009). Thus, if the buds are only paradormant they will be released from dormancy by pruning. However, if the buds are already endodormant, they will not be released from dormancy even if the conditions are favourable for growth. The time of pruning also influenced the number of R-buds. For ‘Star’ and ‘O’Neal’ the number of reproductive buds seems to be related to shoot length, therefore earlier pruning increased the number of flower buds per lateral (Bañados *et al*., 2009). Late pruning of ‘Star ‘and ‘O’Neal’ (February) resulted in a delay in harvest while pruning in December had no significant effect.

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3.7 Conclusion

Pruning of blueberries is one of the major cultural practices influencing fruit quality and a compromise between total yield and desired fruit size must be found. The primary goal of pruning young orchards is to stimulate vegetative growth, eliminate reproductive growth and develop a vase shaped plant. Pruning of mature orchards is important to maintain a good balance between R- and V-growth. Although pruning is done during winter in cold production areas, summer pruning may be an alternative for early ripening cultivars in warmer production areas. The time of summer pruning is important and pruning must be done before R-buds become endodormant in late autumn.

Literature cited

Bañados, P. and S. Strik. 2006. Manipulation of the annual growth cycle of blueberry using photoperiod. Acta Hort. 715:65-71.

Bañados, P., Uribe P. and D. Donnay. 2009. The effect of summer pruning date in ‘Star’, ‘O’Neal’ and ‘Elliott’. Acta Hort. 810:501-508.

Chavez, D.J. and P.M. Lyrene. 2009. Effects of self-pollination and cross-pollination of Vaccinium darrowii (Ericaceae) and other low-chilll blueberries. HortScience 44(6):1538-1541.

Danka, G.D., G.A. Lang and C.L. Gupton. 1993. Honey bee (Hymenoptera : Apidae) visits and pollen source effects on fruiting of ‘Gulfcoast’ southern highbush blueberry. J. Econ. Entomol. 86(1):131-136.

Darnell, L.D. 2006. Blueberry botany/environmental physiology, p.5-13. In: N.F. Childers and P.M. Lyrene (eds.), Blueberries for growers, gardeners, promoters. Horticultural Publications. Gainesville. Florida.

Dogterom, M.H., M.L. Winston and A. Mukai. 2000. Effect of pollen load size and source (self, outcross) on seed and fruit production in southern highbush blueberry cv. 'Bluecrop' (Vaccinium corrybosum cv; Ericaceae). Am. J. Bot. 87:1584-1591.

Eck, P. 1988a. New cultivars, p.20-40. In: Eck, P. (eds), Blueberry science. Rugters university press, New Brunswick and London.

Eck, P. 1988b. Plant development, p.41-65. In: Eck, P. (eds), Blueberry science. Rugters university press, New Brunswick and London.

Eck, P. 1988c. Fruit development, p.66-90. In: Eck, P. (eds), Blueberry science. Rugters university press, New Brunswick and London.

Eck, P. 1988d. Cultural practices, p.135-169. In: Eck, P. (eds), Blueberry science. Rugters university press, New Brunswick and London.

University of Stellenbosch http://scholar.sun.ac.za

Ehlenfeldt, M.K. and R.B.J.T. Martin. 2009. Seed set, fruit weight, and yield in highbush (Vaccinium corymbosum L.) blueberry cultivars 'Duke' and 'Bluecrop'. Acta Hort. 810:93-96.

Greeff, M.P. and P.F. Greeff. 2006. Blueberries in South Africa, p.255-256. In: N.F. Childers and P.M. Lyrene (eds.), Blueberries for growers, gardeners, promoters. Horticultural Publications. Gainesville. Florida.

Gough, R.E. 1983. Time of pruning and bloom date in cultivated highbush blueberry. HortScience. 18(6):934-935.

Gough, R.E. 1994a. Growth and development, p.11-57. In: Gough, R.E. (eds.), The higbush blueberry and its management. The Haworht Press, Inc. Worwood. Australia.

Gough, R.E. 1994b. Pruning, p.137-150. In: Gough, R.E. (eds.), The higbush blueberry and its management. The Haworht Press, Inc. Worwood. Australia.

Gough, R.E., V.G. Shutak and R.L. Hauke. 1978. Growth and development of highbush blueberry. II. reproductive growth, histological studies. J. Amer. Soc. Hort. Sci. 103(4):476-479.

Gupton, C.L. 1984. Effect of pollen source on fruit characteristics of low-chilling highbush type blueberries. HortScience 19(4):531-532.

Gupton, C.L. and J.M. Spiers. 1994. Interspecific and intraspecific pollination effects in rabbiteye and southern highbush blueberries. HortScience 29:324-326.

Hancock, J.F. and J.W. Nelson. 1985. Factors influencing yields of Vaccinium corymbosum L. in Michigan. Acta Hort. 165:107-113.

Huang, Y.H., C.E. Johnson, G.A. Lang and M.D. Sundberg. 1997. Pollen sources influence early fruit growth of southern highbush blueberry. J. Amer. Soc. Hort. Sci. 122(5):625-629.

Jansen, W.A.G.M. 1997. Pruning of higbush blueberries. Acta Hort. 446:333-335.

Krewer, G., D. Staneland, S. NeSmith and B. Mullinix. 2004. Post harvest hedging and pruning of three year pruning trial on Climax and Tifblue rabbiteye blueberry. Small Fruit Revenue. 3:203-212.

Kobashi, K., S. Sugaya, M. Fukushima and S. Iwahori. 2002. Sugar accumulation in highbush blueberry fruit as affected by artificial pollination with different pollen sources in relation to seed number, invertase activities and ABA content. Acta Hort. 574:47-51.

Lang, G.A. and R.G. Danka. 1991. Honey bee mediated cross- versus self-pollination of 'Sharpblue' blueberry increases fruit size and hastens ripening. J. Amer. Soc. Hort. Sci. 116:770-773.

Lang, G.A. and E.J. Parrie. 1992**.** Pollen viability and vigor in hybrid southern highbush blueberries (Vaccinium corymbosum L. x spp.). HortScience 27:425-427.

University of Stellenbosch http://scholar.sun.ac.za

Lyrene, P.M. 1989. Pollen source influences fruiting of 'Sharpblue' blueberry. J. Amer. Soc. Hort. Sci. 114:995-999.

Lyrene, P.M. 1999. Blueberry plant named 'Bluecrisp'. Patent No: US PP11,033 P2. http://www.freepatentsonlin.com/PP11033.

Lyrene, P.M. and B. Sherman. 2000. 'Star' southern highbush blueberry. HortScience 35(5):956-957.

Lyrene, P.M. 2001a. Blueberry plant named 'Jewel'. Patent No: US PP11,807 P2. http://www.freepatentsonlin.com/PP11807.pdf

Lyrene, P.M. 2001b. Blueberry plant named 'Emerald'. Patent No: US PP12,165 P2. http://www.freepatentsonlin.com/PP12165.pdf

Lyrene, P.M. and R.B. Ballington. 2006. Varieties and their characteristics, p.26-37. In: N.F. Childers and P.M. Lyrene (eds.), Blueberries for growers, gardeners, promoters. Horticultural Publications. Gainesville. Florida.

Lyrene, P.M. 2008a. Blueberry plant named 'Snowchaser'. Pub. No: US 2008/0196128 P1. http://www.freepatentsonlin.com/20080196128.pdf

Lyrene, P.M. 2008b. 'Emerald' southern highbush blueberry. HortScience 43(5):1606-1607.

Mackenzie, K.E. 1997. Pollination requirements of three highbush blueberry (Vaccinium corymbosum L.) cultivars. J. Amer. Soc. Hort. Sci. 122(6):891-896.

Mackenzie, K.E. 2009. Pollination practices and the use of bees in *Vaccinium* crops. J. Amer. Soc. Acta Hort. 810:527-538.

Parrie, E.J. and G.A. Lang. 1992. Self- and cross-pollination affect stigmatic pollen saturation in blueberry. HortScience 27:1105-1107.

Sharpe, R.H. and W.B. Sherman. 1971. Breeding blueberries for low-chilling requirement. HortScience 6(2):145-147.

Shutak, V.G. and E.M. Muracci. 1966. Plant and fruit development, p179-198. In: P. Eck an N.F. Childers (eds.), Blueberry culture. Rugters university press, New Brunswick and New Jersey.

Strik, B. and G. Buller E. Hellman. 2003. Pruning severity affects yield, berry weight, and hand harvest efficiency of highbush blueberry. HortScience 38(2):196-200.

Siefker, J.A. and J.F. Hanock, J.F. 1987. Pruning effects on productivity and vegetative growth in the highbush blueberry. HortScience 22:210-211.

Wertheim, S.J. 2005. Pruning, p.176-189. In: Tromp, J., A.D. Webster and S.J. Wertheim (eds.), Fundamentals of temperate zone tree fruit production. Backhuys Publishers. Leiden. The Netherlands.

University of Stellenbosch http://scholar.sun.ac.za

Williamson, J.G. and D.S. NeSmith. 2007. Evaluation of flower bud removal treatments on growth of young blueberry plants. HortScience 42(3):571-573.

Yarborough, D.E. 2006. Blueberry pruing and pollination, p. 75-83. In: N.F. Childers (ed.), Blueberries for growers, gardeners, promoters. Horticultural Publications. Gainesville. Florida.

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Paper 1: The effect of cross-pollination of southern highbush blueberries on fruit set and fruit characteristics.

Abstract: Production of southern highbush blueberries is new to South Africa and new commercial blocks are being established. The question from producers arose whether single cultivar blocks can be planted in order to ease commercial practices. Six experiments to evaluate the self-compatibility and the effect of cross-pollination on fruit set and fruit characteristics for the southern highbush cultivars Star, Emerald, Jewel, Bluecrisp and Snowchaser were conducted. The experiments were conducted in Villiersdorp in the Western Cape Province, South-Africa. All experiments comprised a control where no hand pollination was applied, a self-pollination treatment (selfing) where pollen of the same cultivar was used for pollination, and three to five cross-pollination treatments depending on the overlapping bloom periods of the different cultivars. The effect of cross-pollination on fruit set, berry weight, berry diameter and fruit development period is cultivar specific. Out of our trial the following recommendations can be made: 'Bluecrisp' seems self-incompatible and 'Misty' and 'Emerald' would be recommended as cross-pollinators. For 'Jewel', 'Misty' would be recommended although all pollination treatments gave satisfactory yields. Self-pollinated 'Star' yielded a satisfactory crop; however, 'Emerald' would be recommended as cross-pollinator. For 'Emerald', cross-pollination with 'Jewel', 'Misty' and 'Bluecrisp' is recommended when early maturing fruit and fruit size are important. 'Snowchaser' seems self-compatible and is the only cultivar where solid block plantings are recommended.

Introduction

The genome of southern highbush blueberries (SHB) (*Vaccinium corymbosum* interspecific hybrids) is complex and contains germplasm of southern diploid *V. darrowi* C., hexaploid rabbiteye blueberries (*V. ashei* R.) and the tetraploid northern highbush specie *V. corymbosum* L. (Gupton, 1984). Not all these species are self-compatible and very little is known about the gynoecious interaction and pollen compatibility of SHB (Lang and Parrie, 1992). According to Eck (1988b), solid block plantings of highbush blueberries are yielding satisfactory crops, but more recent literature has indicated that yield can be improved by cross pollination (Lyrene, 1989; Lang and Danka, 1991; Gupton and Spiers, 1994; Haung *et al.*, 1997; Chavez and Lyrene, 2009).

The blueberry inflorescence is entomophilous, thus facilitating insect pollination (Eck, 1988a). Because the stigma is flared outwards and the floret has a drooping appearance, pollen is unlikely to

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fall onto the stigma of the same flower. Blueberry pollination is thus highly dependent on pollinators like bees (Mackenzie, 2009).

Cross-pollinating *V. corymbosum* and *V. corymbosum* interspecific hybrids with compatible pollinators shortens the fruit development period and also has a positive effect on fruit set, fruit size, seed number, sugar accumulation and overall berry quality (Gupton, 1984; Lyrene, 1989; Lang and Danka, 1991; Lang and Parrie, 1992; Gupton and Spiers ,1994; Huang *et al.*, 1997; Chavez and Lyrene, 2009).

Cross-pollinating the southern highbush cultivar Sharpblue, shortens the fruit development period, increases fruit set and the number of mature seeds, and thereby increases fruit size (Lyrene, 1989; Lang and Danka, 1991). In contrast to ‘Sharpblue’, cross-pollination had no effect on fruit set, seed number or fruit size on ‘Gulfcoast’ (Danka *et al.*, 1993). Danka *et al*. (1993) explained that ‘Sharpblue’ contains only 56% of the self-fertile *V. corymbosum* in its genome, while ‘Gulfcoast’ contains 75% of the self-fertile *V. corymbosum* in its genome. They concluded that the effect of cross-pollination will be cultivar-specific in accordance with the contribution of the self-fertile *V. corymbosum* to the genome of the respective cultivars. Thus pollen source tests for every cultivar are necessary before any recommendations can be made regarding the need for cross-pollination (Danka *et al*., 1993).

Various researchers found that berry size positively correlated to seed number (Gupton and Spiers, 1994; Dogterom *et al.*, 2000; Kobashi *et al.*, 2002). Haung *et al.* (1997) investigated the effect of cross-pollination on fruit growth and ovule abortion in ‘Sharpblue’. Ovule abortion was highest when fruit were self-pollinated. Self-pollination also resulted in the weakest ovule development. Blueberry seeds are strong sinks and therefore responsible for drawing resources from the plant resulting in bigger fruit (Yarborough, 2006). Therefore, if cross-pollination increases the number of seeds per fruit, it should lead to an increase in fruit size.

Although the SHB cultivars Star, Emerald, Jewel, Bluecrisp and Snowchaser are partially self-compatible, cross-pollination with other tetraploid SHB are recommended (Lyrene, 1999; Lyrene and Sherman, 2000; Lyrene, 2001a; Lyrene, 2001b; Lyrene, 2008a, Lyrene, 2008b).

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For the South African blueberry industry, early maturing berries of good size are important in order to comply with market requirements. We therefore investigated the effect of cross-pollination between the most important southern highbush cultivars planted in South-Africa on fruit development, maturation and berry size.

Material and methods

Trial sites: Trials were conducted on ‘Emerald’, ‘Snowchaser’, ‘Bluecrisp’, ‘Star’ and ‘Jewel’ during the 2009/2010 growing season. The site was on Melwood farm near Villiersdorp (S 34^{0} 00’ 06.41”; E 19^{0} 16’ 22.60”; 346 m. a. s. l.) Western Cape, South Africa.

Treatment and trial design: For the first ‘Emerald’ trial and for ‘Snowchaser’, two-year-old plants in ten litre plastic bags were used. Three-year-old plants in ten litre plastic bags in the quarantine nursery were used for ‘Star’, ‘Jewel’, ‘Bluecrisp’ and the second ‘Emerald’ trials. Ten healthy, uniform plants of each of the cultivars were selected. A structure covered by bird netting was placed over the plants on 20 October 2010. The plants received standard fertigation.

For each of the six trials summarised in Table 1, the same procedure was followed. During full bloom, inflorescences were enclosed in glycine bags. Before enclosure of individual clusters, all the open florets were removed from the cluster, and only closed florets at the same phenological stage (“balloon stage”) were left in the cluster. The bags were then secured with paperclips to prevent bees from entering. After one week, the bags were removed and all the florets within the cluster that had not yet opened were removed. This remaining clusters, with between three and 15 florets, were all receptive to pollen. On the day of bag removal, pollen was collected from random florets of all the cultivars that were used as pollinators. The pollen was collected by rolling the fully opened florets between the thumb and the forefinger over a petri dish. The fresh pollen was used for pollination and placed on the receptive stigma using a glass rod. Following hand pollination, the individual clusters were again enclosed for another two weeks to prevent pollination by bees.

Each trial included a control treatment where no hand pollination was applied and the bag was kept closed, a self-pollination treatment (selfing) where pollen of the same cultivar was used for pollination, and then three to five cross-pollination treatments depending on the overlapping bloom periods of the different cultivars. The florets were not emasculated. A completely randomised design with ten single-cluster replications of each treatment was used. Enclosure and pollination dates are summarised in Table 1.

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Data recorded and data analysis: At harvest, ripe berries were picked weekly and taken to our laboratory. Fruit set was defined as the percentage florets pollinated that produced a ripe berry. Individual berry weight and diameter were determined after harvest using an electronic balance and calliper. Individual berries were pulped and a refractometer (ATAGO PR 32) was used to determine the total soluble solids (TSS) concentration. The seed number of each individual berry was determined by counting all dark brown seeds.

Data were analysed using the general linear model (GLM) procedure of SAS version 9.1.3 SP2 (SAS Institute, Cary, N.C. 2004). Where appropriate, covariate analysis was performed.

Results and discussion

Cross-pollination of the cultivar Bluecrisp with the cultivars Star, Jewel and Misty, but not with Emerald, resulted in significantly higher fruit set than when own pollen was used (Table 2). Un-pollinated and self-pollinated treatments differed significantly from the cross-pollination treatments for all the fruit characteristics (Table 2). Berries resulting from cross-pollination were significantly heavier with a larger diameter than berries from self-pollinated florets. Berries produced from cross-pollination contained significantly more viable seeds than both self- and un-pollinated treatments. The fruit development period for un-pollinated and self-pollinated fruit was significantly longer than for cross-pollinated fruit. When seed number was used as a covariate, it was significant and the treatment effect for fruit set, fruit weight, diameter and TSS was no longer significant indicating that the positive effect of cross-pollination was due to higher seed numbers. However, the treatment effect for fruit development period remained significant indicting that seed number was not the only factor influencing fruit development. When fruit set was used as a covariate, it was significant for all fruit characteristics except for TSS. However, the treatment effect remained highly significant indicating that fruit set is not the only factor effecting fruit characteristics (Table 2).

In the case of ’Star’, fruit set for all the treatments were above 65% and there was no significant difference between the treatments (Table 3). The un-pollinated treatment resulted in significantly lower fruit weight than cross-pollination and berries had a smaller diameter, contained fewer seeds and had a longer development period than both the self- and cross-pollination treatments. Self-pollination was equal to all cross-pollination treatments for fruit weight and diameter. Cross-pollinating with ‘Bluecrisp’ was the only treatment that significantly shortened fruit development compared to self-pollination. When seed number was used as a covariate, it was significant

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explaining fruit weight, diameter and fruit development period. The treatment effect for fruit diameter and fruit development period remained significant though less than before, indicating that although some of the difference between treatments was due to the difference in seed number, it was not the only factor that affected these variables. Seed number as covariate completely eliminated treatment differences in fruit weight. When fruit set was used as a covariate, the treatment effect for all the fruit characteristics except fruit weight and TSS remained highly significant (Table 3). Our results for 'Star' are in contrast with Lyrene and Sherman (2000) who found that 'Star' benefits from cross-pollination with other tetraploid southern highbush cultivars and will yield a smaller crop when self-pollinated.

For 'Jewel', fruit set was high for all the treatments (57.0% - 82.4%), and there were no significant differences between treatments (Table 4). Berries of the un-pollinated treatment contained significantly fewer seeds than berries of the other treatments, weighed significantly less than after cross-pollination with 'Emerald', 'Star' or 'Misty', and had a smaller diameter and longer development period than all the cross-pollination treatments. 'Misty' was the only cross-pollinator that significantly increased fruit weight and diameter, and shortened the fruit development period compared to self-pollination. When seed number was used as a covariate it was significant for all fruit characteristics except TSS indicating that in positive effect on fruit size and shorter fruit development period was due to the increase in seed number. The treatment effect for fruit weight was the only treatment effect that remained significant (though less than before). Fruit set as covariate was highly significant for all the fruit characteristics. The treatment effect for fruit development period was the only treatment effect that was not significant anymore when fruit set was used as a covariate, indicating that the treatment effect and fruit set both contributed towards the differences between the treatments (Table 4).

At the time the first 'Emerald' florets opened, only 'Snowchaser' and 'Misty' florets were available for cross-pollination. Fruit set when using 'Emerald' pollen in this trial resulted in 73.9% set which differed significantly from no pollination (25.9%) and cross-pollination with 'Snowchaser' (37.0%) and 'Misty' (47.8%) (Table 5). Bird netting was put in place only after early berries had ripened and some berries might have been lost to birds. This might explain the higher fruit set percentage for the self-pollinated treatment where the bulk of the crop was picked after the bird netting was in place. Cross-pollination with 'Snowchaser' and 'Misty' significantly increased fruit weight, diameter and seed number, and resulted in the shortest fruit development period compared to the self- and un-pollinated treatments. There were no significant differences between the two cross-pollination treatments. Seed numbers were similar to those obtained in 'Bluecrisp' (Table 2). When seed

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number was used as a covariate it was significant for fruit weight, diameter and fruit development period, indicating that the positive effect of cross-pollination was due to higher seed numbers. Fruit set as a covariate was only significant explaining fruit development period; however the treatment effect remained highly significant indicating that fruit set was not the only factor influencing the fruit development period (Table 5).

During the second 'Emerald' trial, 'Misty' was again included as cross pollinator, this time compared to 'Jewel', 'Bluecrisp' and 'Star' (Table 6). The un-pollinated treatment resulted in fruit set of only 32.2%, but did not differ significantly from cross-pollination with 'Star' (47.2%) and 'Misty' (40.9%) (Table 6). Since the bird netting was in place prior to harvesting of the 'Misty' treatment, it appears that the low fruit set observed when cross-pollinating with 'Misty' in the first trial might have been due to an incompatibility mechanism rather than to bird damage. Cross-pollination with 'Jewel' resulted in the highest fruit set (75.8%), but did not differ significantly from self-pollination (67.1%) and cross-pollination with 'Bluecrisp' (62.6%) and 'Star' (47.2%). The un-pollinated treatment significantly decreased seed number compared to self-pollination and cross-pollination with 'Misty' and 'Jewel'. No-pollination significantly decreased fruit diameter and weight compared to cross-pollination with 'Misty' and 'Jewel' and together with self-pollination significantly increased the fruit development period compared to all the cross-pollination treatments. Cross-pollinating 'Emerald' with 'Misty' and 'Jewel' resulted in the largest fruit, but not significantly larger than self–pollination or cross-pollination with 'Star'. Pollination with 'Misty' resulted in the highest seed number (23). A similar increase in seed number, fruit size and a shorter fruit development period with a decrease in fruit set — as observed in our trials following cross-pollination of 'Emerald' with 'Misty' and 'Snowchaser' — was reported when other southern highbush blueberries were cross-pollinated (Gupton, 1984). Self-pollination resulted in the second highest seed number, but not significantly different compared to cross-pollination with 'Jewel', 'Bluecrisp' and 'Star'. Of the cross-pollination treatments, 'Misty' resulted in the earliest ripening, but ripening was not significantly advanced compared to cross-pollination with 'Jewel', which again did not significantly advanced ripening compared to cross-pollination with 'Star' and 'Bluecrisp'. When seed number was used as a covariate it was significant explaining fruit weight, diameter and development period. The treatment effects for fruit weight and diameter were no longer significant indicating that the difference between treatments in fruit weight and diameter was due to the difference in seed numbers (Table 6). Although seed number as a covariate was significant explaining fruit development period, the treatment effect remained significant, indicating that other factors in addition to seed number are responsible for the difference in fruit development period between treatments. Though fruit set as a covariate was only significant for fruit weight, when it was used, the treatment effect for fruit weight

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and diameter was no longer significant indicating that the difference in fruit weight and diameter between the treatments is partially due to the difference in set (Table 6).

For ’Snowchaser’, fruit set was the highest in the un-pollinated treatment (78.1%), but it did not differ significantly from cross-pollination with ‘Misty’ (52.3%). Cross-pollination with ‘Misty’ did not differ from self-pollination (41.2%) while self-pollination did not differ significantly from cross-pollination with ‘Emerald’ (12.6%) (Table 7). As in the first ‘Emerald’ trial, harvest of self- as well as cross-pollinated treatments started two weeks before the bird netting was installed. This could explain the low fruit set obtained for all treatments except for the un-pollinated treatment that was picked after the net was in place. The un-pollinated treatment resulted in the smallest fruit, fewest seeds and the longest fruit development period. Cross-pollination with ‘Emerald’ resulted in the heaviest fruit, largest fruit diameter and the shortest fruit development period compared with other treatments except for self-pollination. Cross-pollination with ‘Misty’ did not improve any of the fruit characteristics compared to self-pollination. The seed number was the highest when ‘Snowchaser’ was self-pollinated (44), but not significantly higher compared to cross-pollination with ‘Emerald’ (33). Cross-pollination with ‘Misty’ resulted in an intermediate seed number (28) (Table 7). Seed number as a covariate was significant for fruit weigh, diameter and development period. The significance level for the treatment effect decreased for all these fruit attributes indicating that differences between the treatments were caused by the difference in seed number. Fruit set as a covariate was significant for fruit weight, seed number and development period. The treatment effect for all these remained significant indicating that both fruit set and other aspect must account for the differences between cultivars. ‘Snowchaser’ is the only cultivar where self-pollination resulted in the highest seed number. This, together with the fact that the self-pollinated fruit equalled cross-pollinated berries with regards to quality, indicates that ‘Snowchaser’ is self-compatible.

There was no significant difference in the TSS of berries at harvest in any of the trials (Tables 2 to 6). This is in contrast with the increase in TSS found with an increase in brown viable seeds by Kobashi *et al.* (2002) in northern highbush blueberries. The correlation between seed number and TSS were significant only for ‘Bluecrisp’ and ‘Jewel’ (Table 10). The R-square value for both these cultivars are negative, indicating that TSS increased as seed number decreased.

According to Yarborough (2006), a fruit set of 80% is considered to be a full crop, although one suspects this value may differ between cultivars because of the differences in bloom intensity. In our trials, un-pollinated ‘Emerald’ set poorly, whereas self-pollination resulted in good set. This suggests that pollinators such as bees are important for good fruit set in ‘Emerald’. This is in agreement with

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Yarborough (2006) according to whom pollinators like bees are important for pollination. For 'Jewel', 'Star' and 'Snowchaser', fruit set for the un-pollinated treatments were 57%, 65.1% and 78%, respectively (Table 3, 4 and 7). This seems to indicate that these cultivars will set adequate crops without pollination, or that some self-pollination occurred as florets used in our trials were not emasculated and some seeds did develop (8, 4 and 13 in 'Jewel', 'Star' and 'Snowchaser', respectively). Although the anatomy of blueberry flowers is not conducive to autogamy, the ability of some southern highbush blueberries to set enough fruit with few seeds when selfing these hybrids have been reported (Gupton, 1984). A potential negative effect arising from selfing is the presence of many small, late maturing berries in the crop (Gupton, 1984) as was seen in our trials as berries of the un-pollinated treatment in all the cultivars matured last, had the lowest fruit weight, smallest fruit diameter and the least number of seeds regardless of the fruit set. For 'Bluecrisp' and 'Emerald', yield will be low in the absence of pollinators such as bees while in the case of 'Star', 'Jewel' and 'Snowchaser', a delayed harvest of a large number of small berries could still be achieved.

Increases in fruit set have been reported when cross-pollinating the southern highbush blueberry 'Sharpblue' (Lyrene, 1989) and various southern highbush selections (Gupton, 1984; Chavez and Lyrene, 2009). Other researchers reported that self-pollination of southern highbush blueberries resulted in fruit set better than or equal to cross-pollination (Gupton, 1984; Lang and Danka, 1991; Danka *et al.*, 1993; Gupton and Spiers, 1994). According to Lang and Danka (1991), one of the major factors influencing the results, is the pollination technique that differs between the trials. Multiple pollen deposition by bees instead of a single pollen application by hand improves fruit set (Lang and Danka, 1991).

In our trials, Bluecrisp was the only cultivar where fruit set increased significantly with cross-pollination (Table 2). Self-pollinating 'Bluecrisp' resulted in a fruit set of only 28.1% (Table 2). Cross-pollinating 'Bluecrisp' with 'Star' and 'Misty' increased the fruit set to ca. 65%, and therefore, with regards to fruit set, these two cultivars can be recommended as cross-pollinators as long as bloom periods overlap.

In all the other trials, self-pollination resulted in fruit set equal to or better than cross-pollination. In general, fruit set was highest in 'Jewel' and 'Star' (Table 3 and 4). Taking into account that florets were hand pollinated only once, these two cultivars are likely to achieve 80% fruit set with self- or outcross pollen if pollinators deposit pollen multiple times under field conditions. In both the 'Emerald' trials, cross-pollination with any cultivar except 'Jewel', resulted in a fruit set lower than

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self-pollination (Table 5 and 6). With regards to fruit set, ‘Jewel’ and ‘Bluecrisp’ would be recommended as cross-pollinators with fruit set of 75.8% and 62.6% respectively.

Since none of the florets in our trial were emasculated, the outcross pollen applied by hand and the little pollen from the floret itself contributed to the seed number. Lyrene (1989) reported intermediate seed numbers when mixed pollen treatments were compared to cross- and self-pollination. In commercial plantings, 100% cross-pollination can never be achieved and therefore the mix pollen treatment is a better representation of what is happening in the field (Lyrene, 1989).

In our trials, the Pearson correlation coefficients for fruit weigh and diameter with seed number were highly significant for all the cultivars, indicating that the increase in fruit size was directly correlated to an increase in seed number (Table 8 and 9) as was also indicated by the covariate analysis. A negative correlation for all the cultivars (pooled over all treatments) was found when seed number and fruit weight were plotted against the harvest intervals (Figure 1 and 2). Therefore, fruit with the most seeds will be larger and mature earlier.

For most cultivar pollinator combinations, cross-pollination provided no extra benefit with regards to seed number and fruit size compared to self-pollination. This was the case when cross-pollinating ‘Star’ with any cultivar (Table 3), ‘Jewel’ with ‘Bluecrisp’, ‘Emerald’ and ‘Star’ (Table 4), ‘Emerald’ with ‘Jewel’, ‘Bluecrisp’ and ‘Star’ (Table 6), and ‘Snowchaser’ with ‘Emerald (Table 7). Danka *et al.* (1993) also did not find a difference in fruit characteristics when they cross-pollinated ’Gulfcoast’ with various southern highbush cultivars. However, it is important to note that although cross-pollination was of no apparent benefit, it was as good as self-pollination.

Seed number, fruit weight and diameter benefitted from cross-pollination when cross-pollinating ‘Bluecrisp’ with any cultivar (Table 2) and cross-pollinating ‘Emerald’ with ‘Misty’ and ‘Snowchaser’ (Table 5 and 6). For ‘Bluecrisp’ and the first ‘Emerald’ trial, the Pearson correlation coefficients for fruit weigh and diameter with seed number were the strongest. Respectively 78.9% and 72.4% of the increase in fruit size could be explained by the increase in seed number. Cross-pollinated fruit in both trials contained a significantly higher seed number indicating that pollen source has an influence on seed number (Table 2 and 5). This was also indicated with seed number as a covariate (Table 2 and 5). An increase in seed number, fruit size and a shorter fruit development period when southern highbush blueberries are cross-pollinated was reported by various researchers (Gupton, 1984; Lyrene, 1989; Lang and Danka, 1991; Gupton and Spiers, 1994; Huang *et al.*, 1997;

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Kobashi *et al.*, 2002; Chavez and Lyrene 2009). Haung *et al*. (1997) reported that southern highbush blueberry fruit growth is intimately associated with ovule development which is affected by the pollen source. A large number of seeds may be a greater source of plant growth regulators and therefore the berry becomes a stronger sink and fruit size increases (Haung *et al*., 1997). For these treatments, cross-pollination led to an increase in seed number and fruit size and therefore inter-planting would be highly recommended.

Fruit weight and -diameter increased in response to cross-pollination of ‘Jewel’ with ‘Misty’ even though cross-pollination did not affect seed number. Lang and Danka (1991) reported that the genetic background of the pollen source influences the effect of the seeds on fruit size. In all the instances where cross-pollination increased fruit size and seed number, berries also had a significantly shorter development period. Therefore, in agreement with previous research, it appears that an increase in seed number resulting from cross-pollination accelerates fruit development (Gupton, 1984; Lyrene, 1989; Lang and Danka, 1991; Lang and Parrie, 1992; Gupton and Spiers, 1994; Huang *et al.*, 1997; Chavez and Lyrene, 2009). A shorter stage III development period was reported by Haung *et al.* (1997) with an increase in seed number in cross-pollinated southern highbush blueberries. Even though cross-pollinating ‘Star’ with ‘Bluecrisp’ (Table 3) and ‘Emerald’ with ‘Jewel’, ‘Bluecrisp’ and ‘Star’ (Table 6) did not increase fruit size and seed number compared to self-pollination, it did result in a shorter fruit development period. Therefore the genetic derivation of the seeds and not necessarily the seed number had the influence on the fruit development period.

Even though cross-pollination did not always significantly improve fruit quality or advance harvest maturity, it was always at least equal to self-pollination. This is a clear indication that inter-planting cultivars will not be wrong, as it will only result in the same or even higher yield.

Our results confirm that cross-pollination for ‘Bluecrisp’, ‘Star’, ‘Emerald’ and ‘Jewel’ is beneficial (Lyrene, 1999; Lyrene and Sherman, 2000; Lyrene, 2001a; Lyrene, 2001b). However, under local growing conditions, cross-pollination was more beneficial for ‘Bluecrisp’ and ‘Emerald’ than for ‘Star’ and ‘Jewel, which will both yield satisfactory crops when self-pollinated. In the case of the cultivar Snowchaser, cross-pollination was of little benefit and we therefore recommend solid block plantings, which is contrary to Lyrene (2008a) who found that cross-pollinators are needed.

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Conclusion

When making recommendations regarding cross-pollination, it is firstly important that the bloom period of the cultivars overlap. From the one year's data it seems that 'Bluecrisp' is self-incompatible and cross-pollination with 'Misty' and 'Emerald' would be recommended. 'Misty' can be recommended as cross-pollinator for 'Jewel' although all treatments except the un-pollinated treatment gave satisfactory yields. Self-pollinated 'Star' would yield a satisfactory crop, but an increase in fruit size without a big reduction in fruit set can be obtained when cross-pollinated with 'Emerald'. From all the trials, the fruit set of 'Emerald' differed the most between treatments, indicating this cultivar will set poorly under adverse pollination conditions. Although fruit set was highest in 'Emerald' following self-pollinating, cross-pollination with 'Jewel', 'Misty' and 'Bluecrisp' is recommended when fruit size and early maturing fruit is important. 'Snowchaser' is the only cultivar where self-pollination performed better than cross-pollination and therefore no cross-pollinators are recommended.

Literature Cited

Chavez, D.J. and P.M. Lyrene. 2009. Effects of -pollination and cross-pollination of Vaccinium darrowii (Ericaceae) and other low-chilll blueberries. HortScience 44(6):1538-1541.

Danka, G.D., G.A. Lang and C.L. Gupton. 1993. Honey bee (Hymenoptera : Apidae) visits and pollen source effects on fruiting of 'Gulfcoast' southern highbush blueberry. J. Econ. Entomol. 86(1):131-136.

Dogterom, M.H., M.L. Winston and A. Mukai. 2000. Effect of pollen load size and source (self, outcross) on seed and fruit production in southern highbush blueberry cv. 'Bluecrop' (Vaccinium corrybosum cv; Ericaceae). Am. J. Bot. 87:1584-1591.

Eck, P. 1988a. Cultural practices, p.135-169. In: Eck, P. (eds), Blueberry science. Rugters university press, New Brunswick and London.

Eck, P., 1988b. Fruit development, p.66-90. In: Eck, P. (eds), Blueberry science. Rugters university press. London.

Gupton, C.L. 1984. Effect of pollen source on fruit characteristics of low-chilling highbush type blueberries. HortScience 19(4):531-532.

Gupton, C.L. and J.M. Spiers. 1994. Interspecific and intraspecific pollination effects in rabbiteye and southern highbush blueberries. HortScience. 29:324-326.

Huang, Y.H., C.E. Johnson, G.A. Lang and M.D. Sundberg. 1997. Pollen sources influence early fruit growth of southern highbush blueberry. J. Amer. Soc. Hort. Sci. 122(5):625-629.

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Kobashi, K., S. Sugaya, M. Fukushima and S. Iwahori. 2002. Sugar accumulation in highbush blueberry fruit as affected by artificial pollination with different pollen sources in relation to seed number, invertase activities and ABA content. Acta Hort. 574:47-51.

Lang, G.A. and R.G. Danka. 1991. Honey bee mediated cross- versus self-pollination of ‘Sharpblue’ blueberry increases fruit size and hastens ripening. J. Amer. Soc. Hort. Sci. 116:770-773.

Lang, G.A. and E.J. Parrie. 1992**.** Pollen viability and vigor in hybrid southern highbush blueberries (Vaccinium corymbosum L. x spp.). HortScience 27:425-427.

Lyrene, P.M. 1989. Pollen source influences fruiting of ‘Sharpblue’ blueberry. J. Amer. Soc. Hort. Sci. 114:995-999.

Lyrene, P.M. 1999. Blueberry plant named ‘Bluecrisp’. Patent No: US PP11,033 P2. http://www.freepatentsonlin.com/PP11033.

Lyrene, P.M. and B. Sherman. 2000. ‘Star’ southern highbush blueberry. HortScience 35(5):956-957.

Lyrene, P.M. 2001a. Blueberry plant named ‘Jewel’. Patent No: US PP11,807 P2. http://www.freepatentsonlin.com/PP11807.pdf

Lyrene, P.M. 2001b. Blueberry plant named ‘Emerald’. Patent No: US PP12,165 P2. http://www.freepatentsonlin.com/PP12165.pdf

Lyrene, P.M. 2008a. Blueberry plant named ‘Snowchaser’. Pub. No: US 2008/0196128 P1. http://www.freepatentsonlin.com/20080196128.pdf

Lyrene, P.M. 2008b. ‘Emerald’ southern highbush blueberry. HortScience 43(5):1606-1607.

Mackenzie, K.E. 2009. Pollination practices and the use of bees in *Vaccinium* crops. J. Amer. Soc. Acta Hort. 810:527-538.

Yarborough, D.E. 2006. Blueberry pruing and pollination, p. 75-83. In: N.F. Childers (ed.), Blueberries for growers, gardeners, promoters. Horticultural Publications. Gainesville. Florida.

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Table 1: Trial layout for the different cultivars, pollen source, dates of closing the clusters as well as the date of pollination.

Trial	Female parent cultivar	Outcross pollen source	Date of closing the clusters	Date of hand pollination
Trial 1	Snowchaser	Misty and Emerald	29/07/2010	05/08/2010
Trial 2	Emerald	Misty and Snowchaser	29/07/2010	05/08/2010
Trial 3	Emerald	Misty, Jewel, Bluecrisp and Star	05/08/2010	12/08/2010
Trial 4	Bluecrisp	Misty, Jewel, Emerald and Star	20/08/2010	27/08/2010
Trial 5	Star	Jewel, Bluecrisp and Emerald	20/08/2010	27/08/2010
Trial 6	Jewel	Misty, Jewel, Bluecrisp, Star and	20/08/2010	27/08/2010

Table 2: The effect of cross-pollination on fruit set percentage, fruit weight, fruit diameter, seed number and fruit development period in the cultivar Bluecrisp.

Pollination treatment/ cultivar	Fruit set percentage	Average berry weight (g)	Average fruit diameter (mm)	Average brown seed number	Average fruit development period	Total soluble solids
No-Pollinator	3.3 c[z]	1.53 b	12.8 b	14 b	87 a	14.1[NS]
Blue-Crisp (self)	28.1 bc	1.85 b	14.1 b	16 b	86 a	13.9
Star	73.7 a	2.58 a	16.1 a	35 a	77 b	13.8
Emerald	53.2 ab	2.48 a	16.2 a	29 a	77 b	14.3
Jewel	57.5 a	2.34 a	15.9 a	31 a	79 b	14.5
Misty	66.8 a	2.59 a	16.5 a	34 a	78 b	14.4
Significance level	*0.0001*	*0.0008*	*0.0002*	*0.0004*	*0.0001*	*0.9091*
LSD	*25.614*	*0.4824*	*1.4299*	*10.52*	*3.4731*	*1.8797*
Covariate Seed	*0.0010*	*<.0001*	*<.0001*		*<.0001*	*0.0382*
Treatment	*0.1320*	*0.3454*	*0.1051*		*0.0001*	*0.2537*
Covariate set		*0.0003*	*0.0002*	*0.0004*	*0.0022*	*0.1685*
Treatment		*0.0148*	*0.0030*	*0.0091*	*<.0001*	*0.8427*

Categories with different letters differ significantly at $p < 0.05$ (LSD test)

[NS] no significant differences between categories

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Table 3: The effect of cross-pollination on fruit set percentage, fruit weight, fruit diameter, seed number and fruit development period in the cultivar Star.

Pollination treatment/ cultivar treatment	Fruit set percentage	Average berry weight (g)	Average fruit diameter (mm)	Average brown seed number	Average fruit development period	Total soluble solids (ºBRIX)
No-Pollinator	65.1 NS	1.74 b z	13.9 b	8 c	77 a	13.0 NS
Star (self)	100.0	2.01 ab	15.4 a	15 ab	73 b	11.5
Emerald	92.4	2.29 a	16.5 a	20 a	71 bc	12.2
Blue-Crisp	73.1	2.21 a	16.6 a	15 b	69 c	12.8
Jewel	78.7	2.08 a	15.6 a	15 b	71 bc	12.9
Significance level	*0.1774*	*0.0288*	*0.0008*	*0.0009*	*0.0002*	*0.1218*
LSD	*31.326*	*0.3377*	*1.2242*	*4.8291*	*3.0283*	*1.2919*
Covariate Seed	*0.3802*	*0.0123*	*0.0045*		*0.0068*	*0.1439*
Treatment	*0.3362*	*0.2496*	*0.0137*		*0.0022*	*0.2007*
Covariate set		*0.6157*	*0.2305*	*0.5298*	*0.1147*	*0.1495*
Treatment		*0.0509*	*0.0015*	*0.0027*	*0.0003*	*0.3219*

z categories with different letters differ significantly at $p < 0.05$ (LSD test)

NS no significant differences between categories

Table 4: The effect of cross-pollination on fruit set percentage, fruit weight, fruit diameter, seed number and fruit development period in the cultivar Jewel.

Pollination treatment/ Cultivar	Fruit set percentage	Average berry weight (g)	Average fruit diameter (mm)	Average brown seed number	Average fruit development period	Total soluble solids (ºBRIX)
No-pollinator	57.0 NS	2.19 c z	15.0 c	4 b	79 a	12.4 NS
Jewel (self)	70.4	2.38 bc	15.8 bc	9 a	76 ab	11.8
Blue-Crisp	82.4	2.50 bc	16.1 ab	9 a	74 bc	12.2
Emerald	69.9	2.58 ab	16.2 ab	10 a	73 bc	11.0
Star	69.7	2.67 ab	16.3 ab	11 a	74 bc	11.7
Misty	69.7	2.90 a	17.0 a	12 a	72 c	11.3
Significance level	*0.6566*	*0.0057*	*0.0057*	*0.0160*	*0.0290*	*0.1515*
LSD	*25.19*	*0.3549*	*0.9699*	*4.3658*	*4.5142*	*1.103*
Covariate Seed	*0.0040*	*0.0100*	*0.0003*		*0.0003*	*0.1782*
Treatment	*0.9037*	*0.0407*	*0.1108*		*0.1176*	*0.2682*
Covariate set		*0.0020*	*0.0001*	*0.0004*	*<.0001*	*0.0725*
Treatment		*0.0432*	*0.0449*	*0.0003*	*0.0534*	*0.3656*

z categories with different letters differ significantly at $p < 0.05$ (LSD test)

NS no significant differences between categories

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Table 5: The effect of cross-pollination on fruit set percentage, fruit weight, fruit diameter, seed number and fruit development period in the first 'Emerald' trial.

Pollination treatment/ Cultivar	Fruit set percentage		Average berry weight (g)		Average fruit diameter (mm)		Average brown seed number		Average fruit development period		Total soluble solids (ºBRIX)
No-Pollinator	25.9	b[z]	2.01	b	15.8	b	7	b	75	a	12.9[NS*]
Emerald (self)	73.9	a	1.99	b	15.5	b	11	b	72	a	12.1
Snowchaser	37.0	b	2.66	a	17.4	a	31	a	56	b	13.5
Misty	47.8	b	2.85	a	17.7	a	29	a	57	b	12.0
Significance level	*0.0020*		*0.0010*		*0.0041*		*<.0001*		*<.0001*		*0.4258*
LSD	*24.21*		*0.4857*		*1.3862*		*10.352*		*6.4252*		*2.1368*
Covariate Seed	*0.5770*		*<.0001*		*0.0002*				*<.0001*		*0.3908*
Treatment	*0.0155*		*0.2190*		*0.4141*				*0.0002*		*0.4128*
Covariate set			*0.6676*		*0.3565*		*0.4879*		*0.0442*		*0.7692*
Treatment			*0.0013*		*0.0066*		*<.0001*		*<.0001*		*0.4085*

[z] categories with different letters differ significantly at $p < 0.05$ (LSD test)

[NS] no significant differences between categories

Table 6: The effect of cross-pollination on fruit set percentage, fruit weight, fruit diameter, seed number and fruit development period in the second 'Emerald' trial.

Pollination treatment/ Cultivar	Fruit set percentage		Average berry weight (g)		Average fruit diameter (mm)		Average brown seed number		Average fruit development period		Total soluble solids (ºBRIX)
No-Pollinator	32.2	c	1.77	b	14.9	c	4	c	90	a	12.7[NS*]
Emerald (self)	67.1	ab	2.06	ab	15.8	abc	15	b	90	a	12.6
Misty	40.9	bc	2.41	a	16.7	ab	23	a	79	c	12.4
Jewel	75.8	a	2.57	a	17.3	a	15	b	81	bc	13.0
Blue-Crisp	62.6	ab	1.89	b	15.5	bc	8	cb	85	b	12.9
Star	47.2	abc	2.10	ab	15.9	abc	7	bc	84	b	12.5
Significance level	*0.0110*		*0.0224*		*0.0297*		*0.0004*		*0.0002*		*0.7543*
LSD	*30.31*		*0.5183*		*1.5118*		*7.9539*		*5.0039*		*0.9972*
Covariate Seed	*0.3601*		*0.0002*		*0.0003*				*<.0001*		*0.7129*
Treatment	*0.0147*		*0.1423*		*0.1912*				*0.0025*		*0.6223*
Covariate set			*0.0478*		*0.0754*		*0.3133*		*0.8906*		*0.3731*
Treatment			*0.0720*		*0.1015*		*0.0005*		*0.0003*		*0.8023*

[z] categories with different letters differ significantly at $p < 0.05$ (LSD test)

[NS] no significant differences between categories

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Table 7: The effect of cross-pollination on fruit set percentage, fruit weight, fruit diameter, seed number and fruit development period for cultivar Snowchaser.

Pollination treatment/ cultivar	Fruit set percentage		Average berry weight (g)		Average fruit diameter (mm)		Average brown seed number		Average fruit development period	
No-Pollinator	78.1	a[z]	0.85	c	10.4	b	13	c	75	a
Snowchaser (self)	41.2	bc	1.31	ab	13.0	a	44	a	58	bc
Emerald	12.6	c	1.55	a	13.3	a	33	ab	55	c
Misty	52.3	ab	1.19	bc	11.7	ab	28	b	65	b
Significance level	*0.0120*		*0.0023*		*0.0045*		*<0.0001*		*<.0001*	
LSD	*32.1*		*0.3399*		*1.725*		*11.604*		*7.7987*	
Covariate Seed	*0.1320*		*<.0001*		*<.0001*				*<.0001*	
Treatment	*0.0734*		*0.0961*		*0.4344*				*0.0242*	
Covariate set			*0.0101*		*0.0561*		*0.0446*		*0.0014*	
Treatment			*0.0217*		*0.0176*		*0.0002*		*0.0018*	

[z] categories with different letters differ significantly at $p < 0.05$ (LSD test)

[NS] no significant differences between categories

Table 8: Pooled correlation (R^2) between seed number and fruit weight (g) over all the treatments within a cultivar.

Cultivar	R^2	Significance level
Bluecrisp	0.78	<.0001
Jewel	0.30	<.0001
Star	0.49	<.0001
Emerald 1	0.72	<.0001
Emerald 2	0.55	<.0001
Snowchaser	0.62	<.0001

Table 9: Pooled correlation (R^2) between seed number and fruit diameter (mm) over all the treatments within a cultivar.

Cultivar	R^2	Significance level
Bluecrisp	0.74	<.0001
Jewel	0.42	<.0001
Star	0.48	<.0001
Emerald 1	0.70	<.0001
Emerald 2	0.51	<.0001
Snowchaser	0.50	0.0006

Table 10: Pooled correlation (R^2) between seed number and total soluble solids over all the treatments within a cultivar.

Cultivar	R^2	Significance level
Bluecrisp	-0.16	0.0212
Jewel	-0.16	0.0002
Star	-0.00	0.9791
Emerald 1	0.03	0.8498
Emerald 2	-0.10	0.1143

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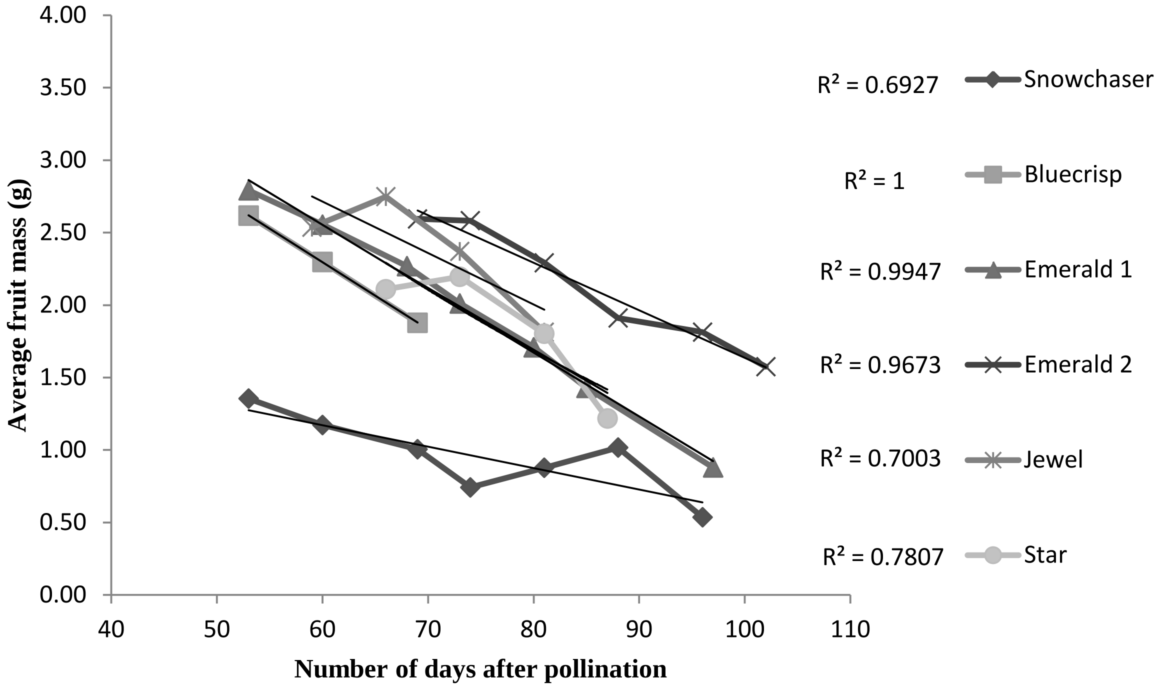

Figure 1: Relationship between fruit weight and harvest interval for the different cultivars.

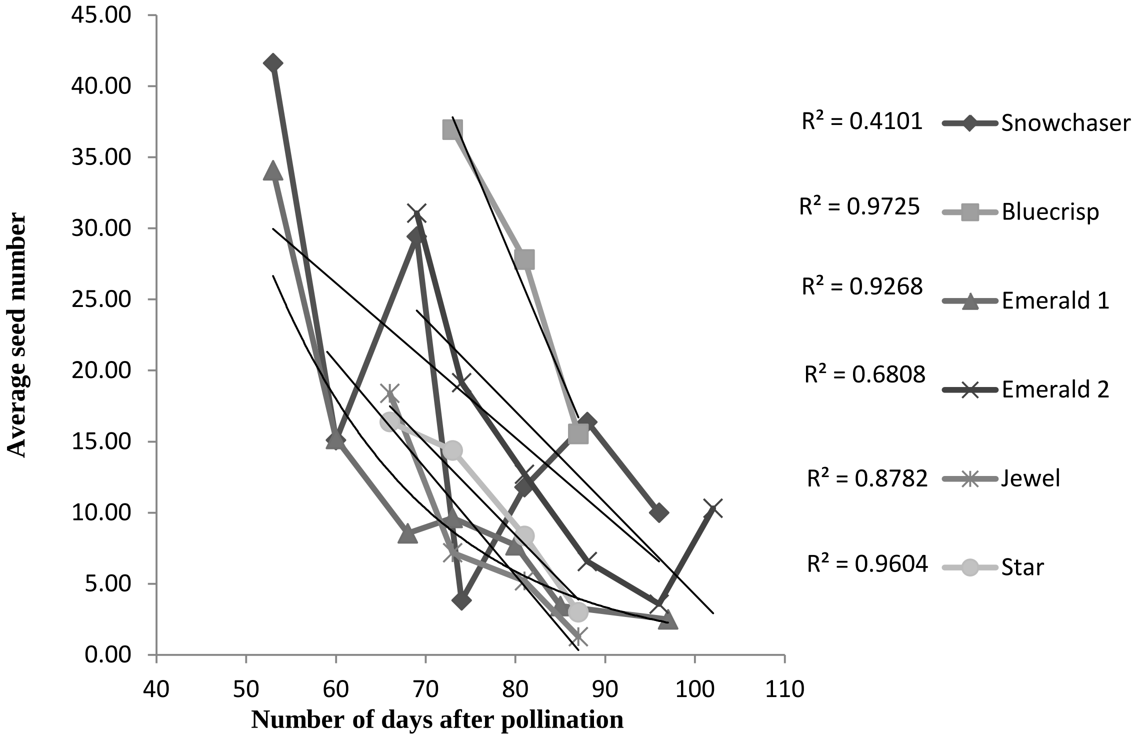

Figure 2: Relationship between seed number and harvest interval for all the cultivars.

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Paper 2: Developing pruning strategies for southern highbush blueberries 'Star', 'Emerald' and 'Jewel: Intensity and combinations of pruning cuts.

Abstract. The southern highbush blueberry (SHB) cultivars Star, Emerald and Jewel were recently introduced to South Africa. Most pruning research has been conducted on rabbiteye and northern highbush blueberry cultivars, evaluating winter pruning effects. Up to five months of the active growing season are left after harvest of SHB under South African growing conditions in which reproductive laterals can develop for the following season. Summer pruning is currently replacing winter pruning for these cultivars. Experiments to establish the effect of pruning severity on total yield, fruit quality and time of harvest were conducted at three sites in the Western Cape, South Africa. The experiment comprised five treatments consisting of an unpruned control (T1), "severe pruning" (T2), "standard pruning" (T3), "standard pruning plus heading" (T4) and a "light pruning" action (T5). We established that the severity of summer pruning on SHB is a compromise between total yield and desired berry size. Summer pruning reduced total vegetative growth and the total number of one-year-old shoots, but increased individual shoot length. Later termination of growth on more vigorous laterals resulted in a delay in flower bud differentiation and therefore a delay in harvest. Summer pruning also increased berry weight and diameter by reducing total yield, but also by developing better quality bearing laterals. An increase in the severity of pruning increased the extent to which the plants responded.

Introduction

The South African blueberry industry is focused on exports and supplies the northern hemisphere in their off-season (Greeff and Greeff, 2006). The highest income is obtained from September until the end of November, spring in the southern hemisphere. Growing conditions in the Western Cape are ideal to cultivate the cultivars Star, Jewel and Emerald to serve this particular market window (personal communication McKenzie, 2010).

Southern highbush blueberries are semi-deciduous shrubs that reiterate by means of shoots that arise from buds located on the crown of the plant. A shoot is called a cane once secondary growth has taken place. Shoot growth of the blueberry is sympodial and episodic. Reproductive buds differentiate basipetally along the shoot at the end of summer from axillary buds on the distal section of current season growth (Gough, 1994). Axillary buds lower down on the shoot remain vegetative. In summer, these vegetative buds will produce lateral shoots that become the bearing wood for the

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following season (Gough, 1994). Each succeeding season, these lateral shoots will produce more lateral shoots that become progressively thinner and weaker. Numerous thin laterals are less productive than vigorous thick laterals (Shutak and Muracci; 1966, Gough, 1994). Thus pruning is very important to stimulate new cane development and strong lateral shoots (Shutak and Muracci; 1966, Gough, 1994; Yarborough, 2006).

The effect of pruning severity and different winter pruning strategies on northern highbush and rabbiteye blueberries are well documented (Gough, 1983; Siefker and Hanock, 1987; Jansen, 1997; Strik *et al.*, 2003; Krewer *et al.*, 2004), but little research has been reported on summer pruning of southern highbush blueberries (Bañados *et al.*, 2009).

In the Northern hemisphere, northern highbush and rabbiteye blueberry plants are usually pruned November until March when the plants are completely dormant (Eck, 1988). In South Africa, up to five months of the active growing season is left after completion of harvest of the early ripening cultivars Jewel, Star and Emerald in November (personal communication McKenzie, 2010).

Pruning is always a compromise between total yield and desired berry size (Yarborough, 2006). Winter pruning reduces the total vegetative growth, but individual shoot length, leaf size and new cane development are increased. Winter pruning also decreases the total number of reproductive buds and thus increases berry size. Increase in the severity of pruning results in stronger regrowth that give rise to larger and better quality berries. Winter pruning hastens and concentrates the harvest and can result in higher prices on the early market (Yarborough, 2006). According to Gough (1994), three aspects of winter pruning should be kept in mind. Firstly, pruning must always be light enough to ensure a heavy crop for the current season. Secondly, pruning must be severe enough to ensure large berry size. And thirdly, pruning must be severe enough to ensure enough good quality bearing wood for the next season’s crop.

In this paper we report on the effect of the severity of summer pruning on new shoot development and berry quality of the southern highbush cultivars Star, Emerald and Jewel under South African conditions.

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Material and methods

The trials were conducted on ‘Star’, ‘Emerald’ and ‘Jewel’ at three different locations during the 2009/2010 growing season in the Western Cape, South Africa.

Trial sites: The first site is on the farm Teeland (S 32^0 56’ 49.26”; E 19^0 04’ 41.33”; 739 m. a. s. l.) on top of the Groot Winterhoek Mountains in the Porterville district. The area accumulated 1300 chill units from 1 May 2009 until 31 August 2009 according to the Highbush model (Eck, 1988). The plants were planted in open soil in Haygrowth tunnels covered with 20% white shade cloth in 2006 at a spacing of 2.5 × 1.5 m after two years in quarantine. Two rows of ‘Star’ alternate with either a row of ‘Jewel’ or ‘Emerald’.

The second site is on the farm Lushof (S 33^0 09’ 37.10”; E 19^0 00’ 27.77”; 86 m. a. s. l.) at the foot of the Groot Winterhoek Mountains in the Porterville district. The area accumulated 664 chill units (Highbush model) from 1 May 2009 until 31 August 2009. The plants were planted in open soil in Haygrowth tunnels covered with 30% black shade cloth in 2008 at a spacing of 2.5 × 1.5 m after two years in quarantine. For ‘Jewel’, one ‘Emerald’ plant was inter-planted every tenth plant down the row for cross-pollination, and for ‘Emerald,’ a ‘Jewel’ plant was inter-planted every tenth plant.

The third site is on the farm Gelukstroom (S 34^0 05’ 25.95”; E 19^0 10’ 22.76”; 358 m. a. s. l.) in the Vyeboom district. The area accumulated 741 chill units (Highbush model) from 1 May 2009 until 31 August 2009. The plants were planted in the open field in 2008 at a spacing of 3 × 1.5 m after two years in quarantine. Two rows of ‘Star’ alternating alternate with two rows of ‘Jewel’.

Treatments and trial design: The trial comprised four pruning treatments and an unpruned control (T1) (Figure 1). A randomised complete block design was used, with 10 blocks per cultivar per site and two plants per plot. In treatment 2 (T2) (“severe pruning”), all shoots were headed back either to 35 cm above the ground or to a lateral thicker than 6 mm. The lateral was then headed back to 20 cm from the inception (Figure 2). Old unproductive canes, old bearing wood and low growing branches were removed. In treatment 3 (T3) (“standard pruning”), all unproductive canes, old bearing wood and low growing weak branches were removed. Canes were headed back to between 3 and 5 productive laterals. If there were no productive laterals on the cane it was headed back to 35 cm (Figure 3). The only difference between T3 and treatment 4 (T4) (“standard pruning plus heading”) was that in T4 all the productive laterals left on the cane were headed back by a third (Figure 4).

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Treatment 5 (T5) ("light pruning") was a "light pruning" treatment where only old bearing wood was removed by heading the laterals to just below the bearing section (Figure 5).

Date of treatment application: Pruning was performed just after harvest was completed on the following dates: **Lushof**, 'Emerald' 4 December 2009; 'Jewel' 5 December 2009; **Gelukstroom**, 'Star' 14 December 2009; 'Jewel' 15 December 2009; **Teeland**, Star 16 December 2009; 'Jewel' 17 December 2009; 'Emerald' 21 December 2009.

Data recorded: On the day of pruning, the weight of all the prunings from each individual plant was recorded. In winter after shoot cessation, the total number of canes (new plus old) as well as the total number of newly developed canes (one-year-old) for each plant at the crown was counted. This data was then used to determine the percentage new canes that developed. At the same time, the volume of each individual plant was measured. During winter, one representative cane per plant was removed and taken to the laboratory at Stellenbosch University. The number of shoots per cane, the total length of each individual new shoot and each individual old shoot was measured. New shoots were classified as shoots that developed during the current season and therefore no older than one year, while old shoots were classified as unproductive shoots two years and older. At each harvest date, the total weight of all the berries of each individual plant was weighed in the field to determine total yield and harvest period per plant. Harvest distribution was then expressed as the percentage crop harvested over three harvest periods. The first harvest period was over the first two to four harvest dates, the middle period over the middle two to five harvest dates, and the last period over the last two to four harvest dates depending on the cultivar. A sample of 20 berries per harvest date per plant was taken to the laboratory. The total weight of 20 berries was recorded and the diameter of each individual berry was determined by digital calliper. This data was used to determine the average berry size per harvest date as well as over the season.

Data analysis: Treatments were compared by analysis of variance using the general linear models procedure of SAS version 9.1.3 SP2 (SAS Institute, Cary, N.C., 2004). Where appropriate, single degree of freedom, orthogonal, polynomial contrasts was fitted and/or covariate analysis performed.

Results

"Severe pruning" (T2) resulted in the most prunings removed, more than T3 and T4 which resulted in intermediate values (Table 1). T5 resulted in the least prunings removed. T1 resulted in the highest number of old unproductive shoots and the longest total old growth remaining on the plant in winter

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after pruning, higher than T5 which resulted in the second highest number of old shoots and total old growth (Table 2 & 3). T3 and T4 resulted in similar intermediate number of shoots remaining but not differing much from T2.

Teeland - 'Jewel': "Light pruning" of 'Jewel' (T5) was the only treatment compared to the control(T1) that did not significantly reduce the average plant volume and total number of canes in the winter following summer pruning (Table 4). Treatments T2, T3 and T4 did not differ from each other in average plant volume or in the total number of canes. There were no significant differences between any treatments in the percentage of new canes that developed. All pruning treatments (T2 to T5) reduced the total number of new shoots that developed and total new growth significantly compared to the unpruned control plants (T1). Although total new growth did not differ significantly between T3, T4 and T5, T5 developed significantly more new shoots. "Severe pruning" (T2) significantly reduced total new growth and the number of new shoots compared to all the pruning treatments and T2 developed the longest average shoot length. T3 and T4 resulted in similar intermediate average shoot lengths, but these were significantly longer than T1 and T5 which again did not differ significantly from each other (Table 4).

No pruning (T1) resulted in the highest yield, but not significantly higher than "light pruning" (T5) (Table 5). "Severe pruning" (T2) resulted in the lowest cumulative yield. T3 and T4 resulted in similar intermediate yields. The average berry weight followed the opposite trend to the yield per plant with high yielding treatments resulting in lower average berry weight. Only T2 resulted in larger berry diameter. When total yield was used as a covariate, it was highly significant for average berry weight and diameter. Although total yield as a covariate was significant, the treatment effect for berry weight and diameter remained significant (Table 5).

For all treatments the first harvest date was on 29 October 2010, with the largest crop harvested on 7 December 2010 and the final harvest date on 4 January 2011 (Figure 6). The percentage of the crop harvested over the first harvest period were the highest for T1 and T5, but not significantly higher than T3 which again did not differ significantly from T4 (Table 5). "Severe pruning" (T2) resulted in the lowest percentage crop harvested over the first harvest period. The percentage of the crop harvested over the middle harvest period followed the opposite trend with T2 resulting in the highest percentage crop harvested. There was no significant difference between the treatments in the percentage crop harvested over the last harvest period. For T1 and T5 the average berry weight remained constant over the harvest period. For T2, T3 and T4 the average berry weight gradually decreased from the first to the final harvest date (Figure 7).

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Teeland – 'Emerald': "Light pruning" (T5) of 'Emerald' resulted in the largest average plant volume in winter after summer pruning, but not significantly larger than T1 which again was not significantly larger than T3 (Table 6). T3 resulted in a similar winter plant volume as T4 which again did not differ significantly from T2. T5 was the only pruning treatment that did not significantly reduced the total number of canes compared to T1. There were no significant differences between any of the treatments in the percentage of new canes that developed. All pruning treatments (T2 to T5) reduced the total new growth and number of new shoots significantly compared to the control (T1). Although light pruning (T5) resulted in the most new growth after T1, it was not significantly more than T3 and T4 which resulted in similar intermediate new growth. "Severe pruning" (T2) reduced the total new growth significantly compared to the other pruning treatments. T2 resulted in the fewest new shoots though not significantly fewer than T3, which again did not differ significantly from T4. T5 resulted in the second highest number of new shoots not differing significantly from T4. T2 resulted in the longest average shoot length, but not significantly longer than T3 which again did not differ significantly from T1, T4 and T5.

"Light pruning" (T5) resulted in the highest yield, but not significantly higher than T1 which again was not significantly higher than T3 (Table 7). T3 and T4 resulted in similar intermediate yields. "Severe pruning" (T2) resulted in the lowest total yield. The average berry weight followed the opposite trend to the yield per plant with low yielding treatments resulting in higher average berry weight. The same opposite trend as for berry weight was observed for berry diameter. T2 resulted in the largest berry diameter. T3 resulted in a significantly smaller berry diameter than T2 but not compared to T4 and T5 which again did not differ significantly from T1. When total yield was used as a covariate, it was highly significant for average berry weight and diameter. Although the covariate was significant for average berry weight, the treatment effect remained significant.

For all treatments the first harvest date was on 29 October 2010, with the peak in cropping on 7 December 2010 and the final harvest date on 4 January 2011 (Figure 8). T1 and T5 resulted in highest percentage crop harvested over the first harvest period (Table 7). T3 and T4 yielded similar intermediate crops over the first harvest period, significantly larger than T2. There were no significant differences in the percentage crop harvested over the second harvest period, while T2 and T4 resulted in the highest percentage crop harvested during the last harvest period, but not significantly higher than T3 which again did not differ significantly from T1 and T5. For all the treatments the average berry weight gradually decreased from the first to the final harvest date (Figure 9).

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Teeland – 'Star': No pruning (T1) of 'Star' resulted in the largest average plant volume and highest number of total canes in the winter after summer pruning, but not significantly larger or more than "light pruning" (T5) (Table 8). T2, T3 and T4 resulted in similar average plant volume and total number of canes. "Light pruning" (T5) and no pruning (T1) resulted in the highest percentage new canes developing, but not significantly higher than T3 and T4 which again did not differ significantly from T2. Al pruning treatments (T2 to T5) significantly reduced the number of new shoots and total new shoot growth compared to T1. T5 resulted in the most new growth and the highest number of new shoots after T1, but not significantly more than T3 and T4. T2 reduced total shoot growth and number of shoots the most, differing significantly from all but T3 in shoot growth. Although T2 resulted in the least new growth, the average shoot length was the longest though not significantly longer than T4 and T5.

"Light pruning" (T5) resulted in the highest yield, but not significantly higher than no pruning (T1) (Table 9). T3 and T4 resulted in similar intermediate yields significantly higher than (T2) which had the lowest cumulative yield. T1 resulted in the lowest average berry weight. T2 and T4 resulted in the highest average berry weight significantly higher than T3 and T5 which in turn resulted in similar intermediate values. Berry diameter followed the same trend as average berry weight with heavier berries having the larger diameters. When total yield was used as a covariate, it was highly significant for average berry weight and diameter. Although the covariate was significant, the treatment effect for berry weight and diameter remained significant.

For all treatments the first harvest date was on 29 October 2010, with the peak in cropping reached by 18 November 2010 and the final harvest date on 21 December 2010 (Figure 10). T5 resulted in the highest percentage of the crop harvested over the first harvest period, but not significantly higher than T1 which again did not differ significantly from T2 and T3 (Table 9). T4 resulted in the lowest percentage, but not significantly lower than T2 and T3. There were no significant differences between the treatments in the percentage crop harvested over the middle harvest period. Over the last harvest period, all the treatments followed the opposite trend from the first harvest period. For all the treatments the average berry weight increased over the first three harvest dates and then gradually decreased from the fourth to the final harvest date (Figure 11).

Lushof – 'Jewel': No pruning (T1) and "light pruning" (T5) of 'Jewel', resulted in the largest average plant volume in winter following the summer pruning, but not significantly larger than T3 (Table 10).

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T2 resulted in the smallest average plant volume, significantly smaller than T4. No pruning resulted in the highest number of total canes, but not significantly more than T5 which again did not differ from T3 and T4. "Severe pruning" (T2) resulted in the fewest canes, but not significantly fewer than T3 and T4. There were no significant differences between any of the treatments in the percentage new cane development. All pruning treatments (T2 to T5) significantly reduced the total new growth and total number of new shoots compared to the unpruned control plants (T1). Of the pruning treatments T5 and T3 resulted in the most total new growth, but not significantly more than T4 which again was not significantly more than T2. T3, T4 and T5 resulted in a similar intermediate total number of shoots per cane, significantly more than T2. T1 with the largest number of total shoots resulted in the shortest average shoot length. T2 resulted in the longest average shoot length, significantly longer than T3, T4 and T5 which had similar intermediate shoot lengths.

No pruning (T1) resulted in the highest total yield, significantly higher than T5 (Table 11). T3 and T4 resulted in similar intermediate yields significantly higher than T2 which resulted in the lowest cumulative yield. Berry weight and diameter followed the opposite trend to total yield with high yielding treatments resulting in lower berry weight and diameters. Total yield as a covariate was highly significant for average berry weight and diameter, but the treatment effect for berry weight and diameter remained significant.

For all treatments, the first harvest date was on 18 October 2010, with the peak in cropping on 5 November 2010 and the final harvest date on 2 December 2011 (Figure 12). The percentage of the crop harvested over the first harvest period were the highest for T4 and T5, but not significantly higher than T1 which again was not significantly higher than T3 (Table 11). T2 resulted in the lowest percentage crop harvested over the first harvest period. All the treatments followed the opposite trend over the second harvest period with the treatments that had a high percentage crop harvested over the first period having the lowest percentage crop harvested over the middle period and vice versa. There was no significant difference between the treatments in the percentage crop harvested over the last harvest period. For all the treatments the average berry weight decreased from the first harvest date to the third harvest date. An increase in average berry weight was observed on the fourth harvest date for all the treatments, where after the average berry weight decreased again until the last harvest date (Figure 13).

<u>Lushof – 'Emerald':</u> All pruning treatments for 'Emerald' (T2 to 5) significantly reduced the average plant volume in the subsequent winter (Table 12). T5 resulted in the second largest average plant volume after T1, but not significantly larger than T3. T2 and T4 resulted in similar plant volumes

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significantly smaller than all the other treatments. T2, T3 and T4 resulted in a similar number of total canes significantly fewer than T1 and T5. There were no significant differences between any of the treatments in the percentage new cane development. All pruning treatments (T2 to T5) significantly reduced the total new growth and number of new shoots compared to the unpruned control plants (T1). T2, T3 and T4 resulted in similar new growth which was significantly shorter than T5. T3 and T4 had a similar intermediate number of new shoots, but significantly fewer shoots than T5. Although T2 resulted in the fewest number of new shoots the average shoot length was the longest. T3 resulted in the second longest average shoot length, significantly longer than T1, T4 and T5.

T1 plants had the highest cumulative yield, but not significantly higher than T5, which again was not significantly higher than T3 (Table 13). T3 and T4 resulted in similar intermediate yields significantly higher than T2 which resulted in the lowest cumulative yield. The high yielding T1 resulted in the lowest average berry weight and smallest berry diameter while the low yielding T2 resulted in the highest average berry weight and largest diameter, but not significantly so for average berry weight when compared to T3. T4 and T5 responded with similar intermediate berry weights. There were no significant difference in average berry diameter between T3, T4 and T5. Total yield as covariate was highly significant for average berry weight and diameter. However, the treatment effect for berry weight and diameter remained significant.

For all treatments the first harvest date was on 18 October 2010, with the biggest cropping on 5 November 2010 and the final harvest date on 2 December 2011 (Figure 14). There were no significant differences in the percentage crop harvested over any of the harvest periods (Table 13). The average berry diameter for all the treatments decreased from the first to the last harvest date (Figure 15).

<u>Gelukstroom – ‘Jewel’</u>: “Light pruning” (T5) of ‘Jewel’ resulted in the largest average plant volume in the subsequent winter, but not significantly larger than T1 and T3 which resulted in similar plant volumes (Table 14). T2 resulted in the largest reduction in plant volume, significantly more than T4. There were no significant differences in the total number of canes per plant. T5 resulted in the highest percentage new canes developing, but not significantly higher than T3 and T1. T2 resulted in the lowest percentage new cane development, but not significantly lower than T4 which in turn did not differ significantly from T1. There was no significant difference in the total new growth between the treatments. Severe pruning (T2) was the only treatment that significantly reduced the number of new shoots that developed. T3, T4 and T5 resulted in similar intermediate shoot numbers, significantly

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more than T2 which resulted in the fewest new shoots. There were no significant differences between any treatments in the average length of the new shoots.

No pruning (T1) and “light pruning” (T5) resulted in the highest total yield, but not significantly higher than T3 which again was not significantly higher than T4 (Table 15). “Severe pruning” (T2) resulted in the smallest total yield. Although T1 and T5 resulted in the same total yield, T1 responded with a significantly smaller average berry weight than T5 which again did not differ significantly in berry size from T3 and T4. “Severe pruning” resulted in the largest average berry weight, but not significantly larger than T4. All pruning treatments (T2 to T5) significantly increased the average berry diameter. Total yield was used as a covariate and was highly significant for average berry weight and diameter. Although total yield as a covariate was significant, the treatment effect for berry weight and diameter and remained highly significant.

For all treatments the first harvest date was on 5 October 2010, with the peak in cropping on 25 November 2010 and the final harvest date on 20 December 2011 (Figure 16). T1 resulted in the highest percentage crop harvested over the first harvest period (Table 15). T5 resulted in the second highest crop, significantly higher than T3 and T4 which had similar intermediate percentages. T2 resulted in the lowest percentage crop harvested over the first harvest period. Over the middle harvest period the treatments induced an opposite trend with treatments having a low percentage over the first harvest period now resulting in the highest percentages. T4 resulted in the highest percentage crop for the second harvest period, but not significantly higher than T2 which again did not differ from T3. T1 resulted in the lowest percentage, significantly lower than T5. “Severe pruning” (T2) resulted in the highest percentage crop harvested over the last harvest period, but not significantly higher than T3 and T5 which again did not differ from T1. T4 resulted in the lowest percentage crop harvested over the last harvest period. The average berry weight for T1 did not change over the entire harvest period and remained the smallest throughout. All the other treatments displayed a decrease in berry weight from the first to the last harvest date (Figure 17).

<u>Gelukstroom – ‘Star’:</u> “Severe pruning” (T2) was the only summer pruning treatment that significantly decreased the average plant volume in the following winter (Table 16). T5 responded with the highest number of canes, but not significantly higher than T1 which again was not significantly higher than T3. T3 and T4 had similar intermediate numbers of canes but significantly higher than T2 which had the least canes. T3 resulted in the highest percentage new cane development, but not significantly higher than T1 and T5 which again did not differ significantly from T4. T2 induced the lowest percentage new cane development. Although T1 resulted in significantly

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more new shoot development than all the pruning treatments, there was no significant difference between any of the treatments in the total length of new growth. T3 and T5 resulted in the longest average new shoot length, but not significantly longer than T2 and T4 which again did not differ significantly from T1.

T1 plants had the highest average yield, but not significantly higher than T5 (Table 17). T3 and T4 responded with similar intermediate yields, but significantly higher than T2 which had the lowest total yield. All pruning treatments significantly increased average berry weight and diameter significantly compared to T1. Although total yield as a covariate was insignificant for average berry weight and diameter, the treatment effect for average diameter became less significant.

For all treatments the first harvest date was on 5 October 2010 (Figure 18). Cropping for T1, T3 and T5 peaked on 2 November 2010 and for T2 and T4 on 17 November 2010. For all treatments the final harvest date was on 20 December 2010. T1 resulted in the highest percentage crop harvested over the first harvest period, significantly higher than T3, T4 and T5 which resulted in similar intermediate percentages (Table 17). T2 resulted in the lowest percentage crop harvested over the first harvest period. Over the middle harvest period, T3, T4, and T5 resulted in the highest percentage crop, but not significantly higher than T2 which again did not differ significantly from T1. Over the last harvest period the trend was opposite compared to the first harvest period. For all the treatments berry weight increased over the first three harvest dates and then gradually decreased again until the last harvest dates (Figure 19).

Discussion

<u>Total number of canes (new plus old) and percentage new cane development.</u>

No pruning (T1) and "light pruning" (T5) for al cultivar/site combinations resulted in the highest number of total canes, higher than the other treatments (T2 to T4) which generally did not differ significantly from each other. In the case of T2, T3 and T4, old unproductive canes were removed by means of a thinning cut, but not in the case of T1 and T5 and could account for the differences observed.

In the case of 'Jewel' (Teeland and Lushof) (Table 4 and 10) and 'Emerald' (Teeland and Lushof) (Table 6 and 8), there were no differences in the percentage new cane development. In contrast, heavy pruning of 'Star' (Teeland and Gelukstroom) (Table 8 and 16) and 'Jewel' (Gelukstroom)

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(Table 14) reduced the percentage of new cane development. Thinning cuts at the crown in winter stimulate new cane development, while heading cuts stimulates lateral shoot development (Gough, 1994). One theory for the response to pruning is that the cytokinins supply increases at the pruning wound and is followed by an increase in auxin activity in the developing buds, which in turn leads to an increase in gibberellin levels. All these hormonal changes initiate growth by promoting the development of vascular connections and activating nutrient translocation (Wertheim, 2005). If this theory is true, it explains why heading cuts in our trial led to an increase in the number of lateral shoots developing at the pruning wound, but not necessarily in new cane production. For northern highbush blueberries one out of every six canes must be removed yearly in winter to stimulate new cane development from the crown (Yarborough, 2006). The same is suspected for southern highbush blueberries, and therefore we conclude that none of the pruning treatments in this trial had enough thinning cuts to increase new cane development. 'Emerald' (Teeland and Lushof) (Table 6 and 12) responded with the highest percentage of new cane development (between 36.4 and 48.7 percent over all the treatments) and therefore seems to reiterate new shoots from the crown much easier than 'Star' and 'Jewel'.

Plant volume and new growth.

'Emerald' (Teeland) (Table 6) and 'Jewel' (Gelukstroom) (Table 14) were the only cultivar/site combinations where "light pruning" resulted in a larger plant volume than no pruning. Only for 'Jewel' and 'Star' (Table 4 and 8) at Teeland, and 'Emerald' at Lushof (Table 12), "standard pruning" reduced the average plant volume compared to T1. 'Jewel' (Lushof and Gelukstroom) and 'Emerald' (Lushof) were the only cultivar/ site combinations where T4 significantly decreased winter plant volume compared to T3. For all the cultivar/site combinations T2 resulted in the smallest average winter plant volume.

In general, all pruning treatments reduced the total new growth and the number of new shoots, but increased the average shoot length compared to the unpruned plants (T1). After T1, T5 developed the longest total new growth, the highest number of new shoots, but the shortest average shoot length. 'Jewel' (Gelukstroom) (Table 4) was the only cultivar where T3 resulted in more new growth than T5. For all the cultivar/site combinations T3 and T4 resulted in similar intermediate effect for total new growth and number of new shoots developing. For 'Emerald' and 'Star', but not in the case of 'Jewel', T4 slightly increased total new growth and number of shoots compared to T3. For all the cultivars T4 reduced the average shoot length compared to T3. "Severe pruning" (T2) of all the cultivars at all the sites resulted in the shortest total growth, the fewest shoots, but the longest average

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shoot length. 'Star' at Gelukstroom (Table 16) was the only cultivar where T3 resulted in longer average shoot length than T2.

Total shoot growth (new growth plus original one-year-old shoot) for apple trees is the greatest with either no heading or only a light heading cut in winter (Wertheim, 2005). Although winter pruning of blueberries generally increases individual shoot length and leaf size, it reduces the total vegetative growth (Gough, 1994; Yarborough, 2006). Summer pruning 'Star' and 'O'Neal' before end of December (SH) increases lateral shoot length compared to unpruned plants (Bañados *et al.*, 2009). The same was observed in our trials when pruning SHB 'Star', 'Emerald' and 'Jewel'. An increase in the severity of pruning increased the extent to which total plant volume, total number of new shoots and new growth decreased, but individual shoot length increased. The reason for the decrease in plant volume and total new growth in our trials is clearly not due to a decrease in individual shoot length, but rather due to the decrease in the total number of one-year-old shoots. The increase in individual shoot length is the reason "standard pruning" only reduced average plant volume for three cultivar/site combinations. However, by not pruning for another consecutive season, one suspects further ramification during subsequent flushes that will gives rise to lateral shoots that become progressively thinner and shorter (Gough, 1994). Eventually the plant will become so complex and the new lateral shoots so short that the total new growth and plant volume for unpruned treatments will decrease compared to the pruning treatments. Another season's data is important to verify this.

Total yield and berry size

No pruning (T1) resulted in the highest yield for all cultivar/site combinations except for 'Emerald' (Teeland) (Table 7), 'Star' (Teeland) (Table 9) and 'Jewel' (Gelukstroom) (Table 15), where "light pruning" (T5) resulted in a similar or slightly higher yield. 'Emerald' (Teeland) (Table 7) and 'Jewel' (Gelukstroom) (Table 15) were the only cultivars where "standard pruning" (T3) did not reduce total yield significantly compared to T1 and T5. T3 and T4 resulted in similar intermediate yields for all the cultivar/site combinations. "Severe pruning" resulted in the largest reduction in total yield for all the cultivar/site combinations. For all the cultivar/site combinations, low yielding T2 resulted in the largest average berry weight and diameter. High yielding T1 and T5 resulted in the smallest average berry weight and diameters. T3 and T4 resulted in similar intermediate berry weight and diameter for 'Jewel' and 'Emerald. In the case of 'Star', T4 resulted in a similar berry weight and diameter as T2. Total yield was a highly significant covariate for berry weight and diameter, for all the cultivar/site combinations except for 'Star' at Gelukstroom (Table 17). Despite the statistical significance of total yield as covariate, the treatment effect remained highly significant for all the cultivar/site

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combinations. This is an indication that the treatment effect on berry size is not solely due to the effect of treatments on total yield.

A decrease in berry size with an increase in crop load is not an unknown phenomenon in blueberries (Yarborough, 2006). Thick vigorous growing laterals bear better quality berries than thin laterals (Shutak and Muracci, 1966; Gough, 1994). In our trials, more “severe pruning” resulted in longer average shoot length and therefore an increase in the thickness and the quality of the laterals. This could be one of the reasons why the treatment effect remained highly significant when yield was used as a covariate. Therefore, the decrease in berry size is due to at least two factors; firstly the increase in competition between berries with an increase in crop load, and secondly, the decrease in lateral length and thickness in response to no or little pruning. Not pruning for another consecutive season might not only lead to an increase in lateral shoot number and a decrease in lateral shoot length, but also to a further decrease in berry size. Minimum berry diameter for export to the UK is 12 mm (Eurafruit SA, 2010). In our trials the average berry diameter for the unpruned plants of ‘Jewel’ at Teeland (Table 5), ‘Jewel’ and ‘Star’ at Gelukstroom (Table 15 and 17) were 12.3, 11.1 and 12 mm, respectively. Considering that this is the average berry diameter, a large percentage of the crop can be assumed to be under the minimum export diameter. For ‘Jewel’ and ‘Star’, the danger exists that no pruning for another consecutive season could reduce the berry size of the entire crop below export standard. In the case of ‘Emerald’ at Teeland and Lushof (Table 7 and 13), the average berry diameter for unpruned plants was 13.8 and 13.5, respectively and therefore berry diameter is with current export standards not a problem for this cultivar. There were no premium prizes in the U.K. for extra-large berries over the last two seasons, and therefore it is of no advantage to produce berries above 18 mm (extra-large) in diameter (Eurafruit SA, 2010).

Harvest period

At Teeland (‘Emerald’ and ‘Jewel’) and Gelukstroom all pruning treatments delayed harvest. In general, the increase in severity of the pruning treatment increased the extent to which the harvest was delayed. T2 always delayed harvest the most. Of the three sites, the most significant delay in harvest was observed at Gelukstroom, and can possibly be subscribed to tougher environmental conditions as plants are grown without shade nets. In contrast to our results, Bañados *et al.* (2009) did not find a delay in harvest when ‘Star’ and ‘O’Neal were summer pruned in December (SH). Winter pruning of northern highbush blueberries advances and concentrates the harvest (Gough, 1994; Yarborough, 2006). Inflorescences on thinner shoots open earlier than on thicker shoots (Eck, 1988). Summer pruning increased average shoot length and more so if severity increased, and therefore resulted in thicker shoots. Differentiation of reproductive buds takes place after shoot cessation (Bañados and

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Strik, 2006). Thicker, more vigorous shoots caused by summer pruning cease extension growth later than thin laterals and delay flower bud differentiation and therefore bloom and harvest. Although winter pruning also results in longer average shoot length, the new growth that is stimulated by winter pruning will leaf out early in spring and not in the same growing season as is the case for summer pruning, and therefore harvest is not delayed.

Pruning recommendations

No and “light pruning” would be recommended if yield is the only priority. The possibility of further decreases in berry diameter and plant vigour if both these treatments are repeated, pose the question of whether these two treatments are sustainable. “Standard pruning” resulted in intermediate yields and berry size. If no pruning and “light pruning” is not sustainable, “standard pruning” would be recommended. Another season’s data should clarify this.

Heading was of no significant horticultural benefit to any of the cultivars and would not be recommended. It would be interesting to see what the effect of time of heading would be and further research is needed.

Although “severe pruning” increased individual shoot length, berry weight and diameter compared to the other pruning treatments, the loss in total yield for a mature orchard is from a horticultural point of view too large and would not be recommended. For young orchards where the main goal is to stimulate vegetative growth, eliminate reproductive growth and to form an open vase shaped plant (Eck, 1988; Gough, 1994; Yarborough, 2006), “severe pruning” could be recommended. The vigorous long laterals that develop in response to “severe pruning” will create an excellent framework to build from.

For the cultivar ‘Jewel’ at Teeland and Gelukstroom, the high fruit set resulted in a large decrease in berry diameter in the case of no pruning and “light pruning”; therefore “standard pruning” would be recommended.

The ability of ‘Emerald’ to differentiate a large number of reproductive buds that sets heavily while still producing large fruit (Lyrene, 2008), were confirmed in our trials. Bearing in mind that this was only one season’s data, “light pruning” would be recommended to increase yield.

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The shorter total new growth, fewer shoots and smaller total yield of 'Star' compared to the other cultivars is proof that 'Star is a less vigorous and lower yielding cultivar (Lyrene and Sherman, 2000). 'Star' was the only cultivar where heading on the day of pruning (T4) resulted in the same yield as "standard pruning". Reproductive buds do not differentiate as far down on one-year-laterals compared to 'Jewel' and 'Emerald' (personal observation) and therefore an increase in the number of laterals is the only way to increase bearing capacity. "Light pruning" of 'Star' resulted in a significantly higher yield than both T3 and T4, and as long as fruit diameter stays above export diameter, "light pruning" would be recommended for 'Star'.

Conclusion

We established that the severity of summer pruning SHB 'Star', 'Jewel' and 'Emerald' under South-African growing conditions is a compromise between total yield and desired berry size. Summer pruning reduced total vegetative growth and the total number of shoots, but increased individual shoot length. Later termination of growth on vigorous laterals resulted in a delay in flower bud differentiation and therefore a delay in harvest. Summer pruning increased berry weight and diameter by reducing total yield, but also by developing better quality laterals. An increase in the severity of pruning increased the level to which the plants responded. Cultivar and environmental factors could play a role in the response to pruning. No pruning and "light pruning" resulted in the highest yield after one season, but another season's data would clarify whether this is sustainable. Heading is not recommended for any of the cultivars as, from a horticultural perspective, none of the variables were significantly improved.

Literature Cited

Bañados, P., and S. Strik. 2006. Manipulation of the annual growth cycle of blueberry using photoperiod. Acta Hort. 715:65-71.

Bañados, P., P. Uribe and D. Donnay. 2009. The effect of summer pruning date in 'Star', 'O'Neal' and 'Elliott'. Acta Hort. 810:501-508.

Eck, P. 1988. Plant development, p.41-65. In: Eck, P. (eds), Blueberry science. Rugters university press. London.

Greeff, M.P. and P.F. Greeff. 2006. Blueberries in South Africa, p.255-256. In: N.F. Childers and P.M. Lyrene (eds.), Blueberries for growers, gardeners, promoters. Horticultural Publications. Gainesville. Florida.

University of Stellenbosch http://scholar.sun.ac.za

Gough, R.E. 1983. Time of pruning and bloom date in cultivated highbush blueberry. HortScience 18:934-935.

Gough, R.E. 1994. Pruning, p.137-149. In: Gough, R.E. (eds.), The higbush blueberry and its management. The Haworht Press, Inc. Worwood. Australia.

Jansen, W.A.G.M. 1997. Pruning of highbush blueberries. Acta Hort. 446:333-335.

Krewer, G., D. Staneland, S. NeSmith and B. Mullinix. 2004. Post harvest hedging and pruning of three year pruning trial on Climax and Tifblue rabbiteye blueberry. Small Berry Revenue. 3:203-212.

Lyrene, P.M. 2008. 'Emerald' southern highbush blueberry. HortScience 43(5):1606-1607.

Lyrene, P.M. and B. Sherman. 2000. 'Star' southern highbush blueberry. HortScience 35:956-957.

Shutak, V.G. and E.M. Muracci. 1966. Plant and fruit development, p179-198. In: P. Eck an N.F. Childers (eds.), Blueberry culture. Rugters university press. New Jersey.

Siefker, J.A. and J.F. Hanock. 1987. Pruning effects on productivity and vegetative growth in the highbush blueberry. HortScience 22:210-211.

Strik, B., G. Buller and E. Hellman. 2003. Pruning severity affects yield, berry weight, and hand harvest efficiency of highbush blueberry. HortScience 38(2):196-200.

Wertheim, S.J. 2005. Pruning, p.176-189. In: Tromp, J., A.D. Webster and S.J. Wertheim (eds.), Fundamentals of temperate zone tree fruit production. Backhuys Publishers. Leiden. The Netherlands.

Yarborough, D.E. 2006. Blueberry pruing and pollination, p. 75-83. In: N.F. Childers (ed.), Blueberries for growers, gardeners, promoters. Horticultural Publications. Gainesville. Florida.

Table 1: Total weight of prunings removed (kg) on the day of pruning.

Pruning treatment	Total mass of prunings removed (kg)			
	Teeland Jewel	Teeland Emerald	Lushof Jewel	Lushof Emerald
no pruning (T1)	0.00 c	0.00 d	0.00 d	0.00 d
“severe pruning” (T2)	1.99 a	1.91 a	0.93 a	0.80 a
“standard pruning” (T3)	1.60 ab	1.51 ab	0.67 b	0.66 b
“standard pruning” + heading (T4)	1.41 b	1.46 b	0.76 b	0.74 ab
“light pruning” (T5)	1.12 b	0.84 c	0.40 c	0.45 c
Significance level	<.0001	<.0001	<.0001	<.0001
LSD	0.4876	2.02809	0.1144	0.1338

Table 2: Total length of the old canes that remained per plant in winter after pruning in summer.

Pruning treatment	Total length old growth (cm)						
	Jewel (Teeland)	Emerald (Teeland)	Star (Teeland)	Jewel (Lushof)	Emerald (Lushof)	Jewel (Gelukstroom)	Star (Gelukstroom)
no pruning (T1)	620.3 a	319.6 a	253.6 a	127.4 a	153..0 a	255.8 a	193.3 a
“severe pruning” (T2)	58.1 c	45.9 c	43.0 b	22.0 c	27.0 c	42.0 c	34.9 d
“standard pruning” (T3)	86.1 c	66.5 c	63.0 c	51.2 b	37.1 c	71.4 bc	65.3 bc
“standard pruning” + heading (T4)	*63.0* c	68.4 c	69.3 c	38.6 bc	34.9 c	54.8 bc	42.5 cd
“light pruning” (T5)	235.9 b	117.7 b	130.9 c	54.8 b	76.2 b	91.5 b	77.3 b
Significance level	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
LSD	*99.403*	*34.515*	36.292	18.08	28.349	39.744	29.254

Table 3: Total number of old shoots (older than one year) that remained per plant in winter after pruning in summer.

Pruning treatment	Total number of old shoots						
	Jewel (Teeland)	Emerald (Teeland)	Star (Teeland)	Jewel (Lushof)	Emerald (Lushof)	Jewel (Gelukstroom)	Star (Gelukstroom)
no pruning (T1)	28 a	16 a	12 a	7 a	7 a	11 a	11 a
"severe pruning" (T2)	3 c	2 c	2 c	1 c	1 c	2 c	2 b
"standard pruning" (T3)	3 c	3 bc	3 c	2 bc	2 c	2 bc	2 b
"standard pruning" + heading (T4)	3 c	3 bc	3 c	2 bc	2 c	2 bc	2 b
"light pruning" (T5)	10 b	5 b	5 b	3 b	4 b	4 b	3 b
Significance level	2	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
LSD	*4.2388*	*2.7194*	2.0706	1.2995	1.7051	1.7265	1.8988

Table 4: Average plant volume, total number of canes per plant, percentage new canes, total new growth, total number of shoots and average shoot length on 'Jewel' bushes at Teeland following different pruning strategies in summer.

Pruning treatment	Average plant volume (m^3)	Total number of new and old canes	Percentage new canes	Total new growth (cm)	Total number of shoots	Average new shoot length (cm)
no pruning (T1)	3.3 a	14 a	9.4 NS*	1077.7 a	115 a	9.4 c
"severe pruning" (T2)	1.5 b	11 b	9.4	393.5 c	22 d	18.5 a
"standard pruning" (T3)	1.9 b	11 b	16.1	717.9 b	53 c	13.6 b
"standard pruning" + heading (T4)	1.7 b	10 b	11.6	627.9 b	52 c	12.7 b
"light pruning" (T5)	3.1 a	13 a	9.3	773.5 b	73 b	10.7 c
Significance level	<.0001	0.0017	0.1421	<.0001	<.0001	<.0001
LSD	0.526	1.889	6.1452	189.5	17.217	1.7614

Table 5: Total yield per plant, average berry weight , average berry diameter, percentage yield over the first four harvest dates, middle four harvest dates and last three harvest dates on 'Jewel' bushes at Teeland following different pruning strategies in summer.

Pruning treatment	Total yield (kg)	Average berry weight (g)	Average berry diameter (mm)	Percentage yield over first four harvest dates	Percentage yield over middle four harvest dates	Percentage over for last three harvest dates
no pruning (T1)	8.4 a	1.34 d	12.3 b	34.2 a	49.3 c	16.6 NS*
"severe pruning" (T2)	4.4 c	1.96 a	14.5 a	20.8 c	61.8 a	17.4
"standard pruning" (T3)	6.0 b	1.63 b	12.9 b	30.2 ab	53.7 bc	16.1
"standard pruning" + heading (T4)	5.9 b	1.59 b	13.0 b	26.4 b	55.3 b	18.3
"light pruning" (T5)	8.2 a	1.41 c	12.2 b	31.8 a	49.9 dc	18.3
Significance level	<.0001	<.0001	0.0002	<.0001	<.0001	*0.3527*
LSD	*1.22*	*0.06*	*0.94*	4.8673	4.3516	*2.6655*
Covariate yield		<.0001	0.0021			
TRT		<.0001	0.0232			

Table 6: Average plant volume, total number of canes per plant, percentage new canes, total new growth, total number of shoots and average shoot length on 'Emerald' bushes at Teeland following different pruning strategies in summer.

Pruning treatment	Average plant volume (m^3)	Total number of new and old canes	Percentage new canes	Total new growth (cm)	Total number of shoots	Average new shoot length (cm)
no pruning (T1)	2.4 a	17 a	41.2 NS*	701.9 a	60 a	12.0 b
"severe pruning" (T2)	1.6 c	13 b	36.4	323.9 c	15 d	30.6 a
"standard pruning" (T3)	2.3 ab	14 b	43.0	425.7 b	22 dc	19.7 ab
"standard pruning" + heading (T4)	1.9 bc	13 b	40.0	440.2 b	28 bc	16.0 b
"light pruning" (T5)	2.6 a	17 a	37.5	521.7 b	34 b	6.0 b
Significance level	0.0005	<.0001	0.4185	<.0001	<.0001	0.1060
LSD	0.4454	2.0319	7.63	100.03	17.217	14.176

Table 7: Total yield per plant, average berry weight , average berry diameter, percentage yield over the first four harvest dates, middle four harvest dates and last three harvest dates on 'Emerald' bushes at Teeland following different pruning strategies in summer.

Pruning treatment	Total yield (kg)	Average berry weight (g)	Average berry diameter (mm)	Percentage yield over first four harvest dates	Percentage yield over middle four harvest dates	Percentage yield over last three harvest dates
no pruning (T1)	7.8 ab	1.73 d	13.8 c	31.8 a	50.0 NS*	18.2 b
"severe pruning" (T2)	5.2 d	2.09 a	15.0 a	22.3 c	53.6	24.1 a
"standard pruning" (T3)	7.0 bc	1.92 b	14.3 b	27.2 b	51.8	21.0 ab
"standard pruning" + heading (T4)	6.7 c	1.91 b	14.3 bc	26.0 b	51.5	22.5 a
"light pruning" (T5)	8.3 a	1.83 c	13.8 bc	30.0 a	51.1	18.9 b
Significance level	<.0001	<.0001	0.0005	<.0001	0.1187	0.0026
LSD	*1.0058*	*00.682*	*0.5452*	2.7344	2.6805	3.1475
Covariate yield		<.0001	0.0004			
TRT		<.0001	0.0966			

Table 8: Average plant volume, total number of canes per plant, percentage new canes, total new growth, total number of shoots and average shoot length on 'Star' bushes at Teeland following different pruning strategies in summer.

Pruning treatment	Average plant volume (m^3)	Total number of new and old canes	Percentage new canes	Total new growth (cm)	Total number of shoots	Average new shoot length (cm)
no pruning (T1)	2.2 a	19 a	19.6 a	524.0 a	45 a	11.8 b
"severe pruning" (T2)	1.1 b	13 b	9.6 b	224.4 c	13 c	17.3 a
"standard pruning" (T3)	1.5 b	14 b	17.4 ab	283.7 bc	22 b	13.5 b
"standard pruning" + heading (T4)	1.4 b	14 b	15.9 ab	316.5 b	24 b	13.1 a
"light pruning" (T5)	2.1 a	18 a	21.5 a	340.5 b	26 b	13.7 a
Significance level	<.0001	<.0001	0.0449	<.0001	<.0001	0.0004
LSD	0.4008	2.6847	7.9218	85.565	7.1402	2.2652

Table 9: Total yield per plant, average berry weight , average berry diameter, percentage yield over the first three harvest dates, middle three harvest dates and last three harvest dates on 'Star' bushes at Teeland following different pruning strategies in summer.

Pruning treatment	Total yield (kg)	Average berry weight (g)	Average berry diameter (mm)	Percentage yield over first three harvest dates	Percentage yield over middle three harvest dates	Percentage yield over last three harvest dates
no pruning (T1)	4.1 a	1.55 c	13.1 d	33.0 ab	51.1 NS*	16.0 dc
"severe pruning" (T2)	2.1 c	1.97 a	14.6 a	27.1 bc	45.2	27.7 a
"standard pruning" (T3)	3.0 b	1.76 b	14.2 b	30.0 bc	50.2	19.8 bc
"standard pruning" + heading (T4)	3.0 b	1.91 a	14.6 a	26.3 c	50.0	23.7 ab
"light pruning" (T5)	4.3 a	1.68 b	13.6 c	37.1 a	48.6	14.3 d
Significance level	<.0001	<.0001	<.0001	0.0057	0.2896	<.0001
LSD	736.8	*0.1189*	0.4023	6.1191	5.7759	4.6559
Covariate yield		<.0001	<.0001			
TRT		<.0001	<.0001			

Table 10: Average plant volume, total number of canes per plant, percentage new canes, total new growth, total number of shoots and average shoot length on 'Jewel' bushes at Lushof following different pruning strategies in summer.

Pruning treatment	Average plant volume (m^3)	Total number of new and old canes	Percentage new canes	Total new growth (cm)	Total number of shoots	Average new shoot length (cm)
no pruning (T1)	1.7 a	11 a	27.3 NS*	670.7 a	65 a	10.8 c
"severe pruning" (T2)	0.7 c	8 c	31.2	310.2 c	16 c	19.6 a
"standard pruning" (T3)	1.6 a	9 bc	32.3	416.0 b	27 b	16.1 b
"standard pruning" + heading (T4)	1.1 b	9 bc	34.8	376.1 bc	30 b	13.2 c
"light pruning" (T5)	1.7 a	10 ab	27.1	440.4 b	35 b	13.1 c
Significance level	<.0001	0.0096	0.2501	*<.0001*	*<.0001*	<.0001
LSD	0.2733	1.5686	8.0181	88.355	10.803	<.0001

Table 11: Total yield per plant, average berry weight , average berry diameter, percentage yield over the first two harvest dates, middle two harvest dates and last two harvest dates on 'Jewel' bushes at Lushof following different pruning strategies in summer.

Pruning treatment	Total yield (kg)	Average berry weight (g)	Average berry diameter (mm)	Percentage yield over first two harvest dates	Percentage yield over middle two harvest dates	Percentage yield over last two harvest dates
no pruning (T1)	3.26 a	1.7 d	13.1 d	23.1 ab	48.3 c	28.6 NS*
"severe pruning" (T2)	1.05 d	2.3 a	15.1 a	16.93 c	57.9 a	25.2
"standard pruning" (T3)	2.42 c	1.9 b	14.2 b	20.2 bc	52.0 b	27.7
"standard pruning" + heading (T4)	2.27 c	1.9 bc	13.8 c	24.5 a	51.4 bc	24.1
"light pruning" (T5)	2.90 b	1.8 cd	13.3 d	24.9 a	49.9 bc	25.2
Significance level	*<.0001*	*<.0001*	*<.0001*	0.0002	<.0001	0.2217
LSD	0.3575	0.0956	*0.3094*	3.527	3.438	4.4373
Covariate yield		*<.0001*	*<.0001*			
TRT		*0.0001*	*0.0005*			

Table 12: Average plant volume, total number of canes per plant, percentage new canes, total new growth, total number of shoots and average shoot length on 'Emerald' bushes at Lushof following different pruning strategies in summer.

Pruning treatment	Average plant volume (m^3)	Total number of new and old canes	Percentage new canes	Total new growth (cm)	Total number of shoots	Average new shoot length (cm)
no pruning (T1)	1.3 a	14 a	48.7 NS*	527.4 a	44 a	12.6 c
"severe pruning" (T2)	0.7 c	10 b	42.5	168.0 c	8 d	22.6 a
"standard pruning" (T3)	1.0 b	10 b	46.2	204.8 c	12 dc	18.0 b
"standard pruning" + heading (T4)	0.7 c	11 b	36.3	208.9 c	15 c	14.3 c
"light pruning" (T5)	1.1 b	14 a	38.8	321.6 b	23 b	14.3 c
Significance level	<.0001	0.0023	0.1766	*<0.0001*	*<0.0001*	*<0.0001*
LSD	0.2309	2.4758	11.236	*76.338*	*6.4821*	3.0913

Table 13: Total yield per plant, average berry weight , average berry diameter, percentage yield over the first two harvest dates, middle two harvest dates and last two harvest dates on 'Emerald' bushes at Lushof following different pruning strategies in summer.

Pruning treatment	Total yield (kg)	Average berry weight (g)	Average berry diameter (mm)	Percentage yield for first two harvest dates	Percentage yield for middle two harvest dates	Percentage yield for last two harvest dates
no pruning (T1)	2.0 a	1.6 c	13.5 c	26.7 NS*	50.0 NS*	28.3 NS*
"severe pruning" (T2)	0.7 d	1.9 a	14.4 a	25.6	49.4	25.0
"standard pruning" (T3)	1.4 bc	1.8 a	14.3 ab	24.9	48.9	26.2
"standard pruning" + heading (T4)	1.3 c	1.7 b	14.0 b	28.5	47.2	24.3
"light pruning" (T5)	1.7 ab	1.7 b	14.1 ab	27.1	46.8	26.2
Significance level	*<0.0001*	*<0.0001*	<.0001	0.7867	*0.4372*	0.7962
LSD	*0.3452*	*0.0846*	*0.3053*	*6.0609*	*5.1727*	*6.7662*
Covariate yield		*0.0022*	*0.0001*			
TRT		*0.0002*	<.0001			

Table 14: Average plant volume, total number of canes per plant, percentage new canes, total new growth, total number of shoots and average shoot length on 'Jewel' bushes at Gelukstroom following different pruning strategies in summer.

Pruning treatment	Average plant volume (m^3)	Total number of new and old canes	Percentage new canes	Total new growth (cm)	Total number of shoots	Average new shoot length (cm)
no pruning (T1)	1.4 a	10 NS*	26.9 ab	638.7 NS*	50.3 a	12.8 NS*
"severe pruning" (T2)	0.8 c	9	8.5 c	453.0	30.0 5c	15.7
"standard pruning" (T3)	1.4 a	9	28.5 a	625.8	47.3 ab	13.7
"standard pruning" + heading (T4)	1.1 b	8	16.1 bc	536.4	40.6 ab	13.4
"light pruning" (T5)	1.5 a	10	32.0 a	564.3	41.2 ab	13.6
Significance level	<.0001	0.5618	0.0003	*0.2016*	0.0292	0.0535
LSD	0.2254	2.7764	10.498	*171.26*	10.803	1.9578

Table 15: Total yield per plant, average berry weight , average berry diameter, percentage yield over the first three harvest dates, middle five harvest dates and last three harvest dates on 'Jewel' bushes at Gelukstroom following different pruning strategies in summer.

Pruning treatment	Total yield (kg)	Average berry weight (g)	Average berry diameter (mm)	Percentage yield for first three harvest dates	Percentage yield for middle five harvest dates	Percentage yield for last three harvest dates
no pruning (T1)	4.7 a	1.1 c	11.1 b	32.4 a	47.5 d	20.2 b
"severe pruning" (T2)	3.3 c	1.6 a	12.9 a	7.7 d	68.0 ab	24.3 a
"standard pruning" (T3)	4.4 ab	1.5 b	12.5 a	13.9 c	65.1 b	21.0 ab
"standard pruning" + heading (T4)	3.9 b	1.5 ab	12.7 a	12.9 c	70.9 a	16.3 c
"light pruning" (T5)	4.7 a	1.5 b	12.5 a	19.5 b	59.1 c	21.3 ab
Significance level	<.0001	<.0001	<.0001	<.0001	<.0001	0.0010
LSD	*580.57*	*0.1114*	0.4128	3.3087	3.7553	3.4465
Covariate yield		*0.0002*	*0.0001*			
TRT		<.0001	<.0001			

Table 16: Average plant volume, total number of canes per plant, percentage new canes, total new growth, total number of shoots and average shoot length on 'Star' bushes at Gelukstroom following different pruning strategies in summer.

Pruning treatment	Average plant volume (m^3)	Total number of new and old canes	Percentage new canes	Total new growth (cm)	Total number of shoots	Average new shoot length (cm)
no pruning (T1)	0.9 a	13 ab	26.6 ab	377.4 NS*	30 a	13.2 b
"severe pruning" (T2)	0.4 b	7 d	5.5 c	340.0	22 b	16.2 ab
"standard pruning" (T3)	0.9 a	11 bc	34.2 a	286.5	16 b	20.0 a
"standard pruning" + heading (T4)	0.9 a	10 c	22.1 b	346.9	22 b	16.5 ab
"light pruning" (T5)	0.9 a	15 a	27.1 ab	296.4	17 b	18.6 a
Significance level	<.0001	<.0001	0.0003	0.1668	0.0020	0.0137
LSD	0.2307	2.4145	10.494	82.204	6.8055	3.8854

Table 17: Total yield per plant, average berry weight , average berry diameter, percentage yield over the first three harvest dates, middle five harvest dates and last three harvest dates on 'Star' bushes Gelukstroom following different pruning strategies in summer.

Pruning treatment	Total yield (kg)	Average berry weight (g)	Average berry diameter (mm)	Percentage yield for first three harvest dates	Percentage yield for middle five harvest dates	Percentage yield for last three harvest dates
no pruning (T1)	2.3 a	1.3 b	12.0 b	38.4 a	43.3 b	18.3 c
"severe pruning" (T2)	0.9 c	1.6 a	13.0 a	7.8 d	49.0 ab	43.3 a
"standard pruning" (T3)	1.4 b	1.6 a	13.3 a	28.5 b	49.6 a	22.0 bc
"standard pruning" + heading (T4)	1.4 b	1.6 a	13.2 a	21.3 b	53.4 a	25.3 b
"light pruning" (T5)	2.0 a	1.5 a	12.9 a	32.0 b	50.7 a	17.3 c
Significance level	<.0001	0.0001	0.0027	<.0001	0.0242	<.0001
LSD	0.3111	0.141	0.6453	5.2226	5.9151	5.6851
Covariate yield		*0.0054*	*0.0537*			
TRT		*0.0188*	*0.0410*			

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Figure 1: Control “No pruning” (T1) ‘Jewel’ plant on 20 December 2010 at Gelukstroom farm.

Figure 2: “Severe pruning” (T2) ‘Jewel’ plant on 20 December 2010 at Gelukstroom farm.

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Figure 3: “Standard pruning” (T3) ‘Jewel’ plant on 20 December 2010 at Gelukstroom farm.

Figure 4: “Standard pruning plus heading” ‘Jewel’ plant on 20 December 2010 at Gelukstroom farm.

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Figure 5: “Light pruning” (T5) ‘Jewel’ plant on 20 December 2010 at Gelukstroom farm.

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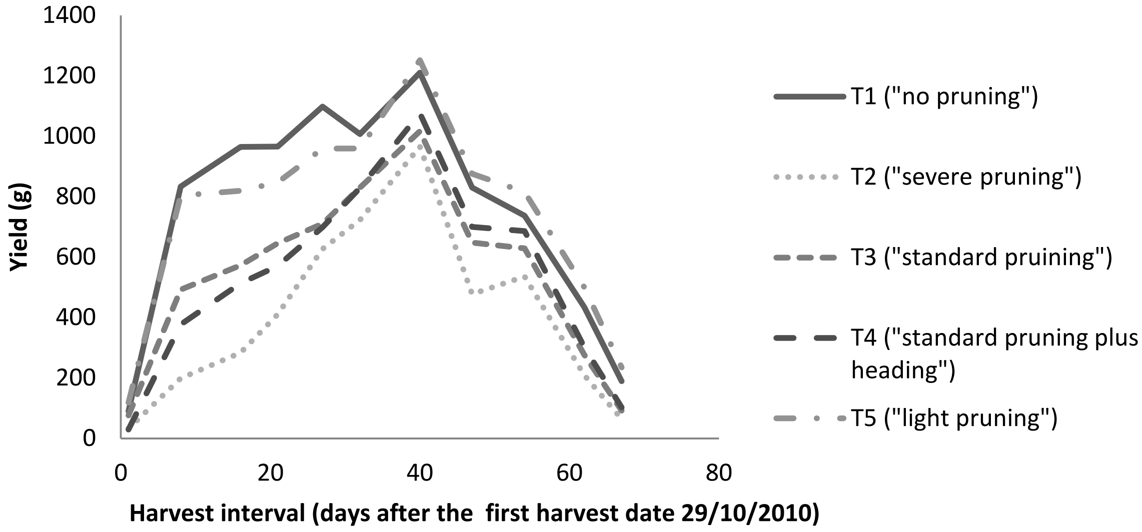

Figure 6: Harvest interval for total yield for 'Jewel' at Teeland farm.

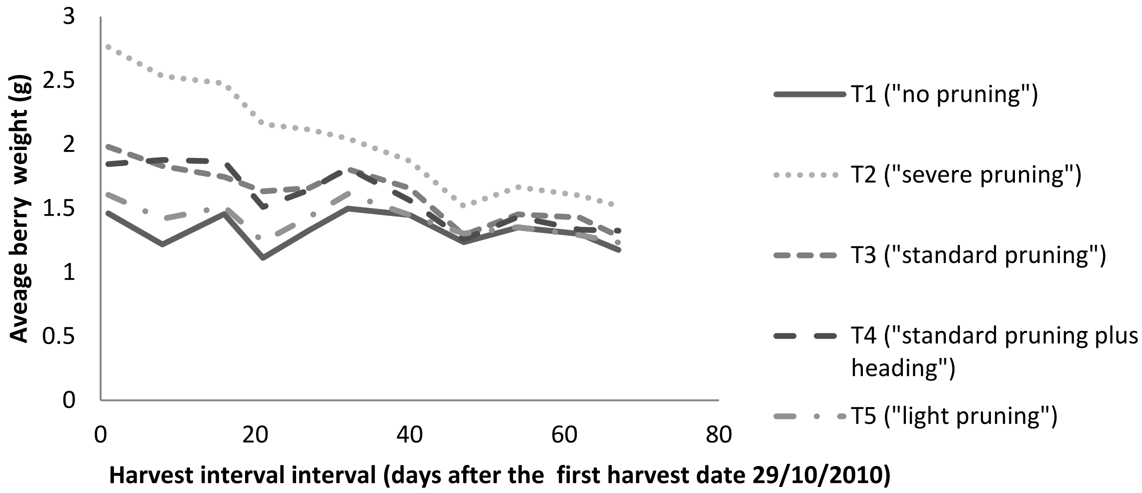

Figure 7: Average berry weight at the different harvest intervals for 'Jewel' at Teeland farm.

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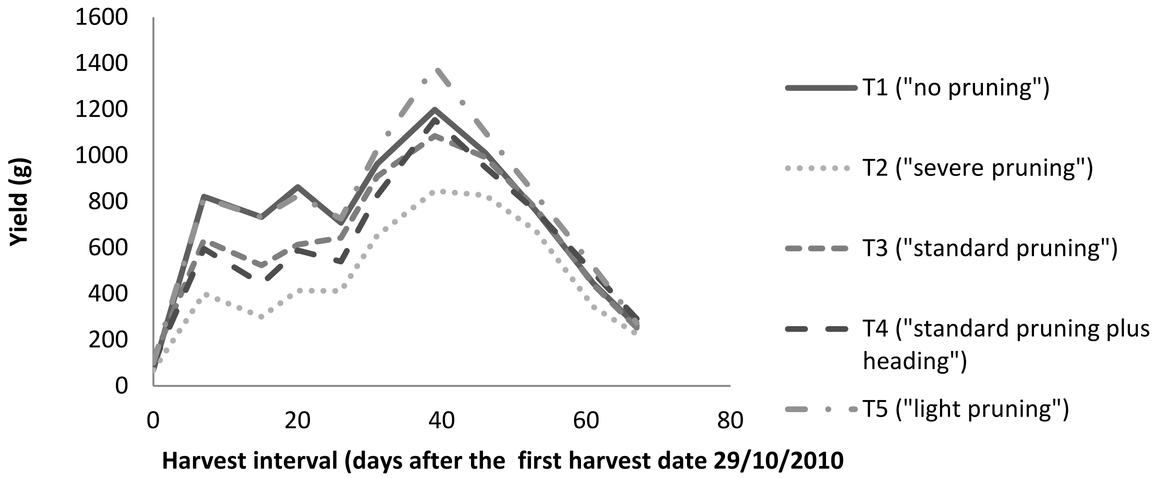

Figure 8: Harvest interval for total yield for 'Emerald' at Teeland farm.

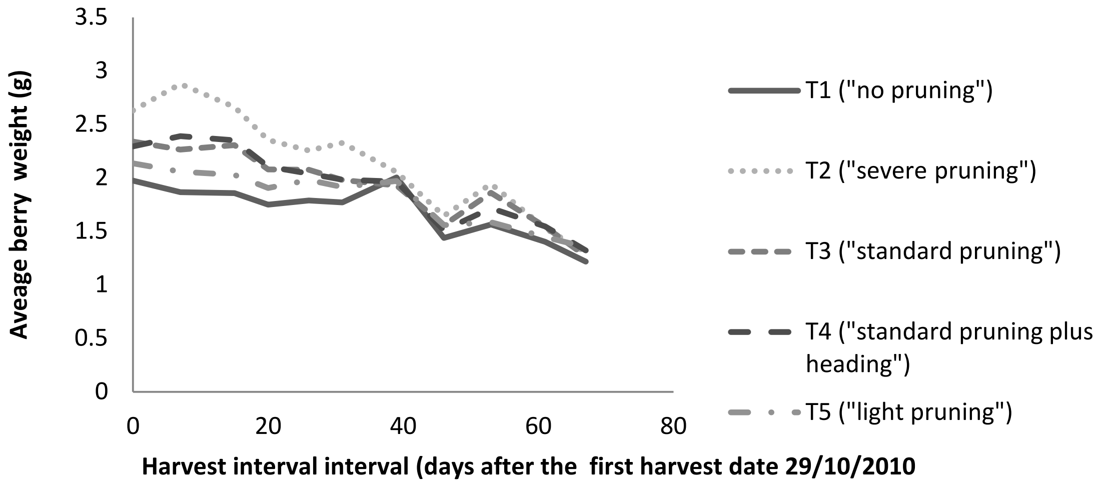

Figure 9: Average berry weight at the different harvest intervals for 'Emerald' at Teeland farm.

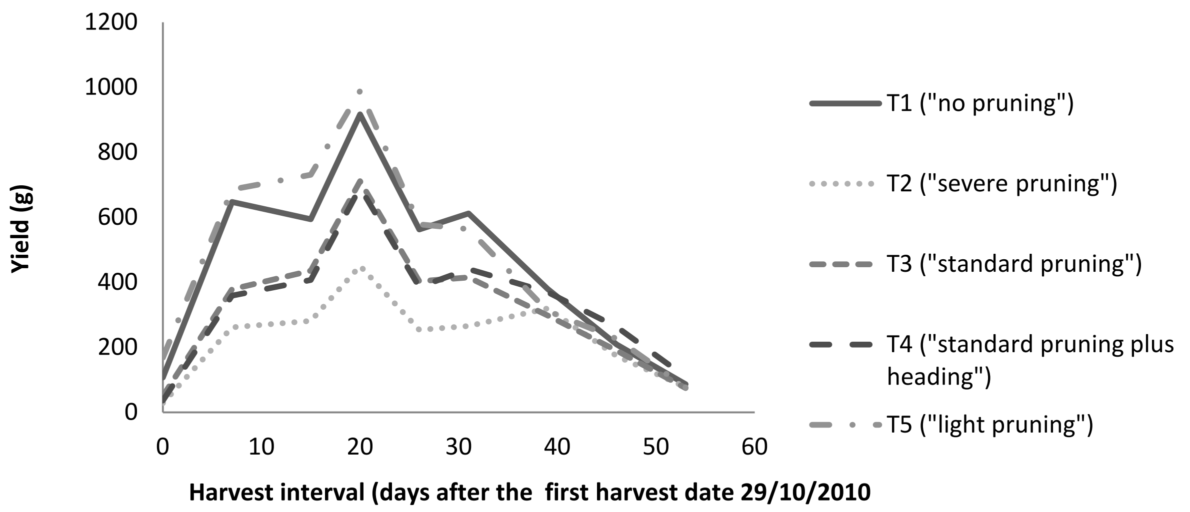

Figure 10: Harvest interval for total yield for ‘Star’ at Teeland farm.

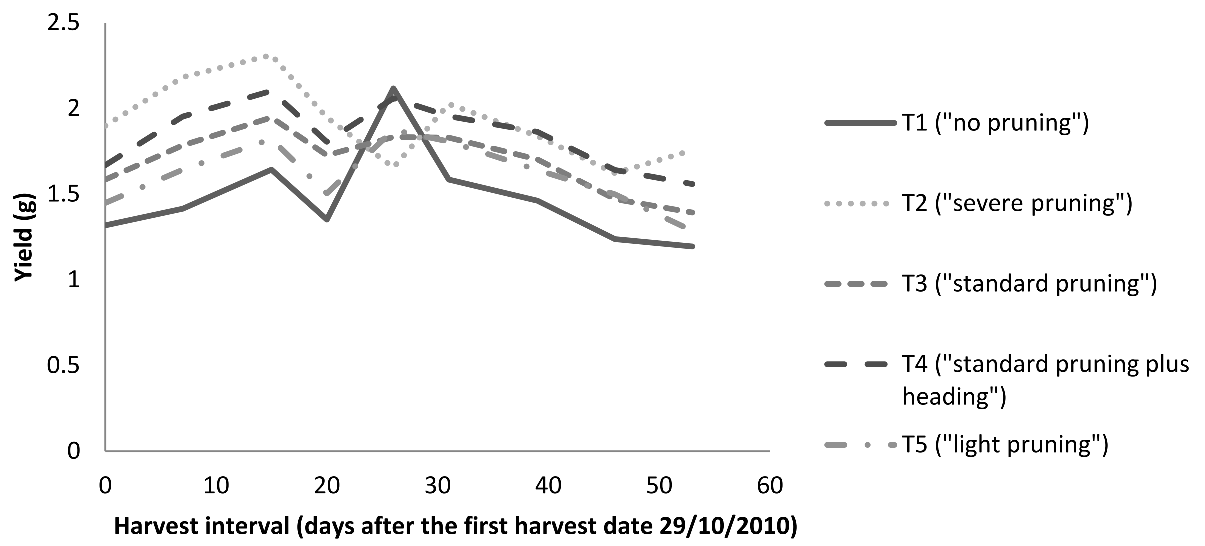

Figure 11: Average berry weight at the different harvest intervals for ‘Star’ at Teeland farm.

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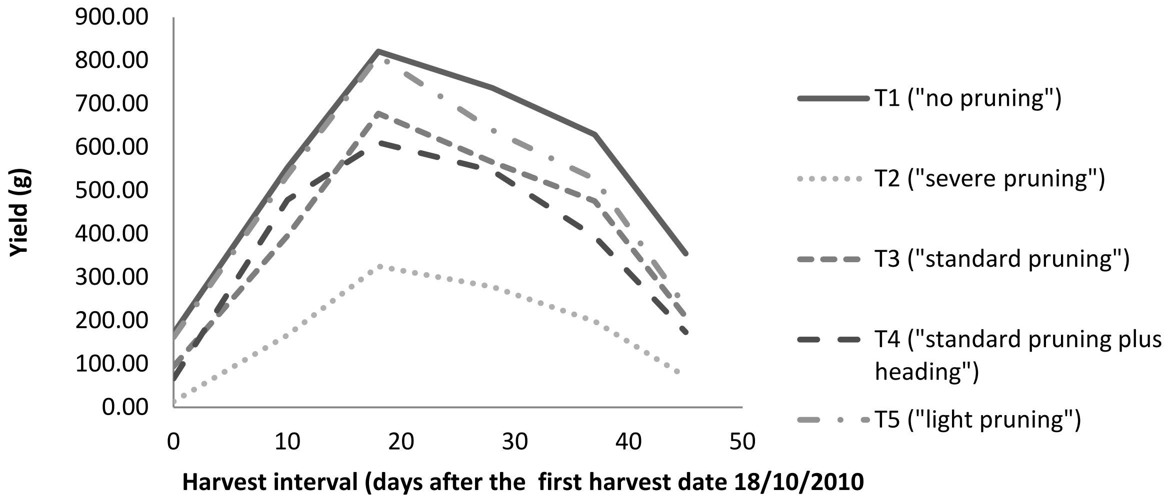

Figure 12: Harvest interval for total yield for ‘Jewel’ at Lushof farm.

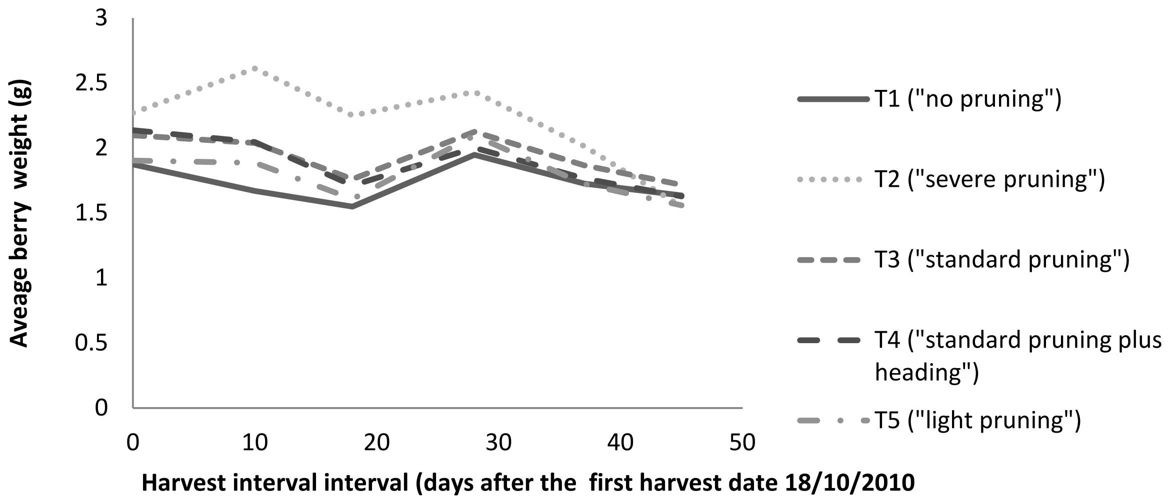

Figure 13: Average berry weight at the different harvest intervals for ‘Jewel’ at Lushof farm.

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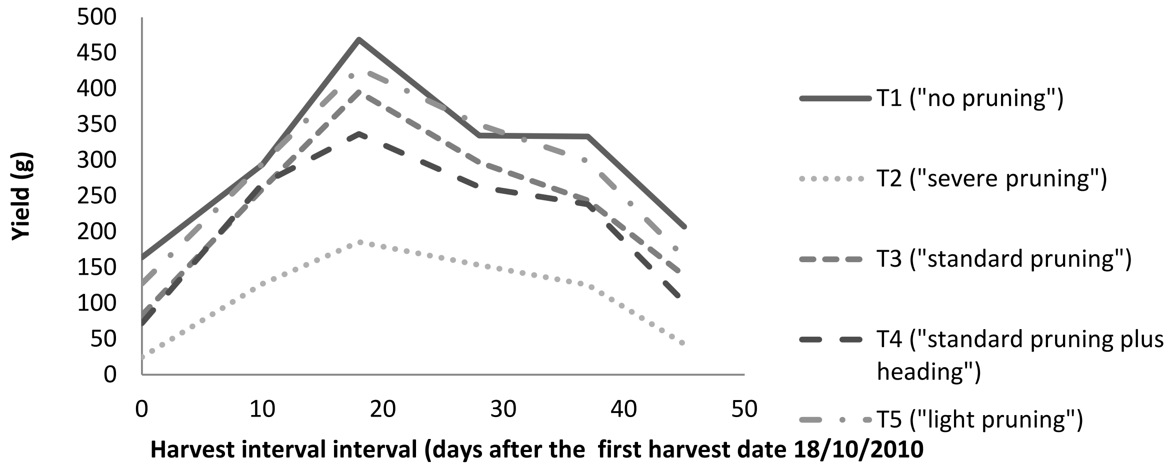

Figure 14: Harvest interval for total yield for ‘Emerald’ at Lushof farm.

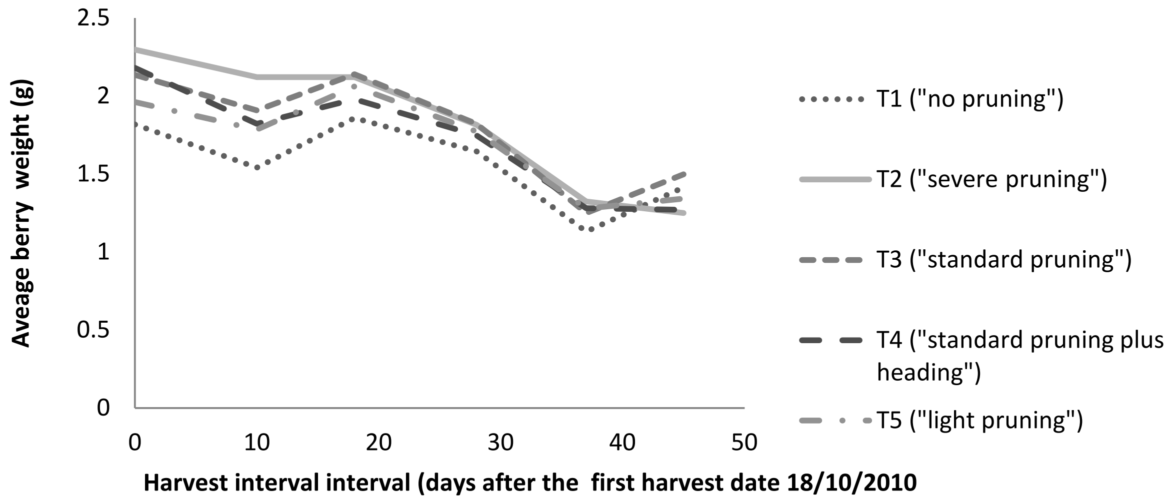

Figure 15: Average berry weight at the different harvest intervals for ‘Emerald’ at Lushof farm.

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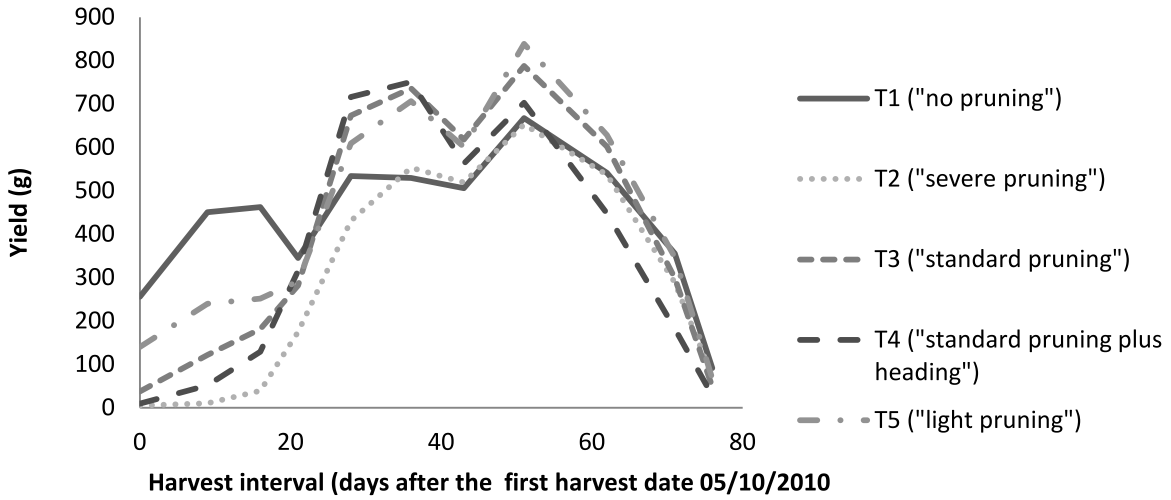

Figure 16: Harvest interval for total yield for 'Jewel' at Gelukstroom farm.

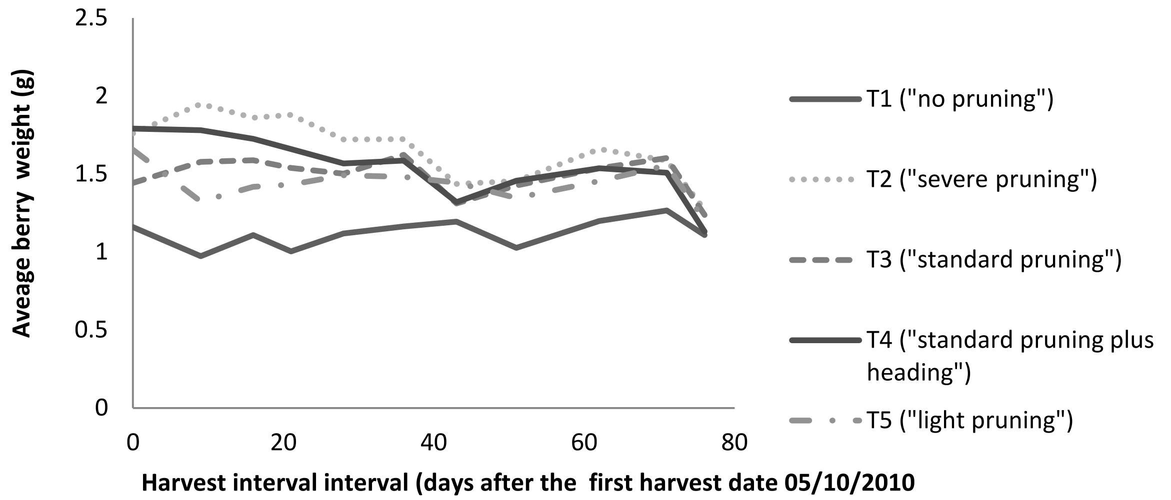

Figure 17: Average berry weight at the different harvest intervals for 'Jewel' at Gelukstroom farm.

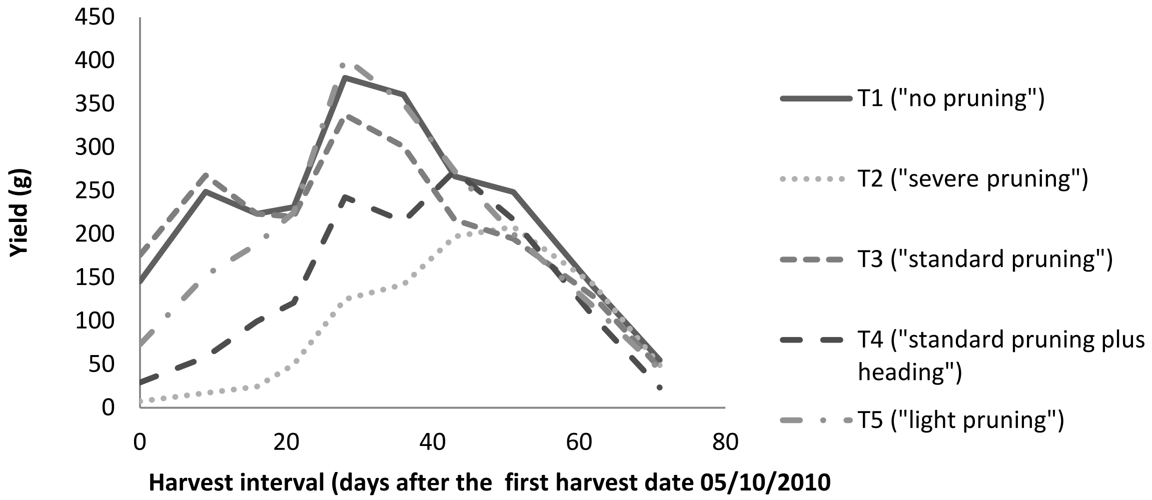

Figure 18: Harvest interval for total yield for 'Star' at Gelukstroom farm.

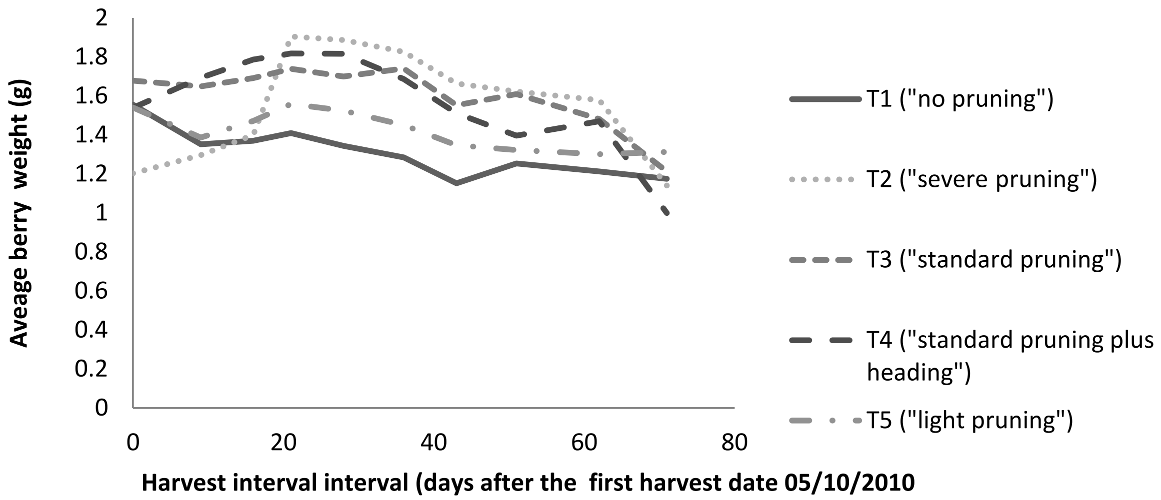

Figure 19: Average berry weight at the different harvest intervals for 'Star' at Gelukstroom farm.

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Paper 3: Evaluating the effect of time of summer pruning on southern highbush blueberries 'Star', 'Emerald' and 'Jewel'.

Abstract. Commercial southern highbush blueberry production is new to South Africa. Currently, producers implement summer pruning instead of winter pruning because of the long period of active shoot growth after harvest. Labour availability is often limiting during this period, which poses the question of until when pruning can be delayed before reducing the following season's crop. The experiment was conducted at two sites in the Porterville district, Western Cape Province of South Africa. The experiment comprised six treatments consisting of an unpruned control and five pruning dates (**Teeland:** 'Star', 'Emerald' and 'Jewel'; 21 December 2009, 11 January 2010, 1 February 2010, 22 February 2010 and 15 March 2010; **Lushof**: 'Jewel' and 'Emerald'; 9 December, 30 December 2009, 22 January 2010, 11 February and 3 March 2010) where "standard pruning" was applied. At Teeland, delaying pruning resulted in a decrease in total new growth and shoot number thereby reducing yield. This was probably due to progressively more buds that became endodormant. For all three cultivars pruning as soon as possible after harvest would therefore be recommended. At Lushof, the effect of time of summer pruning was not significant. This could be due to the fact that plants were younger and more vigorous or because the area is warmer and growth continues for longer. One more season's data is needed before any final conclusions are drawn.

Introduction

Early ripening southern highbush blueberries bear on one-year-old wood (Gough, 1994). Summer pruning can be used to stimulate lateral branching by cutting back vigorous shoots before the onset of winter and endodormancy (Bañados *et al.*, 2009). After harvest, under South African growing conditions, a period of up to five months remains during which blueberries could possibly develop such one-year-old shoots (McKenzie 2010, personal communication).

The time and severity of the pruning cuts are two factors that influence the response of deciduous fruit crops to pruning (Wertheim, 2005). Summer pruning is used to control vigour and increase light distribution in deciduous tree fruit crops. Thus, pruning is done later in the season when the buds are already dormant to avoid new vegetative growth (Wertheim, 2005). In the case of southern highbush blueberries, the objective of pruning is to stimulate new growth and pruning therefore needs to happen before the onset of endodormancy. Time of summer pruning has a significant effect on the number and length of laterals produced (Bañados *et al.*, 2009). In 'Star' and 'O'Neal' in Northern Chile (SH), the capacity to produce laterals decreased from December to March, resulting in a decrease in the number of reproductive buds and total yield the following season (Bañados *et al.*, 2009).

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Labour availability is limited during summer in the South-African blueberry industry. Therefore the question arises until when summer pruning can be delayed under South African growing conditions before reducing the following season's crop. The goal of this research is to evaluate the effect of time of summer pruning on the re-growth and yield of the cultivars Star, Emerald and Jewel at two different sites.

Material and methods

Trial sites: The trials were conducted on 'Star', 'Emerald' and 'Jewel' at Teeland and on 'Emerald' and 'Jewel' at Lushof during the 2009/2010 growing season in the commercial orchards described in Paper 2.

Treatments and trial design: A trial consisted of six treatments, with 10 single-plant repetitions in a randomised complete block design. Treatments consisted of an un-pruned control (T1) and the following pruning dates. **Teeland:** 'Star', 'Emerald' and 'Jewel'; 21 December 2009 (T2), 11 January 2010 (T3), 1 February 2010 (T4), 22 February 2010 (T5) and 15 March 2010 (T6). **Lushof**: 'Jewel' and 'Emerald'; 9 December 2009 (T2), 30 December 2009 (T3), 22 January 2010 (T4), 11 February 2010 (T5) and 3 March 2010 (T6). Pruning consisted of the removal of all unproductive canes, old bearing wood and low growing weak branches. Remaining canes were headed back to between 3 and 5 productive laterals. If there were no productive laterals on a cane and the cane was thicker than 6 mm, it was headed back to 35 cm above the ground.

Data recorded and data analysis: The data was recorded and analysed as described in Paper 2.

Results

In 'Jewel' at Teeland, the pruning weights removed during summer pruning decreased slightly until a sharp increase on the third pruning date, where after it decreased again, while 'Star' showed a big increase at the last pruning date and 'Emerald' at Lushof showed an increase in pruning weights until the second pruning date where after it decreased again (Table 1). In the case of 'Emerald' at Teeland and 'Jewel' at Lushof, the weight of prunings removed increased linearly from the first to the last pruning date (Table 1). All pruning treatments (T2 to T6) equally decreased the total length of old shoots remaining in winter and the number of old shoots left after pruning in 'Emerald' and 'Jewel' (Table 2 and 3). 'Star' at Teeland showed a quadratic trend for the number of shoots left and total shoots remaining in the winter after pruning. It increased from the first pruning date until 22 February (4^{th} pruning date) where after it decreased at the last pruning date (Table 2 and 3).

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Teeland - 'Jewel': All pruning dates decreased the average plant volume compared to the un-pruned control (Table 4). There were no significant trends between the pruning dates, or between the pruning dates and the control plants in the total number of canes in winter after pruning. The percentage new canes that developed decreased linearly from the first to the last pruning date. Pruning reduced the total new growth compared to the control. Total new growth and the total number of new shoots decreased linearly from the first to the last pruning date. All pruning treatments (T2 toT6) significantly increased the average shoot length.

All pruning dates (T2 to T6) reduced the total yield, but increased the average berry weight and diameter compared to the control (T1) (Table 5). Total yield decreased linearly from the first to the last pruning date. Total yield was a highly significant covariate for berry weight and diameter, although the pruning effect remained significant. Berry weight increased linearly from the first to the last pruning date, while berry diameter followed a quadratic trend with a sharp increase from the to the third pruning date where after little further increase was observed. The harvest distribution differed for the middle harvest period where a linear decrease in the harvest percentage was observed with later pruning dates. For the last harvest period there was a sharp increase on the third and fourth pruning dates in percentage crop picked, where after it decreased again for the last pruning date.

Teeland - 'Emerald': All pruning treatments significantly decreased the average winter plant volume (Table 6). Total new growth and total number of new shoots were reduced, but average new shoot length was increased by pruning compared to the control plants. The decrease in new growth and number of new shoots followed a quadratic trend with a sharp decrease from the first to the third pruning date where after it slightly increased again. The average shoot length increased until 22 February, after which it decreased again.

All pruning treatments significantly decreased total yield, but increased berry weight and diameter (Table 7). Total yield decreased linearly with a delay in pruning after harvest. Total yield was a highly significant covariate for berry weight and diameter, although the treatment effect remained significant. Berry weight and diameter increased linearly from the first to the last pruning date. Control plants were generally harvested earlier than pruned plants, resulting in slightly lower yields harvested over the middle and last harvest periods. During the last harvest period, the percentage yield decreased linearly with a delay in pruning.

Teeland - 'Star': There were no significant trends between the pruning treatments, or between the treatments and the control plants in average plant volume, total number of canes or percentage new cane development (Table 8). Al pruning treatments (T2 to T6) significantly reduced total growth and

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number of new shoots, but increased the average new shoot length. Total new growth decreased until 22 February where after it increased again (P= 0.0624). Total number of new shoots followed a quadratic trend with a sharp decrease from the 1st to the 3rd pruning date and no further increase after the 3rd date. Average shoot length showed an opposite quadratic trend with a sharp increase from the 1st tot the 3rd pruning date where after it decreased again.

All pruning treatments significantly decreased total yield, but increased average berry weight and diameter (Table 9). Total yield was a highly significant covariate for berry weight and diameter, although the pruning effect remained significant. Berry weight increased linearly with a delay in pruning while berry diameter followed a quadratic trend increasing sharply from 1st to the 3rd pruning date where after it remained steady. The percentage of the crop harvested over the last harvest period decreased linearly with a delay in pruning.

Lushof - ‘Jewel’: Although pruning reduced the total new growth and number of canes, but increased the average shoot length compared to the control, there were no significant differences in average plant volume and percentage new cane development (Table 10). The percentage new cane development decreased linearly with a delay in pruning.

Total yield was reduced, but average berry weight and diameter were increased by pruning. Total yield was a highly significant covariate for berry weight and diameter, but the treatment effect remained significant. Berry diameter increased from the 1st to the 4th pruning date where after it decreased again. There were no significant differences in the percentage crop harvested over any of the harvest periods (Table 11).

Lushof - ‘Emerald’: There were no significant differences between the pruning treatments and the control in average plant volume, total number of canes or the percentage new cane development (Table 12). All pruning treatments reduced total new growth and number of new shoots, but increased the average shoot length compared to the control. There were no linear or quadratic trends between the pruning dates for the above mentioned variables.

Pruning decreased total yield, but increased berry weight compared to the un-pruned control (Table 12). Berry weight followed a quadratic trend, increasing from the first to the fourth pruning date where after it decreased again to the final pruning date. When total yield was used as a covariate, it was not significant for berry weight and the treatment effect remained highly significant. Pruning advanced fruit ripening compared to the un-pruned control resulting in a higher percentage of the crop harvested over the middle harvest period, but a lower percentage of the crop over the last harvest period.

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Discussion

Teeland and Lushof – Pruned vs. unpruned plants

For all the cultivar/site combinations, the length and number of shoots older than one year was significantly reduced by pruning, indicating that old unproductive wood was successfully removed. Jewel and Emerald at Teeland were the only cultivars where the average plant volume in winter was reduced by summer pruning (Table 4 and 6). These cultivars were on average 2 m^3 larger than 'Star' (Teeland) (Table 8) and 'Jewel' and 'Emerald' (Lushof) (Table 10 and 12) and during pruning up to 1 kg more prunings were removed from these plants (Table 1). The re-growth was apparently not vigorous enough to compensate for the heavier pruning. Jewel at Lushof was the only cultivar/site combination where pruning reduced the total number of canes (old plus new) significantly, while percentage new cane development was not reduced at all.

For all the cultivar/site combinations, total new growth and total number of new shoots were reduced by pruning, but average new shoot length was increased. Further ramification of laterals results in an increase in total new growth and shoot number, but a decrease in lateral shoot length in unpruned plants (Paper 2).

For all the cultivar/site combinations, pruning significantly decreased yield, but increased average berry weight and diameter. Lushof 'Emerald' was the only exception where pruning did not significantly increase berry diameter. Total yield as covariate was highly significant for all the cultivars except for 'Emerald' at Lushof (Table 13). However, the pruning effect remained significant and thus the increase in berry weight and diameter is only partially due to the reduction in total yield. The additional increase in fruit size is probably due to the increase in lateral shoot length and thickness in response to pruning (Shutak and Muracci, 2006; Paper 2).

The only cultivar where pruning caused a statistically significant delay in harvest was Emerald at Teeland, although from a horticultural point of view, the delay was not long enough to reduce market price and therefore it is insignificant. We reported a progressive delay in harvest with an increase in the severity of pruning (Paper 2). Therefore we conclude that the pruning severity for this trial was probably not severe enough to have an effect on the harvest date.

Teeland – trends for different pruning dates

One would expect that the pruning weights removed should either increase with later pruning dates, as more laterals developed during the season and were removed through heading cuts, or it should remain similar. In our trials this was the case except for 'Jewel' at Teeland where it increased until

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the third pruning treatment where after it decreased again (Table 1). The fact that the length and number of old shoots that remained on the plants were similar by winter for all the pruning dates for all the cultivar/combinations (except for 'Star') were similar, is a good indication that the pruning method was applied consistently over all the pruning dates and that the discrepancy observed with 'Jewel' could possibly be ascribed to inter plant variation.

For 'Jewel', 'Emerald' and 'Star' total new growth and number of new shoots were drastically reduced when pruning was delayed after 21 December, independent of whether the trends were linear or quadratic (Table 4, 6 and 8). Bañados *et al*. (2009) obtained similar data and explained that the decrease in growth with a delay in pruning was due to a decrease in the number of new shoots developing because of an increase in the level of endodormancy as the season progresses. Total yield decreased linearly for 'Jewel' and 'Emerald' with a delay in pruning (Table 4 and 6). Although in the case of 'Star', total yield did not show a significant linear or quadratic response to pruning date, pruning decreased the yield from the first to the third pruning date. Even though not statistically significant, the average decrease in yield of 0.8 kg per plant from the first to the third pruning date suggests that pruning should preferably be done as soon as possible after harvest. The reduction in yield when pruning later is related to the reduction in total new growth and the number of new shoots. For 'Emerald', however, one would have expected a larger decrease in yield when pruning was done on 11 January as it resulted in significantly less new growth and fewer new shoots. One possible explanation for this discrepancy is that 'Emerald' differentiates a large number of reproductive buds and sets heavily, but still produces large fruit (Lyrene, 2008), thereby to some extent making up for the lower number of bearing shoots. Generally though, the decrease in total growth and shoot number resulted in a decrease in bearing positions and thereby possibly in the number of reproductive buds and yield.

Instead of a decrease in lateral shoot length as pruning was progressively delayed (Bañados *et al.*, 2009), lateral shoot growth followed a quadratic trend for 'Star' and 'Emerald' at Teeland, increasing sharply from the first to the fourth and the first to the third pruning dates, respectively, where-after it decreased. This is due to the difference in pruning method used compared to Bañados and co-workers. We left three to five vigorous one-year-old laterals per cane and these were included in the measurement of total shoot length during winter. Bañados *et al.* (2009) pruned every shoot on the plant and measured only the newly developed shoots on these laterals. We found an increase in number of laterals with earlier pruning resulting in shorter average shoot length. Therefore, if we measured only the laterals produced after pruning and not including the 3 to 5 laterals that where left per cane, we would probably have observed a decrease in the average shoot length when pruning was done later in the season.

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Changes in berry weight and diameter with pruning date were statistically significant, but all treatments still produced berries with an average diameter exceeding the minimum export standard (> 12 mm diameter) and these differences are therefore probably not of horticultural significance. We unfortunately did not determine the percentage berries with a diameter <12 mm. For all three cultivars there were some statistically significant differences in the harvest periods, though the increase or delay in harvest were never long enough to be of horticultural significance.

Lushof – Trends for different pruning dates

As at Teeland, Jewel at Lushof responded to time of pruning with a similar linear reduction in percentage new cane development, further indicating that early pruning is important to rejuvenate 'Jewel' plants.

There were no linear or quadratic trends in response to pruning time for total yield. The berry weight of 'Jewel' (p=0.0731) and Emerald and the diameter of 'Jewel' increased significantly until the fourth pruning date, though as for Teeland, this increase was not of horticultural significance.

There were no trends in response to pruning time for average plant volume, total number of canes, total new growth, total number of new shoots, the average shoot length and the percentage crop harvested over any of the harvest periods. This is in contrast to what we found at Teeland and to Bañados *et al.* (2009). The trials at Lushof were performed on a block established in 2008 covered with 30% black shade cloth, and therefore these plants were not in full production. The plants at Teeland were established in 2006 covered with 20% white shade cloth and were almost in full production. Two conclusions are possible from this: firstly, it could be an indication that the time of summer pruning is not that important in young, vigorous, low yielding plants, or secondly, that due to the warmer climate and longer growing season at Lushof, the time of summer pruning is not so important. It would be interesting to assess the response to even later pruning in this area. Another season's data should clarify this.

Conclusions

At Teeland, probably due to progressively more buds that became endodormant as the season progressed resulted in a decrease in total new growth and shoot number thereby reducing yield when pruning was delayed after harvest in summer. Pruning as soon as possible after harvest would be recommended for all three cultivars. At Lushof, the effect of time of summer pruning was less significant, possibly due to the fact that plants were younger or due to a difference in climatic conditions. One more season's data is needed before any final conclusions are drawn.

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Literature Cited

Bañados, P., P. Uribe and D. Donnay. 2009. The effect of summer pruning date in ‘Star’, ‘O’Neal’ and ‘Elliott’. Acta Hort. 810:501-508.

Gough, R.E. 1994. Growth and development, p.11-57. In: Gough, R.E. (eds.), The higbush blueberry and its management. The Haworht Press, Inc. Worwood. Australia.

Lyrene, P.M. 2008. ‘Emerald’ southern highbush blueberry. HortScience 43(5):1606-1607.

Shutak, V.G. and E.M. Muracci. 1966. Plant and fruit development, p179-198. In: P. Eck and N.F. Childers (eds.), Blueberry culture. Rugters university press. New Jersey.

Wertheim, S.J., 2005. Pruning, p.176-189. In: Tromp, J., A.D. Webster and S.J. Wertheim (eds.), Fundamentals of temperate zone tree fruit production. Backhuys Publishers. Leiden. The Netherlands.

Table 1: Total weight of prunings removed (kg) on the day of pruning.

Pruning date	Total mass of prunings removed (kg)				
	Jewel (Teeland)	Emerald (Teeland)	Star (Teeland)	Jewel (Lushof)	Emerald (Lushof)
T1 (No pruning)	0.0 d	0.0 d	0.0 c	0.0 c	0.0 c
T2 1st pruning date	1.5 b	1.5 bc	0.6 b	0.5 b	0.5 b
T3 2nd pruning date	1.2 b	1.3 c	0.4 b	0.6 a	0.8 a
T4 3rd pruning date	*2.1* a	1.8 ab	0.6 b	0.6 ab	0.6 ab
T5 4th pruning date	1.9 a	1.7 b	0.6 b	0.7 a	0.7 a
T6 5th pruning date	0.8 c	2.1 a	1.8 a	0.7 a	0.7 ab
Treatment	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<0.0001*
Contrast Contr. vs. pruning	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<0.0001*
Contrast Time linear	*0.0498*	*<.0001*	*<.0001*	0.0114	0.2008
Contrast Time quadratic	*<.0001*	*0.1170*	*<.0001*	0.1232	0.0019

Table 2: Total length of the old canes that remained per plant in winter after pruning in summer.

Pruning treatment	Total length old growth (cm)				
	Jewel (Teeland)	Emerald (Teeland)	Star (Teeland)	Jewel (Lushof)	Emerald (Lushof)
T1 (No pruning)	513.70 a	285.7 a	279.8 a	168.7 a	136.1 a
T2 1st pruning date	86.7 b	46.6 b	65.2 b	53.4 b	36.1 b
T3 2nd pruning date	69.9 b	52.4 b	66.3 b	51.4 b	35.9 b
T4 3rd pruning date	*86.0* b	44.6 b	79.7 b	50.9 b	41.2 b
T5 4th pruning date	78.4 b	39.6 b	93.8 b	53.0 b	40.8 b
T6 5th pruning date	69.1 b	41.1 b	68.8 b	56.4 b	41.3 b
Significance level	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<.0001*
Contrast Contr. vs. pruning	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<.0001*
Contrast Time linear	*0.7702*	*0.6555*	*<.0001*	*0.8500*	*0.5974*
Contrast Time quadratic	*0.9359*	*0.9267*	*<.0001*	*0.7680*	*0.9098*

Table 3: Total number of old shoots (older than one year) that remained per plant in winter after pruning in summer.

Pruning treatment	Total number of old shoots				
	Jewel (Teeland)	Emerald (Teeland)	Star (Teeland)	Jewel (Lushof)	Emerald (Lushof)
T1 (No pruning)	28 a	14 a	15 a	10 a	5 a
T2 1st pruning date	3 b	2 b	3 b	2 b	2 b
T3 2nd pruning date	3 b	2 b	3 b	2 b	2 b
T4 3rd pruning date	*3* b	2 b	3 b	2 b	2 b
T5 4th pruning date	3 b	2 b	4 b	2 b	2 b
T6 5th pruning date	3 b	2 b	2 b	2 b	2 b
Significance level	*0,0001*	*<.0001*	*<.0001*	*<.0001*	0.0004
Contrast Contr. vs. pruning	*<.0001*	*<.0001*	*<.0001*	*<.0001*	*<.0001*
Contrast Time linear	*0.9858*	*0.9084*	*<.0001*	*0.9673*	0.9606
Contrast Time quadratic	*0.8683*	*0.8458*	*<.0001*	*0.8236*	0.5458

Table 4: Average plant volume, total number of canes per plant, percentage new canes, total new growth, total number of new shoots and average new shoot length in winter on 'Jewel' plants at Teeland following different pruning times in summer.

Pruning treatment	Average plant volume (m^3)	Total number new and old canes	Percentage new canes	Total new growth (cm)	Total number of new shoots	Average new shoot length (cm)
T1 (No pruning)	3.8 NS*	12 NS*	7.2 b	1023.2 a	94.2 a	11.8 b
T2 (21/12/2009)	2.9	10	18.4 a	679.1 b	41.4 b	17.3 a
T3 (11/01/2010)	2.9	12	18.8 a	469.4 c	26.3 c	18.6 a
T4 (01/02/2009)	3.3	11	7.3 b	463.4 c	24.2 c	20.0 a
T5 (22/02/2010	3.0	11	6.8 b	347.1 c	18.9 c	19.3 a
T6 (15/03/2010)	3.0	10	7.7 b	307.9 c	15.9 c	20.8 a
Treatment	0.3229	0.2232	0.0407	<.0001	<.0001	<.0001
Contrast Contr. vs. pruning	0.0192	0.1949	0.3888	*<.0001*	*<.0001*	*<.0001*
Contrast Time linear	0.7170	0.5309	0.0048	*<.0001*	0.0006	0.0550
Contrast Time quadratic	0.5068	0.5679	0.3301	0.3245	0.2667	0.6998

Table 5: Total yield per plant, average berry weight , average berry diameter, percentage yield over the first three harvest dates, middle four harvest dates and last three harvest dates on 'Jewel' plants at Teeland following different pruning times in summer.

Pruning treatment	Total yield (kg)	Average berry weight (g)	Average berry diameter (mm)	Percentage yield over first four harvest dates	Percentage yield over middle four harvest dates	Percentage over for last three harvest dates
T1 (No pruning)	7.9 a	1.50 d	12.9 d	36.8 NS*	49.5 ab	13.7 NS*
T2 (21/12/2009)	6.6 ab	1.85 c	13.7 c	32.4	54.3 a	13.3
T3 (11/01/2010)	4.9 c	1.91 bc	14.0 bc	32.7	53.1 a	14.2
T4 (01/02/2009)	5.3 bc	2.00 a	14.5 a	32.7	49.8 ab	15.6
T5 (22/02/2010	5.2 c	1.90 bc	14.1 b	36.4	45.6 b	18.0
T6 (15/03/2010)	4.7 c	2.00 ab	14.3 ab	36.6	50.9 a	12.5
Treatment	*<.0001*	*<.0001*	*<.0001*	*0.4509*	*0.0168*	*0.0693*
Covariate yield		*<.0001*	*<.0001*			
Covariate TRT		*<.0001*	*<.0001*			
Contrast Contr. vs. pruning	*<.0001*	*<.0001*	*<.0001*	0.3083	0.5167	0.4784
Contrast Time linear	*0.0244*	*0.0080*	*0.0016*	0.0678	0.0126	0.6015
Contrast Time quadratic	*0.3324*	*0.2430*	*0.0128*	0.9651	0.0647	0.0216

Table 6: Average plant volume, total number of canes per plant, percentage new canes, total new growth, total number of new shoots and average new shoot length on 'Emerald' plants at Teeland following different pruning times in summer.

Pruning treatment	Average plant volume (m^3)	Total new growth (cm)	Total number of new shoots	Average new shoot length (cm)
T1 (No pruning)	3.4 a	942.6 a	65 a	14.7c
T2 (21/12/2009)	2.5 bc	418.1 b	20 b	21.2b
T3 (11/01/2010)	2.2 c	242.0 c	12 c	23.0b
T4 (01/02/2009)	2.7 bc	161.7 c	7 c	26.9ab
T5 (22/02/2010	2.7 c	163.5 c	5 c	31.3a
T6 (15/03/2010)	2.8 b	174.0 c	8 c	23.5b
Treatment	0.0013	*<.0001*	*<.0001*	*<.0001*
Contrast Contr. vs. pruning	0.0002	*<.0001*	*<.0001*	*<.0001*
Contrast Time linear	0.0513	*<.0001*	*0.0021*	0.0606
Contrast Time quadratic	0.5467	*0.0037*	*0.0330*	0.0225

Table 7: Total yield per plant, average berry weight , average berry diameter, percentage yield over the first three harvest dates, middle four harvest dates and last three harvest dates on 'Emerald' plants at Teeland following different pruning times in summer.

Pruning treatment	Total yield (kg)	Average berry weight (g)	Average berry diameter (mm)	Percentage yield over first four harvest dates	Percentage yield over middle four harvest dates	Percentage yield over last three harvest dates
T1 (No pruning)	9.3 a	1.77 d	13.9 d	33.5 a	48.2 b	18.3 b
T2 (21/12/2009)	5.8 b	1.94 c	14.4 c	27.6 bc	53.1 a	19.3 b
T3 (11/01/2010)	5.7 b	2.07 ab	14.7 bc	24.5 c	52.3 ab	23.2 a
T4 (01/02/2009)	4.6 c	2.13 ab	15.0 a	26.4 bc	54.4 a	19.2 b
T5 (22/02/2010	4.5 c	2.05 b	14.9 ab	29.3 ab	53.1 a	17.6 b
T6 (15/03/2010)	4.0 c	2.14 a	15.0 a	25.9 bc	56.9 a	17.2 b
Treatment	*<.0001*	*<.0001*	*<.0001*	*0.0050*	*0.0184*	*0.0075*
Covariate yield		*<.0001*	*<.0001*			
Covariate TRT		*0.0012*	*0.0064*			
Contrast Contr. vs. pruning	*<.0001*	*<.0001*	*<.0001*	0.0004	0.0023	0.4280
Contrast Time linear	*<.0001*	*<.0001*	*0.0001*	0.7814	0.1089	0.0086
Contrast Time quadratic	*0.8884*	*0.0678*	*0.0550*	0.9401	0.3650	0.1621

Table 8: Average plant volume, total number of canes per plant, percentage new canes, total new growth, total number of new shoots and average new shoot length on 'Star' plants at Teeland following different pruning times in summer.

Pruning treatment	Average plant volume (m^3)	Total number new and old canes	Percentage new canes	Total new growth (cm)	Total number of new shoots	Average new shoot length (cm)
T1 (No pruning)	1.5 NS*	19 NS*	18.0 NS*	361.8 a	39 a	9.5 d
T2 (21/12/2009)	1.3	11	13.6	236.8 b	18 b	13.4 c
T3 (11/01/2010)	1.1	14	19.1	196.9 bc	14 bc	14.2 bc
T4 (01/02/2009)	1.3	24	21.9	157.7 bc	9 c	19.0 a
T5 (22/02/2010	1.4	17	24.3	138.3 c	9 c	15.6 abc
T6 (15/03/2010)	1.5	15	22.0	183.1 bc	10 c	17.8 ab
Treatment	0.4956	0.4130	0.7162	*<.0001*	*<.0001*	*<.0001*
Contrast Contr. vs. pruning	0.2838	0.6350	0.6926	*<.0001*	*<.0001*	*<.0001*
Contrast Time linear	0.1256	0.3773	0.1692	*<.0001*	*<.0001*	*<.0001*
Contrast Time quadratic	0.6282	0.1241	0.3941	*0.0624*	*<.0001*	0.0348

Table 9: Total yield per plant, average berry weight , average berry diameter, percentage yield over the first three harvest dates, middle three harvest dates and last three harvest dates on ‘Star’ plants at Teeland following different pruning times in summer.

Pruning treatment	Total yield (kg)	Average berry weight (g)	Average berry diameter (mm)	Percentage yield over first three harvest dates	Percentage yield over middle three harvest dates	Percentage yield over last three harvest dates
T1 (No pruning)	3.7 a	1.51 c	13.0 d	35.5 NS*	48.4 NS*	16.1 NS*
T2 (21/12/2009)	2.1 b	1.75 b	13.8 c	29.6	45.7	24.8
T3 (11/01/2010)	1.5 bc	1.74 b	14.1 bc	31.8	46.8	21.4
T4 (01/02/2009)	1.3 c	1.97 a	14.8 a	37.0	46.6	16.4
T5 (22/02/2010	1.8 bc	1.98 a	14.8 a	35.0	47.3	17.8
T6 (15/03/2010)	1.4 c	1.95 a	14.5 ab	35.7	47.1	17.1
Treatment	<.0001	<.0001	<.0001	0.3964	0.9877	0.2073
Covariate yield		0.0040	0.0002			
Covariate TRT		0.0003	<.0001			
Contrast Contr. vs. pruning	<.0001	<.0001	<.0001	0.5792	0.5548	0.2765
Contrast Time linear	0.1480	0.0012	0.0012	0.0816	0.6823	0.0392
Contrast Time quadratic	0.1474	0.2413	0.0126	0.3265	0.8605	0.2629

Table 10: Average plant volume, total number of canes per plant, percentage new canes, total new growth, total number of new shoots and average new shoot length on ‘Jewel’ plants at Lushof following different pruning times in summer.

Pruning treatment	Average plant volume (m^3)	Total number new and old canes	Percentage new canes	Total new growth (cm)	Total number of new shoots	Average new shoot length (cm)
T1 (No pruning)	1.7 NS*	11 a	24.9 NS*	845.5 a	79 a	10.8 a
T2 (09/12/2009)	1.6	9 b	29.2	415.7 b	17 b	16.9 b
T3 (30/12/2009)	1.6	10 ab	29.6	341.2 b	17 b	19.9 b
T4 (22/01/2010)	1.6	8 b	13.5	365.7 b	21 b	18.3 b
T5 (11/02/2010	1.6	8 b	21.7	353.5 b	20 b	18.0 b
T6 (03/03/2010)	1.6	8 b	17.6	356.5 b	22 b	16.7 b
Treatment	0.9996	0.0068	0.0530	<.0001	<.0001	<.0001
Contrast Contr. vs. pruning	0.7225	0.0006	0.5671	<.0001	<.0001	<.0001
Contrast Time linear	0.9935	0.1518	0.0196	0.5155	0.6091	0.5327
Contrast Time quadratic	0.9905	0.8376	0.3420	0.5466	0.2152	0.1042

Table 11: Total yield per plant, average berry weight , average berry diameter, percentage yield over the first two harvest dates, middle two harvest dates and last two harvest dates on 'Jewel' plants at Lushof following different pruning times in summer.

Pruning treatment	Total yield (kg)	Average berry weight (g)	Average berry diameter (mm)	Percentage yield over first two harvest dates	Percentage yield over middle two harvest dates	Percentage yield over last two harvest dates
T1 (No pruning)	2.5 NS*	1.82 c	14.1 c	22.1 NS*	51.0 NS*	27.0 NS*
T2 (09/12/2009)	1.7	2.03 b	14.8 ab	26.3	52.9	20.8
T3 (30/12/2009)	1.7	2.07 a	15.1 ab	25.0	50.5	24.5
T4 (22/01/2010)	2.0	2.09 ab	15.1 ab	25.1	51.6	23.3
T5 (11/02/2010	2.0	2.22 a	15.4 a	23.8	52.0	24.2
T6 (03/03/2010)	1.9	2.04 b	14.5 bc	23.0	48.7	28.3
Treatment	*0.0654*	*<0.0001*	*0.0042*	*0.8976*	*0.7624*	*0.3745*
Covariate yield		*0.0493*	*0.0217*			
Covariate TRT		*<.0001*	*0.0103*			
Contrast Contr. vs. pruning	*0.0041*	*<.0001*	*0.0012*	0.3696	0.9430	0.3323
Contrast Time linear	*0.3403*	*0.2315*	*0.6295*	0.3596	0.2844	0.0774
Contrast Time quadratic	*0.4213*	*0.0731*	*0.0205*	0.9548	0.7280	0.7374

Table 12: Average plant volume, total number of canes per plant, percentage new canes, total new growth, total number of new shoots and average new shoot length on 'Emerald' plants at Lushof following different pruning times in summer.

Pruning treatment	Average plant volume (m^3)	Total number new and old canes	Percentage new canes	Total new growth (cm)	Total number of new shoots	Average new shoot length (cm)
T1 (No pruning)	1.1 NS*	15 NS*	49.3 NS*	481.5 a	40 a	12.4 a
T2 (09/12/2009)	0.9	14	47.4	123.4 b	7 b	19.3 b
T3 (30/12/2009)	1.0	13	47.9	136.2 b	6 b	26.0 b
T4 (22/01/2010)	1.1	15	49.5	111.2 b	6 b	22.7 b
T5 (11/02/2010	0.9	13	55.0	103.7 b	6 b	19.7 b
T6 (03/03/2010)	1.1	14	53.1	113.1 b	6 b	20.7 b
Treatment	0.1185	0.5550	0.7142	*<.0001*	*<.0001*	0.0076
Contrast Contr. vs. pruning	0.1550	0.2141	0.7662	*<.0001*	*<.0001*	*0.0008*
Contrast Time linear	0.1047	0.9724	0.1467	*0.5559*	*0.7274*	*0.6532*
Contrast Time quadratic	0.4811	0.4332	0.9855	*0.9366*	*0.9706*	*0.2010*

Table 13: Total yield per plant, average berry weight , average berry diameter, percentage yield over the first two harvest dates, middle two harvest dates and last two harvest dates on 'Emerald' plants at Lushof following different pruning times in summer.

Pruning treatment	Total yield (kg)	Average berry weight (g)	Average berry diameter (mm)	Percentage yield for first two harvest dates	Percentage yield for middle two harvest dates	Percentage yield for last two harvest dates
T1 (No pruning)	1.8 a	1.64 a	13.4 NS*	21.5 NS*	46.8 NS*	31.6 a
T2 (09/12/2009)	1.2 b	1.63 a	13.3	23.2	49.6	26.9 ab
T3 (30/12/2009)	1.3 b	1.79 b	13.7	26.5	52.4	21.1 c
T4 (22/01/2010)	1.1 b	1.80 b	13.7	23.2	51.8	25.0 bc
T5 (11/02/2010	1.1 b	1.87 b	13.4	26.6	52.3	21.1 c
T6 (03/03/2010)	1.0 b	1.78 b	13.2	27.2	50.2	22.6 bc
Treatment	*0.0003*	*0.0001*	*0.7785*	*0.2844*	*0.1813*	*0.0020*
Covariate yield		*0.7624*	*0.2554*			
Covariate TRT		*<.0001*	*0.6596*			
Contrast Contr. vs. pruning	*<.0001*	*0.0020*	*0.7061*	0.0998	0.0186	0.0003
Contrast Time linear	*0.1341*	*0.0030*	*0.6356*	0.2337	0.8976	0.1651
Contrast Time quadratic	*0.6841*	*0.0050*	*0.1796*	0.8345	0.2052	0.3760

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General discussion and overall conclusion

The South-African blueberry industry is export driven. Commercial production of the southern highbush blueberries (SHB) 'Jewel', 'Emerald', 'Star', 'Snowchaser' and 'Bluecrisp' recently started in the Western Cape. The early ripening berries of superior quality produced from September to December are currently increasing the South-African market share in the United Kingdom (personal communication, McKenzie 2010). New orchards are currently being planted and the question was raised whether cross-pollination could further increase fruit quality and earliness. To further increase profitability, the understanding of the effect of severity and time of summer pruning of SHB under local growing conditions is required to develop sustainable pruning strategies.

We established that the effect of cross-pollination on fruit set, berry weight, berry diameter and fruit development period under local conditions is cultivar dependant. Due to the nature of cross-pollination trials another season's data is required before any final conclusions are drawn. When making recommendations regarding cross-pollination, it is firstly important that the bloom period of the cultivars overlap. 'Bluecrisp' appears self-incompatible and 'Misty' or 'Emerald' are recommended as cross-pollinators to increase fruit set, berry size and to advance harvest maturity. 'Snowchaser' seems self-compatible and solid block plantings are recommended. 'Misty' and 'Emerald' are recommended as cross-pollinators for 'Star' and 'Jewel', respectively, even though these cultivars will set an adequate crop when self-pollinated, but fruit characteristics were improved with cross-pollination. Although 'Emerald' seems self-compatible, the fruit set tends to vary greatly and cross-pollination with 'Jewel', 'Misty' and 'Bluecrisp' is recommended to obtain early maturing berries of the right size. However, as stated earlier, this research should be repeated before final recommendations are made.

We established that summer pruning of SHB is a compromise between total yield and desired berry size. All the pruning treatments (severity and time) reduced total vegetative growth and shoot number, but increased individual shoot length compare to no pruning. We further established that the decrease in winter plant volume and total new growth observed after pruning was not due to a decrease in average shoot length, but rather due to the decrease in number of new shoots after pruning. Summer pruning increased berry weight and diameter by reducing total yield, but also by developing better quality bearing wood. Time of summer pruning did not affect berry size enough to be of any horticultural significance. Vigorous laterals stimulated by pruning grew for longer thereby delaying reproductive bud initiation and harvest. An increase in the severity of pruning increased the

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level to which the plants responded for all the variables measured. We also established that heading cuts in summer result in an increase in the number of laterals at the pruning wound, but not in new cane development from the crown.

At Teeland, probably due to progressively more buds that became endodormant, total new growth and shoot number and therefore yield were decreased when pruning was delayed. The time of summer pruning at Lushof did not have a significant effect on any of the variable studied. This is probably due to the warmer production area or due to the fact that the plants were younger and more vigorous. However, to prevent a decrease in yield the following season at Teeland, pruning as early as possible after harvest would be recommended. Another season's data will clarify whether the recommendation would also be applicable to Lushof.

No pruning and "light pruning" would be recommended if yield is the only priority. However, further ramification and therefore a further decrease in average shoot length and berry diameter will probably result from this after successive seasons. This can be a problem especially in the case of 'Jewel' and 'Star', where a large percentage of the berries produced are already under the minimum export diameter. In the case of 'Emerald', it seems to be less of a problem due to the ability of this cultivar to differentiate a large number of reproductive buds that set heavily while still producing large fruit (Lyrene, 2008). This, however, poses the question of whether no pruning and "light pruning" are sustainable and another season's data is important to clarify this.

Though "standard pruning" resulted in a decrease in yield compared to no pruning and "light pruning", berries of all the cultivars were of exceptional quality and above minimum export diameter. The more condense harvest with larger fruit will ease management over the harvest period. A loss in plant vigour, a decrease in berry diameter or yield is not expected when "standard pruning" is repeated consecutive seasons. Another season's data will clarify whether "standard pruning" is more sustainable and if the difference in yield between "standard pruning" and "light pruning" will decrease after consecutive seasons' pruning.

Heading of one-year-old laterals had no horticultural benefit in any of the cultivars studied as yield was never significantly increased.

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Because of the large decrease in yield, “severe pruning” will not be recommended for mature orchards. The increase in individual shoot length and the decrease in yield indicate that the energy is directed towards vegetative growth after “severe pruning”. As the main goal of young orchards is to stimulate vegetative growth, eliminate reproductive growth and to form an open vase shaped plant (Shutak and Muracci, 1966; Eck, 1988; Gough, 1994; Yarborough, 2006) “severe pruning” directly after planting can be recommended.

In order to decrease the difference in yield between “light pruning” and “standard pruning”, but still stimulate plant vigour, a combination of these treatments needs to be studied. In our trial, heading cuts resulted in an increase in shoot number at the pruning wound, and not in an increase in the number of new canes that developed from the crown. Research on the time and number of thinning cuts to stimulate new cane development from the crown, especially in the case of ‘Jewel’ where rejuvenation from the crown seems to be limited, needs to be conducted.

This study increased our insight into the effect of cross-pollination and time and severity of pruning of SHB under local conditions. This helped us to identify cross-pollinators for specific cultivars and to develop sustainable pruning strategies to increase berry size and quality and thereby increasing profitability.

Literature cited

Eck, P. 1988. Cultural practices, p.135-169. In: Eck, P. (eds), Blueberry science. Rugters university press. London.

Gough, R.E. 1994. Pruning, p.137-150. In: Gough, R.E. (ed.), The higbush blueberry and its management. The Haworht Press, Inc. Worwood. Australia.

Lyrene, P.M. 2008. ‘Emerald’ southern highbush blueberry. HortScience 43(5):1606-1607.

Shutak, V.G. and E.M. Muracci. 1966. Plant and fruit development, p179-198. In: P. Eck an N.F. Childers (eds.), Blueberry culture. Rugters university press. New Jersey.

Yarborough, D.E. 2006. Blueberry pruing and pollination, p. 75-83. In: N.F. Childers (ed.), Blueberries for growers, gardeners, promoters. Horticultural Publications. Gainesville. Florida.