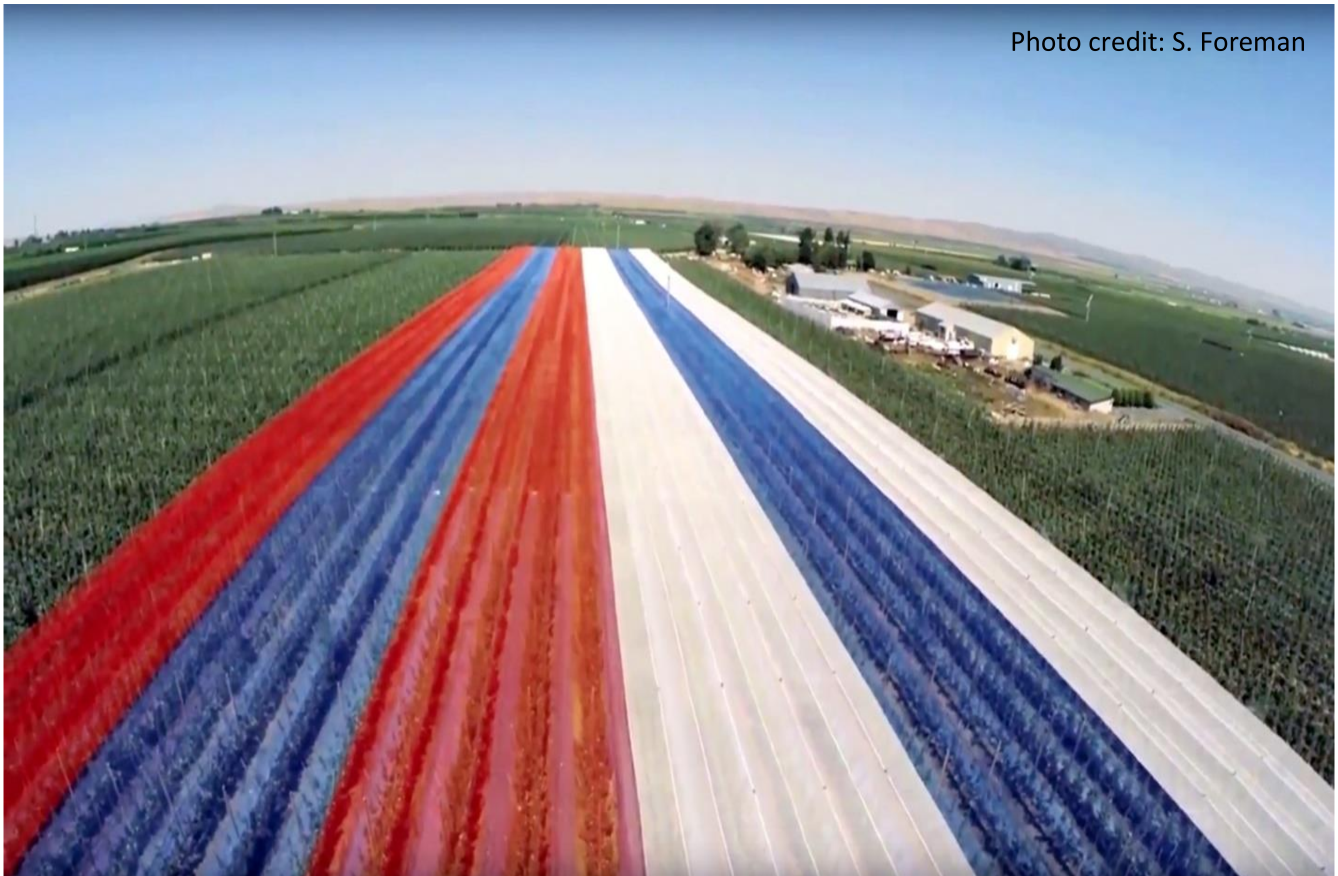

USE OF PROTECTIVE NETTING IN WASHINGTON STATE APPLE PRODUCTION

WSU PEER REVIEWED
TB60E

If readability or compliance provides an issue, please contact Dr. Desmond Layne at drl0021@auburn.edu

By, **Giverson Mupambi**, Postdoctoral Research Associate, WSU Tree Fruit Research & Extension Center, Washington State University; **Desmond R. Layne**, Professor of Pomology & Director of AFS/IPS Programs, Department of Horticulture, Washington State University; **Lee A. Kalcsits**, Assistant Professor, Department of Horticulture & WSU Tree Fruit Research & Extension Center, Washington State University; **Stefano Musacchi**, Professor & Endowed Chair, Tree Fruit Physiology and Management, Department of Horticulture & WSU Tree Fruit & Research Extension Center, Washington State University; **Sara Serra**, Assistant Professor, Department of Horticulture & WSU Tree Fruit Research & Extension Center, Washington State University; **Tory Schmidt**, Project Manager, Washington Tree Fruit Research Commission; and **Ines Hanrahan**, Executive Director, Washington Tree Fruit Research Commission

Table of Contents

Abstract

Washington State (WA) is the largest producer of apples in the United States. The major apple growing regions in WA are located in the semi-arid eastern half of the state which experiences harsh environmental conditions due to the rain shadow effect from the Cascade Mountain Range. The adoption of protective netting to reduce fruit sunburn and tree stress is gaining momentum in WA. The objective of this publication is to give the current status on the adoption of protective netting in WA.

The information disseminated in this publication was collected from previous research conducted in WA and a survey done during the summer of 2017, representing 46,000 of the estimated 179,146 acres planted to apples in WA. Types of protective netting structures commonly used by commercial apple growers in WA are discussed. These are, namely, exclusion netting; continuous over-the-top; louvered or partial overhead; and drape netting.

The benefits of using protective netting for WA apple growers are also discussed. The main benefit is the improvement in fruit quality through sunburn reduction. Other benefits include a reduction in hail damage, wind damage, bird pests, and insect pests, and an increase in water savings.

At the time of the survey, the total acreage for apples using protective netting was 2,347 acres (approximately 5.1%); an additional 3,417 acres (approximately 7.4%) were planned to be covered with protective netting in 2018. The most common cultivars under netting were ‘Honeycrisp’ and ‘Granny Smith’. The survey identified establishment costs and the annual maintenance cost as economic considerations for using protective netting. In conclusion, protective netting is being increasingly adopted by apple growers in WA as an alternative to traditional sunburn mitigation strategies, like overhead cooling and sunburn protectants.

Introduction

Washington State (WA) is the largest apple producer in the United States. The major apple growing regions are Okanogan, Lake Chelan, Wenatchee Valley, Columbia Basin, and the Yakima Valley. All of these regions are located in the semi-arid eastern half of WA which experiences harsh environmental conditions due to the rain shadow effect from the Cascade Range. The apple-growing season is characterized by high light intensities, high temperatures, and windy conditions, which may negatively impact both the tree and the fruit.

The use of protective netting is gaining momentum in WA and other apple-producing regions that experience similar harsh growing conditions. Primarily, protective netting (also called anti-hail netting or shade netting) is a technology used in apple production to reduce the amount of solar radiation that reaches the tree canopy and protect the fruit against sunburn. In addition to attenuating excessive solar radiation, protective netting increases light scattering which results in improved light penetration into the tree canopy and improved tree productivity (Willey 2016).

Although rare, damage from hail may occur during the growing season. Protective netting acts as a physical barrier against hail thereby protecting the fruit from damage. Hail damage not only affects fruit yield during the current growing season but it can also affect the following season by damaging the developing flower buds that represent next year's crop. Additionally, hail damage can increase phytosanitary problems, especially fire blight (Rosenberger 2014).

Protective netting reduces the exposure of trees and fruit to wind, and it can also serve as a physical barrier to exclude or deter fruit-damaging birds, bats, or insects (Shahak et al. 2004). If the netting covers both the top and sides of the orchard down to the ground level, it can exclude animals, like deer or elk, which may damage the apple crop.

Until recently, most nets used in commercial orchards were either black or white. However, recently developed, colored "photoselective" nets (e.g., yellow, red, blue color) are now available. These colored nets modify the spectral quality of the solar radiation that passes through it. The modification of solar radiation passing through colored nets can influence plant physiological processes, such as stomatal conductance and photosynthesis, thereby affecting tree growth and development (Bastías et al. 2011).

WA Apple Industry Survey

During the summer of 2017, a comprehensive 18-question orchard netting survey was provided to owners or managers of major apple-producing companies in WA. Responses from more than twenty apple orchard owners or managers were received, representing approximately 46,000 acres of the estimated total 179,146 acres (approximately 26%) planted to apple in WA (USDA 2017). Based on the surveyed acreage, 2,347 acres (approximately 5.1%) was under nets, while an additional 3,417 acres (approximately 7.4%) were planned to be covered with protective netting in 2018. Survey responses to questions by commercial WA apple growers are highlighted in several of the figures that follow.

Types of Protective Netting Infrastructure Used by Apple Growers in WA

Currently, there is no published information on structural design for protective netting superstructures in WA or any other apple producing regions. TrellX, a WA company that designs trellis superstructures, can design structures that are protective netting "ready". In terms of general design, there are three types of netting structures commonly used by WA apple growers: exclusion netting (Figure 1); continuous over-the-top netting (Figure 2); and louvered or partial overhead netting (Figure 3). At the time of our survey in 2017, there were no commercial growers using drape netting structures, and they were used mostly on experimental plots since they are very easy to install (Figure 4). However, in 2018, some commercial growers started to use drape netting, although this type of structure is still not very common.

The advantages and disadvantages of these four systems are noted in Table 1 through Table 4, respectively. Based on our survey, the most common protective netting structure used by WA apple growers was continuous over-the-top (Figure 2 and Figure 5), and factors that influenced a grower's decision on the netting structure included cost, amount of protection needed, and tree row orientation.

In terms of cost, louvered or partial overhead is the cheapest, followed by continuous over-the-top, with exclusion netting being the most expensive. Exclusion netting offers the most protection and can be used on sites where wind damage is a higher risk. Louvered or partial overhead netting structures are generally limited to orchards planted to a north-south tree row orientation where it can offer the most protection from damaging solar radiation in the afternoon to the west.

Exclusion Netting (Both Top and Sides)

Figure 1. Exclusion protective netting structure covering both top and sides in a commercial apple orchard in WA. The side of the netting adjacent to the road has been rolled up to allow equipment access for spraying and harvest. (Photo credit: G. Mupambi.)

Table 1. Advantages and disadvantages of using exclusion protective netting structures.

Advantages	Disadvantages
+ Offers full protection against hail damage and sunburn. + Improved spray efficacy, due to reduced wind and increased drying times. + Offers added protection against pest (partial insect exclusion) and wind damage. + Tree row orientation does not matter.	− Most expensive, because more netting materials are needed. − More labor cost to install. − Increased risk of spray-phytotoxicity, due to increased drying times. − Sides must be lifted to facilitate orchard access for spraying and other horticultural tasks. − In hail-prone areas, will need special configuration to "dump" hail on the ground, otherwise, structure may collapse.

Continuous Over-the-Top

Figure 2. Continuous over-the-top protective netting structure in a commercial apple orchard in WA. This orchard has reflective fabric on the orchard floor to improve fruit skin coloration. (Photo credit: G. Mupambi.)

Table 2. Advantages and disadvantages of using continuous-over-the top protective netting structures.

Advantages	Disadvantages
+ Tractors, sprayers, platforms, etc. have easy access to, and maneuverability in and out of, the orchard. + Less expensive to install compared to exclusion netting, since less netting material is required. + Offers full protection against hail damage, and reduces fruit sunburn damage. + Reduces exposure to wind. + Tree row orientation does not matter.	− Does not offer the same protection as exclusion netting from wind and pests because the sides are open. − In hail-prone areas, will need special configuration to “dump” hail on the ground, otherwise, structure may collapse.

Louvered or Partial Overhead

Figure 3. Louvered or partial overhead protective netting structure in a commercial apple orchard in WA. Row orientation is north-south with the covered side of the tree row facing west, protected from the afternoon sun. (Photo credit: L. Kalcsits.)

Table 3. Advantages and disadvantages of using louvered or partial overhead protective netting structures.

Advantages	Disadvantages
+ Tractors, sprayers, platforms, etc. have easy access to, and maneuverability in and out of, the orchard. + Least expensive system; less material used for installation.	– Does not offer the same protection as exclusion netting from wind and pests. – Does not offer full protection from hail. – Installation of individual protective netting panels for each row may be labor intensive. – Tree row orientation needs to be north-south.

Drape Netting

Figure 4. Drape netting structure deployed in a commercial orchard in WA (2018). None of the survey respondents indicated they used this type of structure in 2017. (Photo credit: G. Mupambi.)

Table 4. Advantages and disadvantages of using drape netting structures.

Advantages	Disadvantages
+ Tractors, sprayers, platforms, etc. have easy access to, and maneuverability in and out of, the orchard. + There are no costs involved for erecting a netting superstructure.	– Fruit that is in contact with the net can become damaged by the abrasive action of the net when it moves in response to wind. – Change in tree branch orientation from contact with netting material may result in photooxidative sunburn of previously unexposed fruit surfaces. – Installation of individual protective netting panels for each row may be labor intensive.

Benefits of Using Protective Netting for WA Apple Growers

Sunburn Reduction

Sunburn is a physiological disorder of apples caused by high fruit-surface temperatures and excessive solar radiation (Racsko and Schrader 2012). The apple-growing season in WA is characterized by high ambient temperatures and high light intensities (Figure 6 and Figure 7, respectively). Under such conditions, unprotected fruit are highly susceptible to sunburn injury.

On very hot, sunny days, the sun-exposed fruit surface heats up because it has limited evaporative cooling capacity and a poor ability to dissipate heat. Apple fruit temperature is affected both by direct radiant heating from the sun and advective heating from hot air moving through the orchard (Evans et al. 1995).

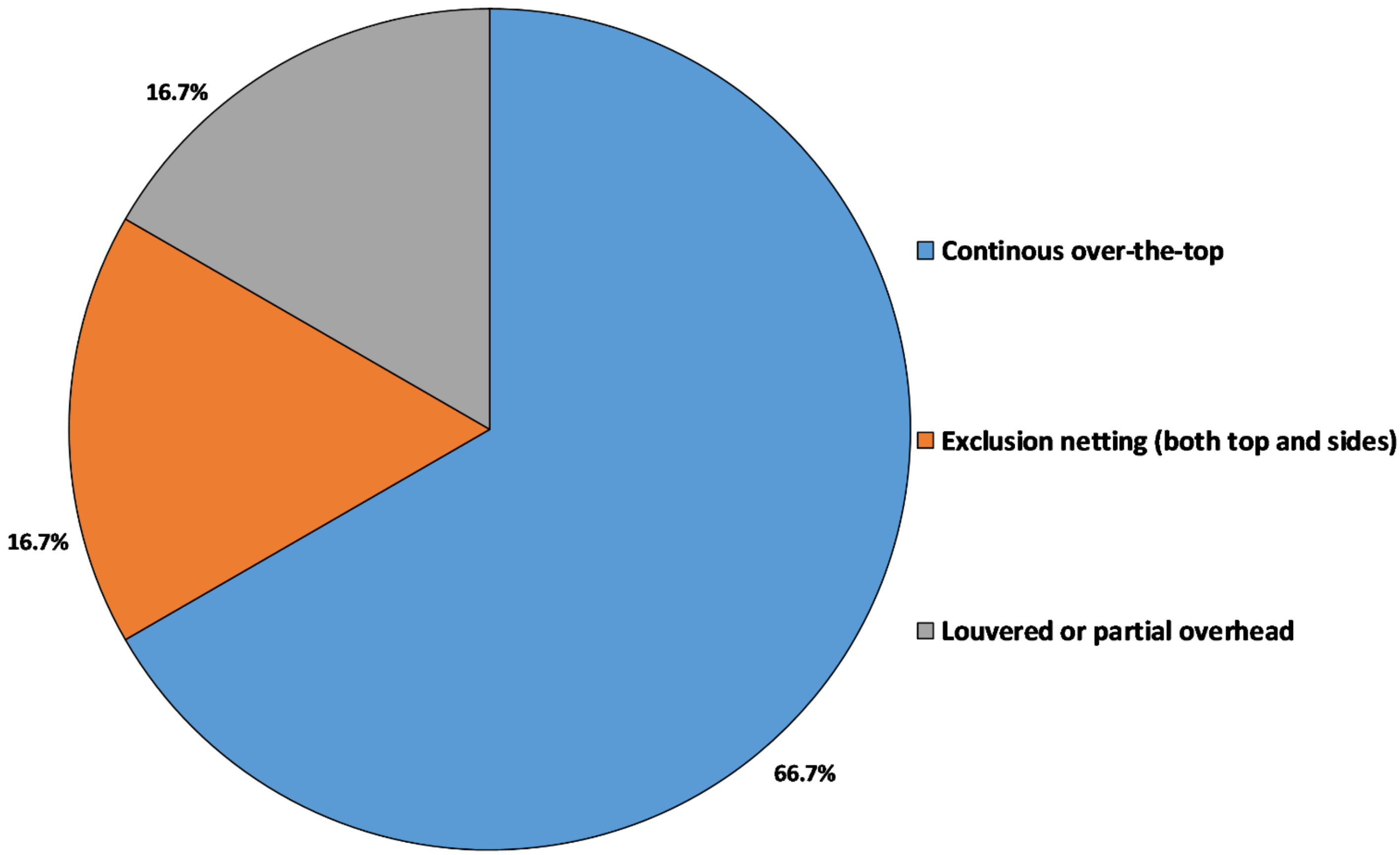

Figure 5. Types of protective netting structures used by apple growers, representing 46,000 acres in WA as determined by a survey in 2017.

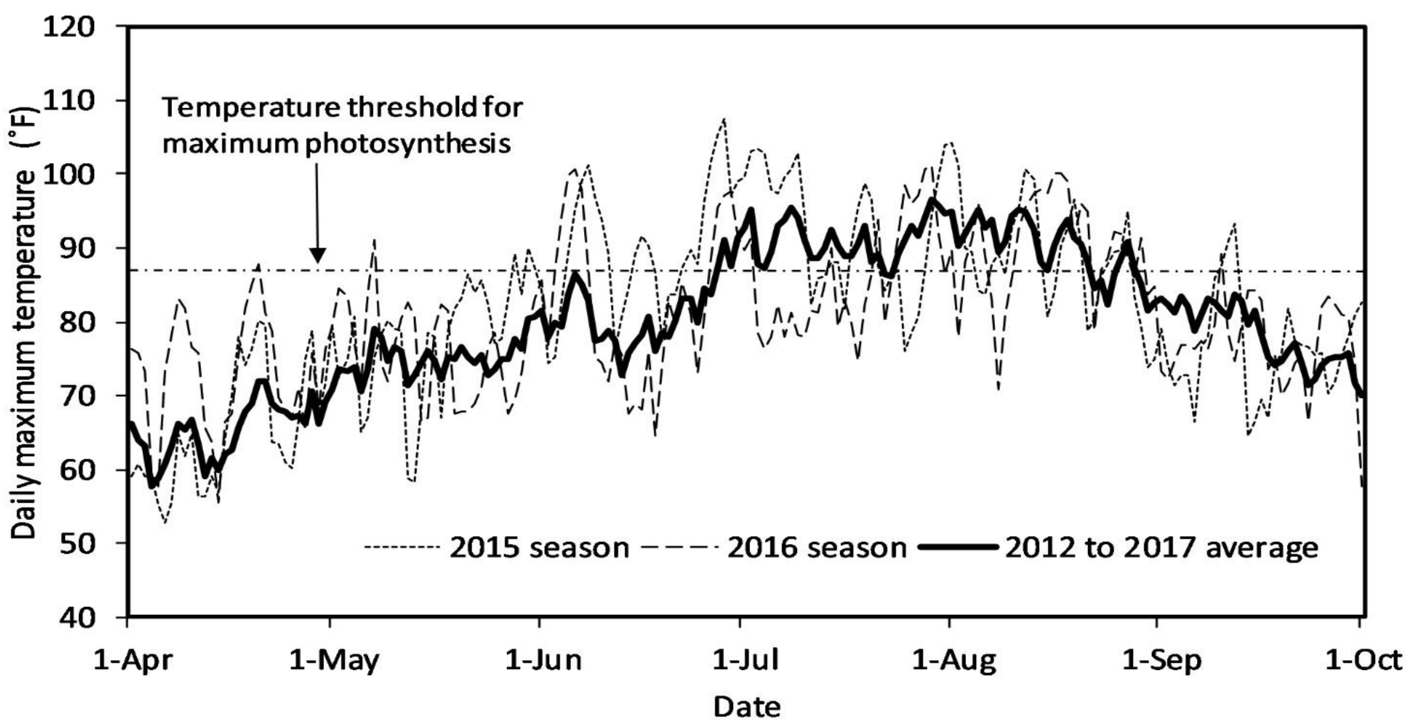

Figure 6. Daily maximum ambient air temperatures during the apple growing season at WSU TFREC Wenatchee, WA, from 2012–2016. The horizontal line indicates the optimum temperature for photosynthesis in field-grown apple trees (Gindaba and Wand 2007).

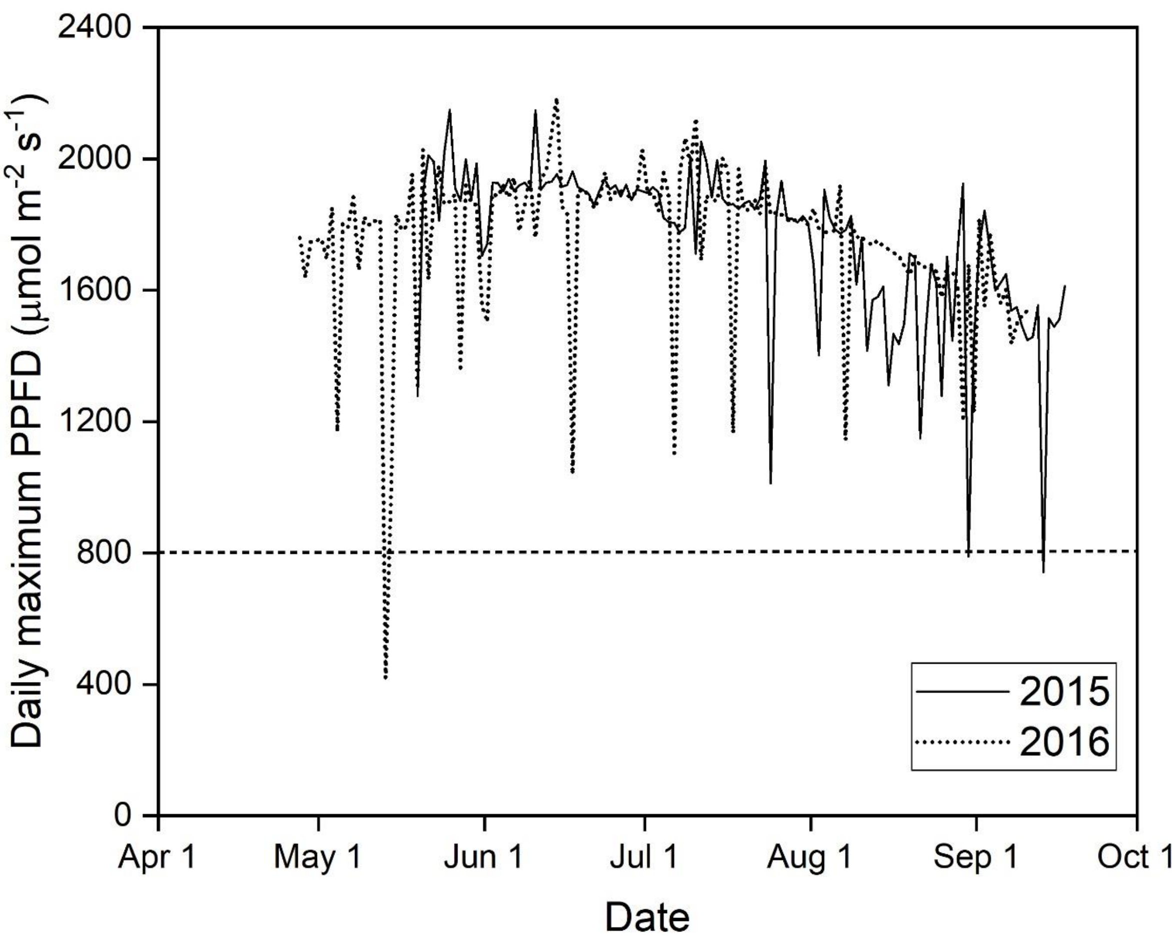

Figure 7. Daily maximum light intensity, measured in photosynthetic photon flux density (PPFD), during the apple growing season at WSU TFREC Wenatchee, WA for 2015–2016. The horizontal line indicates the light saturation for maximal photosynthesis in apple (Campbell et al. 1992).

Sunburn losses in WA average 10% of total production annually, costing growers millions of dollars (Schrader et al. 2008). Protective netting decreases sunburn in apple by reducing the fruit surface temperature and the amount of damaging solar radiation reaching the fruit surface. Previous research conducted in WA has demonstrated that protective netting is consistently effective in reducing the sunburn incidence in apple, compared to an uncovered control (Table 5).

Because sunburn damage results in fruits that cannot be sold as dessert apples, they represent a source of significant economic losses for apple growers.

'Granny Smith' is a sunburn-sensitive cultivar that is being increasingly grown under protective netting in WA. Representative fruit with no and various levels of sunburn damage are presented in Figure 8. Sunburned fruits classified as tan and black must be discarded, while fruit with a Y2 and Y3 designation are still marketable but, typically, downgraded and sold at a reduced price. Y1 and Y0 fruit are considered high-grade Class 1 fruit. Of the apple growers we surveyed, most indicated that the primary reason for using protective netting was to reduce sunburn (Figure 14).

Table 5. Scientific studies (2014–2017) demonstrating the effectiveness of protective netting in reducing sunburn incidence in WA apple orchards, compared to an uncovered control.

Cultivar	Netting structure	Net color and shade percentage	Reduction in sunburn incidence	Authors
‘Honeycrisp’	Continuous over the top of the orchard only	Pearl (19%)[a] Blue (22%)[a] Red (25%)[a]	15.6%, 26.5%, 24.7%	Kalcsits et al. 2017
‘Honeycrisp’[c]	Drape net (3 rows)	White (20%)[b]	14%	Mattheis et al. 2015
‘Honeycrisp’[c]	Drape net (3 rows)	White (20%)[b]	4%	Mattheis et al. 2015
‘Granny Smith’	Exclusion net	White (30%)[b]	41%	Kalcsits et al. 2018
‘Granny Smith’	Exclusion net	White (20%)[b]	43%	Schmidt 2014
‘Granny Smith’	Drape net (3 rows)	White (20%)[b]	22%	Schmidt 2014
‘Granny Smith’	Drape net (3 rows)	White (20%)[b]	26%	Schmidt 2015

[a]Actual measured shade percentage.
[b]Shade percentage as specified by the net supplier.
[c]Two separate orchards near Gleed, WA.

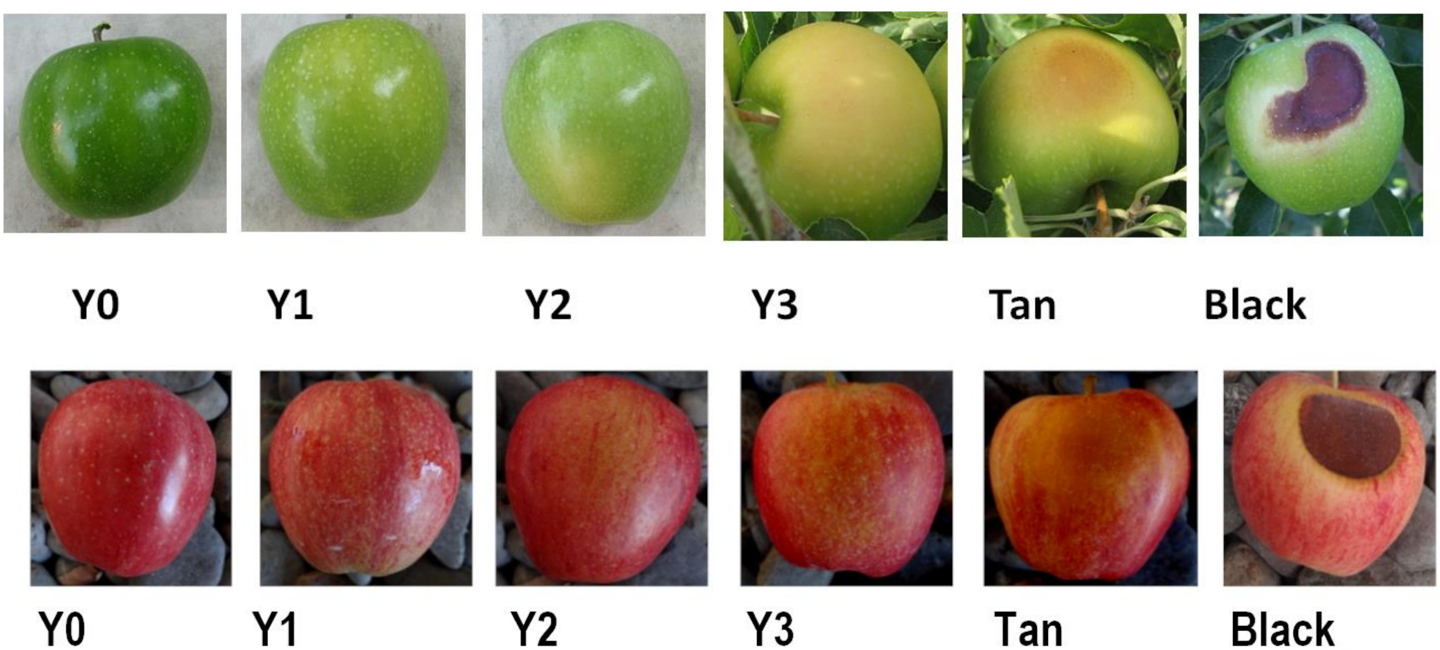

Figure 8. Sunburn scale for visual damage assessment in ‘Granny Smith’ (top) and ‘Gala’ apple fruits at commercial harvest (bottom). The scale was modified from Schrader et al., 2003. (Photo credit: I. Hanrahan and M. Mendoza.)

Hail Protection

Hail can damage the current season’s crop and also affect the following crop by damaging flower buds for the next season. Severity of damage to the fruit will depend on the intensity of the storm, size of hail stones, fruit developmental stage, etc. (Figure 9, 10). Hail can also significantly damage young trees due to their smaller canopy size (Figure 11). During the last 10–20 years in WA, hail incidents have occurred sporadically in some isolated pockets, like in Lake Chelan and Royal Slope in the Columbia Basin (Tory Schmidt, unpublished data). In a year where there was a hail storm, protective netting dramatically reduced the number of fruit that were damaged (Figure 12) (Schmidt 2014). Crop insurance to cover hail damage is available to apple growers to reduce their risk of economic losses from hail damage but, of course, it must be purchased in advance of a hail event.

Figure 9. Hail-damaged apple fruits on the tree. (Photo credit: S. Musacchi.)

Figure 10. Hail-damaged pear fruits on the tree. (Photo credit: S. Musacchi.)

Figure 11. Hail damage on a young tree. (Photo credit: S. Musacchi.)

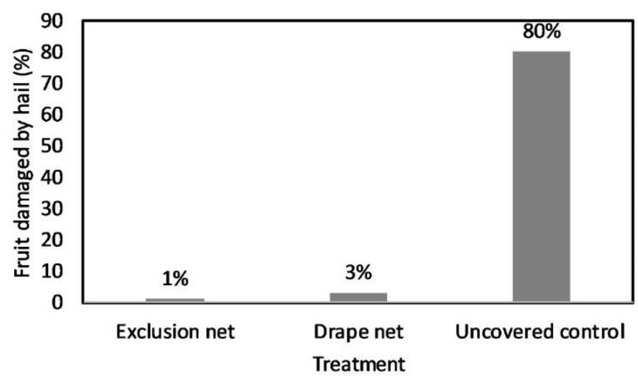

Figure 12. The influence of drape, or exclusion, netting versus an uncovered control on the percentage of 'Granny Smith' apples that were damaged during a hail event at the WSU Sunrise Research Orchard, Rock Island, WA (Schmidt 2014).

Positive Effect on Volumetric Soil Water Content

Comparing soil moisture content at two depths (8 in. and 16 in.), we observed consistently higher soil moisture in a commercial apple orchard where trees were under protective nets when compared with those that were not (Figure 13) (Kalcsits et al. 2017). Soil water loss due to evapotranspiration was reduced under nets when compared to trees exposed to full sun. As a result, orchard managers may choose to reduce irrigation volume or frequency, leading to improved water use efficiency in orchard blocks covered with protective netting.

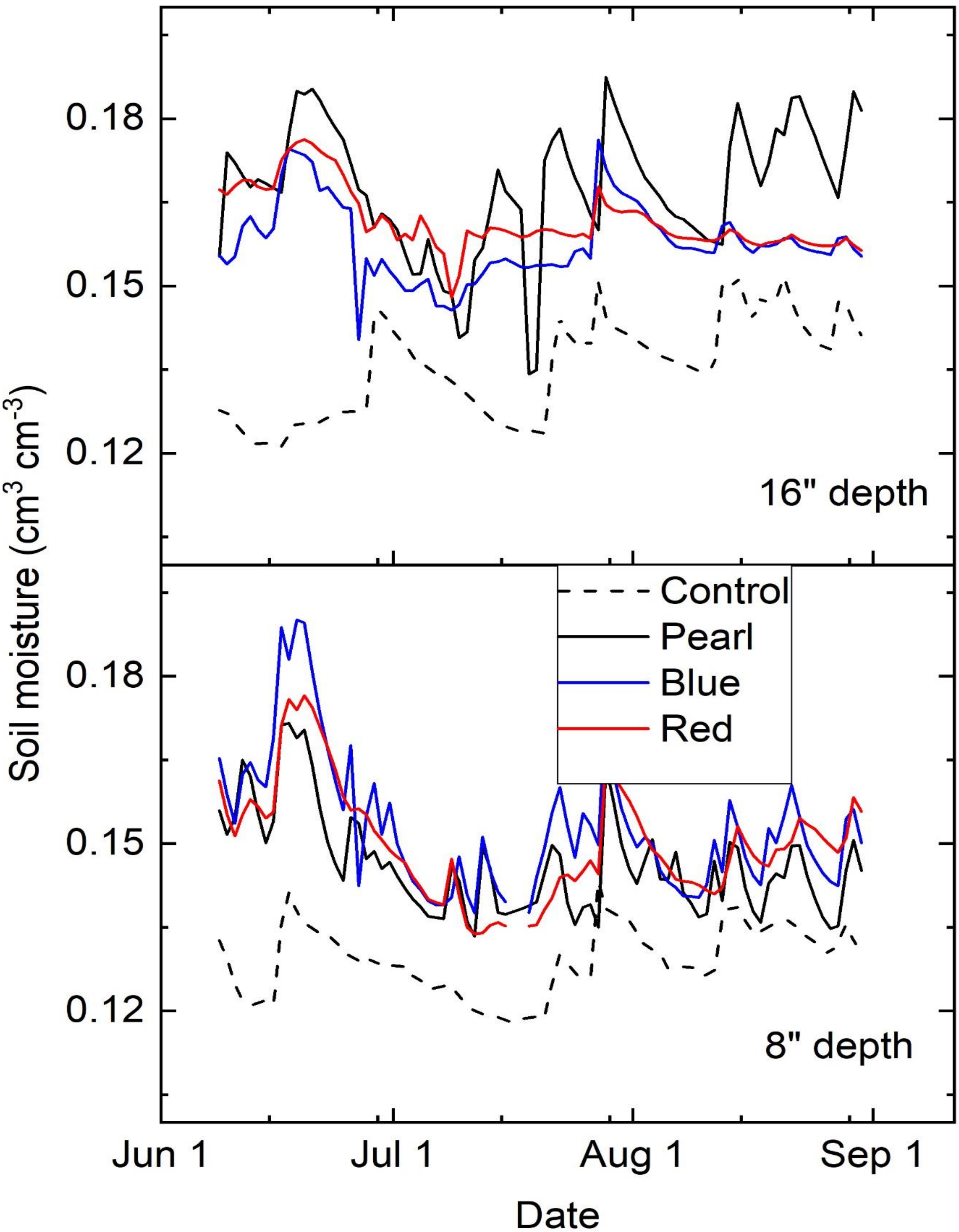

Figure 13. Soil moisture content at 8 in. (bottom) and 16 in. (top) soil depth during the growing season, under pearl, blue, and red photoselective protective netting, compared to an uncovered control (Adapted from Kalcsits et al., 2017).

Current Status of Protective Netting

Acreage under Netting and Uses of Protective Netting

Based on our grower survey, approximately 5.1% of the apple acreage in WA was under nets while an additional 7.1% was to be covered in 2018. Surveyed WA growers indicated that the most important reason for using protective netting was to reduce sunburn (Figure 14). Other reasons for using protective netting indicated by surveyed growers included water savings, reduced tree stress, reduced wind and hail damage, and the exclusion of birds and insect pests (Figure 14).

When using protective netting for sunburn reduction, 81% of survey respondents indicated they used protective netting in conjunction with another sunburn reduction strategy while the remaining growers used protective netting alone. The most common sunburn reduction strategy used in conjunction with protective netting by WA apple growers was evaporative overhead cooling (Figure 15). Some of the growers also indicated that they used particle films and chemical sunscreens in conjunction with protective netting.

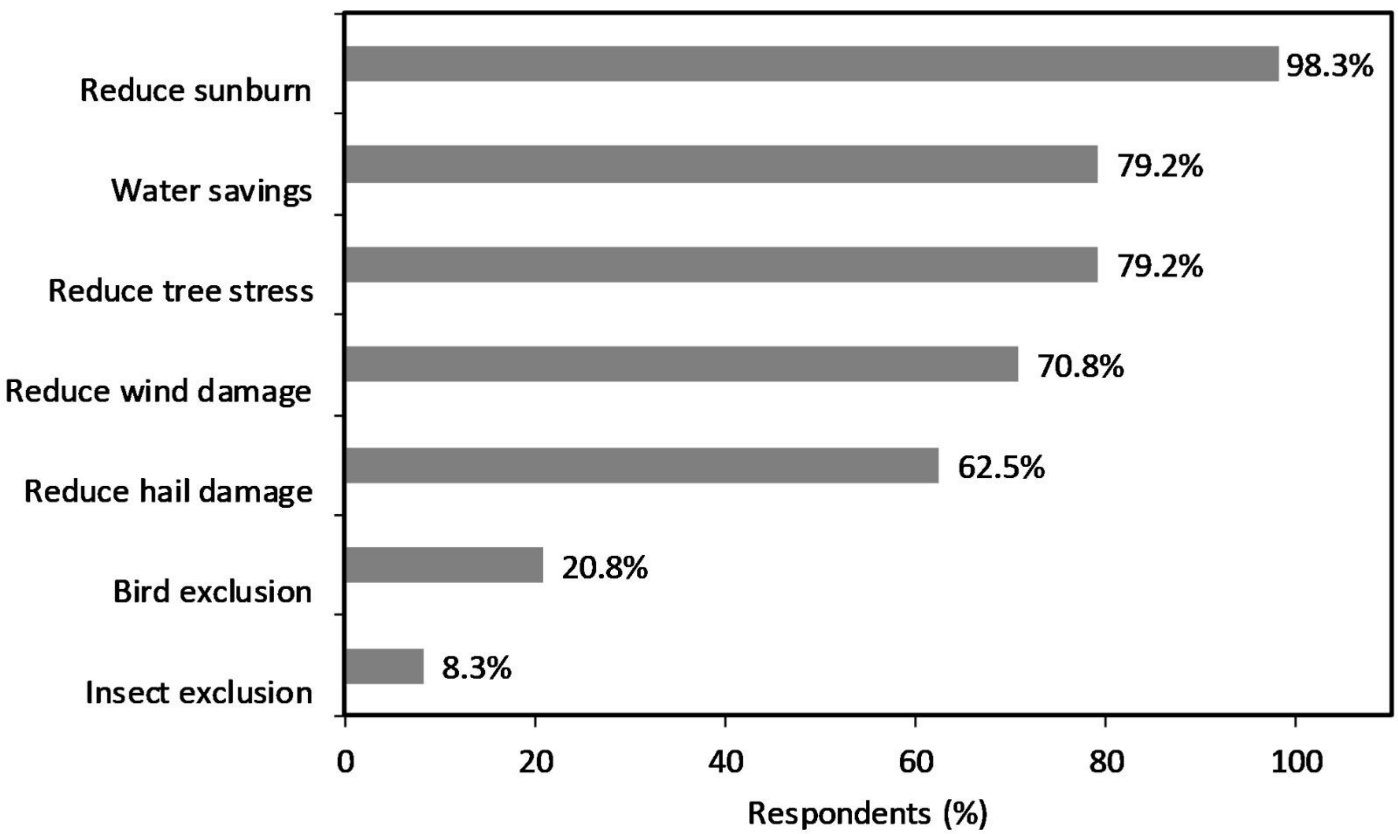

Figure 14. Major reasons for using protecting netting in apple production in WA. *Survey participants had the option to make multiple choices.

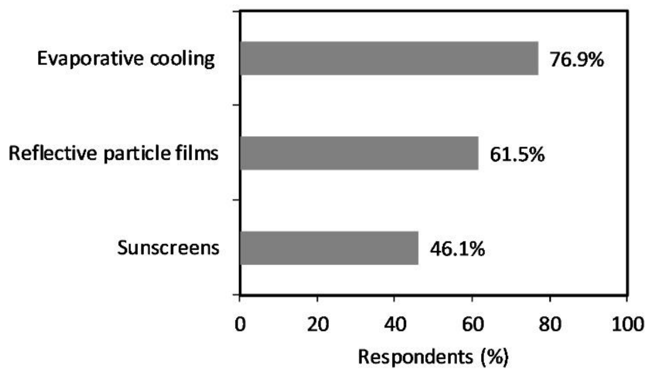

Figure 15. Strategies used in conjunction with protective netting to reduce sunburn by WA apple growers. *Survey participants had the option to make multiple choices.

Cultivars under Netting

The decision to use protective netting in the production of a particular apple cultivar is influenced both by its sensitivity to sunburn and its economic value. For high value cultivars like 'Honeycrisp', the expense associated with netting can easily be justified due to increased percentage of top-grade fruit. For the sunburn sensitive 'Granny Smith' cultivar, previous WA research has shown reductions in sunburn incidence of up to 43% (Table 5). In fact, based on the WA farms surveyed, 'Honeycrisp' and 'Granny Smith' accounted for 89% of the acreage under protective netting (Figure 16). From the WA farms surveyed, other cultivars grown under protective netting include 'Fuji', 'Jazz', 'Gala', 'Envy', and 'Pink Lady'.

Netting Suppliers, Color, and Shade Percentage

There is a variety of protective netting products available to apple growers in WA. Based on our survey, the most common protective netting products used by WA apple growers are supplied by Extenday and Wilson Irrigation. Other suppliers include GreenTek, FarmSolutions.net, and Proline. According to our survey, pearl/white netting is used by the vast majority of WA apple growers (Figure 17a); other colors include red and black. Most surveyed WA growers indicated they used 16–20% shade while some used a slightly higher or lower shade percentage (Figure 17b).

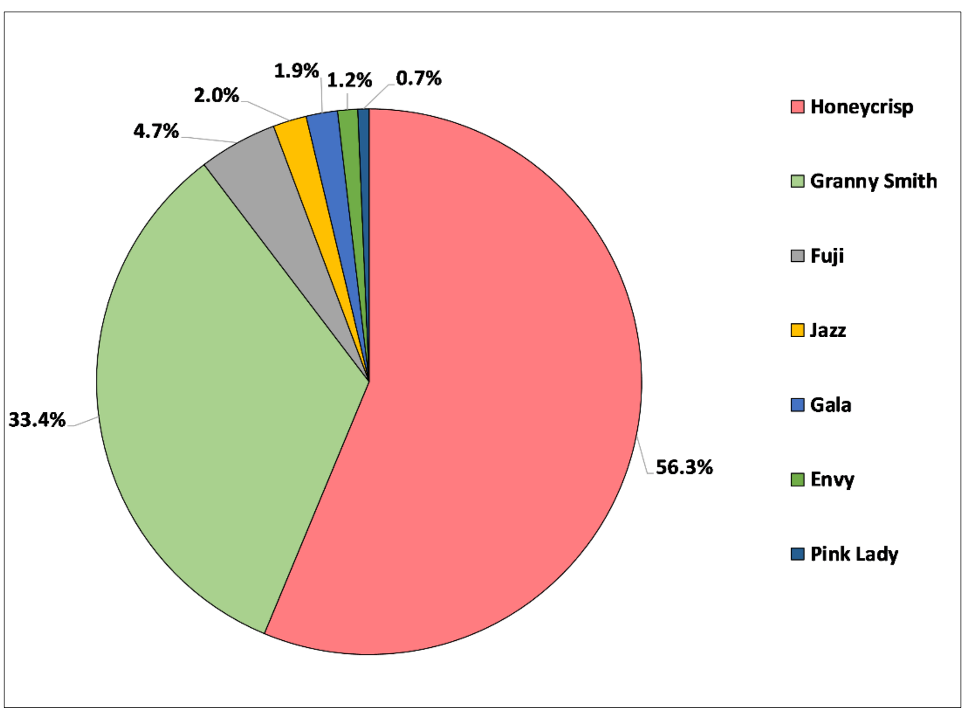

Figure 16. Apple cultivars grown under protective netting in WA expressed as a percent of total acreage under nets.

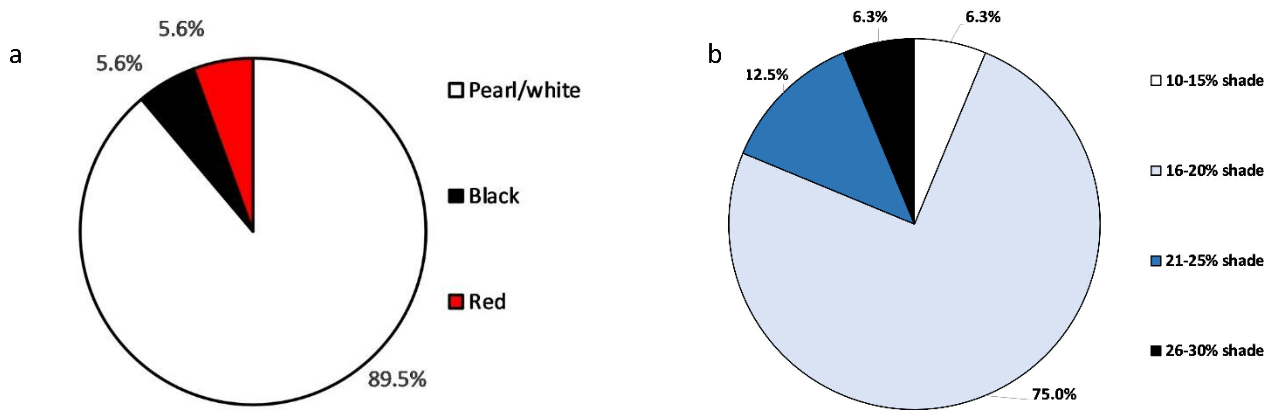

Figure 17. Protective netting color (a) and shade percentage (b) used by surveyed apple growers in WA.

Impact of Protective Netting on Fruit Color

When asked if they had fruit coloration problems under protective netting, 41.2% indicated they observed reduced coloration of fruit under nets whilst 29.4% reported no problems with fruit color under netting. About 29.4% of surveyed growers were unsure if fruit color was affected by protective netting.

Establishment and Annual Maintenance Costs of Protective Netting

The initial cost for establishing protective netting includes the netting material, support poles and cables, and labor for installation (Whitaker and Middleton 1999). Another factor that affects the cost of establishment is whether the netting structure is included when establishing the orchard or if the netting structure is retrofitted after the orchard is established. Our survey indicated that the cost of installing a continuous over the top netting system ranged from $2,000 to over $13,000 per acre, with most survey respondents indicating that establishment costs were $10,000–$11,999 per acre (Figure 18). Survey respondents indicated that the estimated cost of a partial overhead netting system was $4,000–$5,000 per acre. Generally speaking, it is less expensive to establish netting at the time of orchard establishment since the support poles can also be utilized as part of a tree trellis support system. In our survey, 70% of the respondents indicated that they had retrofitted protective netting to existing orchards while 38% indicated they established protective netting with a new orchard. In terms of future net-covered plantings, 83% of the respondents indicated that they planned to include protective netting at the time new orchards will be established.

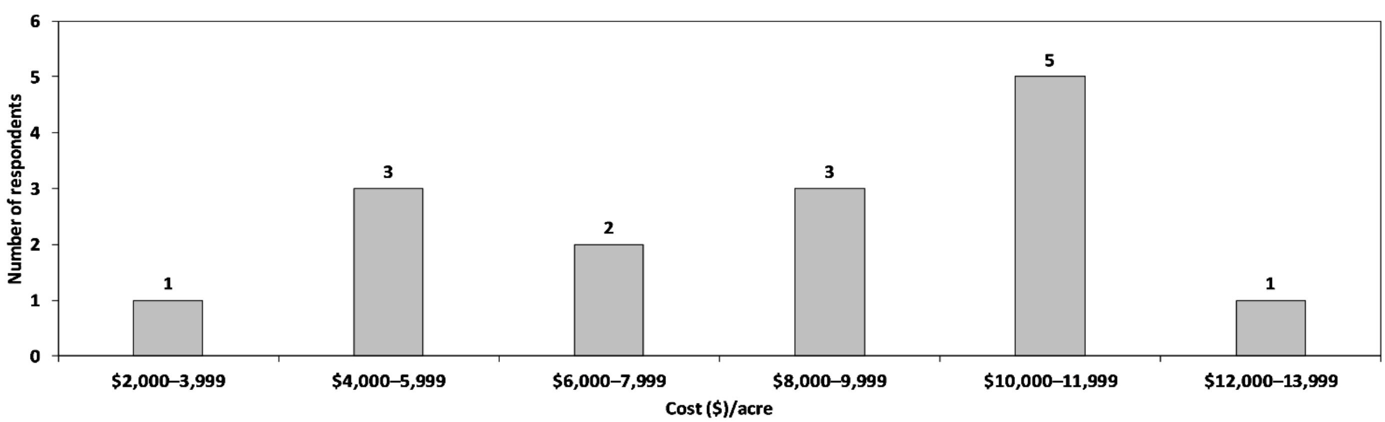

Figure 18. Grower estimated cost of establishing a new, continuous over-the-top netting system per acre in an apple orchard in WA.

Annual costs for maintaining shade nets in apple orchards include structure maintenance, net maintenance, retensioning of connecting cables, and unfurling and furling the shade net (Whitaker and Middleton 1999). Unfurling the nets after pollination and furling the nets after harvest is necessary for regions that receive a lot of snow to reduce the risk of damage to the netting and the supporting infrastructure from heavy snow loads. By furling the net and covering it during the winter, its longevity can be extended by several years. Surveyed WA growers estimated that the annual cost of maintaining a protective netting system varied from about $100–$2,564 per acre (Figure 19). Of growers surveyed who are currently using nets, the majority indicted they did not do a cost benefit analysis before installing the system. However, once the nets have been established, the growers indicated that they estimated a financial benefit of $2,200–$5,250 per acre per year for orchards where protective netting was used.

Other Sunburn Mitigation Strategies

In addition to protective netting, other alternative strategies that are used by WA apple growers to protect fruit against sunburn damage include overhead cooling and sunburn suppressants (Racsko and Schrader 2012).

Overhead Cooling

Overhead cooling involves the application of water over the entire tree canopy by sprinklers during heat stress conditions. As the water evaporates, it cools the fruit and leaves due to its high latent heat of vaporization. Previous research in WA indicated that the optimum amount of water for overhead cooling was 38 gpm/acre (Evans et al. 1995). The overhead cooling was turned on when fruit core temperature reached 91°F and turned off when the core temperature reached 86°F. Evans et al. (1995) also concluded that an efficient overhead cooling system needed to be adjusted according to the prevailing conditions. Overhead cooling irrigation can be run continuously under high vapor pressure deficit conditions and pulsed under low vapor pressure deficit conditions, although this is not always feasible in the orchard (Evans et al. 1995).

The use of overhead cooling close to harvest has come under scrutiny recently due to concerns about food safety. Untreated surface water is used for evaporative cooling, and this has potential to contaminate fruit with human pathogens, such as *E. coli*. However, a recent study in WA using generic *E. coli* found that overhead cooling had no impact on survival rates of *E. coli* compared to a control that did not receive overhead cooling (Zhu et al. 2017).

Another limiting factor for using overhead cooling is the large amount of water required. As long as

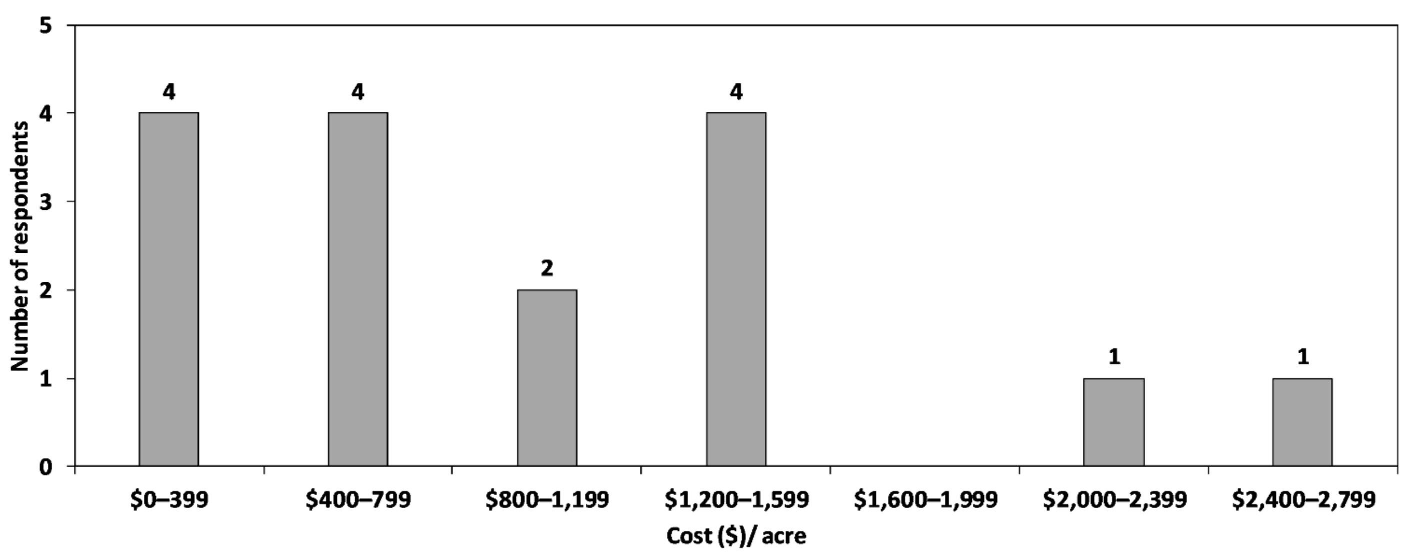

Figure 19. Estimated annual cost of maintaining an established continuous over the top protective netting system per acre in an apple orchard in WA.

primary water sources (e.g., Columbia River) maintain adequate supply during the growing season, overhead cooling may continue to be a viable means to mitigate the potential for sunburn damage in WA apples. However, should water become limiting due to drought, other remedies will be necessary to protect fruit from sunburn.

Sunburn Protectants

Sunburn development in apple fruit can be reduced using particle films and by sunscreens applied directly to fruit in the orchard (Racsko and Schrader 2012). Particle films act by blocking, reflecting, and scattering solar radiation to reduce sunburn damage while sunscreens reduce sunburn damage by absorbing damaging ultraviolet radiation. Surround WP (NovaSource, Phoenix, Arizona), a kaolin clay-based particle film, and the sunscreen, Raynox (Pace International, LLC, Seattle, WA), which contains organic-chemical absorbing agents in addition to physical inorganic constituents, like Carnauba wax, had similar efficacy over four years in WA conditions where both products reduced sunburn incidence in apple by about 50% on average (Schrader 2003). One disadvantage of these protectants is that they need to be reapplied as the fruits grow and expand in volume and surface area. Reapplication may be difficult if labor is in short supply due to harvest or other orchard operations. Reflective particle films can accumulate in the stem and calyx end of the fruit and are difficult to remove on a commercial packing line thereby adversely impacting fruit physical appearance and marketability (Glenn and Purteka 2005). In contrast to particle films, the sunscreen, Raynox, was reported to leave no unattractive residue on fruit (Schrader 2003).

Information Gaps

As the use of protective netting by WA apple growers continues to increase, there is a need for additional research-based information to assist them in decision-making. According to our survey, WA growers indicated that the top research information needed was to determine the optimal shading factor and protective netting color for each cultivar (Figure 20). This was followed by economic research including cost-benefit analysis and return on investment (ROI) for using protective netting. Other needs that survey respondents expressed included structural design of netting structures, research on optimizing fruit color under protective netting, and research on the benefits of establishing young trees under netting to improve early orchard yields.

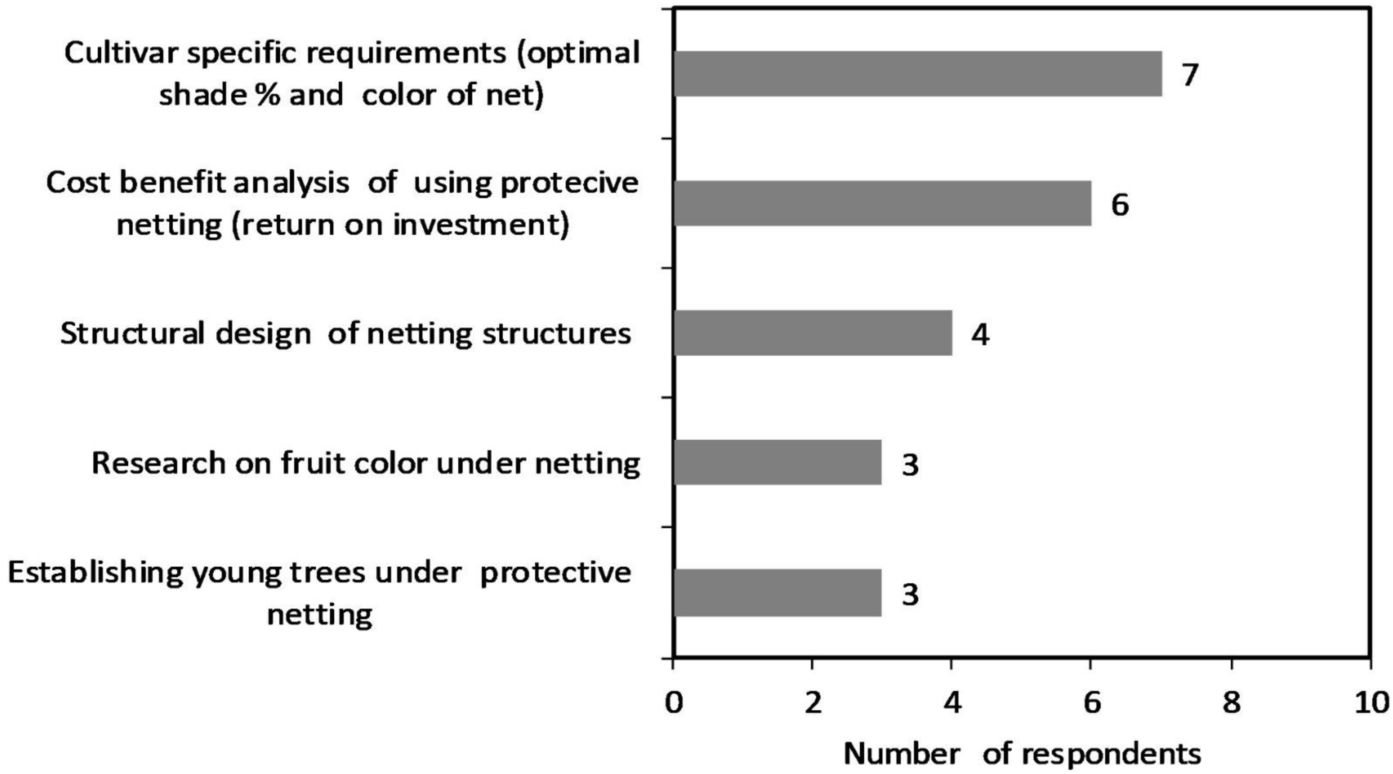

Figure 20. Top five research-based information needs indicated by WA apple growers in 2017 in relation to the adoption of protective netting. *Survey participants had the option to make multiple choices.

Acknowledgments

The authors would like to thank Tianna DuPont, WSU Tree Fruit Extension Specialist, for assistance with the apple grower survey.

Further Reading:

Mupambi, G., B.M. Anthony, D.R. Layne, S. Musacchi, S. Serra, T. Schmidt, and L.A. Kalcsits. 2018. The Influence of Protective Netting on Tree Physiology and Fruit Quality of Apple: A Review. *Scientia Horticulturae* 236:60–72.

References

Bastías, R.M., P. Losciale, C. Chieco, F. Rossi, and L. Corelli-Grappadelli. 2011. Physiological Aspects Affected by Photoselective Nets in Apples: Preliminary Studies. *Acta Horticulturae*. 907: 217–220.

Campbell, R.J., R.P. Marini, and J.B. Birch. 1992. Canopy Position Affects Light Response Curves for Gas Exchange Characteristics of Apple Spur Leaves. *Journal of the American Society for Horticultural Science* 117: 467–472.

Evans, R.G, M.W. Kroeger, and M.O. Mahan. 1995. Evaporative Cooling of Apples by Overtree Sprinkling. *Applied Engineering in Agriculture* 11: 93–99. doi: 10.13031/2013.25721.

Glenn, D.M., and G.J. Puterka. 2005. Particle Films: A New Technology for Agriculture. *Horticultural Reviews* 31: 1–44.

Gindaba, J., and S.J.E. Wand. 2007. Do Fruit Sunburn Control Measures Affect Leaf Photosynthetic Rate and Stomatal Conductance in ‘Royal Gala’ Apple? *Environmental and Experimental Botany* 59: 160–165. doi: 10.1016/j.envexpbot.2005.11.001.

Kalcsits, L., L. Asteggiano, T. Schmidt, S. Musacchi, S. Serra, D. Layne, and G. Mupambi. 2018. Shade Netting Reduces Sunburn Damage and Soil Moisture Depletion in 'Granny Smith' Apples. *Acta Horticulturae* 1228: 85–90. doi: 10.17660/ActaHortic.2018.1228.11.

Kalcsits, L., S. Musacchi, D.R. Layne, T. Schmidt, G. Mupambi, S. Serra, M. Mendoza, et al. 2017. Above and Below-Ground Environmental Changes Associated with the Use of Photoselective Protective Netting to Reduce Sunburn in Apple. *Agricultural and Forest Meteorology* 237–238: 9–17.

Mattheis, J., D. Rudell, and I. Hanrahan. 2015. Identification of Procedures to Extend 'Honeycrisp' Storage Life. Final project report. Washington Tree Fruit Research Commission.

Racsko, J., and L.E. Schrader. 2012. Sunburn of Apple Fruit: Historical Background, Recent Advances and Future Perspectives. *Critical Reviews in Plant Sciences* 31: 455–504.

Rosenberger, D. 2014. Assessing Hail-Related Fire Blight Risks.

Schmidt, T. 2014. Crop Load and Canopy Management of Apple. Final project report. Washington Tree Fruit Research Commission.

Schmidt, T. 2015. Crop Load and Canopy Management of Apple. Continuing project report. Washington Tree Fruit Research Commission.

Schmidt, T. 2017. n.d. Project Manager, Washington Tree Fruit Research Commission, Wenatchee, WA.

Schrader, L. 2003. Control of Sunburn in Apples with RAYNOX. Final project report. Washington Tree Fruit Research Commission.

Schrader, L.E., J. Sun, D. Felicetti, J.-H. Seo, L. Jedlow, and J. Zhang. 2003. Stress-Induced Disorders: Effects on Apple Fruit Quality. Proc. Washington Tree Fruit Postharvest Conf. 10 July 2015.

Schrader, L., J. Sun, J. Zhang, D. Felicetti, and J. Tian. 2008. Heat and Light-Induced Apple Skin Disorders: Causes and Prevention. *Acta Horticulturae* 772: 51–58. doi: 10.17660/ActaHortic.2008.772.5.

Shahak, Y., E.E. Gussakovsky, E. Gal, and R. Ganelevin. 2004. ColorNets: Crop Protection and Light-Quality Manipulation in One Technology. *Acta Horticulturae* 659: 143–151. doi: 10.17660/ActaHortic.2004.659.17.

USDA. 2017. Washington Tree Fruit Acreage Report, 2017. USDA/National Agricultural Statistics Service.

Whitaker, K., and S. Middleton. 1999. The Profitability of Hail Netting in Apple Orchards. 43rd Annual Conference of the Australian Agricultural and Resource Economic Society. Christchurch, 20–22 January 1999.

Willey, N. 2016. Environmental Plant Physiology. Garland Science, New York.

Zhu, M., I. Hanrahan, K. Killinger, and J.S. Meschke. 2017. Assessment of Overhead Cooling Practices for Apple Food Safety. Final project report. Washington Tree Fruit Research Commission.

Issued by Washington State University Extension and the US Department of Agriculture in furtherance of the Acts of May 8 and June 30, 1914. Extension programs and policies are consistent with federal and state laws and regulations on nondiscrimination regarding race, sex, religion, age, color, creed, and national or ethnic origin; physical, mental, or sensory disability; marital status or sexual orientation; and status as a Vietnam-era or disabled veteran. Evidence of noncompliance may be reported through your local WSU Extension office. Trade names have been used to simplify information; no endorsement is intended. Published February 2019.