Impact of management regimes on fruit quality of sweet cherry (*Prunus avium* L.)

Running title: Comparing management regimes in cherry orchards

Abstract

The impact of alternative farming systems on fruit quality of orchard crops has been rarely examined. This study compared the effect of two management regimes with or without effective microorganisms (EM) on fruit quality of sweet cherry (*Prunus avium* L. cultivar Sweetheart). After four years, EM had no effect on quality however, fruit from regime 2 based on organic amendments and no herbicide had higher TSS and malic acid concentration but reduced size, compression firmness and stem retention force than fruit from regime 1 which was based on current conventional fertigation practices combined with herbicide application. All quality attributes reached ‘export finest’ standard for all treatments, providing evidence that organic amendment regimes can supply fruit acceptable for export markets.

KEYWORDS: Effective Microorganism™; soil amendment; sustainable; humates; nutrients

INTRODUCTION

In recent years, the commercial focus of the Australian sweet cherry (*Prunus avium* L.) industry has been on fruit size and quality rather than total yield per tree. Consequently, management practices have aimed to produce superior quality fruit for a premium price to enable access to niche markets in Asia (James et al. 2011). Conventional management systems involve extensive use of chemical fertilisers, herbicides and pesticides. For example, nitrogen (N) application rates in Australia range from 75-200 kg N ha^{-1}, which is consistent with usage reported in United States and Turkey, the two largest global producers of sweet cherry. The standard method of weed control in perennial orchards is to maintain a bare earth strip along the tree row using herbicides (Bound 2014); commonly used herbicides include glyphosate, simazine, paraquat and diquat. According to Radcliffe (2002), glyphosate usage in Australia is approaching 15,000 tonnes per annum.

Reliance on synthetic fertilisers and pesticides/herbicides can have serious environmental impacts (Radcliffe 2002; Pimentel et al. 2005; Zhang et al. 2011). As such, interest in alternative farming systems including organic and integrated farming (a combination of organic and conventional techniques) has increased in recent years. However, some uncertainty remains as to whether fruit quality in alternative systems can be maintained. There is some evidence indicating that for apples, organic and integrated systems increase fruit quality characteristics without compromising yield (Reganold et al. 2001). However, very few studies have examined the impact of alternative systems in sweet cherry, which has a maximum storage life of four-six weeks (Padilla-Zakour et al. 2007), and hence is substantially more perishable than apples.

Alternative management systems are distinguished from conventional systems by the use of organic based fertilisers such as manures, bio-fertilisers and humic based fertilisers (Rigby and Cáceres 2001; Pettit 2004). Bio-fertilisers are also referred to as microbial amendments or microbial fertilisers, and one that is receiving increased attention is effective micro-organisms (EM) (Priyadi et al. 2005; Javaid 2006; Hu and Qi 2013). EM are a mixture of beneficial microorganisms, predominantly lactic acid bacteria and yeasts (Higa and Wididana 1991) that are purported to promote the microbial decomposition of complex organic compounds, detoxification of harmful gasses, production of anti- microbial or fungal compounds, and production of plant hormones (Higa and Wididana 1991; Gourlay, 2015). Although EM have been studied in a wide range of crops (Xu 2001; Xu et al. 2001; Javaid 2006; Hu and Qi 2013), very few studies have been conducted on perennial fruit crops, particularly sweet cherry. This study compared the impact of two management regimes and soil applied EM on fruit quality in a commercial sweet cherry orchard. The management regimes were based on either current conventional practices with fertigation and herbicide application for weed control or organic amendments and mowing for weed control.

MATERIALS AND METHODS

A field trial was established on a commercial orchard in the Derwent Valley (42.7077° S, 146.9458° E) in southern Tasmania. Mean annual rainfall at the site is 573 mm, and mean pan evaporation is in excess of 949 mm (Australian Bureau of Meteorology). Mean daily maximum and minimum temperatures are 23.4 and 9.7 °C in summer and 11.9 and 1.9 °C in winter. The soil is dolerite clay (Isbell 1996). Uniform, mature, regular bearing eight-year-old sweet cherry trees, cultivar ‘Sweetheart’ were selected in the spring (October) of 2012. Trees were on ‘Colt’ rootstock and pruned to a Kym Green Bush system (Green 2005) with a planting spacing of 4.0 x 1.8 m and an east-west row orientation. All trees received daily irrigation via micro-sprinklers at a rate of 48 L/h for 3 h (a total of 12.5 mm) per week throughout the growing season (November to February).

Trial design

Treatments were allocated at random to five-tree plots within each block in a complete randomised block design to give four replicates per treatment. The treatments were a factorial arrangement of two management regimes and soil applied EM (nil [EM-] or recommended label rate [EM+]). Regime 1was based on current conventional fertigation practices with trees fertigated weekly during the growing season, and receiving a total of 80, 15 and 60 kg ha^{-1} N, P and K, respectively for the season. Weeds were controlled with a herbicide program using glyphosate and Basta™ (200 g/L glufosinate-ammonium, Bayer Crop Science Pty Ltd) every 3-4 months. Regime 2 used organic amendments and targeted minerals based on annual soil analysis; weeds were controlled by mowing. The organic amendments were applied in spring and autumn. Ferbon™ (lignite-based soil conditioner, Interstate Energy Group, Bacchus Marsh, Australia) was applied at 300 kg ha^{-1} in the first two seasons, and humified compost (Foundation Aerobic Compost, Pure Living Soils, Tasmania, Australia) at 800 kg ha^{-1} combined with soluble humate granules (Nutri-Tech Solutions, Australia) at 20 kg ha^{-1} in the following two seasons. The chemical properties of both organic amendments are presented in Table 1. Targeted minerals applied to regime 2 in September 2012 and 2013 were sulphates of ammonia (30 kg ha^{-1}), potassium (20 kg ha^{-1}), manganese (25 kg ha^{-1}), zinc (2 kg ha^{-1}) and copper (2 kg ha^{-1}), and sodium borate (8 kg ha^{-1}). In 2014 and 2015, only manganese sulphate was applied at rate of 15 and 25 kg ha^{-1}, respectively. Weeds in the regime 2 were controlled by mowing.

Soil EM amendment (EM1, VRM Pty Ltd) was applied monthly at the recommended rate (15 L activated EM ha^{-1}) throughout the experimental period, commencing in October 2012. EM amendment was prepared by adding 75 mL of activated EM solution and 5 g of Acadian soluble seaweed extract (SSE) in 10 L of non-chlorinated water for each plot.

Sampling and assessments

Fruit were harvested on 18th January 2016 at normal commercial harvest time. Harvested fruit was weighed and five samples of 30 unblemished fruit with a skin colour rating of at least 3 (Table 2) were collected from each replicate for fruit quality assessment. Fruit assessments were conducted at 0, 14, 28, 42 and 56 days post-harvest. Samples stored at 14, 28, 42 and 56 days post-harvest were placed in PeakFresh® bags and stored at 0 °C.

At each assessment date, quality assessments included fruit weight, diameter, pedicel diameter, skin colour, compression firmness, flesh firmness, skin puncture force, flesh colour, stem retention force, total soluble solids content (TSS), malic acid (MA) concentration and juice pH.

Both fruit and pedicel diameters were measured with digital callipers (DigiMax, Wiha-41101, Wiha Switzerland). Skin and flesh colour rating were measured using the Australian Cherry Colour Guide (Cherry Growers Australia). Fruit compression firmness was measured with a FirmTech 2 (Bioworks Inc, USA). Flesh firmness and skin puncture force were both measured with a fruit texture analyser (Guss model GS-20, South Africa). Due to equipment failure, data for skin puncture force and flesh firmness at 14 days post-harvest was not obtained. Stem retention force was measured using a stand mounted Mark-10 Series 5 force gauge (Mark-10, USA).

Fruit from each replicate were juiced collectively and duplicate samples taken for measurement of TSS, pH and MA concentration. TSS content, expressed as °Brix, was measured with an Atago PR-1 digital refractometer (Atago Co. Ltd., Japan). Juice pH was the initial pH value of 10 mL juice samples measured using a Mettler Toledo G20 compact titrator (Mettler Toledo, Australia). MA concentration was calculated as g L^{-1}.

Australian sweet cherry industry standards which classifies fruits into ‘domestic’ and ‘export finest’ were used as a reference for fruit quality (Table 2).

Statistical Analysis

All data was analysed by three-way analysis of variance (ANOVA). Block was treated as a random factor, while management regime, soil EM application and storage time were considered fixed factors. The assumptions of ANOVA such as homogeneity of variance and the Gaussian distribution were evaluated by the use of quantile–quantile plots and residual plots for all variables. Fisher’s protected least significant difference post hoc tests were used to determine significant differences among treatment means. All analyses were performed using IBM SPSS statistics 23. Significance was calculated at p = 0.05.

The focus of this study was to examine the effects of management regime and soil applied EM and their interactions on fruit quality from harvest up to 56 days post-harvest.

Results

Management regime significantly influenced seven out of the thirteen physical and chemical fruit quality attributes during storage (Table 3). Fruit size, in terms of weight and diameter, were significantly higher in regime 1 than regime 2. Fruit from regime 1 was 0.9 g (5%) heavier than from regime 2, and 1.1 mm (4%) greater in diameter. Fruit compression firmness was also 11% higher in the regime 1 compared with regime 2. There was no difference in flesh firmness or skin puncture force. Stem retention force was (10%) greater in regime 1 than regime 2. There was no difference in skin colour between regimes, but flesh colour was darker in regime 2 (Table 4). TSS and MA concentration were higher (~5%) in regime 2 than regime 1 (Table 4).

There were no interactions between management regime, EM and storage period for fruit quality attributes, with the exception of stem retention force (Table 3). There was a significant interaction between management regime and storage period. From harvest to 14 days post-harvest, stem retention force was higher in regime 1 compared with regime 2, however these differences disappeared from 28 days post-harvest in both regimes (Figure 1).

Compared with untreated trees (EM^-), adding EM to the soil had no effect on fruit quality attributes (Table 5). Similarly, neither management regime nor storage period interactions modified this response (Table 3).

Discussion

Four years after the initial imposition of treatments, over half of the thirteen fruit quality attributes tested were found to be significantly influenced by management regime. Specifically, fruit size, stem retention force and compression firmness were higher in regime 1 which followed conventional nutrition and herbicide practices. However, fruit from regime 2 based on organic amendments had higher TSS and MA concentrations. Despite differences between management regimes, all quality attributes measured were above the cherry ‘export finest’ standards, as described in Table 1. Although we only have 1 year of fruit quality data, it suggests management regimes using organic amendments and no herbicide can produce fruit high quality fruit. However, further research will be required to confirm this.

As previously mentioned, the impact of alternative management systems on fruit quality has been rarely studied for sweet cherry. However, the findings in this study are similar to those reported for apple (*Malus domestica* L.) species. For example, similar studies on organic apples were reported to have higher TSS than conventional apples. This was achieved five years after converting a 5-year-old orchard from conventional to organic management (Amarante et al. 2008). Similarly, in a 10-year study, Peck et al. (2006) found the organic system produced apples of higher TSS than the conventional system. In this study, the cherries produced in regime 2 using organic amendments had increased MA concentration as reported for organic apples (Velimirov 2004). Alternatively, Reganold et al.

(2001) noted that while the sugar-acid ratio was highest in organic apples, there was no differences in TSS or MA.

Although compression firmness differed between the two management regimes (regime 1, 346 ± 5 g mm^{-2} and regime 2, 311 ± 5 g mm^{-2}), both were above the industry standard of > 300 g mm^{-2}. Hence the lower compression firmness in regime 2 did not impact ‘export finest’ quality. It is also worth noting that while there were differences in compression firmness between the management regimes, flesh firmness was not affected. Normally these two attributes are closely correlated (Bound, unpublished data). In contrast, fruit firmness has been shown to be higher in organic than conventional apples (Amarante et al. 2008), though this response may vary with season (Reganold et al. 2001; Peck et al. 2006). Currently, there is insufficient understanding of the factors affecting fruit size and firmness of sweet cherry, but Neilsen et al. (2007) and Jönssson et al. (2009) suggest that the lack of mineral nutrition or slow release of nutrients from compost and manure could lead to lower nutrient availability for fruit development, hence producing smaller and less firm fruit.

Stem retention is an important attribute in the market, with a minimum force of 500 g being the benchmark in Australia for both domestic and export fruit. In this study, stem retention force was significantly lower in regime 2 at harvest and 14 days post-harvest, but it was still above the industry standard from harvest through to 28 days post-harvest. Although the stem retention force value did drop below the industry threshold in either regime after 42 days in storage, the stem retention force observed in this study would be considered acceptable at 28 days post-harvest as the shelf life of sweet cherries typically ranges from 30 to 40 days (Padilla-Zakour et al. 2007).

After four years of monthly application of EM, results from this study indicate that EM had no effect on fruit quality of sweet cherry. There is currently a lack of information regarding the impact of EM on sweet cherry fruit quality, but in other studies examining microbial inoculants such as plant growth-promoting rhizobacteria (PGPR), Esitken et al. (2006) reported positive impacts on fruit diameter and titratable acidity of sweet cherry. Karakurt et al. (2011) reported improvement in sour cherry fruit set, plant growth (shoot thickness and leaf area) and fruit quality (TSS, MA, fruit size) with EM application. In addition, Karlidag et al. (2007) reported a positive impact on apple fruit size and foliar nutrition. The lack of consistency in results from different studies with EM may be due to the soil types and soil nutrient levels. Microorganisms in the bio-fertiliser product interact differently with soil of different properties (Bossio et al. 1998). Furthermore, the orchard used had received high levels of inorganic inputs for eight years prior to the trial. As such, the effect of EM may have been masked in both management regimes.

Conclusion

This study suggests that management regimes using organic based amendments and exclusion of herbicide can produce sweet cherry fruit of comparable quality to more conventional regimes based on inorganic fertilisers and herbicide use. However, soil applications of EM had no impact on fruit quality. Further studies are required to examine how soil type effects the efficacy of bio-fertiliser such as EM in perennial orchards. More importantly, quality attributes of all fruit met ‘export finest’ standards of the Australian sweet cherry industry. Therefore, the management regime based on organic amendments as used in this study should be considered as a feasible management option for producing high quality sweet cherries more sustainably.

References

Amarante, C. V. T., C. A. Steffens, Á. L. Mafra, and J. A. Albuquerque. 2008. Yield and fruit quality of apple from conventional and organic production systems. *Pesquisa Agropecuária Brasileira* 43(3):333–340.

ANON. 2016. Export packing In CGA cherry export manual. Australia: Cherry Growers Australia Inc.

Bossio, D. A., K. M. Scow, N. Gunapala, and K. J. Graham. 1998. Determinants of soil microbial communities: effects of agricultural management, season, and soil type on phospholipid fatty acid profiles. *Microbial Ecology* 36(1):1–12.

Bound, S. A. 2014. Mulch application in hops, grapes and olives. *Acta Horticulturae 1018*:361–368.

Compant, S., B. Duffy, J. Nowak, C. Clément, , and E. A. Barka. 2005. Use of plant growth-promoting bacteria for biocontrol of plant diseases: principles, mechanisms of action, and future prospects. *Applied and Environmental Microbiology* 71(9):4951–4959.

Esitken, A., L. Pirlak, M. Turan, and F. Sahin. 2006. Effects of floral and foliar application of plant growth promoting rhizobacteria (PGPR) on yield, growth and nutrition of sweet cherry. *Scientia Horticulturae* 110(4):324–327.

Gourlay, R. 2015. Effective microorganisms (EM)™ : The mother culture for biological farming. New South Wales: Environmental Research and Information Consortium Pty Ltd.

Green, K. 2005. High density cherry systems in Australia. *Acta Horticulturae*. 667:319–324.

Hayat, R., S. Ali, U. Amara, R. Khalid, and I. Ahmed. 2010. Soil beneficial bacteria and their role in plant growth promotion: a review. *Annals of Microbiology* 60(4):579–598.

Higa, T, and G. N. Wididana. 1991. The concept and theories of effective microorganisms. Paper read at Proceedings of the first international conference on Kyusei nature farming. US Department of Agriculture, Washington, DC, USA.

Hu, C., and Y. Qi. 2013. Long-term effective microorganisms application promote growth and increase yields and nutrition of wheat in China. *European Journal of Agronomy* 46:63–67.

Isbell, R. F. 1996. The Australian soil classification. Collingwood, Australia: CSIRO.

Iwaishi, S. 2001. Effect of organic fertilizer and effective microorganisms on growth, yield and quality of paddy-rice varieties. *Journal of Crop Production* 3(1):269–273.

James, P, P.F. Measham and P. Domeney. 2011. Australian cherry production guide. Australia: Cherry Growers Australia Inc.

Javaid, A. 2006. Foliar application of effective microorganisms on pea as an alternative fertilizer. *Agronomy for Sustainable Development* 26(4):257.

Jönssson, Å., N. Hilde, and R. Kimmo. 2009. Fungal disease and fruit quality in an apple orchard converted from integrated production to organic production. *Journal of Sustainable Agriculture 34*(1):15–37.

Karlidag, H., A. Esitken, M. Turan, and F. Sahin. 2007. Effects of root inoculation of plant growth promoting rhizobacteria (PGPR) on yield, growth and nutrient element contents of leaves of apple. *Scientia Horticulturae 114*(1):16–20. doi: http://dx.doi.org/10.1016/j.scienta.2007.04.013

Karakurt, H., K. Recep, D. Fatih , A. Rafet, and Ş. Fikrettin. 2011. Effects of plant growth promoting rhizobacteria on fruit set, pomological and chemical characteristics, color values, and vegetative growth of sour cherry (Prunus cerasus cv. Kütahya). *Turkish Journal of Biology* 35(3):283–291.

Mahdi, S. S., G. I. Hassan, S. A. Samoon, H. A. Rather, S. A. Dar, and B. Zehra. 2010. Bio-fertilizers in organic agriculture. *Journal of Phytology* 2:(10).

Megali, L., G. Glauser, and S. Rasmann. 2014. Fertilization with beneficial microorganisms decreases tomato defenses against insect pests. *Agronomy for Sustainable Development 34*(3):649–656.

Megali, L., B. Schlau, and S. Rasmann. 2015. Soil microbial inoculation increases corn yield and insect attack. *Agronomy for Sustainable Development 35*(4):1511–1519.

Neilsen, G., F. Kappel , and D. Neilsen. 2007. Fertigation and crop load affect yield, nutrition, and fruit quality of ‘Lapins’ sweet cherry on Gisela 5 rootstock. *HortScience* 42(6):1456–1462.

Okorski, A., J. Olszewski, K. Glowacka, S. Okorska, and A. Pszczolkowska. 2010. The effect of the application of the biological control agent EM1 on gas exchange parameters and productivity of *Pisum sativum L.* infected with Fusarium oxysporum Schlecht. *Acta Agrobotanica 63*(2).

Padilla-Zakour, O. I., I. Ryona, H. J. Cooley, T. L. Robinson, J. Osborne, and J. Freer. 2007. Shelf-life extension of sweet cherries by field management, post-harvest treatments and modified atmosphere packaging. *New York Fruit Quarterly*.

Peck, G. M., P. K. Andrews, J. P. Reganold, and J. K. Fellman. 2006. Apple orchard productivity and fruit quality under organic, conventional, and integrated management. *HortScience* 41 (1):99–107.

Pettit, R. E. 2004. Organic matter, humus, humate, humic acid, fulvic acid and humin: Their importance in soil fertility and plant health. *CTI Research*.

Pimentel, D., P. Hepperly, R. Seidel, J. Hanson, and D. Douds. 2005. Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems. *BioScience 55*(7):573–582

Priyadi, K., A. Hadi, T. H. Siagian, C. Nisa, A. Azizah, N. Raihani, and K. Inubushi. 2005. Effect of soil type, applications of chicken manure and effective microorganisms on corn yield and microbial properties of acidic wetland soils in Indonesia. *Soil Science & Plant Nutrition* 51(5):689–691.

Radcliffe, J. C. 2002. Pesticide use in Australia. Australian Academy of Technological Sciences and Engineering. Downloaded 7/4/17 from www.atse.org.au/Documents/Publications/Reports/Climate_Change/Pesticide-Use-in-Australia-2002.pdf

Reganold, J. P., J. D. Glover, P. K. Andrews, and H. R. Hinman. 2001. Sustainability of three apple production systems. *Nature* 410(6831):926–930.

Rigby, D., and D. Cáceres. 2001. Organic farming and the sustainability of agricultural systems. *Agricultural Systems* 68(1):21–40.

Seufert, V., N. Ramankutty, and J. A. Foley. 2012. Comparing the yields of organic and conventional agriculture. Nature 485(7397):229-232.

Schellhorn, N., A. Renwick, and S. Macfadyen. 2013. The real cost of pesticides in Australia food boom. The Conversation. Downloaded 7/4/17 from http://theconversation.com/the-real-cost-of-pesticides-in-australia-food-boom-20757

Velimirov, A. 2004. Integrative methods of product quality assessment in connection with the P-value-determination (3 examples: food preference test, sensory evaluation and self-decomposition test). *Journal of Horticultural Science and Biotechnology* 31:17–21.

Xu, H. l. 2001. Effects of a microbial inoculant and organic fertilizers on the growth, photosynthesis and yield of sweet corn. *Journal of Crop Production 3*(1):183–214

Xu, H. L., R. Wang, and M. A. U, Mridha. 2001. Effects of organic fertilizers and a microbial inoculant on leaf photosynthesis and fruit yield and quality of tomato plants. *Journal of Crop Production 3*(1):173–182.

Zhang, W. J., F. B. Jiang, and J. F. Ou. 2011. Global pesticide consumption and pollution: with China as a focus. *Proceedings of the International Academy of Ecology and Environmental Sciences* 1(2):125.