A Survey of *Vaccinium* Cultural Practices in Australia Emphasizing Implications for Mycorrhizal Infection

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ABSTRACT. A survey was conducted of 171 blueberry growers in four Australian states to collect detailed information on cultural practices that have been shown to effect the infection of commercial plantings with ericoid mycorrhizal fungi. Explanatory factors including climatic and edaphic variables and growers' attitudes to blueberry production and marketing were also collected and assessed to interpret survey responses. The survey found that there were highly significant relationships between a number of cultural practices and the geographic location of growers. Differences between northern and southern growing regions in crop scheduling and pre-plant soil amendment were especially significant. Crop

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scheduling in northern Australia has implications for the distribution of mycorrhizae in northern Australian blueberry plantings.

KEYWORDS. Ericoid mycorrhizal fungi, cultural practices, *Vaccinium*, blueberry

INTRODUCTION

Infection with ericoid mycorrhizal fungi (EMF) is important to blueberry production because it potentially increases fertilizer use efficiency (Scagel, 2005) and increases berry yields (Powell and Bates, 1981); the latter effect was demonstrated to occur irrespective of nursery inoculation or field infection of plants. Distribution and intensity of EMF infection can be effected by cultural practices including mulch type, soil mounding, fertilizer amount and type, and preplanting treatments (Goulart et al., 1995; Scagel and Yang, 2005). Other factors that indirectly affect EMF include the age of the plants and field, cultivars, and soil factors such as pH and nutrient levels (Scagel, 2005; Stevens et al., 1997).

Inoculation of blueberry plants has been shown to result in increased efficiency of fertilizer use by mycorrhizal plants (Scagel, 2005). Reduced fertilizer inputs have implications for the environment by lessening the potential leaching of nutrients into land and water resources, especially given blueberries preference for ammonium nitrogen (Powell, 1982). For the blueberry industry in Australia, sustainable production practices are being emphasized due to a focus on blueberries in the health food market (Australian Blueberry Grower's Association, 2005; Scagel and McLean, 2005).

The Australian blueberry industry is characterized by cultivation of highbush (*Vaccinium corymbosum* L.) in southern regions and southern highbush hybrids or rabbiteye cultivars (*V. ashei* Reade) in the warmer northern regions (Patel, 1997). The genus *Vaccinium* is not native to Australia and although indigenous EMF may form relationships with blueberries in Australia, their distribution and function in blueberry production systems is unknown (Scagel and McLean, 2005). A previous survey of blueberry production in Australia did not focus in detail on practices that effected mycorrhizal infection (Field, 2006). Further information on plant age and cultural practices would assist in understanding factors influencing the distribution of EMF in Australian commercial blueberry fields.

Additionally, knowledge of blueberry growers' interest in organic systems and sustainability may be an indicator of their receptiveness to utilizing EMF as a production tool. Knowledge of growers' perceptions of problems faced in blueberry production may be relevant to understanding whether EMF can play a role in ameliorating some of their concerns.

MATERIALS AND METHODS

The survey consisted of fourteen questions and was sent to 171 growers in the eastern states of Australia from northern New South Wales (NSW), Queensland, Tasmania, and Victoria. For the purposes of this article, NSW and Queensland will be referred to as the northern growing region, while Tasmania and Victoria will be referred to as the southern growing region. The number of growers surveyed comprised a sizeable proportion of the entire target population, as the mailing lists were coordinated with lists from the respective state Departments of Primary Industries. An advertisement was placed in *The Australian Blueberry Grower*, the journal of the Australian Blueberry Grower's Association, ensuring that as large a number of growers as possible would be surveyed.

The survey was designed to collect precise qualitative information about cultural practices used in blueberry production in Australia and to identify differences that might exist in production practices and attitudes. To accurately interpret the extent to which intrinsic geographic differences contributed to variation in cultural practices, other data such as soil type and cultivars grown was requested. As the survey was designed with field-grown commercial blueberry production in mind, commercial fruit growers in each state were the target population.

Prior to distribution, the survey proforma as well as a plain language statement regarding the purpose of the survey, use and storage of data, and privacy was approved according to the University of Melbourne's Human Ethics Advisory process. The 14 questions included in the survey asked growers about: (1) climatic and edaphic factors that might influence management decisions; (2) production systems; i.e., mounds, raised beds; (3) mulching practices; (4) pre-plant soil weed–seed bank management such as cultivation and herbicide application; (5) planting hole amendment with organic or other material; (6) fertilizers used; (7) frequency of replanting; (8) cultivars grown; (9) pruning frequency; (10) pruning methods; (11) geographic location of respondent for classification purposes; (12) what major difficulties the respondent faced in production; and (13) respondents' attitudes to the importance of the organic market and any effects the organic market had on their production practices. The survey also included space for any comments on the survey format or method.

Responses were analyzed using Pearson chi square tests (χ^2) or Fisher's exact test where minimum expected values in contingency tables were not high enough for chi square. A large number of responses from the southern region in conjunction with a smaller number of responses from the northern region necessitated the use of Fisher's exact test in many cases for statistical analysis; low expected frequencies characteristically arose from the northern region due to the smaller number of growers there. Differences were considered significant at $P \leq 0.05$. Questions concerning climatic and edaphic variables, cultivars grown, organic production, and problems faced in production were asked in order to assist in interpreting other responses. Cross-tabulations were analyzed using these descriptive factors, geographic location, and cultural practices. Statistical analysis was conducted using Minitab™ version 15.0 (Minitab™ Inc., State College, Pa.).

RESULTS AND DISCUSSION

Response to Survey

Twenty-two percent of the 171 surveys distributed were returned. The greatest number of surveys were distributed to and returned from the southern Australian states of Tasmania and Victoria, which reflected the majority (~64%) of growers that resided in these states. Except for a survey that was completed and returned by a wholesale blueberry nursery grower in northern NSW, all growers who returned the survey were at least in part field-based operations.

Cultivar Variation Due to Geographic Location

The wholesale nursery grew low-chill cultivars favored by growers in the northern NSW and Queensland. Cultivar selection for field plantings was related to geographic region ($\chi^2 = 20.927$, $P < 0.001$, df = 1; Table 1). 'Brigitta' was the most common cultivar grown in the southern region and 'Sharpeblue' was the most common cultivar grown in the northern region, with these cultivars being grown by 96.5% and 19% of respondents, respectively. Northern highbush cultivars were most commonly grown in the southern region and southern highbush and rabbiteye cultivars were most commonly grown in the northern region.

TABLE 1. Responses from growers concerning which blueberry plants are grown in commercial production fields in northern (New South Wales and Queensland) and southern (Victoria and Tasmania) blueberry growing regions in Australia

Cultivar	Proportion of responses (%)^z			
	Southern		Northern	
	% Total	% Region	% Total	% Region
Northern highbush	58.6	74.0	2.4	11.0
Bluecrop	7.1	9.0	0.6	2.8
Blue Rose	6.5	12.0	0	0
Brigitta	16.6	21.0	1.8	8.3
Denise	7.7	9.8	0	0
Elliott	4.1	5.3	0	0
Northland	5.3	6.8	0	0
Reka	3.5	4.5	0	0
Other	8.3	10.5	0	0
Southern highbush	0.6	0.7	10.1	47.2
Biloxi	0	0	2.4	11.1
Misty	0	0	3.5	16.7
Sharpeblue	0.6	0.7	4.4	19.4
Rabbiteye	15.4	19.5	7.1	33.3
Brightwell	1.2	1.5	1.2	5.5
Climax	0	0	1.8	8.3
Maru	3.0	3.8	0	0
Powderblue	3.5	4.5	1.8	8.3
Premier	1.2	1.5	1.2	5.5
Tifblue	2.4	3.0	1.2	5.5
Other	0.6	0.7	0	0
Other	4.1	5.3	1.8	8.3

^{z}Comparison of Brigitta vs. non-Brigitta between regions significant at $\chi^2 = 20.927$, df = 1, $P \leq 0.000001$.

The climate of the primary blueberry growing regions in the northern region is dramatically different than that of the southern region. For example, mean annual minimum and maximum temperatures in northern NSW are 12 and 26°C, respectively, and average annual rainfall is 1055 mm (Australian Bureau of Meteorology). In comparison, mean annual minimum and maximum temperatures in the southern growing region are 10 and 19°C, respectively, and average annual rainfall is 652 mm. Based on climactic differences it is not surprising that different cultivars are grown in the different regions. Cultivars of rabbiteye and southern highbush blueberry that tolerate warmer temperatures and require less chilling hours for fruiting are important in the northern growing blueberry growing region of Australia (Ireland and Wilk, 2006). Similar differences in cultivar selection occur in the different blueberry growing regions of North America (Gough, 1993; Lyrene and Williamson, 1997). As mycorrhizal relationships and plant responses to EMF are often cultivar specific (Scagel and Yang, 2005; Stevens et al., 1997), knowledge of the specific EMF associated with the primary cultivars grown in the different regions would assist growers in determining the potential mycorrhizal responsiveness of blueberry field plantings.

Soil Factors

Blueberry plants were more commonly grown on clay loam and sandy loam soil in the northern growing region compared to the southern region; sand and finer textured loam soils were restricted to the southern region (Table 2). Soils from blueberry fields in the northern region tended to have higher pH than soils in the southern growing region, with 37.5% of respondents from the northern growing region citing pHs of greater than 5.5 (Table 2). Between 65% and 87% of growers reported performing tests on soils for nutrients and only 46% to 62% of growers reported performing tests on leaves for nutrients. More growers in the northern region reported performing nutrient analyses on soil and leaves than growers in the southern region.

Root morphology and the effect of soil on blueberry growth and yield have been well described. Plant growth is higher in acid pH, well-drained soils with a large relative proportion of sand particles (Korcak et al., 1982). When blueberries are cultivated on non-native soils, mulches are recommended to maximize soil available water and add organic matter (Magee and Spiers, 1995).

Planting Conditions

The majority (~72%) of respondents grew blueberry plants in soil mounds compared to raised beds (~28%). The incorporation of organic material, particularly peat, into planting holes was restricted to southern states and thus related to location (Fisher's exact test, $P < 0.01$). Most growers reported incorporation of materials into planting holes to aid plant establishment in new fields. In the southern region, 79% of growers incorporated some type of organic material into the hole during planting, compared to only 33% of growers in the northern region. In the northern

TABLE 2. Responses from growers concerning specific soil factors for commercial blueberry production fields in northern (New South Wales and Queensland) and southern (Victoria and Tasmania) blueberry growing regions in Australia

Soil Factor	Proportion of responses (%)		
	% Total	% Region	
		Southern	Northern
Type			
Clay	21.6	24.1	12.5
Clay loam	18.9	17.2	25.0
Sand	5.4	6.9	0
Sandy loam	21.6	17.2	37.5
Sandy clay loam	8.1	10.3	0
Loam	10.8	13.8	0
Other soil[z]	13.5	10.3	25.0
pH			
4–4.5	10.8	13.8	0
4.5–5.0	32.4	24.5	25.0
5.0–5.5	32.4	24.5	25.0
5.5–6.0	13.5	6.9	37.5
No response	10.8	10.3	12.5

[z]Other soil = Peat/sand or other.

region, 55% of the growers added fertilizer to the planting hole, compared to only 23% in the southern region. The incorporation of peat and seaweed-based organic material into planting holes was restricted to the southern region. Approximately 35% of growers in the southern region incorporated peat into the planting hole and 15% incorporated seaweed- or kelp-based products.

Fertilizer and other pre-plant soil management practices (e.g., pH alteration and herbicide application) were similar between regions. Prior to planting, approximately 69% of growers prepared fields using cultivation, 53% of growers added organic matter, 17% of growers used materials to alter soil pH, and 32% used pre-planting applications of herbicides.

Incorporation of organic materials into the soil at planting has been reported to aid establishment of blueberry plants in field plantings (Odneal and Kaps, 1990). Theoretically, the incorporation of organic substances into planting holes should increase soil moisture retention around the root system (Spiers, 1986) and the acid pH of peat-rich substrates should provide an appropriate environment for mycorrhizal colonization (Haynes and Swift, 1985). Peat incorporation has been reported as beneficial both to mycorrhizal infection and blueberry growth and establishment; however, a consistent response between peat or organic matter incorporation and mycorrhizal infection has not so far been demonstrated in the field (Goulart et al., 1995). The reasons for differences in peat incorporation between the regions are unexplained, but the NSW Department of Primary Industries advice does not suggest peat incorporation for growers in the northern region (Ireland and Wilk, 2006). This survey suggests that the practice of organic matter amendment in planting holes is regionally specific and has the potential to cause differences in mycorrhizal infection and function in blueberry plantings between regions.

Postplanting Practices

A variety of different materials was reported as being used as mulches for blueberry plants (Table 3). Approximately 70% of growers reported using some type of organic material as mulch and 10% did not mulch plants. In general, the use of different mulch materials was similar

TABLE 3. Responses from growers concerning the type of materials used for mulch in commercial blueberry production fields in northern (New South Wales and Queensland) and southern (Victoria and Tasmania) blueberry growing regions in Australia

Mulch Material	Proportion of responses (%)		
	% Total	% Region	
		Southern	Northern
Sawdust/woodchip	26.4	25.6	30.0
Pine bark	13.2	16.3	0
Black plastic	9.4	9.3	10.0
Woven Weedmat	7.5	4.6	20.0
Compost	17.0	16.3	20.0
Straw	7.5	7.0	10.0
Groundcover plants	5.7	7.0	0
None	9.4	9.3	10.0
Other[z]	3.8	4.6	0

[z]Other = newspaper and stone.

between growing regions, although the use of pine bark and ground cover plants as mulches was only reported in the southern growing region.

The responses about the use of mulches in this survey support those of a recent survey by the Department of Primary Industries (Field, 2006), indicating that plastic mulches are not used as frequently as reported in the early days of the blueberry industry in Australia (e.g., Shelton and Freeman, 1989). Mulch can exert a significant effect on EMF distribution. Contradictory evidence exists regarding the effects of plastic mulch on the yield and mycorrhizal status of blueberries (Magee and Spiers, 1995; Starast et al., 2006), while there is evidence that the more common organic mulches reported by survey respondents can positively effect yield and mycorrhizal infection (Goulart et al. 1995; Scagel & Yang 2005). Recent data from the blueberry growing regions of the US Pacific West coast indicated that 42% of sampled blueberry fields were un-mulched and the absence of mulch was correlated with poor mycorrhizal inflection and lower root biomass (Scagel and Yang, 2005). No mulch type was significantly related to growing region and given the majority of growers use organic mulches there is probably little capacity in Australia to influence EMF infection and function by focusing on this cultural practice.

A variety of nutrient sources were reported as being used in growing blueberries (Table 4). Sixty-one percent of respondents cited applying nutrients as inorganic fertilizers. Potash and blood and bone were only used in the southern region.

Blueberry production practices traditionally favor application of ammonium; however, high soil ammonium can negatively influence root growth and mycorrhizal infection (Goulart et al., 1995; Scagel and Yang, 2005; Starast et al., 2005). Fertilizer practices recommended by Australian advisory bodies as guidelines for nutrients are largely derived from U.S. sources (Ireland and Wilk, 2006). While plants have ready access to the nutrients available from inorganic sources of nutrients, organic nutrient sources require breakdown by soil microorganisms before nutrients can be taken up by roots. Ericoid mycorrhizal fungi can take up both organic and inorganic sources of nutrients and transfer these nutrients to their plant partner (Read et al., 1989). The influence of different fertilizer types on EMF infection and plant growth is complex, with significant variation in responses to organic and inorganic fertilizer types between cultivars as well as EMF isolates. The effective use of organic nutrient sources in blueberry production requires further exploration of the role of EMF in nutrient assimilation from organic sources and the complex relationships identified by previous studies (Scagel, 2005).

TABLE 4. Responses from growers concerning the type of nutrient sources used during commercial blueberry production fields in northern (New South Wales and Queensland) and southern (Victoria and Tasmania) blueberry growing regions in Australia

Nutrient Source	Proportion of responses (%)		
	% Total	% Region	
		Southern	Northern
Inorganic			
Urea	9.7	10.3	7.1
NH4-salt[x]	6.9	6.9	7.1
Superphosphate	4.2	3.4	7.1
Potash	5.5	6.9	0
Complete	22.2	22.4	21.4
NPK Fertigation	5.5	5.2	7.1
Other[y]	6.9	8.6	0
Organic			
Blood and bone	4.2	5.2	0
BioDynamic 500	4.2	3.4	7.1
Compost	8.3	8.6	7.1
Sea/aqua sol	9.7	10.3	7.1
Dynamic lifter	4.2	1.7	14.3
Organic fish	2.8	1.7	7.1
Other[z]	4.2	3.4	7.1
None	1.4	1.7	0

[x]Ammonium nitrate or ammonium sulfate.
[y]Other=Iron chelate, $MgS0_4$, Gypsum.
[z]Other=Guano, Searles Organic Fertilizer®.

Pruning

Pruning practices between the growing regions were similar. Approximately 75% of the growers pruned plants annually and the remainder of the plants were pruned every 2–4 years. The majority of the pruning practices consisted of tip or light pruning and removal of old canes (data not shown).

Frequency of Plant Replacement

The frequency at which plants were replaced in field production was related to geographic location. Growers in northern region replaced plants

TABLE 5. Responses from growers concerning the frequency at which blueberry plants are replaced in commercial production fields in northern (New South Wales and Queensland) and southern (Victoria and Tasmania) blueberry growing regions in Australia

Frequency of plant replacement	Proportion of responses (%)		
	% Total	% Region	
		Southern	Northern
6–8 Years	5.5	0.00	25.0
9+ Years	27.8	28.6	25.0
At plant death	47.2	50.0	37.5
No response	19.4	21.4	12.5

every 6–8 years compared to growers in the southern region, while more growers in the southern region reported only replacing plants at death (Fisher's exact test, $P < 0.05$; Table 5).

The difference in frequency of plant replacement between the two growing regions was unexpected and has not been reported in prior surveys of blueberry production in Australia (Field, 2006). A few survey respondents from the southern region noted lack of plant availability and cost as reasons for not replacing plants (data not shown). Growers in the northern region may have readier and cheaper access to plants than growers in the southern states due to the existence of a large wholesale nursery in northern NSW. This regional availability of plant materials may also be partially responsible for the higher frequency of replanting in the northern region.

Previously observations of the Australian blueberry industry noted cultural differences between the northern and southern growing regions; these overviews have typically emphasized the spacing of plants in northern Australian production systems, which they describe as high-density plantings, rather than limitations on the productive life of northern Australian plantings (Patel, 1997; Trehane, 2004). The region is characterized by an emphasis on high yield per unit area plantings of low-chill cultivars of rabbiteye and southern highbush that mature quickly and produce marketable crops rapidly from cuttings under warm and humid conditions. This system is similar to that used for low-chill cultivars in the southern United States; a study there found that growing southern highbush cultivars at extremely close spacing under warm conditions resulted in increased berry production per unit area but seemed to indicate such spacing intrinsically caused a speedier decline in plant productivity in Arkansas than in conventionally spaced plants (Moore et al., 1993).

The hypothesis typically advanced to explain shorter productive life spans of plants in high-density production systems is that competition for light among closely packed plants leads to a decline in flower-bud set and fruit initiation (Eck and Stretch, 1986). In northern Australia some plants will fruit for the entire year with careful management (Patel, 1997). This is, however, often accompanied by high rates of applied nutrients and can be associated with a higher disease occurrence (Lyrene and Williamson, 1997). As EMF infection has been linked to productivity in blueberry (Powell and Bates, 1981) and intensity of EMF infection has been shown to be linked to both field age and cultivar (Scagel and Yang, 2005), the results of this survey indicate that the productivity decline of plants in some northern Australian blueberry plantings could be explored in relation to EMF infection intensity in these plantings rather than light competition.

While factors such as ease of plant availability, warmer temperatures, and low-chill cultivars may lead to the establishment of high-density plantings of blueberries, the effects of these production systems on blueberry roots and EMF is unclear; given the clear geographical separation of these production systems in Australia identified by this survey, northern Australia presents an ideal ground for studying these effects in situ.

Challenges to Production

Growers reported several challenges to production (Table 6). Growers in the northern region more frequently cited problems of any type with the exception of weed and soil-borne factors, which were more prevalent in the southern region. Pest and disease incidence were related to geographic location, with insect pest and disease incidence being more frequently reported in northern states ($\chi^2 = 6.181$, df = 1, $P < 0.05$). The increased perception of pest and disease problems in the northern region is particularly interesting given more frequent re-planting in the northern region.

In a previous survey of the U.S. blueberry industry, growers in the warmer southern states listed comparatively fewer insect pests as problems than growers in cooler northern states, so the use of low-chill cultivars does not necessarily predispose to frequent citation of pest problems by survey respondents (Hancock and Draper, 1989). The interactions between defoliation by any means and mycorrhizal biology are poorly

TABLE 6. Responses from growers concerning the major challenges to commercial blueberry production in northern (New South Wales and Queensland) and southern (Victoria and Tasmania) blueberry growing regions in Australia

Challenge	Proportion of responses (%)		
	% Total	% Region	
		Southern	Northern
Labor	7.0	5.4	12.5
Drought	15.5	18.2	6.2
Disease[z]	15.5	12.7	25.0
Birds	18.3	20.0	12.5
Weeds	7.0	9.1	0
Site factors	4.2	5.4	0
Late frost	4.2	5.4	0
High temperature	2.8	1.8	6.2
Insect pests	5.6	0	25.0
Other[y]	11.3	12.7	6.2
No difficulties	5.6	5.4	6.2
No response	2.8	3.6	0

[z]Comparison of disease and insect problems vs. all other problems between regions significant at $\chi^2 = 6.181$, df = 1, $P < 0.013$.
[y]Other = Low pollinator number, establishment costs, nutrition, and miscellaneous causes for plant death.

understood, and in light of the results of this survey, the northern states of Australia may provide suitable ground for the examination of these processes. Most of the previous studies in this field have examined relationships between defoliation by herbivory in forest mycorrhizae (e.g., Gange et al., 2002).

Product Market

Approximately 11% of the growers surveyed were currently growing blueberries using organic production techniques and approximately 55% of the growers reported that the organic market has no influence on their production. Field (2006) identified the organic market as being of little importance in the Australian blueberry industry. Results from our survey generally support that assertion. Growers seemed to express a desire not to use too many chemicals in production, recognizing a resistance to high chemical use in the general market, but most growers did not wish to become organic growers. Only 14% of the respondents indicated that they were "thinking about organic certification." In the northern region where finer-textured soils were absent or comprised a lower percentage of responses, weed control without herbicides was cited as a primary problem of organic production by 12.5% of respondents as opposed to 6.9% of respondents in the southern region.

CONCLUSIONS

In general, there were only a few cultural practices potentially important to EMF infection and function that differed between blueberry growing regions in Australia. Cultivar selection, pre-plant amendments, and frequency of plant replacement could potentially affect EMF infection intensity and distribution in commercial production settings. Cultivar differences and pre-plant site amendments that are likely to impact EMF as well as plant establishment and root distribution were significantly different in the northern Australian blueberry industry than in southern region. Plants were replaced more frequently in the northern Australian blueberry growing region than elsewhere, with possible impacts on EMF. Given the potential shown in the literature for EMF to affect the productive capacity and vigor of blueberries, it appears that there are areas of blueberry cultural practices in the northern states that could be of interest for further research. The survey also provided a percentile representation of the current state of blueberry cultural practices in Australia, problems in blueberry production, and the extent of encroachment of organic production and markets into the industry.

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