Mycorrhizal Status of Sand-Based Cranberry (*Vaccinium macrocarpon*) Bogs in Southern Oregon

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ABSTRACT. Ericoid mycorrhizal fungi (EMF) form symbiotic relationships with cranberry plants providing increased access to nutrients from fertilizers and soil. We conducted a survey assessing the mycorrhizal status of cranberry from bogs grown under conventional and organic production practices and ranging in age from two to thirty-eight years. Root colonization by EMF increased with bog age regardless of production practices. Root colonization on plants from bogs less than 10 years old was 7.5%, 10 to 12 years old was 28%, 15 to 21 years old was 70%, and 32-38 years old was 90%. In contrast, root colonization of other ericaceous plants growing adjacent to bogs all had colonization levels greater than 90%. The low level of EMF colonization of cranberry in young bogs may be related to fertilizer use in both organic and conventional production systems.

KEYWORDS. Cranberry, ericoid mycorrhizal fungi, nitrogen, *Vaccinium macrocarpon*

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The author wishes to acknowledge the technical assistance of Kathy Eggemeyer and Lisa Tribbet. The author also wishes to thank R.G. Linderman, R.P. Schreiner, A.P. Poole, and J.M. Hart for their helpful comments.

INTRODUCTION

Most members of the Ericaceae, including cranberry (*Vaccinium macrocarpon* Ait.), are calcifuge plants that grow naturally in acid soils of low to moderate fertility. Roots of wild *Vaccinium* species are virtually all colonized with ericoid mycorrhizal fungi (EMF), and the extensive hyphae of these fungi form a loose network in the soil so that the volume of soil explored by the plant is greatly increased (Read, 1996). Shoots of cranberry colonized by mycorrhizal fungi can contain more nitrogen (N) and a greater concentration of N on a dry weight basis than non-mycorrhizal plants grown in a sterilized soil; mycorrhizal plants can also absorb N directly from organic sources that are not directly available to non-mycorrhizal plants (Stribley and Read, 1974a, b). Mycorrhizal fungi may also improve the general physiological condition of the host plant through enhanced uptake of other deficient nutrients, such as phosphorus (P) and zinc (Zn) (Stribley and Read, 1976; Stribley et al., 1975).

Although cranberry plants can form ericoid mycorrhizae, which may be beneficial to plants in terms of fertilizer use efficiency, little is known about whether these fungi are present during conventional or organic cranberry production and how they may influence fertilizer use. Currently, there are no reports detailing the extent and timing of mycorrhizal colonization of cranberry grown under the sand-based production conditions used in Oregon, and there are no reports of field trials detailing the influence of inoculation of cranberry with mycorrhizal fungi under field production. This paper reports the results from a survey of several sand-based cranberry bogs in southern Oregon to determine the presence and extent of colonization by ericoid mycorrhizal fungi under organic and conventional production conditions.

MATERIALS AND METHODS

Sampling. Samples containing soil and roots of cranberry were collected from several different bogs in southern Oregon during March, May, July, September, and November, 2000. Depending on the sample date, soil cores (2.5 cm diameter $\times$ 38.1 cm long = 188 cm^3 volume) were taken from 3-6 representative sample locations per bog. Bogs were loosely classified as "organic" or "conventional" based on the primary type of fertilizer used during production. Bogs receiving fertilizer derived from organic sources (e.g., fish, bone meal) were classified as organic and bogs receiving only primarily inorganic sources of fertilizer were classified as conventional. Sampling was done in nine to twelve bogs growing under organic production practices (ranging from 2-10 years old) and in sixteen to twenty bogs growing under conventional production practices (ranging from 2-38 years old). Random soil cores were also taken adjacent to several bogs within the native vegetation that included the following ericaceous plant species: *Ledum groenlandicum*, *Rhododendron macrophyllum*, *Rhododendron occidentale*, and *Vaccinium ovatum*. For each core from within and adjacent to bogs, soil was removed from roots by washing and a weighed subsample of roots was used for subsequent microscopic evaluation of colonization by EMF. The remaining roots were weighed, then oven-dried at 65°C for 48 h and weighed again. Weight of the subsample for ericoid mycorrhizae assessment was calculated into the total root dry weight.

Mycorrhizal Colonization. Root colonization by EMF was assessed on 1-cm sections after clearing and staining by modified procedures of Phillips and Hayman (1970), replacing lacto-phenol with lacto-glycerin. Percentage of root length with signs of colonization by EMF was estimated by the method of Biermann and Linderman (1980).

Data Analysis. Data were subjected to two different Analysis of Variance (ANOVA) procedures using Statistica® statistical package (Statsoft, Inc., Tulsa, OK, USA, 1996). Data from bogs less than 11 years old were subjected to a three-factor ANOVA with production practice (organic or conventional), bog age (2, 3, 4, 6, 7, 8, or 10 years), and sampling date (March, May, July, September, or November) as main effects. Data from bogs growing cranberry using conventional production practices were subjected to a two-factor ANOVA with bog age (2, 3, 4, 6, 7, 8, 10, 12, 15 18, 21, 32, or 38), and sampling date (March, May, July, September, or November) as main effects. Data for percentage colonization (% root length with EMF) were arcsin transformed prior to analysis to correct for unequal variance and best model fit. Actual data are reported in tables and figures. Contrast analyses were used for planned comparisons of means to address the following questions: (1) Is root colonization by mycorrhizal fungi different on plants growing under organic or conventional production practices; (2) Do levels of root colonization by EMF change with bog age; and (3) Do levels of root colonization by EMF change during the growing season?

RESULTS AND DISCUSSION

The role of mycorrhizal fungi in cranberry nutrition is a poorly understood aspect of cranberry production (Ek, 1990) even though there is evidence that EMF can enhance uptake of ammonium, nitrate, and organic sources of nutrients and transfer them to their plant symbiont. Ericaceous plants generally have poor nitrate-reducing abilities (Michelsen et al., 1996; Johansson, 2000). In sandy cultural conditions, such as those found in southwest Oregon bogs, a significant amount of nitrification may occur, creating situations where plant access to nitrate may be largely dependent upon EMF colonization and uptake by hyphae in the soil.

In this survey we found a significant increase in root colonization with bog age (2 to 38 years) for cranberry grown under conventional practices (Table 1, Contrast 1). Root colonization of plants grown under conventional practices could be grouped into four significantly different groups: < 10, 10-12, 15-21, and 32-38 years (Table 1, Contrast 5, 6, and 7). Average levels of root colonization on plants from bogs less than 10 years old was 7.5%, 10 to 12 years old was 28%, 15 to 21 years old was 70%, and by 32-38 years, plants showed colonization levels greater than 90 percent (Figure 1). In contrast, EMF colonization on ericaceous plant species naturally established adjacent to bogs of all ages showed colonization levels greater than 90 percent (data not shown).

In this survey, we only sampled from cranberry bogs at five times during 2000 and found a significant difference in root colonization by EMF at different times of the year (Table 1, Contrast 2). EMF colonization of plants grown under conventional practices could be grouped by sampling date into two significantly different groups: March-May-July and September-November (Table 1, Contrast 4). Levels of EMF colonization at different times of year varied with the age of the bog, with older bogs showing larger seasonal differences than younger bogs (Figure 1). Seasonal variation in EMF colonization has also been described for *Calluna* (Johansson, 2000). With Cranberry, increased EMF colonization in the fall could be a result of seasonal variation in root growth of cranberry. Cranberry root production occurs after the first flush of new vegetative growth and late in the fall after vegetative growth has ceased for the season (De Moranville, 1992).

It is possible that the low levels of colonization by EMF we measured from young bogs are related to the low organic matter content in the soil. When bogs age, there is an increase in organic matter accumulation

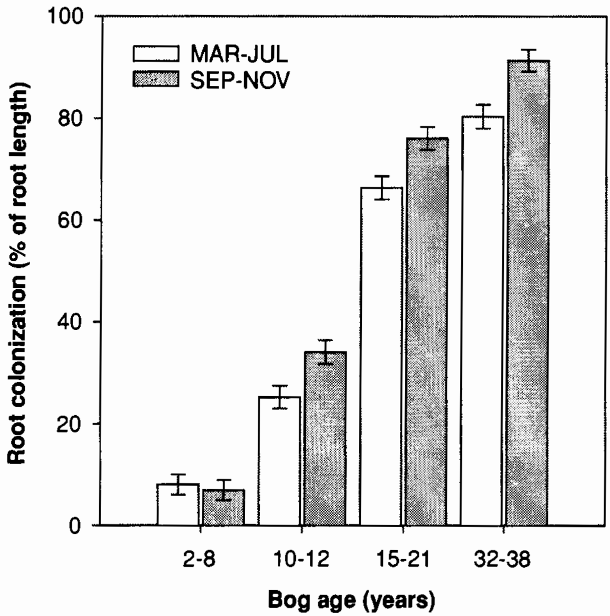
TABLE 1. ANOVA and orthogonal contrasts of root colonization by ericoid mycorrhizal fungi on cranberry from bogs grown under conventional (CO) production practices.

Source	df	MS	F	P
Sampling Date (SD)	4	276.5	15.86	*< 0.0001*
Bog Age (BA)	11	19226.3	1103.13	*< 0.0001*
SD * BA	44	130.7	7.50	*< 0.0001*
Error	186	17.4		
Contrasts				
1) BA Linear (Linear Relationship within BA)	1	192420.2	11040.31	*< 0.0001*
2) SD Trend (Trend between SD)	1	690.5	39.616	*< 0.0001*
3) SD Trend (BA Linear)	1	939.5	53.902	*< 0.0001*
4) MAR, MAY, JUL vs. SEP, NOV (BA Linear)	1	1261.8	72.400	*< 0.0001*
5) < 10 years vs. < 10-12 years (SD Trend)	1	186.9	10.726	*0.0013*
6) 10-12 years vs. 15-21 years (SD Trend)	1	312.6	17.934	*0.0001*
7) 15-21 years vs. 32-38 years (SD Trend)	1	141.6	8.127	*0.0048*

that may be more conducive to root colonization by EMF than the low organic matter sand-based soils originally used to construct the bog. The seasonal changes in colonization levels that we measured could also be related to seasonal changes in organic matter accumulation and nutrient levels within the soil. Others have found that the colonization of blueberry varies significantly with the cultivar rate of fertilizer application, and the amount and type of soil organic matter present in the soil (Czesnik and Eynard, 1990; Eynard and Czesnik, 1989; Powell, 1982). Blueberries grown in soils with high organic matter content and low pH usually have higher mycorrhizal colonization and in some instances better growth (Blasing, 1989; Czesnik and Eynard, 1990; Eynard and Czesnik, 1989; Haynes and Swift, 1985; Yang et al., 1998).

Plants with EMF often have higher N and P concentrations than non-mycorrhizal plants (Read and Stribley, 1973). These higher concentrations are a result of the fungus enhancing uptake of soluble inorganic N and P (Mitchell and Read, 1981; Stribley and Read, 1976) and also using organic or insoluble N and P compounds in the soil (Kerley and Read, 1995; Read et al., 1989; Stribley and Read, 1980). When ^{15}N labeled ammonium was fed to mycorrhizal and non-mycorrhizal *Vaccinium* growing in sterile soil, mycorrhizal plants had significantly greater yields and total N content than non-mycorrhizal plants, although

FIGURE 1. Ericoid mycorrhizal colonization on roots from cranberry plants growing under conventional production practices in bogs with ages ranging from 2 years to 38 years. MAR-JUL represents mean of samples taken in March, May, and July, 2000. SEP-NOV represents mean of samples taken in September and November, 2000. Bars on columns represent standard errors.



the mycorrhizal plants had lower ^{15}N enrichment (Stribley and Read, 1974b). This indicated that in mycorrhizal plants the label was diluted by uptake of alternative N sources.

In this survey, we could only include samples from cranberry bogs grown under organic practices that were less than 11 years of age. We found that root colonization by EMF increased with increasing bog age for plants grown under organic and conventional practices (Table 2, Contrast 1); however, the magnitude of this age-related increase in colonization was significantly different between plants grown under the two production practices (Table 2, Contrast 2). There was no significant difference in colonization from plants growing in bogs that were 2-8 years old (Table 2, Contrast 3); however, plants growing in 10-year-old bogs under conventional practices had significantly greater root colonization than plants grown under organic practices (Table 2, Contrast 4, and Figure 2). EMF only colonized approximately 25% of the root

TABLE 2. ANOVA and orthogonal contrasts of root colonization by ericoid mycorrhizal fungi on cranberry from bogs less than eleven years old grown under either organic (OR) or conventional (CO) production practices.

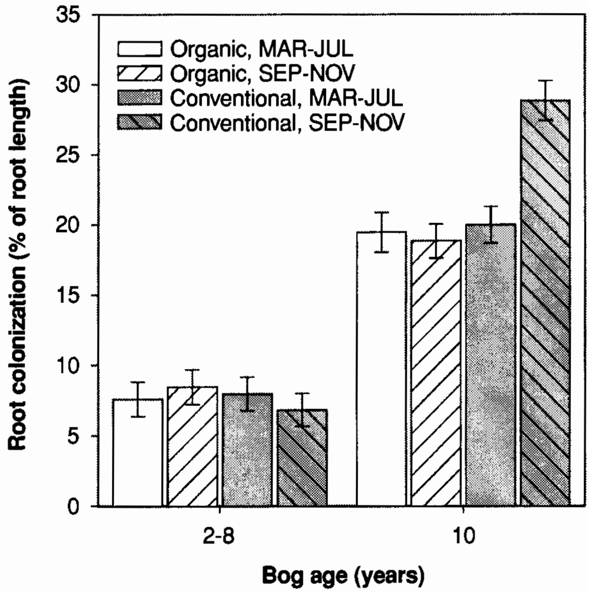
ANOVA Source	df	MS	F	P
Production Practice (PP)	1	4.7	0.78	*0.3780*
Sampling Date (SD)	4	11.2	1.87	*0.1161*
Bog Age (BA)	6	1374.1	229.70	*< 0.0001*
PP * SD	4	8.1	1.35	*0.2497*
PP * BA	6	38.5	6.43	*< 0.0001*
SD * BA	24	19.7	6.29	*< 0.0001*
PP * SD * BA	24	26.8	4.47	*< 0.0001*
Error	238	5.9		
Contrasts				
1) BA Linear (Linear Relationship within BA)	1	6307.7	1054.38	*< 0.0001*
2) OR vs. CO (BA Linear)	1	93.2	15.58	*0.0001*
3) OR vs. CO (< 10 years)	1	10.7	1.791	*0.1819*
4) OR vs. CO (< 10 years vs. 10 years)	1	163.3	27.30	*< 0.0001*
5) SD Trend (Trend between SD)	1	32.5	5.43	*0.0205*
6) SD Trend (BA Linear)	1	149.2	24.93	*< 0.0001*
7) MAR, MAY, JUL vs. SEP, NOV (BA Linear)	1	172.0	28.75	*< 0.0001*
8) OR vs. CO (SD Trend)	1	1.7	0.29	*0.5889*
9) OR vs. CO (SD Trend) (BA Linear)	1	124.8	20.85	*< 0.0001*

length on cranberry plants when bogs were 10 years old; in contrast, EMF colonization on ericaceous plants growing adjacent to bogs less than 11 years of age all showed colonization levels greater than 90 percent.

We found colonization by EMF on plants grown under organic and conventional practices was significantly different depending on sampling date (Table 2, Contrast 5). Seasonally-related changes in colonization were not significantly different between plants grown under the two production practices (Table 2, Contrast 8), but were significantly different between plants growing in different age bogs (Table 2, Contrast 6). Plants growing in bogs less than 10 years old showed little seasonal difference in colonization, while plants from 10 year-old bogs showed significantly higher colonization levels in the fall (Table 2, Contrast 7) but only for plants growing under conventional practices (Figure 2).

Differences in colonization between plants grown under organic and conventional practices could be related to both organic matter accumu-

FIGURE 2. Ericoid mycorrhizal colonization on roots from cranberry plants growing in bogs with ages ranging from 2 years to 10 years grown under organic or conventional production practices. MAR-JUL represents mean of samples taken in March, May, and July, 2000. SEP-NOV represents mean of samples taken in September and November, 2000. Bars on columns represent standard errors.



lation and nutrient availability. In general, under conventional production practices organic matter accumulation may be higher due to larger plant size. In addition to an ability to readily use ammonium and nitrate, EMF can also use amino acids, proteins, chitin, and lignin and transfer the N from these organic sources to the plant (Bajwa and Read, 1985; Kerley and Read, 1995, 1997, 1998; Stribley and Read, 1980). Ericaceous plants use organic N in fresh litter and the complexed N in recalcitrant organic matter by the activity of proteases and amino acid uptake by EMF (Michelsen et al., 1996).

The ability of EMF to exploit organic sources of N is an important factor to consider when assessing optimal cultural and fertilization practices for cranberry production. For instance, under organic production practices, organic forms of N are the primary form of N delivered to the plant. Under these conditions, plants without mycorrhizae must rely on the breakdown of this N by other soil microorganisms before the plant can take it up. Under conventional production practices, colonization by mycorrhizal fungi may allow plants access to other sources of available N, thereby requiring less fertilizer N to achieve the same nitrogen concentration as non-mycorrhizal plants.

CONCLUSION

Under field conditions in southern Oregon we have found that mycorrhizal colonization of cultivated cranberry is low until bogs are over 10 years old. Questions that now need addressing include whether this low colonization during the early years of bog establishment is a result of a low number of fungal propagules, or cultural conditions not conducive for colonization (e.g., soil organic matter content or fertility levels), and whether increasing colonization during early years of bog establishment can increase productivity and/or decrease the fertilizer inputs necessary to sustain productivity.

GROWER BENEFITS

The current low-value of cranberry crops due to over-production is resulting in financial problems for growers. New uses for cranberry may eventually increase market demand; however, in the interim these producers need alternative strategies to increase crop value by filling specialty niches and/or decreasing production costs by decreasing inputs (e.g., increasing nutrient use efficiency). The level of cranberry root colonization by mycorrhizal fungi has implications to the efficiency of fertilizer uptake in both organic systems and conventional production systems, and is an important factor to consider when assessing optimal cultural and fertilization practices for cranberry production.

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