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Blueberry—Soil interactions from an organic perspective

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ABSTRACT

Demand for organic blueberries has risen in response to consumers' interest in healthy eating and greater awareness of the environment. Although organic production systems share many challenges with conventional systems, they have specific limitations and questions. Synchronisation of plant nutrient demand with the release of mineral nutrients from organic nutrient sources presents a particular challenge for the organic grower. In this paper we address belowground challenges in blueberry production from an organic perspective, such as soil properties and amendments as well as the choice of mulching material and organic fertilisers. We also address potential toxicity problems for blueberries associated with high concentrations of aluminium and manganese as well as salt stress. Symbiosis with ericoid mycorrhizal fungi is of potential interest in organic blueberry production as the fungi may improve plant access to nutrients from organic sources. The effects of management factors and limitations associated with the commercial utilisation of the symbiosis are also discussed.

1. Introduction

With a growing consumer interest in health-improving foods, blueberry production is increasing worldwide (Brazelton, 2015). High anthocyanin concentrations in blueberry extracts have been related to antioxidant activity in human cells (Bornsek et al., 2012). Health-promoting benefits of blueberries have been studied, and claims include anti-cancer properties (Johnson and Arjmandi, 2013), neuroprotective effects (Giacalone et al., 2011) and reduction of high blood pressure (Johnson et al., 2015).

The main blueberry types in cultivation are highbush (*Vaccinium corymbosum* L.), rabbiteye (*Vaccinium ashei* Reade) and lowbush (*Vaccinium angustifolium* Aiton) blueberries, together with interspecific hybrids such as half-highs (*V. corymbosum* x *V. angustifolium*) and southern highbush blueberries originating from crosses between *V. corymbosum*,*Vaccinium darrowii* Camp and other blueberry species.

The global production of fresh and processed blueberries grew with 65% for highbush and almost doubled for wild/lowbush blueberries from 2010 to 2014 (Brazelton, 2015). In the period from 2007 to 2014, the worldwide highbush blueberry production area increased by 90% from 58,400 ha to 110,800 ha (Brazelton, 2015). North America represented more than 50% of the area and almost 60% of the global highbush blueberry production in 2014 (Brazelton, 2015).

The state of the industry and research of organic highbush blueberry production has recently been reviewed by Strik (2014). Based on survey results, the worldwide highbush blueberry area devoted to organic production was estimated to be 5% in 2010–2011, with USA and Chile representing almost 80% of the area (Strik, 2014). In 2014, 6% of the harvested highbush blueberry area in the United States was organic (USDA, 2015).

Although reduced yields have been reported as a challenge for organic blueberry production (Strik, 2014), there are few direct comparisons of yields in organic versus conventional blueberry fields. Four years after the establishment of organic and conventional rabbiteye blueberries in Georgia, USA, vegetative growth and yield of the organic plants had reached 90% and 70%, respectively, of the growth and yield of the conventional plants (Tertuliano et al., 2012). From a regression analysis of grower survey data for 717 highbush blueberry fields in the Maule region in Chile, Retamales et al. (2015) concluded that conventional fields had a higher probability of obtaining a high yield than organic fields. Other crop factors positively related to high yields were field age up to 11–15 years, the inclusion of polleniser plants, mulching, and weed control with

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mixed methods in contrast to manual weed control, mulch or herbicides as single measures.

Management of weeds, insects and diseases, together with competition and market limitations, have been listed as important limiting factors for the expansion of organic blueberry production worldwide (Strik, 2014). Nutrient management, along with weed control, were identified by organic highbush blueberry growers in Michigan, USA, as their main challenges (Grieshop et al., 2012).

The aim of this paper is to identify the main challenges related to soil requirements, substrate composition and organic matter management in organic blueberry production. We will discuss blueberry mineral nutrient requirements and their fulfilment by organic fertilisers. Finally, we will address the potential and limitations of utilising the ericoid mycorrhizal symbiosis in blueberry production. We will conclude by suggesting prospects for future research.

2. Soil and organic matter

2.1. Soil and pre-plant amendments

Blueberries generally prefer light, acid soils (see Section 2.2) with a high content of organic matter combined with good water-holding capacity (Bläsing, 1985; Coville, 1910; Korcak et al., 1982; Korcak, 1988a). According to Eck (1988), light soils with a high content of sand are the best soils for blueberry production, while organogenic soils, i.e. soils originating from organic substances, and soils with a lower content of sand combined with a good soil structure may also be used. Soils with a moderate clay content need additions of high amounts of organic matter, while heavy clay soils and sands should be avoided (Eck, 1988; Gough, 1994). Blueberry species and cultivars may differ in their soil preferences (Korcak, 1989; Tasa et al., 2012), therefore, when planting, attention must be paid to both soil type and cultivars. For example, Tasa et al. (2012) observed a higher yield for the half-high cultivar 'Aino' in a peat soil than in a mineral soil, while the yield of 'Northblue' was lower in the peat than in the mineral soil.

Organic amendments such as peat, bark, sawdust, leaf mould and animal or green manures are often incorporated into the soil before planting of a blueberry crop to increase soil organic matter content, aeration and water-holding capacity, and to improve plant growth and yield (Gough, 1994; Haynes and Swift, 1986; McArthur, 2001; Moore, 1993; Odneal and Kaps, 1990; Retamales and Hancock, 2012). On suboptimal soils, such as soils with a high pH or clay content, substituting the soil in the blueberry root zone with an organic growing substrate has been recommended (e.g. Schmid et al., 2009).

The importance of peat for successful cultivation of the wild swamp blueberry (*V. corymbosum*) was noted by Coville (1910). Due to its low pH, peat has often been used for root zone pH adjustment in blueberry production (Albert et al., 2010; McArthur, 2001; Moore, 1993). In many regions, peat is a limited resource and the sustainability of its use in organic production is being challenged. According to the International Federation of Organic Agriculture Movements Standard (IFOAM, 2014), peat is allowed as a potting mix but not for soil conditioning in organic plant production. However, in many countries, such as the USA, Canada, and most European countries, peat is permitted as a soil improver according to their organic regulations, while restrictions are presently being discussed in the European Union (EU, 2013).

A common soil amendment in blueberry production is sawdust from conifers (Eck, 1988; Moore, 1993; Retamales and Hancock, 2012). Odneal and Kaps (1990) report that four litres of fresh or aged pine bark per plant can substitute peat as a pre-plant amendment for highbush blueberries on mineral soils in Missouri, USA. In Switzerland, a number of growing substrates for organic highbush blueberry production, including bark, sawdust, and a mixture of bark and sawdust from oak, beech or pine, have been compared with peat in a pot experiment (Schmid et al., 2009). Stabilised substrates containing peat or sawdust from pine or oak had a lower pH of 4.8 and 5.3, respectively, compared with beech sawdust or beech, oak or pine bark, or sawdust:bark mixes. Plant growth in pine sawdust was about 40% of the growth in peat during years two and three, probably due to immobilisation of nitrogen (N) by the degrading sawdust, but was close to the level in peat in the fifth year. Pine was more stable to degradation compared with bark or the other sawdust substrates. Also, larvae of *Trichius fasciatus* L. were less attracted to pine than to beech or oak sawdust. Based on these results, the authors recommend a flat ditch system with pine sawdust for blueberry growers on alkaline soils in Switzerland (Schmid et al., 2009).

Green manure crops may also increase soil organic matter, in addition to supplying nitrogen and suppressing weed growth (Carroll et al., 2015; Gough, 1994; Neilsen et al., 2009). A range of pre-plant green manures and row middle cover crops has been suggested for blueberry production, as shown in Table 1. While nitrogen-fixing crops may accumulate up to 200 kg N ha^{-1} or more depending on the site and species (Büchi et al., 2015), other green manure or cover crop species, such as rye, may take up nitrogen from deeper soil layers and increase nitrogen concentration in the upper soil layers (Thorup-Kristensen, 2006). In regions where the green manure crop is not overwintering, a winter cover crop may be grown to avoid nitrogen losses. For North American conditions, Gough (1994) suggests sowing a green manure crop in early summer and incorporating it into the soil in early autumn the year before blueberry crop establishment, followed by a winter cover crop to be incorporated in the soil early the following spring.

2.2. Soil pH requirement and management

The optimum pH for blueberries has been reported within the range of 4.0–5.5 (Korcak, 1988a). Harmer (1944) concluded that the best pH for highbush blueberries in muck soils was 4.0–5.2, depending on the soil type, with an optimum range of pH 4.5–4.8. The optimal pH was somewhat higher for fruit production than for vegetative growth. Similarly, Hall et al. (1964) observed the highest shoot weight of *V. angustifolium* clones at the lowest pH tested, 4.2, in a soil + sawdust mix, and between 4.9 and 5.5 in a potting compost consisting of soil, peat and sand.

Before the establishment of an organic blueberry culture in soils with a pH above the optimum level for blueberries, elemental sulfur (S^0) may be added to increase soil acidity (Carroll et al., 2015; Gough, 1994; Retamales and Hancock, 2012). The minimum recommended time interval between sulfur application and planting varies from six months (Gough, 1994) to one year (Retamales and Hancock, 2012), the time needed for soil pH reduction depending on the sulfur formulation. For organic blueberries in particular, incorporation of peat or pine bark has been recommended to obtain at least part of the pH reduction needed, to restrict negative effects of sulfur on soil organisms and improve soil humus (Kuepper and Diver, 2004). In an organic cultivation system with pine sawdust ditches combined with alkaline ground water (357 mg L^{-1} $CaCO_3$) for irrigation, the addition of 30 g S per plant per year was needed to reduce the pH from 5.2 to 4.4, insuring good plant development and yield of highbush blueberries (Schmid et al., 2009). In contrast, adding a corresponding amount of acid-equivalents as citric acid only marginally affected pH, possibly due to volatilisation or leaching of citric acid (Schmid et al., 2009). If the soil pH is below 4.0, pH can be increased to the optimum range by ground dolomitic limestone (Hart et al., 2006), which has the additional advantage of containing magnesium.