AN ABSTRACT OF THE THESIS OF

Handell O. Larco for the degree of Master of Science in Horticulture presented on July 23, 2010.
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Abstract approved:

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A 0.4 ha planting of blueberry (*Vaccinium corymbosum* L.) was established in Oct. 2006 to evaluate the effects of cultivar (Duke and Liberty), planting method (flat versus raised beds), weed management (sawdust mulch and hand-weed control; compost plus sawdust mulch with acetic acid, flaming, and hand-weeding used as needed; and weed mat plus hand-weeding as needed), and type and rate of fertilizer (feather meal and liquid fish emulsion at 29 and 57 $kg \cdot ha^{-1}$ N) on plant growth, yield, fruit quality, irrigation requirements, and weed presence. The site was certified organic in 2008. Plants grown on raised beds were larger than on flat ground. The leaf nitrogen concentration (%N) in all treatments ranged from slightly below normal to slightly above normal in Aug. 2007 and Aug. 2008, depending on fertilizer treatment and mulch. Plants receiving 57 kg of $N \cdot ha^{-1}$ as fish emulsion had the highest leaf %N in both years, especially when grown with weed mat mulch, while plants fertilized with the low rate of feather meal had lower than recommended %N, especially in sawdust mulched plots. In Oct. 2007, total plant dry weight (DW) was higher in 'Liberty' than 'Duke', raised beds than flat ground, and when fertilized with fish emulsion rather than feather meal, but was

not affected by weed management system. Root DW was greatest in 'Duke' and lowest in plants receiving 57 kg of $N \cdot ha^{-1}$ as fish emulsion when grown with weed mat. In Oct. 2008, treatment effects on total plant DW were similar to what was observed in 2007. Root DW in 'Duke' was not affected by planting on raised beds, but was greater in plants grown with the organic mulches and fertilized with 29 kg of $N \cdot ha^{-1}$ of fish emulsion. In 'Liberty', the greatest root DW was in plants with compost plus sawdust mulch and fertilized with 29 kg of $N \cdot ha^{-1}$ of fish emulsion, while leaf area was greatest in plants grown on raised beds with sawdust mulch and fertilized with 57 kg of $N \cdot ha^{-1}$ of fish emulsion. In 2008, yield was highest when 29 $kg \cdot ha^{-1}$ N of fish was applied and when plants were grown on raised beds with weed mat in 'Duke' (0.56 $kg \cdot plant^{-1}$), and with compost plus sawdust in 'Liberty' (0.57 $kg \cdot plant^{-1}$). Fruit were firmer at harvest when plants were fertilized with fish rather than feather meal and when soil was mulched with sawdust compared to weed mat. Weed presence increased from 2007 to 2008. Hand-weeding was required in all treatments in both years. Weed mat plots had the fewest weeds, whereas compost plus sawdust mulched plots had the highest weed coverage. In weed mat plots, the only weeds that emerged were in the area of the planting hole. In the compost plus sawdust mulched treatment, acetic acid applied at a 20% concentration on hot days, provided acceptable control of annual weeds, but was moderately effective on perennial weeds. Flaming was somewhat effective when used on small weeds on hot days. Soil water content was lower through the growing season on raised beds than on flat ground, especially under weed mat; this system thus required 148% more irrigation water than did plots mulched with sawdust, and compost plus sawdust to maintain an adequate percent soil water content for blueberry plant growth. Soil temperature at 5 cm depth was higher under weed mat and more variable through the year than in the organic mulched treatments. The extra irrigation water required in weed mat mulched treatments may have been associated with increased soil temperatures and soil water evaporation, and greater plant evapotranspiration. The organic production systems studied produced typical plant growth and yield, as compared to conventional production systems.

Effect of Planting Method, Weed Management, and Fertilizer on Plant Growth and Yield of Newly Established Organic Highbush Blueberries

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Handell O. Larco, Author

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Chapter 1: Introduction

The production of highbush blueberries (*Vaccinium corymbosum* L.) has been rapidly increasing with worldwide planted area increasing from 43,765 ha in 2005 (Brazelton and Strik, 2007) to 65,990 ha in 2008 (U.S. Highbush Blueberry Council, un-published). The very rapid increase in planted area led to concerns about production quickly surpassing consumer/market demand. This was realized in 2007, 2008, and 2009, as Oregon grower prices per kg declined for fresh ($3.52, $3.16, and $2.44, respectively) and processed ($3.17, $1.98, and $1.04, respectively) fruit from the record high prices per kg for fresh fruit obtained in Oregon in 2004, 2005, and 2006 ($2.13, $2.66, and $3.94, respectively; NASS and USDA, 2007; 2009). Yet in many countries including China, the planting of new blueberry fields has continued, particularly for its own high-value niche fresh market (Li and Yu, 2009).

Industries worldwide are trying to find ways to increase consumer demand for blueberries, focusing research and marketing efforts on the healthful properties of blueberry fruit (BHNRC et al., 2007) and strengthening newly emerging markets, including organic production. In the United States, while there were 220 ha of highbush blueberries produced organically in 2003 (Strik and Yarborough, 2005), organic blueberry area increased to 790 ha in 2008 (NASS and USDA, 2010). Organically certified blueberries are considered to be in a separate market segment from conventional fruit (Sciarappa et al., 2008). Grower prices for organically grown blueberries are generally 20 to 100 % higher than for conventionally produced fruit (Krewer, 2001). In the northeastern U.S. market, organic and conventional blueberry grower price was $4.73 and $2.42 per kg, respectively (Sciarappa et al., 2008). The higher price paid for organically certified blueberries is considered a premium intended to offset greater production costs associated with organic production systems including certification, higher product costs for fertilizer and weed control materials, and higher labor requirements.

The costs of establishing a transitional to organic highbush blueberry field (planting year and first growing season) planted on raised beds with sawdust mulch, hand weeding, and fish emulsion fertilizer at a rate of 50 kg of $N \cdot ha^{-1}$ were $32,850 per ha in Oregon (Strik et al., 2009). In contrast, establishment costs for a conventional highbush blueberry field, similarly on raised beds with sawdust mulch were $23,457 per ha in 2005 (Eleveld et al., 2005). The main differences between these two economic studies were the use of herbicides and ammonium sulfate fertilizer in the conventional production system.

Although certified organic blueberries might command a higher price that could cover some of the added costs of more expensive agricultural inputs (organic fertilizers, herbicides such as vinegar, fungicides, insecticides, and labor), it is important to produce good, sustainable yields of high quality fruit. One might expect yields in organic production systems to be similar to those in conventional systems since blueberries are well adapted to organic culture (Kueper and Diver, 2004). Furthermore, blueberries tend to be less susceptible to pest problems perhaps because they are a relatively new Native American crop that has been domesticated in the last 100 years (Sciarappa et al., 2008). An efficient use of organic agricultural inputs, precise cultural practices, and an understanding of the interactions among production system components and the environment could significantly lower production costs, increase yield, and indeed increase grower returns.

In the northwestern U.S., there has been no study, prior to this one, describing the effects of different planting methods, organic fertilizers, mulches, and weed control methods in organic production systems and their effect on plant growth, yield, and fruit quality. This study was designed to address high priority issues raised by organic blueberry growers in Oregon.

Planting method. Highbush blueberries have shallow roots (Eck and Childers, 1966), a highly branched and extremely fine root system (Valenzuela-Estrada et al., 2009), and fine roots of less than 50 μm in diameter (Coville, 1910; Eck and Childers, 1966). Thus, this ericoid plant is relatively susceptible to drought injury (Bryla and Strik, 2006) and requires a well-drained soil and sufficient irrigation to achieve acceptable yields. Planting on raised beds is a common production system in blueberry fields (Strik, 2007) to improve drainage and help protect plants from standing water (Scherm and Krewer, 2008). It has been reported that raised beds do not mitigate high soil temperatures during the summer (White, 2006), but improve soil conditions by lowering compaction and providing greater internal drainage (Magdoff and Van Es, 2000). Raised beds thus help prevent saturated soils and pest problems like phytophthora root rot (Bryla and Linderman, 2007). In contrast, planting on flat ground is considered to increase soil moisture and reduce soil temperature during the fruiting season, which is beneficial for the root growth of southern highbush blueberries (Spiers, 1995). White (2006) found that growing highbush blueberry plants on raised beds that were formed with sawdust incorporated before planting, reduced plant growth. This was likely a result of increased soil porosity, water percolating rapidly through the raised bed, and increased soil temperature.

Fertilization. Nitrogen (N) is one of the most important mineral nutrients studied in blueberry fertilization due to its effect on plant biomass accumulation, yield, and possible nitrate contamination of groundwater. Results of N fertilization studies in blueberry have been variable, but, in general, best growth and yield have been achieved with modest amounts of N fertilizer applied, depending on the region, cultivar, and production system (Eck, 1988; Hanson, 2006; Hart et al., 2006; Martin et al., 2001; Strik et al., 1993).

Mature blueberry plants have the most rapid N fertilizer uptake in the period from bloom to harvest (Bañados, 2006; Throop and Hanson, 1997); however, fertilizer uptake continues through the remaining portion of the growing season (Bañados, 2006; Bañados et al., 2006). Application of inorganic fertilizers is recommended starting at bloom and continuing until mid- to late-June in mid-season cultivars (Hart et al., 2005). Even though split applications of inorganic fertilizers are recommended to increase efficiency of fertilizer uptake, slow release products may also help improve efficiency (Hart et al., 2006). In contrast, although organic fertilizers may have a slow to medium release rate for N, fertilizer efficiency might be improved if these products are applied earlier than bud break to allow time for mineralization to occur, especially in early highbush blueberry cultivars like Duke (Larco et al., 2006). Split applications are recommended when using fast release fertilizers and are widely utilized in fertigation systems, while single applications are recommended for slow release or inorganic coated fertilizers (Hart et al., 2005; Strik et el., 1993).

In ‘Duke’ fertigation through the drip irrigation system over a six-week application period increased yield and fruit firmness compared to a split broadcast fertilizer application (Pavlis, 2006). In young highbush blueberry plants, fertigation in a twelve week split application regime led to greater fruit yield and plant volume than three granular applications with the same rate of ammonium sulfate (Finn and Warmund, 1997). However, despite increased plant size and yield, there were no significant differences in leaf N concentration; the authors speculated that fertigation improved fertilizer efficiency and placement (Finn and Warmund, 1997). Split applications of fertilizer N should be done at low rates for maximum plant growth in young plants (Bañados, 2006; Bañados et al., 2006) and increased yield in mature plants (Hanson and Retamales, 1992). Fertilizer uptake efficiency in young, northern highbush blueberry has been low, ranging from 13% to 17%, although fertilizer N accounted for 58% to 70% of the total N in the plant (Bañados, 2006; White, 2006). Bañados (2006) reported that young plants are much more sensitive than mature plants to under and over fertilization with N, since young plants do not have large reserves of N and have a small root system susceptible to high soil EC or salt. Mature northern highbush blueberry plants have a higher fertilizer uptake efficiency, 17 to 32% (Bañados, 2006; Retamales and Hanson, 1989), and can tolerate higher rates of N fertilizer (100 to 200 $kg \cdot ha^{-1}$ N) without compromising plant development or yield (Bañados, 2006). Higher rates of nitrogen fertilization have also been found to decrease growth and yield (Eck, 1977).

Organic blueberry farmers commonly use OMRI-approved (Organic Materials Review Institute) fish emulsion, as a direct liquid application or injected through the drip irrigation, and granular feather meal as sources of nitrogen. Products such as fish emulsion or fish hydrolyzed have a C:N ratio between 4 and 4.7, release carbon as a result of their rapid decomposition in the soil, and will have a plant available nitrogen (PAN) of about 50% in 7 days, and at least 60% within 28 days after application under optimal conditions (Gale et al., 2006). Some of these fertilizers contain chelating agents like fulvic acids to make minerals more bio-available for plant absorption, providing a slow release of nitrogen and increasing plant cell membrane permeability (Wyatt and McGourty, 1990). The concentration of nitrogen (N), phosphorus (P) and potassium (K) can vary among commercially available fish fertilizers, because of the acids and chelating agents added in the final product. Typically, simple fish hydrolyzed will have an analysis of 2-5-0.3 (N-P-K), but can also be 4-1-1 as in Fish Agra, the fertilizer used in our study.

Fish hydrolyzed is recommended for application in fertigation systems or foliarly. In alfalfa (*Medicago sativa* L.), foliar applications of hydrolyzed fish increased yield by 14% by the second cutting (Kelling et al., 1997). Hydrolyzed fish protein, 14-0.5-0.7, could be injected into drip irrigation systems through low-volume emitters, using up to 224 $kg \cdot ha^{-1}$ N, and through microsprinkler or drip and drip-tape irrigation systems with minimal clogging (Schwankl and McGourty, 1992).

Feather meal is classified as a slow release fertilizer (Penhallegon, 1992) and should be applied early in the season to allow time for mineralization to occur and to match time of nutrient demand by the crop. Kueper and Diver (2004) have recommended applying feather meal from one to four weeks ahead of the suggested applications for soluble fertilizers. Calculations for timing applications should be based on the C:N ratio of the fertilizer, which in feather meal ranges from 4 to 8 (Gale et. al., 2006). About 60% of the PAN is released in about 28 days (Andrews and Foster, 2007). Feather meal has very high cumulative decomposition, releasing about 74% of PAN after 70 days of application (Gale et al., 2006). Inorganic fertilizer may also be available the year after application if it becomes part of the organic pool of available N; any remaining fertilizer N should be considered when calculating fertilizer contributions (Strik, et. al., 1993) to avoid excessive fertilization (Magdoff and Es, 2000).

Mulching. Among the different inert mulches reported as options for orchards (Granatstein and Mullinix, 2008), Douglas-fir (*Pseudotsuga menziesii* M.) sawdust and weed mat are the most commonly used by commercial blueberry growers in Oregon; Douglas-fir bark is used by some growers if sawdust is not readily available. Its cost is comparable, but bark decomposes more quickly than sawdust. Various composts are being trialed by some organic blueberry growers. Sawdust bark and compost are organic mulches, because they add organic matter to the soil and need to be replenished when they decompose over time. Organic matter must be replenished as it decomposes to prevent the blueberry roots, growing in the interface between the mulch and the soil surface, from becoming exposed (Gough, 1980). Mulches that are suitable for blueberry production systems also contribute to maintaining a desirable soil organic matter content (Bell and Johnstone, 1962), a soil pH of 4.2 to 5.5, optimal for highbush blueberry plants

(Hart et al., 2006; Strik et al., 1993), and increase metal-retention capacity through complexation, primarily with aluminum (Al) in soils with a pH less than 4.5 (Yang, 2005).

Sawdust mulch has a positive impact on plant growth, yield (Clark and Moore, 1991; Karp et al., 2006; Kozinski, 2006; White, 2006), root distribution (Spiers, 2000), number of whips (White, 2006), number of one-year-old shoots (Kozinski, 2006; White, 2006), water-holding capacity, and extreme temperature fluctuations (Cox, 2009; White, 2006). Furthermore, sawdust mulch reduces seed germination of non-desirable plants. There are successful blueberry plantings with no mulch of any kind (Strik, 2007), including in South Georgia, where rabbiteye cultivars are grown in un-mulched sandy loam soils with only 1.5% organic matter (Williamson et al., 2006). However, organic mulches derived from wood chip materials can increase soil moisture from 15 to 20 %, reducing irrigation requirement by 20 to 30% compared to un-mulched soil, primarily in the top 0.10 m (Granatstein and Mullinix, 2008). The temperature of mulched soils measured at a depth of 5 cm can be 4.7 C° cooler on a warm day in spring (Granatstein and Mullinix, 2008), and 8.9 C° cooler on a hot day in the summer (Krewer et al., 1997). However, White (2006) found no cooling effect of sawdust mulch compared to bare soil at a soil depth of 0.02, 0.15, and 0.30 m during the growing season. In winter, sawdust mulch reduced soil temperature (White, 2006). One of the main concerns when using organic mulches such as sawdust is the high C:N ratio leading to immobilization of fertilizer nitrogen, especially when mulch is fresh (Krewer et al., 2009; White, 2006). Increased N fertilizer application is thus recommended when fresh mulch is applied, to compensate for immobilization of N (Hart et al., 2005; Williamson et al., 2006.

There has been no research published in highbush blueberry on the effect of using compost as mulch in young plantings. The most common compost being trialed by growers is developed from yard debris. One of the major concerns with using this and other composts is their relatively high pH (7 or above) and EC or salt content. If compost mulch increases soil pH at the mulch-soil interface, there might be a negative impact on the growth of blueberry roots (Li et al., 2006). The advantage of compost is that it provides slow N-release, which depending on the compost's components, can provide from 7 to 11% apparent N recovery (ANR) from the total N in the compost within a three-year period (Sullivan et al., 1998). In an experiment using two types of compost derived from urban waste and municipal solid waste on grapevines, Pinamonti (1998) found that compost mulch increased plant growth and pruning weight 120-140% compared to plants grown with no mulch.

Weed mat or landscape fabric is considered an inert mulch in orchard production (Granatstein and Mullinix, 2008) and is approved for use as a weed barrier by the USDA Organic National Program (NOP, 2006) under the category of plastic and cover mulches petroleum-based other than polyvinyl chloride. In orchards, weed mat has been widely used mainly due to its effective weed control, although weeds appear in the planting hole and removal by hand may be required in commercial crops (Runham et al., 2000). Sciarappa (2008) reported almost complete control of hairy crabgrass (*Digitaria sanguinallis* L.), foxtail species, (*Setaria* spp.) and broadleaf weeds, when using weed mat plus a mulch of coffee grinds around the planting area in an organic blueberry study in New Jersey over two growing seasons. However, concerns have been expressed about possible negative impacts of increasing soil temperature on plant growth (Williamson et al., 2006). Magee and Spiers (1995) found that white-on-black plastic polyethylene based mulches led to greater plant growth and yield than did black plastic or black woven fabric mulches in southern highbush cultivars due to a decreased soil temperature in the more reflective mulches. Similarly, black plastic mulch produced higher soil temperatures (15.1 C° to 26.2 C°) than paper mulch (14.9 C° to 22.5 C°) at 0.10 m depth, during one growing season in courgettes (*Curbita pepo* L.) and celery (*Apium graveolens* L.) in the U.K. (Runham et al., 2000). In red raspberries in Oregon, black plastic had no significant effect on plant growth. Although black plastic mulch increased soil temperature at 0.15 m compared to bare soil or straw mulch from July to November (Strik et al., 2006).

Weed management. Sawdust mulch and weed mat have been shown to reduce weed presence in many crops (Sciarappa et al., 2008; Cox, 2009). While conventional growers can use registered pre-emergent and contact herbicides as part of a weed management program in blueberries (e.g. Strik et al., 1993), fewer options are available for certified organic growers. Many organic growers have relied on hand-weeding, hoeing and use of mulches to manage weeds in blueberry fields. However, as organic production becomes more common, various products are being trialed for their effectiveness as a contact herbicide. Acetic acid (vinegar) at a concentration of 20% was an effective post-emergence herbicide (Garrett and Beck 1999; Webber et al., 2005) controlling at least 79% of annual weeds and from 35 to 65% of broadleaf and grass weeds (Fausey, 2003).

However, acetic acid used at 9% was not effective at controlling hairy vetch (*Vicia villosa* R.), black oats (*Avena strigosa* S.), winter palmer amaranth (*Amaranthus palmeri* W.), and common purslane (*Portulaca oleraceae* L.; Moran and Greenberg, 2008).

Use of intense heat to fully control weeds organically can be done by exposing weeds to heat for 2.3 seconds at about 190°C or 0.3 seconds at about 500°C, causing the rupture of cell walls due to affections in the cortex region of the stern and depletion of proteins allocated in the leaves (Lalor and Buchele, 1968). Parish (1990), also suggested that temperature must be raised to 100°C for at least 0.1 second to burst cell membranes, however, coagulation of proteins occurs between 50°C and 70°C. ‘Flame weeding’ with a propane flamer has some benefits such as avoiding chemical residues in the soil and eliminating the risk of development of weed resistance. Organic growers can use the flamer as a contact herbicide to control annual and perennial weeds as required.

Diver (2002) suggested that flaming can be more effective on broadleaf weeds when they are up to 5 cm tall and in grasses before they develop a protective sheath (usually before they reach 2.5 cm in height), otherwise a second pass might be required. Annual weeds can be easily controlled with one pass, while repeated flaming is more likely required to suppress perennial weeds (Lanini, 2004).

Use of flamers, however, has issues including high-energy consumption, the need for an ideal driving speed, requirement for regular weed control (Lanini, 2004), an adequate distance between the targeted weed and the mouth of the burner, and difficulty of controlling weeds that emerge between the crop plants without injuring the crop (Heiniger, 1998).

There is also a commonly used ‘flame weeding’ technique, which uses an infrared heat source. Infrared weed control can be used to do in-row selective flaming to avoid risk of igniting dry vegetation. The infrared devices use a propane tank to heat a ceramic or a steel plate, which radiates temperatures up to 1,093 °C (Diver, 2002); such a tool might be of more use than a direct flame in sensitive crops such as blueberries. On the other hand, open flame devices use less energy than infrared units while still reaching desired temperatures to kill weeds (Rifai et al., 2003).

The long-term goal of this study is to develop organic production systems for highbush blueberry that maximize plant growth, yield, and fruit quality, facilitate weed, water, and nutrient management, and provide an economic benefit to growers. Specifically, the objectives of this study were to: 1) evaluate organic weed management systems for effectiveness and economic feasibility; 2) determine the effectiveness of organic fertilizer treatments at a low and high rate for yield, plant nutrient status, and growth; 3) compare planting on raised beds and flat ground for soil and plant water status, plant growth, and ease of weed management; and 4) determine whether cultivar has some impacts ease of management in an organically fertilized production system.

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Chapter 2: Effect of planting method, mulching, and fertilizer on plant growth and yield of newly established organic highbush blueberries

Abstract

A 0.4 ha planting of blueberry (*Vaccinium corymbosum* L.) was established in Oct. 2006 to evaluate the effects of cultivar (Duke and Liberty), planting method (flat versus raised beds), weed management (sawdust mulch and hand-weed control; compost plus sawdust mulch with acetic acid, flaming, and hand-weeding used as needed; and weed mat plus hand-weeding as needed), and type and rate of fertilizer (feather meal and liquid fish emulsion at 29 and 57 $kg\cdot ha^{-1}$ N) on plant growth, yield, and fruit quality. The site was certified organic in 2008. Plants grown on raised beds were larger than on flat ground. The leaf nitrogen concentration (%N) in all treatments ranged from slightly below normal to slightly above normal in Aug. 2007 and Aug. 2008, depending on fertilizer treatment and mulch. Plants receiving 57 kg of $N\cdot ha^{-1}$ as fish emulsion had the highest leaf %N in both years, especially when grown with weed mat mulch, while plants fertilized with the low rate of feather meal had lower than recommended %N, especially in sawdust mulched plots. In Oct. 2007, total plant dry weight (DW) was higher in 'Liberty' than 'Duke', raised beds than flat ground, and when fertilized with fish emulsion rather than feather meal, but was not affected by weed management system. Root DW was greatest in 'Duke' and lowest in plants receiving 57 kg of $N\cdot ha^{-1}$ as fish emulsion when grown with weed mat. In Oct. 2008, treatment effects on total plant DW were similar to what was observed in 2007. Root DW in 'Duke' was not affected by planting on raised beds, but was greater in plants grown with the organic mulches and fertilized with 29 kg of $N\cdot ha^{-1}$ of fish emulsion. In 'Liberty',

the greatest root DW was in plants with compost plus sawdust mulch and fertilized with 29 kg of $N \cdot ha^{-1}$ of fish emulsion, while leaf area was greatest in plants grown on raised beds with sawdust mulch and fertilized with 57 kg of $N \cdot ha^{-1}$ of fish emulsion. In 2008, yield was highest when 29 $kg \cdot ha^{-1}$ N of fish was applied and when plants were grown on raised beds with weed mat in 'Duke' (0.56 $kg \cdot plant^{-1}$), and with compost plus sawdust in 'Liberty' (0.57 $kg \cdot plant^{-1}$). Fruit were firmer at harvest when plants were fertilized with fish rather than feather meal and when soil was mulched with sawdust compared to weed mat. Overall, raised beds and fish fertilizer at the low rate were of more benefit to newly established highbush blueberries than flat ground and feather meal fertilized plants. Nitrogen uptake can be variable depending primarily on mulching, fertilizer type and cultivar. The use of compost plus sawdust did not present major differences affecting planting growth and yield compared to sawdust or weed mat. Both, mulch type, and fertilizer type and rate, affected plant growth, yield and fruit quality.

Introduction

The production of highbush blueberries (*Vaccinium corymbosum* L.) has been rapidly increasing with 65,990 ha planted in 2008 (U.S. Highbush Blueberry Council, un-published). In the United States, organic blueberry area increased to 790 ha in 2008 (NASS and USDA, 2010). While organic blueberries can command a 20% to 100% higher price than conventional blueberries, there has been relatively little research on whether a sustainable, profitable production system can be developed.

Highbush blueberries have shallow roots (Eck and Childers, 1966), a highly branched and extremely fine root system (Valenzuela-Estrada et al., 2009), with the smallest roots less than 50 μm in diameter (Coville, 1910; Eck and Childers, 1966). Consequently, blueberry plants require a well drained soil and sufficient irrigation to achieve acceptable yields. Planting on raised beds is a common production system in blueberry fields (Strik, 2007) to improve drainage and help protect plants from standing water (Scherm and Krewer, 2008). Raised beds help prevent saturated soils, reduce compaction, improve internal drainage (Magdoff and Van Es, 2000) and reduce pest problems like phytophthora root rot (Bryla and Linderman, 2007). In contrast, planting on flat ground is thought to increase soil moisture and reduce soil temperature during the fruiting season, which is beneficial for the root growth of southern highbush blueberries species (Spiers, 1995).

Nitrogen (N) is one of the most important mineral nutrients studied in blueberry fertilization. In general, the best growth and yield have been achieved with modest amounts of N fertilizer applied, depending on the region, cultivar, and production system (Eck, 1988; Hanson, 2006; Hart et al., 2006; Martin et al., 2001; Strik et al., 1993). Mature blueberry plants had the most rapid N fertilizer uptake in the period from bloom to harvest (Bañados, 2006; Throop and Hanson, 1997), although fertilizer uptake continued through the remaining portion of the growing season (Bañados, 2006; Bañados et al., 2006). In contrast, in young highbush blueberry plants, fertigation in a 12-week split application regime led to greater fruit yield and plant volume than three granular applications at the same rate of ammonium sulfate (Finn and Warmund, 1997).

Organic blueberry farmers commonly use OMRI-approved (Organic Materials Review Institute) fish emulsion, as a direct liquid application or injected through the drip irrigation system, and granular feather meal as sources of nitrogen. Hydrolyzed fish protein, 14-0.5-0.7, could be injected into drip irrigation systems through low-volume emitters, using up to 224 $kg \cdot ha^{-1}$ N, and through microsprinkler or drip and drip-tape irrigation systems with minimal clogging (Schwankl and McGourty, 1992).

The best time to apply organic fertilizers is often based on the C:N ratio of the fertilizer. Feather meal is classified as a slow release fertilizer (Penhallegon, 1992) and should be applied early in the season to allow time for mineralization to occur to match time of nutrient demand by the crop. Feather meal has a very high cumulative decomposition, releasing about 76% of plant available nitrogen (PAN) after 70 days of application (Gale et al., 2006).

Among the different inert mulches reported as options for orchards (Granatstein and Mullinix, 2008), Douglas-fir (*Pseudotsuga menziesii* M.) sawdust and weed mat are the most commonly used by commercial blueberry growers in Oregon. Many mulches that are suitable for blueberry production systems also contribute to maintaining a desirable soil organic matter content. Sawdust mulch has a positive impact on plant growth, yield (Clark and Moore, 1991; Karp et al., 2006; Kozinski, 2006; White, 2006), root distribution (Spiers, 2000), number of whips (White, 2006), number of one-year-old shoots (Kozinski, 2006; White, 2006), water-holding capacity, and extreme temperature fluctuations (Cox, 2008; White, 2006). Furthermore, mulch reduces seed germination of non-desirable plants. There has been no research published in highbush blueberry on the effect of using compost as mulch in young plantings. Compost may provide benefit as a mulch in blueberry through slow N-release which, depending on the compost's components, can provide from 7% to 11% apparent N recovery (ANR) from the total N in the compost within a 3-year period (Sullivan et al., 1998).

Weed mat or landscape fabric is considered inert mulch in orchard production (Granatstein and Mullinix, 2008) and is approved for usage as a weed barrier by the USDA Organic National Program (NOP, 2006). In orchards, weed mat has been widely used, mainly due to its effective weed control, although weeds appear in the planting hole and removal by hand may be required in commercial crops (Runham et al., 2000). However, concerns have been expressed about possible negative impacts of increasing soil temperature under weed mat on plant growth (Williamson et al., 2006). Magee and Spiers (1995) found that white-on-black plastic polyethylene based mulches produced greater plant growth and yield than black plastic or black woven fabric mulches in southern highbush cultivars due to a decreased soil temperature in the more reflective mulches.

The objectives of this study were to evaluate the impact of weed management systems, organic fertilizer, raised bed plantings, and cultivar on plant growth, yield, and plant nutrient status.

Materials and Methods

Experimental location. The 0.43 ha research trial was established 9 Oct. 2006 on a site in transition to organic production at the North Willamette Research and Extension Center (NWREC; 45°16' 47.55" N and 122°45' 21.90" W), Aurora, OR. Prior to planting, the site was in wheat. The soil was a Willamette silt loam (fine-silty mixed superactive mesic Pachic Ultic Argixeroll) with an organic matter content of 3.7% and pH of 4.9 prior to planting. The research planting was certified as organic in May 2008 by Oregon Tilth (OTCO; Salem, OR).

Site preparation. Buckwheat (*Fagopyrun esculentum* M.) was seeded at a rate of 67 $kg \cdot ha^{-1}$ on 30 May 2006, as a pre-plant cover crop and was incorporated into the soil, prior to seed head formation, on 26 July 2006. Rows were marked and were sub-soiled once using a 3-shank ripper (0.41 m) followed by three passes of a single shank ripper (0.51 m). Rows were then power spaded in early September while the soil was still dry. The site was irrigated until the wetting front was about 0.3 m deep. A few days later, when the soil was dry, the rows were roto-tilled to a depth of 0.15 m before using a bed shaper (depending on treatment). Raised beds were 0.31 m high, 0.38 m wide at the top, and 1.5 m wide at the base when established, but had settled to 0.25 m high by fall, 2007.

Certified organic grass seed (*Festulolium braunii* K.Richt.) was established between rows at a rate of 28 $kg \cdot ha^{-1}$ on 14 Oct. 2006. The between row cover crop was kept from encroaching into the rows by maintaining the edges with a 20% vinegar (acetic acid) solution directed spray, as required, generally every 3 weeks during the growing season.

Treatments. The treatments compared in years 1 and 2 (2007 and 2008) were: i) planting into “raised beds” or on "flat ground"; ii) the cultivars Duke and Liberty (*Vaccinium corymbosum* L.); iii) the mulching treatments a) Douglas-fir (*Pseudotsuga menziesii* M.) sawdust mulch (9 cm deep) and pulling weeds by hand, as required, b) compost (yard debris; 4 cm deep) plus sawdust (5 cm) mulch on top and weed management using vinegar (20% acetic acid), propane flaming, and hand pulling as needed; and c) landscape fabric (weed mat) with sawdust mulch (5 cm) in the 20 cm diameter planting hole and hand-weeding; and iv) method and rate of fertilization: feather meal (Nature Safe, Cold Spring, KY) and fish emulsion (“Fish Agra”, Northeast Organics Inc., Manchester-by-the-Sea, MA) at a rate of 29 and 57 kg of $N \cdot ha^{-1}$.

The feather meal (granular formulation; pH 5.7; EC 1.7 $mS \cdot cm^{-1}$; 13% N; 2% Ca; 1.3% S) was applied by hand to the top of the mulch, as a split application on 3 Apr. and 16 May, 2007 and 4 Mar. and 22 Apr., 2008. Plants were individually fertilized with 0.25 or 0.50 $kg \cdot plant^{-1}$ of product per application to achieve the seasonal rate of 29 and 57 $kg \cdot ha^{-1}$ of N, respectively.

The fish emulsion (pH 3.7; EC 20.4 $mS \cdot cm^{-1}$; 4% N; 1% P_2O_5: 1% K_2O; 0.8% Ca; 1.7% S; 800 ppm Mg; 29 ppm Zn; 76 ppm Al; 54 ppm Cu; 327 ppm Fe; 5 ppm Mn; 2.5 ppm B) was applied every 2 weeks from 16 Apr. to 9 July, 2007 and from 15 Apr. to 8 July, 2008. The fish emulsion was diluted in a mix of 4 L of $product \cdot 40\ L^{-1}$ of H_2O, just prior to application, to a rate of 0.23 or 0.47 $kg \cdot plant^{-1}$ of product per application for 29 or 57 $kg \cdot ha^{-1}$ of N, respectively.

The compost (Rexius, Eugene, OR) and sawdust (Decorative Bark, Lyons, OR) mulches were applied on 12 Oct., 2006. Weed mat was folded from 0.15 m to 0.13 m (Baycor, TenCate Protective Fabrics, Union City, GA) was applied on 1 Feb., 2007. The sawdust mulch, soil, and yard debris compost were analyzed at the beginning of the study (Soil Control Lab, Watsonville, CA).

The 24 treatments were arranged in a split-split plot design with 5 replicates. The raised beds and flat ground (2 levels) were randomly assigned to single rows as main plots; within the rows, fertilizer treatments (4 levels) were randomly assigned as subplots, and cultivar and weed management practices were randomly assigned as sub-subplots. Plots were 4.6 m long with 6 plants each. Plant spacing was 0.76 m by 3 m (4,385 plants per ha) with 2-year-old container grown (4 L) plants established.

Irrigation and soil moisture. Plants were irrigated by a single lateral of drip tubing located below the mulch treatment, with 2 $L \cdot h^{-1}$ in-line emitters spaced every 0.3 m. The system was designed so that raised beds and flat ground rows could be irrigated independently to adjust for differences in water use if needed. A second lateral (0.45 m between 2 lines) was also installed to allow for differences in irrigation requirement with use of weed mat mulch. Irrigation was controlled with a timer (see Chapter 3).

Plant growth. The number of whips taller than 0.1 m and with a diameter greater than 3 mm was recorded on one plant per plot in late Sep 2007 and 2008. A single plant per plot was dug up in early Oct. 2007 and 2008. Soil was removed from the root system using a high-pressure hose and tap water. Leaves were removed from plants after digging in 2007, whereas leaves were stripped from plants before digging in 2008. Plants were separated into roots, crown, leaves, and 1-year and older wood (2007) or 1-year, 2-year, and older wood (2008). Leaves were stored at 2°C prior to measurement of total leaf area per plant (LI-3100 leaf area meter, Lambda Instruments Corporation, Lincoln, NE). Plant parts were placed in labeled paper bags and dried to a constant weight (~ 3 d) at 60°C (Fisher Scientific Isotemp oven Model 655F. Montreal, Que., Canada). Leaf area index (LAI) was calculated as the ratio of the leaf area divided by the calculated area occupied by the plant canopy.

Total plant dry weight (DW; sum of all plant components), shoot-root ratio (top DW, including the crown, divided by root DW), and percentage of total DW accounted for by roots, crown, and 1-year, 2-year, and older wood were calculated.

Tissue analysis. Leaf samples were collected for all treatments in three replications in early August of both years and values compared with standard nutrient concentrations (Hart et al., 2006). Fifty leaves per plot were collected per plot in the morning by removing the fully expanded leaves at nodes 4, 5, and 6; sampling was done on all sides of the plants (Gough, 1994), with vigorously growing whips avoided (Hart et al., 2006). Samples were sent to the Central Analytical Laboratory (Oregon State University, Corvallis, OR) in 2007 and to Brookside Laboratories, Inc. (New Knoxville, OH) in 2008.

Yield. After planting in Oct. 2006, plants were pruned to remove fruit buds and shape bushes, if necessary. Plants were pruned in Jan. 2008 with pruning severity adjusted based on individual plant size to achieve a balance between bush size and anticipated yield (if any) in 2008 (Strik and Buller, 2005). Data were collected on yield and average berry weight (25 berries per plot) on each harvest date. Fruit firmness was measured on a 25-berry sub-sample using a FirmTech 2 (BioWorks, Inc., Wamego, KA) with berries oriented calyx end sideways. Six berries were then sub-sampled and frozen for later determination of percent soluble solids, using a digital refractometer (PR-100/Atago, Tokyo, Japan).

Statistical analysis. Analysis of all treatment effects was done as a complete factorial for a split-split plot design using the PROC MIXED procedure in the SAS software package version 8 (SAS Institute, Cary, NC). Treatment means were compared using a Fisher's protected least significant difference (LSD) test. Results for both years were analyzed separately, because of differences in plant age in the field and environmental differences between years (data not shown).

Results and Discussion

First growing season (2007)

Leaf tissue analysis. In late June 2007, plants fertilized with feather meal looked stressed; growth was poor and the leaves were turning red. Tissue analysis (12 July) confirmed that plants fertilized with feather meal had low leaf N (1.1 to 1.5% N) in 'Duke' and 'Liberty', with the lowest values in the sawdust mulched plots (data not shown), likely due to immobilization of fertilizer N. In contrast, plants fertilized with fish emulsion had from 2.3 % to 2.8 % leaf N. The feather meal treatment plants were thus fertilized with an additional 4 kg of $N \cdot ha^{-1}$ fish emulsion on each of two dates, 28 June and 5 July 2007; the fertilizer was applied as a liquid soil drench above the root zone. The plants improved considerably in appearance with leaf tissue N and were within or above the normal (1.8% to 2.0%) range (Hart et al., 2006) for all treatments in Aug. 2007 (Table 2.1). Leaf tissue samples taken by Aug. 2007, showed that planting method had no significant effect on any leaf nutrient concentrations; thus planting method data were pooled for the leaf nutrient analysis.

Leaf N concentration (%N) was significantly affected by fertilizer and mulch, but not by cultivar (Table 2.1). The leaf %N obtained in all treatments ranged from 1.71 to 2.14%, slightly below normal to slightly above normal (Hart et al., 2006). Plants receiving 57 kg of $N \cdot ha^{-1}$ as fish emulsion had the highest leaf

%N, especially when grown with weed mat mulch. The N in fish emulsion was likely more available to plants in weed mat than in the organic mulched treatments where more fertilizer N may have been immobilized due to the greater superficial area and depth of sawdust and compost plus sawdust around the plants. Even though there was sawdust around plants ("planting hole") in the weed mat treatment plots, this sawdust was more rapidly lost; the sawdust in the weed mat plots did not form as hard a surface crust as in the organic mulched plots, and thus seemed more susceptible to loss by wind.

The concentration of P in the leaves was affected by mulch, cultivar, and the interaction of fertilizer by cultivar, whereas leaf %K was affected by the main effect of all treatments except planting method and all two-way interactions. Leaf concentrations of P and K were in the normal range for all treatments, but %K increased with the rate of fertilizer applied, especially when fertilized with fish emulsion, even though K is an immobile nutrient in the soil (Hart et al., 2006). In southern highbush blueberries, %K tended to be increased in 'Star' and decreased in 'Misty' with a high rate of fertilizer (Wilber and Williamson, 2008).

Tissue concentrations of Ca, Mg, and B were below recommended levels only in plants fertilized with fish emulsion, at the low or high rate. Boron deficiencies are common in rainy areas, especially in the alluvial soils common in Oregon. Possible symptoms of B deficiency, shoot tip die back, were observed in some plots, but were minimal and could not be attributed to one specific treatment. Boron deficiency may have been the result of a dilution effect, as the vigorous plants growing on weed mat and fertilized with the high rate of fish emulsion also had the lowest leaf Ca and Mg concentrations. There was a significant effect of fertilizer on leaf Cu, Mn, Fe, and Zn concentration with a reduction of Mn and Zn in plants receiving fish fertilizer.

Cultivar had a significant effect on all nutrient concentrations except for N and Zn. The leaves of ‘Duke’ had higher levels of Mn than those of ‘Liberty’ and P was higher in ‘Liberty’ than in ‘Duke’.

Plant dry weight. After the first growing season, in Oct. 2007, total plant dry weight (DW) was significantly affected by planting method, fertilizer, and cultivar, but not by mulch. There was a significant fertilizer by mulch and mulch by cultivar interaction (Tables 2.2 and 2.3).

Plants grown on raised beds produced 3 to 4% more total plant DW than those grown on flat ground, depending on cultivar. Plants grown on raised beds likely had greater total plant DW due to greater soil drainage (Scherm and Krewer, 2008) and the additional irrigation water raised beds received to compensate for higher water evaporation (see Chapter 3).

Nitrogen fertilization with fish emulsion led to greater total plant DW than fertilization with feather meal. When grown on raised beds, ‘Duke’ and ‘Liberty’ plants fertilized with a low rate of fish emulsion had 62% and 67% more total plant DW than plants fertilized with a low rate of feather meal, respectively. The combination of 29 kg of $N \cdot ha^{-1}$ of fish emulsion and sawdust mulch in flat ground and raised beds produced the greatest growth in ‘Duke’ (318 g and 378 g total DW; Table 2.2), while the combination of 29 kg of $N \cdot ha^{-1}$ of fish emulsion plus weed mat produced the greatest total plant DW in ‘Liberty’ in flat ground and raised beds (455 g and 400 g; Table 2.3).

'Liberty' plants were significantly larger than 'Duke', likely due to genetic differences. 'Liberty' has been observed to be more vigorous in grower fields than 'Duke' (Strik, personal communication). However, we did see a significant mulch by cultivar interaction with 'Liberty' plants having more total plant DW when grown with weed mat mulch compared to organic mulches, whereas mulch type had less effect on total plant DW in 'Duke'.

Root DW. Root DW was affected by fertilizer and cultivar but not by planting method, and there was a significant fertilizer by mulch and mulch by cultivar interaction. 'Duke' plants had a greater root DW than 'Liberty' plants (Tables 2.2 and 2.3).

The difference in root DW between the high rate of fish emulsion and feather meal was minimal. However, plants fertilized with 29 kg of $N \cdot ha^{-1}$ as fish emulsion had a larger root DW than those fertilized with the same rate of feather meal. Plants fertilized with fish emulsion and feather meal at the low rate had a greater root DW than plants receiving the higher rate of these fertilizers. The low rate of fish emulsion produced the greatest root DW in 'Duke' (30.0 g) and in 'Liberty' (24.2 g), whereas plants fertilized with the high rate of fish emulsion had the lowest root DW in 'Duke' (19.2 g) and in 'Liberty' (19.4 g).

The combination of a low rate of fish emulsion and sawdust mulch led to the greatest root DW among all treatments in 'Duke' (36.1 g) and 'Liberty' (26.8 g) plants. Plants fertilized with fish emulsion and grown under weed mat had the least root DW after one growing season, whereas in plants fertilized with feather meal, the root growth was enhanced by weed mat (Table 2.2). The interaction of fertilizer and mulch on root DW was perhaps a result of weed mat mulch allowing the penetration of higher amounts of fertilizer, especially at the high rate of fish emulsion, also resulting in high %N in the leaf tissue (Table 2.1). The first of two applications of feather meal (3 Apr., 2007), was supposed to be washed into the root zone through rainfall. However, insufficient rainfall after the first application (72.14 mm of water rainfall from 3 Apr., 2007 until 16 May, 2007) and the high carbon to nitrogen ratio (C:N) of the sawdust (C:N=441) more likely immobilized the N in the granular feather meal. The root DW of plants in weed mat plots was enhanced by the feather meal, but also perhaps by the additional late applications of fish fertilizer and the greater amount of irrigation required in this treatment (see Chapter 3). Additional irrigation may have increased nutrient absorption, since blueberry plants have an extremely fine root system (Valenzuela-Estrada et al., 2009) and hairy roots of less than 50 μm in diameter (Coville, 1910; Eck and Childers, 1966).

Crown DW. Crown DW was significantly affected by fertilizer and cultivar but not by planting method, and there was a significant interaction between fertilizer and mulch type (Tables 2.2 and 2.3).

Treatment effects on crown DW were very similar to those described for root DW. The low rate of fish emulsion produced plants with a crown DW of 43.6 g in ‘Duke’ and 52.7 g in ‘Liberty’. In contrast, plants fertilized with the high rate of fish emulsion had the lowest crown DW in ‘Duke’ and ‘Liberty’, 29.2 g and 27 g, respectively. ‘Duke’ plants receiving the low rate of feather meal had greater crown DW (38.3 g) than when receiving the high rate of feather meal (32.7 g). However in ‘Liberty’, plants fertilized with the high rate of feather meal had greater crown DW (47.8 g) than those fertilized with the low rate of feather meal (43.8 g). ‘Liberty’ plants had a 26% greater crown DW than ‘Duke’.

Top growth. One-year and older wood DW was significantly affected by planting method, fertilizer, mulch, and cultivar. There was a significant planting method by mulch, fertilizer by cultivar, and mulch by cultivar interaction (Tables 2.2 and 2.3).

There was greater one-year and older wood DW produced on raised beds than on flat ground, particularly in ‘Duke’. ‘Duke’ plants grown on raised beds had 17% more one-year and older wood than plants grown on flat ground, while this difference was only 6% in ‘Liberty’ plants.

Plants fertilized with fish emulsion had more than twice the DW of one-year and older wood than plants fertilized with feather meal. Fertilization with the low rate of fish emulsion produced the greatest one-year and older wood DW, on average, in ‘Duke’ and in ‘Liberty’, especially when grown on raised beds, 155 g and 202 g, respectively.

Weed mat promoted top growth relative to the two organic mulches. ‘Liberty’ plants grown on flat ground with weed mat had 37% greater one-year and older wood DW than plants grown under sawdust mulch. ‘Liberty’ plants grown on flat ground with compost plus sawdust had 14% more one-year and older wood DW than plants grown with sawdust. In ‘Duke’, plants grown on flat ground with a weed mat had 18% and 9% greater one-year and older wood DW than plants grown in sawdust or compost plus sawdust, respectively.

‘Liberty’ plants had 30% greater biomass in the one-year and older wood DW than did ‘Duke’ plants when grown on raised beds and 45% greater DW when they were grown on flat ground.

Leaf DW was significantly affected by planting method, fertilizer, mulch, and cultivar. The interactions of planting method by mulch, fertilizer by mulch, mulch by cultivar, and planting method by fertilizer by cultivar, were significant (Tables 2.2 and 2.3).

In ‘Duke’, plants on raised beds had 21% greater leaf DW than on flat ground. In contrast, there was very little planting method effect on leaf DW in ‘Liberty’. Plants fertilized with fish emulsion produced at least double the leaf DW of plants fertilized with feather meal. ‘Duke’ plants grown on raised beds and fertilized with the low rate of fish emulsion had 133% more leaf DW than plants fertilized with the same rate of feather meal (Table 2.2). On the other hand, ‘Liberty’ plants grown on raised beds, receiving the high rate of fish emulsion, had 66% more leaf DW than plants fertilized with the high rate of feather meal (Table 2.3).

The effect of mulch on leaf DW was similar to the effect observed in the one-year and older wood DW. Plants in weed mat plots had greater leaf DW than those grown with organic mulches in most cases, except for ‘Duke’ when grown on raised beds with sawdust mulch. ‘Duke’ plants had 29% to 49% less leaf DW than ‘Liberty’ plants when grown on raised beds or flat ground, respectively.

Similar to leaf DW, the leaf area of ‘Duke’ was 21% greater when plants were grown on raised beds compared to flat ground (Table 2.4). In ‘Liberty’ this difference was minimal, only 7% (Table 2.5).

Plants grown on weed mat had greater leaf area than those grown with organic mulches, but differences were minimal, less than 10 % on average. The greater leaf growth on weed mat may have been a result of higher soil temperature than in the organic mulches (see Chapter 3).

Fish emulsion increased leaf area considerably to more than double that of plants fertilized with feather meal, regardless of fertilizer rate. Leaf area index (LAI) was not significantly affected by treatment (Table 2.4 and 2.5).

The number of whips per plant was significantly affected by mulch, cultivar, and the interaction of planting method by fertilizer (Tables 2.4 and 2.5). More whips were produced on plants grown with organic mulches than weed mat. Even though weed mat plots had sawdust around the holes, the difference in soil properties based on C:N, soil temperature and soil porosity in the entire plot made weed mat plots more similar to what has been observed in bare soil production systems. Similarly, a decreased number of whips were consistently found in ‘Elliott’ plants grown without mulch compared to those grown with sawdust mulch (White, 2006). In this study, ‘Duke’ plants grown with sawdust had an average of 4 whips, followed by 3 whips per plant in compost plus sawdust plots and 2 whips per plant in weed mat. In ‘Liberty’, the average number of whips per plant was 10, 9, and 8 for compost plus sawdust, sawdust, and weed mat mulch, respectively. ‘Liberty’ has also been observed to produce a higher number of whips per plant than ‘Duke’ in grower fields (Strik, personal communication).

Shoot to root ratio. The shoot to root ratio (shoot:root) was calculated as the sum of all above-ground plant DW (including the crown) divided by total root

DW. Shoot:root was significantly affected by fertilizer, mulch, and cultivar, but not by planting method (Tables 2.6 and 2.7).

The shoot:root was higher in plants fertilized with 57 kg of $N \cdot ha^{-1}$ of fish emulsion than in other fertilization treatments. The shoot:root ranged from 4 to 12 in ‘Duke’ and from 6 to 15 in ‘Liberty’ plants, depending on fertilization rate and product.

The shoot:root was higher in weed mat plots than in compost plus sawdust and sawdust mulches, especially in plants fertilized with fish emulsion, and in ‘Liberty‘. Even though ‘Liberty’ plants had a greater crown DW than ‘Duke’ on average (26%), ‘Liberty’ had a lower root DW and greater above-ground DW. The higher shoot:root in ‘Liberty’ made these plants sensitive to wind damage. In Nov. 2007, winds of 64 $km \cdot h^{-1}$ were recorded (Agrimet, 2007) causing 1.5% of the ‘Liberty’ plants to break off at the crown. No ‘Duke’ plants were damaged in the wind storm. Of the damaged ‘Liberty’ plants, all were fertilized with fish emulsion, 55% received 57 kg of $N \cdot ha^{-1}$, 73% were on a raised bed, and 73% were grown on weed mat. ‘Liberty’ plants produced a greater DW, but biomass accumulation was proportionally greater in the top than in the roots, particularly when fertilized with fish emulsion and when grown on weed mat at higher soil temperature. Spiers (1995) found, in southern highbush and rabbiteye blueberries, that root growth was greater when soil temperature decreased from 27 to 16 °C than when soil temperature decreased from 38 to 27 °C. Shoot growth was greater when soil temperatures decreased from 38 to 27°C than from 27 to 16 °C, when shoot and leaf temperature were the same. He also noted the susceptibility of blueberry plants to up-rooting in high winds when grown without organic mulch

(Spiers, 2000). Organic mulch improves plant anchoring by promoting more even root growth from the plant crown. Also, mulched plants are less susceptible to drought conditions. We observed more drought conditions in the weed mat plots on raised beds – these required more irrigation water (see Chapter 3).

The partitioning of total plant DW is presented in Tables 2.6 and 2.7. In raised beds, ‘Liberty’ plants fertilized with the high rate of fish emulsion and grown with weed mat had a root, crown, and one-year and older wood percentage of 4, 9, and 52%, respectively. In contrast, ‘Liberty’ plants fertilized with the high rate of feather meal and grown with weed mat had total DW partitioning of: root (8%); crown (18%); and one-year and older wood (48%). Trellis at 0.6 m from the soil surface was installed in winter 2007-08 in all treatment rows due to the observed susceptibility of ‘Liberty’ to wind damage.

Flower bud number. The number of flower buds per lateral in winter 2007/08 was significantly affected by fertilizer ($p<0.001$) and mulch ($p<0.05$) but not by planting method or cultivar. There was a significant interaction of cultivar by fertilizer ($p<0.05$; data not shown).

Plants fertilized with fish emulsion had greater number of flower buds than plants fertilized with feather meal. ‘Duke’ plants averaged between 6 to 7 flower buds per lateral when the plants were fertilized with fish emulsion and 4 to 6 flower buds when fertilized with feather meal. On the contrary, ‘Liberty’ plants averaged 4 to 8 when fertilized with fish emulsion and 4 to 6 flower buds per lateral when fertilized with feather meal. In both cultivars, the combination of sawdust mulch and fertilization with feather meal led to the lowest number of flower buds per lateral, 4 to 5. Thus the number of flower buds per lateral appeared negatively affected by the reduced growth or plant stress observed in plants fertilized with feather meal.

Pruning time. The time required to prune was significantly affected by fertilizer ($p<0.001$), mulch ($p<0.001$), and cultivar ($p<0.001$) but not by planting method (data not shown).

Pruning time was related to plant vigor. The treatment that required the most time to prune was plants fertilized with fish emulsion. 'Duke' plants growing with compost plus sawdust mulch required from 35 - 45 and 30 - 35 hours per hectare to prune when fertilized with fish emulsion and feather meal, respectively. In comparison, 'Liberty' plants took longer to prune, taking 45 - 55 and 35 - 45 hr/ha for plants fertilized with fish emulsion and feather meal, respectively when mulched with compost plus sawdust.

Second growing season (2008)

Plant yield. Total plant yield was significantly affected by planting method, fertilizer, mulch, and cultivar. There was also a significant fertilizer by cultivar interaction (Tables 2.8 and 2.9).

Yield per plant was considerably greater in plants grown on raised beds than on flat ground regardless of mulch, fertilizer, or cultivar. Plants grown on raised beds produced 34% and 44% greater yield than those grown on flat ground in 'Liberty' and 'Duke', respectively. Higher yields were a result of greater top growth (greater DW in Oct. 2007) and a 10% greater berry weight (Tables 2.8 and 2.9); there was no effect of raised beds on flower number per lateral (data not shown).

Top growth as measured in Oct. 2007 was a good predictor of yield. The low rate of fish emulsion produced the highest yield in both cultivars, followed by the high rate of fish emulsion in 'Duke' and the high rate of feather meal in 'Liberty'. In other studies, responses of young blueberry plants to inorganic N fertilizer have been variable. Yield increased with low to higher rates and responses were cultivar dependent (Wilber and Williamson, 2008). Bañados et al. (2006) found the greatest plant DW and yield of 'Bluecrop' with the lowest rate of fertilizer applied. In 'Elliott', fertilizer rate had no impact on yield in the third growing season (White, 2006).

There was little difference between the average effects of weed mat and compost plus sawdust mulches on yield; however, plants grown with these mulches produced a greater yield than those grown with sawdust mulch. In 'Duke', the highest yield obtained was for plants fertilized with the low rate of fish emulsion grown on weed mat (556 g) rather than sawdust (410 g). Whereas in 'Liberty', plants fertilized with the low rate of fish emulsion grown with compost plus sawdust mulch had the greatest plant yield (571 g), despite the greatest total plant DW occurring in weed mat by the end of the first season. In comparison yields reported by Krewer et al., (2009) in the production of organic rabbiteye blueberries in Georgia where pine straw, ground cover, and pine bark had greater yields per plant, 900 g, 700 g, and 600 g, respectively, after the second growing season. In conventional cropping production systems in Oregon; 'Elliott', 'Bluecrop', and 'Duke' grown at 1.2 m produced 950 g, 820 g, and 660 g per plant, respectively, in the second growing season (Strik and Buller, 2005). Yield in this study was likely lower, because percent fruit set was reduced due to rainfall during bloom in 2008 (data not shown) and because average yields were reduced when plants fertilized with feather meal were pruned more severely to reduce yield and promote vegetative growth.

'Liberty' plants averaged 38% higher yield than 'Duke' when grown on raised beds and 49% when grown on flat ground. An economic analysis is required to determine whether this higher yield offset the added 15 hour per hectare required to prune 'Liberty'.

Berry weight. Average berry weight was significantly affected by planting method, fertilizer, and cultivar, but not by mulch (Tables 2.8 and 2.9).

Plants grown on raised beds produced 10% heavier fruit than those grown on flat ground in both cultivars, perhaps due to the extra irrigation the raised beds received to maintain adequate soil moisture (see Chapter 3). However, plants grown on raised beds also had a larger canopy (Tables 2.10 and 2.11) which may have promoted berry growth. Bryla et al. (2009), also found that greater fruit size in highbush blueberry was not only a response to a reduction in sink strength through pruning, but was also likely a response to an increase in irrigation. Of note, however, is that even though plots with weed mat required more irrigation than the organic mulches to maintain adequate soil moisture, there was no mulch effect on berry weight.

Among all fertilizer treatments, the low rate of fish emulsion produced the highest yield per plant and the largest fruit (Tables 2.8 and 2.9). On average, 'Duke' plants (2.2 g) had larger fruit than 'Liberty' (2.1 g), with larger differences observed on flat ground (Tables 2.8 and 2.9). Berry weight was considered typical if not slightly above average for the cultivars grown (Bryla and Strik, 2007; Pavlis, 2006; Strik and Buller, 2005). In contrast, ‘Duke’ plants grown in an organic trial in Nova Scotia, Canada, produced heavier fruit (2.5 g) in the fifth growing season (Burkhard et at., 2009); however, as the authors mentioned, fruit size was likely higher than normal due to the low plant yield (142 g) they observed. There is often a negative correlation between yield and berry weight (Bryla et al., 2009; Strik et al., 2003). Thus, the severe pruning done on fish fertilized plants, to limit crop (Strik and Buller, 2005), and on feather meal fertilized plants, to eliminate most of the crop and promote vegetative growth, allowed plants to produce an acceptable yield in the second growing season without reducing fruit size.

Percent soluble solids. Percent soluble solids (ºBrix) of fruit was significantly affected by planting method, fertilizer, and cultivar, but not by mulch (Tables 2.8 and 2.9).

On average e, ‘Liberty’ fruit had a higher percent soluble solids (16.0%) than did ‘Duke’ fruit (13.8%). In a fruit storage experiment, ‘Liberty’ also had greater percent soluble solids (19.7%) than ‘Duke’ (14.2%; Yang et al., 2009).

Plants growing on flat ground produced fruit with a higher percent soluble solids (16.5%) than those on raised beds (15.6%), primarily in ‘Liberty’ plants. There were minimal effects of planting system on ‘Duke’. The increased soluble solids on flat ground may have been related to the lesser amount of water required compared to raised beds, but may also be an indirect effect of fruit size. In processing tomatoes, decreasing irrigation reduced yield and increased percent soluble solids in the fruit without affecting total sugar content in the fruit (Bryla et al., 2009; Cahn et al., 2001; Colla et al., 2001).

We found that plants fertilized with the high rate of fish emulsion produced fruit with a greater percent soluble solids than any other fertilizer treatment, except in ‘Liberty’ plants grown on flat ground. Plants fertilized with the high rate of fish emulsion produced plants with a large canopy relative to the root system and berry size also tended to be smaller. With only one year of yield data, we are not sure at this point whether this treatment effect will continue through subsequent fruiting years.

Fruit firmness. Berry firmness was significantly affected by fertilizer, mulch, and cultivar, but not by planting method. There was an interaction between fertilizer and cultivar (Tables 2.8 and 2.9).

The high and low rates of fish fertilizer produced firmer fruit than did fertilization with feather meal in both ‘Duke’ and ‘Liberty’. Fruit from weed mat plots were less firm than that from any of the organic mulches, especially when fertilized with feather meal. In highbush blueberry, fruit firmness and percent soluble solids decreased as water regimes were increased (Bryla et al., 2009). In our study, weed mat plots required more water than any of the organic mulches, however percent soluble solids was not affected by mulch treatment. ‘Duke’ had 24% firmer fruit than ‘Liberty’, on average. Similar differences between cultivars have been reported by Yang et al. (2009). They concluded that early ripening cultivars, such as ‘Duke’, have greater firmness than late cultivars, such as ‘Liberty’, ‘Elliott’, and ‘Aurora’.

Plant dry weight. After the second season, in Oct. 2008, total plant DW was significantly affected by planting method, fertilizer, and cultivar, but not by mulch. There was a significant fertilizer by mulch, fertilizer by cultivar, and planting method by fertilizer by mulch interaction (Table 2.10 and 2.11).

The effects of planting method on total plant DW were more pronounced at the end of the second season than the first. There was a greater total plant DW in plants grown on raised beds than on flat ground in both cultivars – 27% and 14% larger plants in ‘Duke’ and ‘Liberty’, respectively. The positive effects of raised beds on plant DW may require further investigation but may be due to greater irrigation and improved physical soil conditions, even though root DW was not increased by planting method in any year. White (2006) and Spiers (1998) found that raised beds formed in fine sandy loam soils and clay loam soils with soil amendments were not beneficial, in the short term, for northern and southern highbush blueberry plants, mainly due to water stress in the root zone and faster movement of nutrients through the soil. In contrast, we found a greater plant DW on raised beds formed in a clay loam soil without any type of soil amendment, even though greater amounts of water were required as compared to flat ground.

Fertilization with the low rate of fish emulsion continued to produce the greatest total plant DW compared to other fertilization treatments, although the difference between the low and high rate of fish in ‘Duke’ was greater (23% heavier at low rate) than it was in ‘Liberty’ (1% difference between low and high rate) when grown on raised beds. Southern highbush blueberry cultivars, Misty and Star, also showed different responses in plant canopy DW to fertilizer rate, where the medium rate produced greater canopy DW on ‘Misty’, whereas the high rate produced greater total canopy DW in ‘Star’ (Wilber and Williamson, 2008).

Mulch type had no impact on total plant DW at the end of the second season. However, plants grown with sawdust mulch tended to have the greatest total plant DW, especially when grown on raised beds, followed by compost plus sawdust and weed mat plots. The treatment combination of the low rate of fish emulsion with sawdust mulch produced the largest total plant DW in ‘Duke’ (1088 g), whereas in ‘Liberty’, the high rate of fish emulsion combined with sawdust mulch (1307 g) produced the largest plants even though leaf tissue %N was considered above normal, based on standards (Hart et al., 2006). It is possible that ‘Liberty’ plants require a higher rate of N fertilizer than ‘Duke’, as reflected in their greater biomass accumulation.

When ‘Liberty’ plants were grown on raised beds with weed mat, total plant DW was greater when fertilized with feather meal at high or low rate than when fertilized with fish emulsion at high or low rate (Table 2.11). Similarly in ‘Duke’, when plants were grown on raised beds, they also tended to have a lower total plant DW when grown on weed mat and fertilized with the high rate of fish emulsion rather than feather meal. However, at the low rates of fertilizer, unlike ‘Liberty’, fertilization with fish emulsion produced a greater total plant DW than feather meal in ‘Duke’ plants (Table 2.10). Our results illustrate that cultivars respond differently to organic fertilizers and rates of fertilizer. Treadwell et al. (2007) stated that managing N in organic production is challenging not only because of the need to coordinate fertilizer application with mineralization, but also because the planting media which are affected by temperature, water holding capacity (WHC), aeration, bulk density, and C:N ratio interact with the physical and chemical characteristics of the fertilizer used.

At the end of the first season, ‘Liberty’ plants were larger than ‘Duke’ plants. Although, this was still the case at the end of the second growing season, ‘Duke’ plants had a greater biomass accumulation from the first to the second growing season than did ‘Liberty’. ‘Duke’ plants had a 208% increase in total plant DW from the end of the first season to the end of the second growing season, while ‘Liberty’ increased 167%, on average. There was a significant interaction between fertilizer and cultivar, because ‘Liberty’ showed a positive response to the high rate of fish emulsion, whereas ‘Duke’ did not show an increase in growth with the higher rate.

Root DW. The root DW was significantly affected by fertilizer and mulch, but not by planting method or cultivar. There was a significant interaction between fertilizer and mulch (Tables 2.10 and 2.11).

Plants fertilized with fish emulsion and feather meal at the low rate had greater root DW than when high rates were applied, similar to what was observed the first season. Young blueberry plants are very sensitive to under or over fertilization due to their small root system which is susceptible to high salt (EC), ammonium toxicity, or because they have little reserve N to support physiological processes (Bañados et al., 2006). The low rate of fish emulsion produced the greatest root DW in ‘Duke’ (114.9 g), but not in ‘Liberty’, where the low rate of feather meal produced a greater root DW (106.4 g) than the low rate of fish emulsion (98.5 g). In contrast, the high rate of fish emulsion significantly decreased root DW in ‘Duke’ by 63% and in ‘Liberty’ by 31%.

Unlike the first season, mulch type significantly affected root DW in Oct. 2008. Root DW was greater in plants grown under organic mulches than with a weed mat (Tables 2.8 and 2.9). The reduction in root DW under weed mat could be a result of the elevated soil temperatures and/or a decline in soil quality (Neilsen et al., 2003). For example, soil bulk density, in Nov. 2008 at 0.2 m, was increased under weed mat on raised beds (1,367 $kg\cdot(m^3)^{-1}$) and flat ground (1,315 $kg\cdot(m^3)^{-1}$) as compared to sawdust mulch on raised beds (1,197 $kg\cdot(m^3)^{-1}$) and flat ground (1,008 $kg\cdot(m^3)^{-1}$) and compost plus sawdust mulch on raised beds (1,200 $kg\cdot(m^3)^{-1}$) and flat ground (1,083 $kg\cdot(m^3)^{-1}$).

In ‘Duke’, after two growing seasons, the greatest root DW (156.2 g) occurred in plants grown with sawdust mulch and fertilized with the low rate of fish emulsion (Table 2.10); root DW in this treatment increased 307% through the second growing season compared to 166% in plants grown with weed mat and fertilized with the high rate of fish emulsion. In ‘Liberty’, plants mulched with sawdust and fertilized with the low rate of feather meal (149.5 g) or the low rate of fish emulsion with compost plus sawdust mulch (157.2 g) had the greatest root DW (Table 2.11).

Even though there was an effect of mulch on soil temperature and weed mat plots required extra irrigation to maintain adequate soil moisture compared to organic mulches, we observed cultivar preferences to mulch type or differences in adaptability to various mulches. Wu et al. (2006) found that three-year-old ‘Bluecrop’ plants had greater root DW with moss as a mulch than with no mulch, while the opposite was found in ‘St. Cloud’.

Although ‘Duke’ (25.5 g) had a significant but slightly greater root DW than ‘Liberty’ (22.3 g) at the end of the first season, there was no significant effect of cultivar on root DW after the second growing season. ‘Duke’ plants thus accumulated more root DW (99.2 g) than did 'Liberty' (95.9 g) from Oct. 2007 to 2008. Root growth may be influenced by genetic or cultivar traits, such as response to the environment (e.g. soil temperature) or plant reserves in the spring. Gough (1994) found that root growth in 'Bluecrop' occurred predominantly after fruiting in late summer. It is not known what impact cultivar or environmental factors have on blueberry root growth.

Root growth may also have been influenced by soil properties in the root zone. The soil in the compost plus sawdust and sawdust mulches had a pH ranging from 4.9 to 5.6, with sawdust mulched plots having lower soil pH than compost plus sawdust after two growing seasons. In contrast, soil pH under weed mat mulch ranged from 4.3 to 5.0 (Table 2.12). However, the soil pH in all treatments was within the acceptable range for northern highbush blueberry, 4.5 to 5.5 (Hart et al., 2006). Conversely, Cox (2009) found that soil pH decreased with the use of woodchip mulch compared to weed mat in a two-year study. Soil organic matter (OM) in compost plus sawdust plots was higher ranging from 4.5 to 4.8, compared to sawdust and weed mat plots in which OM ranged from 3.4 to 3.8% (Table 2.12). There is evidence that root growth may be reduced at a low pH in combination with a low percent organic matter (Strik et al., 1993), an effect that was not observed in our experiment after two growing seasons. In the weed mat plots, the reduction in soil pH observed was mainly caused by the amounts of H^+ released from the absorption of NH_4^+ into the roots in the process of ammonification (Raven, 1988) due to the accumulation of high rates of fish fertilizer (Table 2.12). Therefore the attributed decrease in root DW was likely due to a reduction in soil pH as a result of excessive applications of fish emulsion fertilizer. The reduction on roots DW with high rate of fish fertilizer could also be the result of a physiological plant response where the plants had less need to produce roots at high N levels.

Crown DW. Crown DW was affected by fertilizer, mulch, and cultivar, but not by planting method. There was an interaction between fertilizer and mulch (Tables 2.10 and 2.11).

Similar to what was observed at the end of the first season, the greatest crown DW was found in plants fertilized with the low rate of fertilizer in both cultivars. In 'Duke', the greatest crown DW was found in plants fertilized with the low rate of fish emulsion (86.1 g), whereas in 'Liberty', the low rate of feather meal produced a greater crown DW (114.2 g) than the other fertilizer treatments.

Differences in crown DW due to mulch type were observed only at the end of the second season. The organic mulches, compost plus sawdust and sawdust, produced a greater crown DW than weed mat in both cultivars. In plants grown with weed mat, fertilization with fish emulsion, at either rate, led to a lower crown DW than in plants fertilized with feather meal.

At the end of the first season, 'Duke' and 'Liberty' plants had heavier crowns than roots (41% and 103%, respectively). Conversely, by the end of the second growing season, 'Liberty' plants had only 7% greater crown DW than root DW, whereas in 'Duke' the roots were 38% heavier than the crowns. In Oct. 2008, 'Liberty' plants had 42% greater crown DW than 'Duke' plants.

Top growth. The DW of one-year-old wood was significantly affected by planting method, mulch, and cultivar, but not by fertilizer. Also, the interactions of fertilizer by mulch, fertilizer by cultivar, and planting method by fertilizer by mulch were significant (Tables 2.10 and 2.11).

Growing plants on raised beds led to a 49% and 30% increase in one-year-old wood DW in 'Duke' and 'Liberty' plants, respectively, compared to plants grown on flat ground. This may lead to a positive effect on yield in the third growing season (2009). 'Liberty' plants had more one-year-old wood DW than did 'Duke' plants, especially when grown on flat ground.

Plants grown with weed mat had less one-year-old wood DW than plants grown with sawdust or compost plus sawdust mulch. In raised beds, 'Duke' and 'Liberty' plants grown with sawdust had a greater one-year-old wood DW than plants grown on weed mat. One-year-old wood DW was enhanced by sawdust when used as mulch compared to bare soil, regardless of fertilizer rate applied (White, 2006). In other studies, sawdust mulch only reduced one-year-old DW and leaf DW during the first growing season (Yang et al., 1998; Wu et al., 2006).

Two-year and older wood DW was significantly affected by fertilizer and cultivar, but not by planting method or mulch. There was a significant fertilizer by cultivar and mulch by cultivar interaction (Tables 2.10 and 2.11).

Plants fertilized with fish emulsion had a greater two-year and older wood DW than plants fertilized with feather meal. This likely was a reflection of the larger biomass accumulation that plants fertilized with fish emulsion had at the end of the first season. Plants fertilized with the low rate of fish emulsion had greater two-year and older wood DW than those receiving the high rate of fish emulsion in 'Duke' plants, again mirroring the impact of low and high rates of fish emulsion on one-year-old DW in the first season. In contrast, the low rate of fish fertilizer and feather meal had lesser two-year and older wood DW than the high rate of fertilizer in 'Liberty' plants, opposite of the effect on one-year-old DW in the first season. 'Liberty' plants may have taken up more N than 'Duke' plants, due to the larger plant size, and growth in older, reserve tissue may have occurred in addition to new growth.

Leaf DW and leaf area were significantly affected by planting method, fertilizer, mulch, and cultivar. There was a significant planting method by mulch and fertilizer by mulch interaction for leaf DW and leaf area, and mulch by cultivar interaction for leaf DW (Tables 2.10 and 2.11).

Growing plants on raised beds increased leaf DW by 34% in 'Duke' and by 17% in 'Liberty' and leaf area by 31% in 'Duke' and 18% in 'Liberty' compared to plants grown on flat ground. The difference in leaf DW and leaf area per plant between 'Duke' and 'Liberty' was minimal when grown on raised beds (~ 7%).

Leaf DW and leaf area were greater in plants fertilized with fish emulsion, particularly at the high rate where leaf area was 30% to 71% greater than at the low rate of fish emulsion and the high rate of feather meal, respectively. When planted on flat ground, plants fertilized with the high rate of fish emulsion, had 37% and 67% greater leaf DW than plants fertilized with the high rate of feather meal in 'Duke' and 'Liberty', respectively.

In contrast to the first growing season where plants grown with weed mat had the greatest leaf DW, by Oct. 2008, growing plants with organic mulches led to a greater leaf area and leaf DW per plant. Similar to the first growing season, 'Liberty' had a greater leaf DW and leaf area than 'Duke'.

Leaf area index (LAI) was significantly affected by fertilizer (Tables 2.13 and 2.14). Plants fertilized with fish emulsion had a higher LAI than those fertilized with feather meal, primarily in 'Liberty' plants which had an average LAI of 3.8 for fish emulsion, compared to an LAI of 2.6 in plants fertilized with feather meal. There was no significant effect of cultivar on LAI, although 'Duke' plants tended to have a lower LAI than 'Liberty'.

The number of whips was significantly affected by fertilizer, mulch, and cultivar, and the interaction of fertilizer by cultivar (Tables 2.13 and 2.14). Treatments effects were more apparent in 'Liberty' plants, due to their larger number of whips than 'Duke'. Fertilization with feather meal led to the production of 1 to 5 more whips per plant than fertilization with fish emulsion, depending on cultivar. Even though there was no effect of fertilizer on whips per plant at the end of the first growing season, there may have been residual fertilizer N in the fish emulsion treatments in spring 2008, providing greater N in these plots than in the feather meal plots, thus inhibiting the production of whips. 'Duke' again produced fewer whips per plant (average of 3) than did 'Liberty' (9).

Mulch had no effect on whips per plant in 'Duke', whereas in 'Liberty' the fewest whips were produced in weed mat plots (7) and the most in plants mulched with sawdust or compost plus sawdust (10). These results are comparable to data obtained at the end of the first season.

Shoot to root ratio. The shoot:root was significantly affected by fertilizer, mulch and cultivar but not by planting method (Tables 2.15 and 2.16).

Similar to what was found at the end of the first season, shoot:root ratio was higher in plants fertilized with the high rate of fish emulsion and lowest in plants fertilized with the low rate of feather meal. Weed mat had the highest shoot:root ratio in average, and primarily when plants where fertilized with fish emulsion. This higher ratio was a result of the lesser biomass accumulation in the root system, which might be caused due to root respiration differences. In both cultivars, shoot:root was lower at the end of the second season that at the end of the first season. In ‘Duke’, the shoot:root was from 3 to 7, whereas in ‘Liberty’ the ratio was higher (3 to 12).

Fertilization with feather meal led to a greater partitioning of DW to the roots and crown than fertilization with fish fertilizer, with less partitioned to two-year and older wood. In contrast to the first year, there was no significant effect of fertilizer on the percent of total DW partitioned to one-year-old DW.

Flower bud number per lateral. Flower bud number was significantly affected by cultivar ($p<0.05$; data not shown). However, the differences in flower buds/lateral were very small between ‘Duke’ (5 to 7) and ‘Liberty’ (5 to 6). Unlike after the first season, there were fewer treatment effects on flower buds/lateral after the second growing season.

Pruning time. Pruning time was significantly affected by cultivar ($p<0.001$; data not shown). ‘Liberty’ plants required 80 hours per hectare to prune compared to 65 hr/ha in ‘Duke’. The time required to prune increased 45% in ‘Liberty’ and 44% in ‘Duke’ plants from the end of the first growing season to the end of the second one.

Tissue nutrient concentration. In 2008, all nutrients except Ca, Fe, Cu, Zn, and Al were affected by fertilizer. Mulch type affected concentrations of N, Ca, Mg, B, Mn, and Zn. Cultivar affected all nutrients except Ca. There were relatively few treatment interactions on leaf nutrient concentration in the second fruiting season (Table 2.17). Fe increased to about double the amount of ppm from the first season to the second season. In contrast, B decreased from the first to the second growing season.

Tissue %N was above normal in all plants fertilized with the high rate of fish emulsion, whereas the only treatments having below normal tissue %N were those fertilized with the low rate of feather meal, and the high rate of feather meal in 'Liberty' plants only. However, in 2008, plants fertilized with feather meal that had below normal leaf N levels, did not show any N deficiency symptoms as was observed in 2007. There was also no effect of fertilizer on the one-year-old wood DW in 2008. Lower tissue %N can occur in situations in which growth is vigorous and tissue N is diluted. In this particular case, the low rate of feather meal may also have had a lower leaf %N either because not all of the feather meal N was available or the low rate was not enough to meet plant requirements for N. In this study there is evidence supporting the latter, since no significant differences were observed in flower bud formation in 2008 indicating that the N released from the low rate of feather meal was enough for the plant to produce an adequate number of flower buds based on its plant canopy. The relatively heavy pruning done in the low rate of feather meal treatments in 2007/08 to remove most of the fruit buds led to greater biomass production and the formation of an almost equal amount of flower buds as with the other fertilizer treatments. This effect was clearly observed in 'Liberty' plants receiving the low rate of feather meal in combination with weed mat, which had the lowest leaf %N of 1.46 (Table 2.17) yet the number of fruit buds produced were similar to the that found in plants fertilized with the high and low rates of fish emulsion or the high rate of feather meal and with any mulch treatment. This suggests that the rate of fertilizer nitrogen should be increased relative to the size of a specific cultivar to obtain the recommended leaf N levels without compromising plant growth or plant N reserves for subsequent years.

In 2008, feather meal was applied earlier than in 2007, and considerable rainfall likely helped move the fertilizer N into the root zone. Feather meal has been shown to require up to 70 days for 74% of the fertilizer N to be available to plants (Gale et al., 2006). It is thus possible, that all or some of the second portion of the feather meal application was lost through volatilization. Previous research in Oregon has shown that young blueberry plants can only take up 30 to 52% of inorganic fertilizer N (Bañados, 2006; White, 2006). Plants in this study likely required a higher rate of feather meal to account for inefficiencies in fertilizer uptake and possible loss of fertilizer N through immobilization or volatilization. The high rate of feather meal provided sufficient fertilizer N in 'Duke' plants only. When fertilizing with fish emulsion, the low rate was likely sufficient, because of greater efficiency of uptake with the total N divided into seven applications and provided in a liquid form.

Plants grown with weed mat had a slightly lower leaf %N compared to those grown with organic mulches, except in plots fertilized with the high rate of fish emulsion. This difference was perhaps due to more vigorous top growth in the weed mat treatments and subsequent dilution of N. However, there may also have been greater N available from mineralization in the organic mulch treatments, since the soil under the organic mulches had a higher percent organic matter.

Interestingly, plants grown with compost plus sawdust mulch did not have higher leaf %N than those grown with sawdust mulch. Compost has been shown to decompose relatively slowly providing from 7 to 11% from the total N within a three-year period (Sullivan et al., 1998) – with only 1.1% total N in the compost, there was not much additional available N in the compost mulch treatment during the length of the establishment period. Total plant DW was greater in the compost plus sawdust mulched plants than in those grown on weed mat, especially in 'Duke' grown on raised beds and 'Liberty' fertilized with the low rate of N on raised beds.

Leaf N concentrations were higher in 'Duke' than in 'Liberty' plants. 'Liberty' plants seem to require more fertilizer N than 'Duke' due to greater plant vigor. Total plant DW of 'Liberty' was greater than that of 'Duke' in both years.

Conclusion

Organically grown northern highbush blueberry plants, 'Duke' and 'Liberty,' were adapted to most of the production systems tested in our study. We found that production on raised beds greatly improved total plant DW in both cultivars as compared to flat ground, mainly due to the extra irrigation required (Chapter 3) and other soil properties; differences among these production systems, including light intensity, soil compaction, water percolation, and irrigation frequency, require further investigation.

Fertilization with fish emulsion, split into seven applications, produced greater total plant DW during the two growing seasons than did fertilization with feather meal. However in 'Liberty,' the high rate of fish fertilizer did not result in greater plant biomass accumulation than did the low rate of fish emulsion, as in 'Duke'. The high rate of feather meal produced greatest total plant DW by the end of the second season and when combined with weed mat among 'Duke' plants fertilized feather meal. The earlier application of feather meal was advantageous for allowing mineralization to occur during the second growing season. The high rate of fish emulsion produced the smallest root and crown DW, especially when combined with weed mat. 'Liberty' plants tended to require more N than 'Duke' and have greater and more upright growth than 'Duke'. However, using fast-release N fertilizers could increase 'Liberty' plants susceptibility to breaking at the crown during intense winds in the fall (>64 $km \cdot h^{-1}$), due to the high shoot-root ratio (Table 2.15 and 2.16).

The organic mulches in this study resulted in heavier total plant DW after two growing seasons in both cultivars than did weed mat. Weed mat mulch produced greater soil temperature and behaved more like a bare soil than a mulched soil, thus requiring greater amounts of irrigation water than the organic mulches. The greater soil temperatures may have increased plant transpiration and plant water requirements; however more studies are required to determine the impact of weed mat mulch on plant canopy temperatures and plant water status. After two growing seasons, the greatest total plant DW was obtained with sawdust mulch and the low rate of fish fertilizer in 'Duke' and sawdust with the high rate of fish fertilizer in 'Liberty'.

Yield was greater on raised beds than on flat ground; plants grown on raised beds also had larger fruit than plants grown on flat ground. The low rate of fish emulsion increased yield and berry size in both cultivars. Yield and berry size were greater with the low rate of fish emulsion in both cultivars, and the combinations of the low rate of fish emulsion and weed mat in ‘Duke’. The low rate of fish emulsion with compost plus sawdust mulch in ‘Liberty’ produced the greatest yields. Plants fertilized with the high rate of fish emulsion and grown on raised beds had fruit with greater percent soluble solids. Firmness was greater in plants with the organic mulches and fertilized with fish emulsion in both cultivars.

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Table 2.1 Effect of nitrogen fertilizer on leaf nutrient content, on 'Duke' and 'Liberty' plants, 2 Aug. 2007, NWREC (n=6; mean).

Cultivar	N Fertilizer rate and type ($kg \cdot ha^{-1}$ N)	Mulch type	Macronutrients N (%)	Macronutrients P (%)	Macronutrients K (%)	Macronutrients Ca (%)	Macronutrients Mg (%)	Micronutrients Fe (ppm)	Micronutrients B (ppm)	Micronutrients Cu (ppm)	Micronutrients Mn (ppm)	Micronutrients Zn (ppm)
Duke D												
	29 Feather B	Comp+Sawd C	1.83	0.14	0.62	0.51	0.15	60.17	49.33	5.67	120.67	11.67
		Sawdust C	1.94	0.14	0.52	0.63	0.19	67.17	48.33	6.33	165.33	11.00
		WeedMat C	1.95	0.14	0.57	0.52	0.15	63.17	41.33	6.00	153.83	11.00
	29 Fish B	Comp+Sawd C	1.83	0.16	0.66	0.37	0.10	58.00	23.00	6.67	91.33	11.33
		Sawdust C	1.71	0.14	0.57	0.39	0.11	56.33	18.83	7.00	103.50	10.00
		WeedMat C	1.96	0.16	0.65	0.35	0.10	60.33	18.83	6.67	99.00	9.00
	57 Feather B	Comp+Sawd C	1.80	0.15	0.63	0.50	0.15	62.33	45.50	6.50	116.00	11.67
		Sawdust C	1.82	0.15	0.55	0.58	0.18	73.00	44.17	6.33	156.83	12.83
		WeedMat C	1.88	0.17	0.62	0.44	0.13	57.00	32.00	6.50	135.00	12.67
	57 Fish B	Comp+Sawd C	1.97	0.16	0.70	0.38	0.10	60.00	23.67	6.50	100.50	9.17
		Sawdust C	2.02	0.16	0.59	0.40	0.10	57.50	19.83	6.33	117.00	9.00
		WeedMat C	2.14	0.17	0.79	0.36	0.10	62.67	19.83	6.83	93.67	7.83
Liberty D												
	29 Feather B	Comp+Sawd C	1.85	0.19	0.61	0.45	0.13	61.83	39.67	6.17	94.33	12.17
		Sawdust C	2.01	0.20	0.61	0.48	0.13	61.33	37.00	5.67	121.50	12.33
		WeedMat C	2.01	0.23	0.65	0.42	0.12	51.83	29.67	6.33	104.67	14.67
	29 Fish B	Comp+Sawd C	1.75	0.16	0.56	0.38	0.11	52.50	23.83	6.00	80.50	9.67
		Sawdust C	1.79	0.16	0.53	0.38	0.11	50.17	20.00	6.17	90.50	9.50
		WeedMat C	2.01	0.19	0.61	0.38	0.11	56.83	21.50	6.50	93.00	10.83
	57 Feather B	Comp+Sawd C	1.77	0.19	0.62	0.46	0.13	61.17	37.83	6.33	97.83	12.83
		Sawdust C	1.87	0.19	0.56	0.47	0.14	63.00	36.17	6.00	111.50	12.50
		WeedMat C	1.87	0.19	0.60	0.39	0.12	50.50	27.33	6.00	106.67	11.67
	57 Fish B	Comp+Sawd C	1.96	0.17	0.62	0.34	0.10	55.17	22.83	5.67	89.00	8.83
		Sawdust C	1.92	0.17	0.55	0.35	0.10	54.67	20.17	6.00	94.00	8.50
		WeedMat C	2.08	0.18	0.65	0.33	0.09	54.67	20.33	5.50	88.33	8.33
Significance[z]												
Planting method	(A)[y]		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
N fertilizer rate and type	(B)		***	n.s.	*	***	***	n.s.	***	*	***	***
Mulch type	(C)		***	**	***	***	***	n.s.	***	n.s.	***	n.s.
Cultivar	(D)		n.s.	***	***	***	***	***	***	**	***	n.s.
B x C			n.s.	n.s.	**	*	**	***	***	n.s.	**	n.s.
B x D			n.s.	***	***	***	***	n.s.	***	n.s.	***	*
C x D			n.s.	n.s.	*	n.s.	***	n.s.	n.s.	n.s.	*	n.s.

[z]*Significant at $P < 0.05$; **significant at $P < 0.01$; ***significant at $P < 0.001$; ns=not significant.

[y]A = Planting method, B = Nitrogen Fertilizer rate and type, C = Mulch type, D = Cultivar.

Table 2.2 Effect of organic production systems on plant dry weight of 'Duke' after one growing season, 2 Oct. 2007, NWREC (n=5; mean ± SE).

Planting method		N Fertilizer rate and type (kg·ha^{-1} N)		Mulch type		Plant dry weight: Roots (g)	Crown (g)	1-yr & older wood (g)	Leaves (g)	Total plant (g)
Flat	A									
		29 Feather	B	Comp+Sawd	C	25.8 ± 2.2	35.4 ± 5.1	76.8 ± 8.2	33.8 ± 4.3	171.0 ± 16.2
				Sawdust	C	24.8 ± 2.7	34.8 ± 4.6	63.0 ± 9.9	30.4 ± 5.1	153.0 ± 17.7
				WeedMat	C	30.6 ± 3.3	38.0 ± 4.6	108.4 ± 24.4	45.2 ± 3.1	222.2 ± 29.0
		29 Fish	B	Comp+Sawd	C	33.6 ± 3.7	51.0 ± 4.7	135.4 ± 17.4	88.4 ± 6.6	308.4 ± 28.7
				Sawdust	C	33.8 ± 4.5	50.2 ± 11.9	141.8 ± 8.6	92.6 ± 6.2	318.4 ± 23.9
				WeedMat	C	21.0 ± 2.1	27.8 ± 4.4	121.4 ± 18.1	88.8 ± 6.7	259.0 ± 26.9
		57 Feather	B	Comp+Sawd	C	29.6 ± 2.3	42.2 ± 6.5	86.4 ± 5.2	39.6 ± 3.8	197.8 ± 13.3
				Sawdust	C	21.0 ± 2.6	29.0 ± 5.3	56.8 ± 4.7	27.0 ± 5.2	133.8 ± 11.1
				WeedMat	C	24.8 ± 3.5	32.2 ± 2.7	90.8 ± 7.2	46.4 ± 7.2	194.2 ± 18.4
		57 Fish	B	Comp+Sawd	C	17.0 ± 0.9	27.4 ± 3.9	115.4 ± 15.9	72.2 ± 8.7	232.0 ± 20.4
				Sawdust	C	21.2 ± 2.4	31.2 ± 7.1	120.2 ± 13.7	93.2 ± 11.5	265.8 ± 30.1
				WeedMat	C	13.6 ± 2.4	18.8 ± 4.1	128.4 ± 27.1	83.8 ± 13.6	244.6 ± 44.8
Raised	A									
		29 Feather	B	Comp+Sawd	C	31.8 ± 3.6	46.2 ± 8.7	109.4 ± 11.3	50.4 ± 6.9	237.8 ± 29.3
				Sawdust	C	22.8 ± 1.7	43.4 ± 3.1	77.0 ± 12.2	40.2 ± 8.8	183.4 ± 20.9
				WeedMat	C	30.0 ± 5.4	31.8 ± 4.2	90.8 ± 7.1	44.8 ± 2.9	197.4 ± 14.1
		29 Fish	B	Comp+Sawd	C	30.2 ± 2.7	39.0 ± 2.0	148.8 ± 8.9	92.2 ± 3.2	310.2 ± 11.1
				Sawdust	C	38.4 ± 5.0	55.4 ± 5.8	169.0 ± 17.5	115.4 ± 7.1	378.2 ± 29.0
				WeedMat	C	23.2 ± 2.6	38.4 ± 3.1	145.8 ± 24.9	108.0 ± 13.0	315.4 ± 40.1
		57 Feather	B	Comp+Sawd	C	22.4 ± 2.9	31.4 ± 7.9	86.8 ± 10.7	38.8 ± 5.5	179.4 ± 25.5
				Sawdust	C	25.4 ± 3.0	29.8 ± 4.2	103.2 ± 7.3	53.2 ± 7.1	211.6 ± 11.4
				WeedMat	C	25.6 ± 2.9	31.8 ± 5.7	103.4 ± 12.6	53.2 ± 9.8	214.0 ± 28.8
		57 Fish	B	Comp+Sawd	C	19.2 ± 3.3	31.8 ± 4.0	135.0 ± 16.4	80.8 ± 6.4	186.0 ± 19.8
				Sawdust	C	29.2 ± 1.7	36.6 ± 4.9	167.2 ± 18.4	129.8 ± 9.9	233.0 ± 19.7
				WeedMat	C	16.4 ± 4.9	29.6 ± 5.6	125.2 ± 15.6	88.0 ± 11.6	171.2 ± 23.7
Significance[z]										
Planting method		(A)[y]				n.s.	n.s.	*	*	*
N fertilizer rate and type		(B)				**	***	***	***	***
Mulch type		(C)				n.s.	n.s.	**	**	n.s.
Cultivar		(D)				**	***	***	***	***
A x B						n.s.	n.s.	n.s.	n.s.	n.s.
A x C						n.s.	n.s.	*	*	n.s.
B x C						**	*	n.s.	**	**
B x D						n.s.	n.s.	*	n.s.	n.s.
C x D						*	n.s.	**	***	**

[z]*Significant at $P < 0.05$; **significant at $P < 0.01$; ***significant at $P < 0.001$; ns=not significant.

[y]A = Planting method, B = Nitrogen Fertilizer rate and type, C = Mulch type, D = Cultivar.

Table 2.3 Effect of organic production systems on plant dry weight of 'Liberty' after one growing season, 2 Oct. 2007, NWREC (n=5; mean ± SE).

Planting method	N Fertilizer rate and type (kg·ha^{-1} N)	Mulch type	Plant dry weight: Roots (g)	Crown (g)	1-yr & older wood (g)	Leaves (g)	Total plant (g)
Flat A							
	29 Feather B	Comp+Sawd C	23.4 ± 2.7	53.2 ± 10.4	120.4 ± 5.7	63.6 ± 6.1	260.6 ± 22.5
		Sawdust C	23.2 ± 2.3	36.6 ± 5.5	87.8 ± 10.1	44.4 ± 4.2	192.0 ± 10.2
		WeedMat C	25.2 ± 2.0	43.6 ± 9.7	124.2 ± 5.2	69.8 ± 4.5	262.8 ± 9.9
	29 Fish B	Comp+Sawd C	19.6 ± 3.4	52.8 ± 5.6	176.0 ± 23.8	117.0 ± 14.1	365.4 ± 37.2
		Sawdust C	25.6 ± 5.0	61.4 ± 8.0	180.8 ± 5.4	120.4 ± 8.1	388.2 ± 15.8
		WeedMat C	28.6 ± 5.3	53.6 ± 14.1	229.6 ± 23.1	142.8 ± 12.7	454.6 ± 49.0
	57 Feather B	Comp+Sawd C	23.4 ± 2.0	43.6 ± 10.2	116.4 ± 9.6	53.2 ± 10.0	236.6 ± 25.1
		Sawdust C	23.8 ± 3.6	40.0 ± 3.4	74.4 ± 5.9	42.0 ± 5.4	180.2 ± 13.5
		WeedMat C	25.6 ± 2.0	46.2 ± 8.0	116.8 ± 10.3	64.6 ± 4.3	253.2 ± 15.9
	57 Fish B	Comp+Sawd C	19.4 ± 4.5	30.6 ± 6.5	173.8 ± 14.9	116.4 ± 6.9	340.2 ± 25.9
		Sawdust C	16.2 ± 3.4	48.0 ± 5.3	172.2 ± 14.9	123.6 ± 12.4	360.0 ± 31.2
		WeedMat C	23.2 ± 5.1	38.0 ± 5.1	234.4 ± 19.5	148.8 ± 14.8	444.4 ± 38.6
Raised A							
	29 Feather B	Comp+Sawd C	18.6 ± 3.1	47.0 ± 9.6	111.4 ± 8.5	60.0 ± 2.5	237.0 ± 12.9
		Sawdust C	24.0 ± 5.7	36.2 ± 4.1	104.8 ± 17.9	52.2 ± 7.0	217.2 ± 29.7
		WeedMat C	21.0 ± 4.0	46.4 ± 7.2	120.4 ± 8.0	67.2 ± 6.2	255.0 ± 20.9
	29 Fish B	Comp+Sawd C	22.4 ± 1.9	51.2 ± 7.9	203.4 ± 6.3	122.2 ± 6.8	399.2 ± 13.2
		Sawdust C	28.0 ± 6.8	50.0 ± 7.9	190.4 ± 23.4	122.0 ± 9.9	390.4 ± 45.8
		WeedMat C	21.0 ± 2.9	47.0 ± 8.2	212.0 ± 26.0	120.2 ± 11.2	400.2 ± 41.8
	57 Feather B	Comp+Sawd C	20.8 ± 1.6	53.6 ± 5.6	147.4 ± 12.2	80.4 ± 5.9	302.2 ± 17.1
		Sawdust C	18.0 ± 2.6	42.6 ± 3.5	109.4 ± 8.1	58.8 ± 8.9	228.8 ± 21.4
		WeedMat C	27.8 ± 6.0	60.6 ± 8.4	165.2 ± 15.2	91.0 ± 14.9	344.6 ± 32.0
	57 Fish B	Comp+Sawd C	18.6 ± 2.7	37.8 ± 8.1	188.8 ± 22.2	130.8 ± 10.3	376.0 ± 24.8
		Sawdust C	23.4 ± 6.6	34.4 ± 5.6	178.4 ± 23.9	124.0 ± 16.0	360.2 ± 41.3
		WeedMat C	14.6 ± 2.5	33.2 ± 8.3	183.6 ± 22.0	120.8 ± 8.8	352.2 ± 40.4
Significance[z]							
Planting method	(A)[y]		n.s.	n.s.	*	*	*
N fertilizer rate and type	(B)		**	***	***	***	***
Mulch type	(C)		n.s.	n.s.	**	**	n.s.
Cultivar	(D)		**	***	***	***	***
A x B			n.s.	n.s.	n.s.	n.s.	n.s.
A x C			n.s.	n.s.	*	*	n.s.
B x C			**	*	n.s.	**	**
B x D			n.s.	n.s.	*	n.s.	n.s.
C x D			*	n.s.	**	***	**

[z]*Significant at $P < 0.05$; **significant at $P < 0.01$; ***significant at $P < 0.001$; ns=not significant.

[y]A = Planting method, B = Nitrogen Fertilizer rate and type, C = Mulch type, D = Cultivar.

Table 2.4 Effect of organic production systems on plant dry weight of 'Duke' after one growing season, 2 Oct. 2007, NWREC (n=5; mean ± SE).

Planting method		N Fertilizer rate and type (kg·ha^{-1} N)		Mulch type		Whip no.	Leaf area (cm²)	Leaf area index
Flat	A							
		29 Feather	B	Comp+Sawd	C	3.4 ± 0.5	2516.2 ± 295.8	1.5 ± 0.3
				Sawdust	C	4.8 ± 0.7	2564.4 ± 537.7	1.0 ± 0.2
				WeedMat	C	3.8 ± 0.9	3609.6 ± 346.2	2.0 ± 0.4
		29 Fish	B	Comp+Sawd	C	2.6 ± 0.6	6162.2 ± 416.6	1.7 ± 0.2
				Sawdust	C	4.0 ± 0.3	6552.8 ± 391.5	1.5 ± 0.2
				WeedMat	C	2.0 ± 0.5	6346.6 ± 513.5	1.9 ± 0.5
		57 Feather	B	Comp+Sawd	C	2.8 ± 1.1	2866.6 ± 271.4	1.8 ± 0.1
				Sawdust	C	2.8 ± 0.7	2136.2 ± 343.2	1.3 ± 0.2
				WeedMat	C	2.2 ± 0.7	3581.2 ± 497.3	2.7 ± 1.0
		57 Fish	B	Comp+Sawd	C	2.8 ± 0.4	5078.6 ± 754.0	1.3 ± 0.1
				Sawdust	C	2.8 ± 0.7	6699.6 ± 776.3	1.9 ± 0.3
				WeedMat	C	4.0 ± 0.8	5737.4 ± 873.3	1.4 ± 0.1
Raised	A							
		29 Feather	B	Comp+Sawd	C	3.8 ± 0.7	3850.4 ± 569.9	2.4 ± 0.4
				Sawdust	C	2.6 ± 0.4	3321.2 ± 694.5	1.9 ± 0.5
				WeedMat	C	1.4 ± 0.4	3460.2 ± 251.4	1.7 ± 0.3
		29 Fish	B	Comp+Sawd	C	4.4 ± 0.8	7048.6 ± 379.0	2.2 ± 0.3
				Sawdust	C	4.4 ± 0.9	8443.4 ± 561.1	2.1 ± 0.5
				WeedMat	C	2.6 ± 0.7	7747.0 ± 1114.9	1.8 ± 0.2
		57 Feather	B	Comp+Sawd	C	2.8 ± 0.6	2982.2 ± 488.1	1.5 ± 0.2
				Sawdust	C	4.2 ± 1.2	4045.6 ± 436.5	1.9 ± 0.3
				WeedMat	C	1.0 ± 0.3	4066.0 ± 773.9	1.5 ± 0.2
		57 Fish	B	Comp+Sawd	C	1.8 ± 0.5	5561.6 ± 417.8	1.6 ± 0.2
				Sawdust	C	3.8 ± 0.7	9037.0 ± 653.7	1.7 ± 0.1
				WeedMat	C	1.8 ± 0.6	5785.0 ± 971.6	1.6 ± 0.2
Significance[z]								
Planting method			(A)[y]			n.s.	*	n.s.
N fertilizer rate and type			(B)			n.s.	***	n.s.
Mulch type			(C)			**	*	n.s.
Cultivar			(D)			***	***	n.s.
A x B						*	n.s.	n.s.
A x C						n.s.	n.s.	n.s.
B x C						n.s.	**	n.s.
B x D						n.s.	n.s.	n.s.
C x D						n.s.	**	n.s.

[z]*Significant at $P < 0.05$; **significant at $P < 0.01$; ***significant at $P < 0.001$; ns=not significant.

[y]A = Planting method, B = Nitrogen Fertilizer rate and type, C = Mulch type, D = Cultivar.

Table 2.5 Effect of organic production systems on plant dry weight of 'Liberty' after one growing season, 2 Oct. 2007, NWREC (n=5; mean ± SE).

Planting method		N Fertilizer rate and type ($kg \cdot ha^{-1}$ N)		Mulch type		Whip no.	Leaf area (cm^2)	Leaf area index
Flat	A							
		29 Feather	B	Comp+Sawd	C	11.0 ± 1.5	4940.8 ± 524.7	1.4 ± 0.2
				Sawdust	C	7.0 ± 0.8	3445.0 ± 326.6	1.2 ± 0.1
				WeedMat	C	9.2 ± 1.8	5026.6 ± 378.5	1.5 ± 0.5
		29 Fish	B	Comp+Sawd	C	9.2 ± 2.1	7577.8 ± 952.6	1.4 ± 0.2
				Sawdust	C	12.6 ± 3.0	8230.0 ± 526.8	1.9 ± 0.4
				WeedMat	C	8.6 ± 1.5	9144.6 ± 824.5	1.9 ± 0.5
		57 Feather	B	Comp+Sawd	C	8.0 ± 1.0	4271.4 ± 613.7	1.8 ± 0.2
				Sawdust	C	6.6 ± 1.5	3167.8 ± 500.9	1.2 ± 0.2
				WeedMat	C	6.8 ± 0.7	4745.6 ± 346.0	1.9 ± 0.2
		57 Fish	B	Comp+Sawd	C	9.8 ± 1.5	8155.4 ± 606.9	1.9 ± 0.2
				Sawdust	C	10.4 ± 1.7	8764.0 ± 886.4	1.5 ± 0.2
				WeedMat	C	8.8 ± 1.3	10195.2 ± 1189.1	1.5 ± 0.4
Raised	A							
		29 Feather	B	Comp+Sawd	C	7.8 ± 1.2	4290.6 ± 170.7	1.4 ± 0.2
				Sawdust	C	7.0 ± 1.1	4032.8 ± 575.0	1.9 ± 0.1
				WeedMat	C	6.0 ± 1.6	5084.0 ± 542.3	1.6 ± 0.3
		29 Fish	B	Comp+Sawd	C	12.8 ± 2.2	8585.8 ± 355.2	2.2 ± 0.4
				Sawdust	C	9.8 ± 1.4	8742.4 ± 841.1	1.5 ± 0.2
				WeedMat	C	8.2 ± 2.7	8663.2 ± 753.9	1.9 ± 0.3
		57 Feather	B	Comp+Sawd	C	13.0 ± 1.8	5895.6 ± 455.3	1.3 ± 0.1
				Sawdust	C	8.2 ± 1.1	4744.2 ± 629.7	1.6 ± 0.4
				WeedMat	C	9.8 ± 1.7	6800.0 ± 1225.8	1.5 ± 0.4
		57 Fish	B	Comp+Sawd	C	11.2 ± 2.4	8879.8 ± 439.8	1.9 ± 0.3
				Sawdust	C	10.0 ± 2.4	8485.8 ± 988.1	1.5 ± 0.1
				WeedMat	C	8.2 ± 1.5	8500.8 ± 750.4	1.7 ± 0.3
Significance[z]								
Planting method			(A)[y]			n.s.	*	n.s.
N fertilizer rate and type			(B)			n.s.	***	n.s.
Mulch type			(C)			**	*	n.s.
Cultivar			(D)			***	***	n.s.
A x B						*	n.s.	n.s.
A x C						n.s.	n.s.	n.s.
B x C						n.s.	**	n.s.
B x D						n.s.	n.s.	n.s.
C x D						n.s.	**	n.s.

[z]*Significant at $P < 0.05$; **significant at $P < 0.01$; ***significant at $P < 0.001$; ns=not significant.

[y]A = Planting method, B = Nitrogen Fertilizer rate and type, C = Mulch type, D = Cultivar.

Table 2.6 Effect of organic production systems on plant dry weight of 'Duke' after one growing season, 2 Oct. 2007, NWREC (n=5; mean ± SE).

Planting method		N Fertilizer rate and type ($kg \cdot ha^{-1}$ N)		Mulch type		Proportion of total plant dry weight: Shoot:root ratio	Roots (%)	Crown (%)	1-yr & older wood (%)
Flat	A								
		29 Feather	B	Comp+Sawd	C	4.4 ± 0.5	15.3 ± 1.3	20.4 ± 2.1	44.8 ± 2.2
				Sawdust	C	4.0 ± 0.2	16.3 ± 0.5	23.5 ± 3.0	40.9 ± 2.6
				WeedMat	C	4.7 ± 0.4	14.0 ± 0.9	18.1 ± 2.8	47.0 ± 3.7
		29 Fish	B	Comp+Sawd	C	5.7 ± 0.6	11.1 ± 1.1	16.6 ± 0.5	43.4 ± 1.8
				Sawdust	C	5.9 ± 0.6	10.6 ± 1.2	15.1 ± 2.3	44.7 ± 1.1
				WeedMat	C	7.0 ± 0.3	8.1 ± 0.3	10.8 ± 1.6	46.1 ± 2.0
		57 Feather	B	Comp+Sawd	C	4.5 ± 0.6	15.4 ± 2.0	20.8 ± 2.2	43.8 ± 0.9
				Sawdust	C	4.4 ± 0.7	15.7 ± 1.7	22.0 ± 3.6	42.7 ± 2.2
				WeedMat	C	5.3 ± 0.6	12.7 ± 1.2	16.8 ± 1.1	47.0 ± 1.0
		57 Fish	B	Comp+Sawd	C	8.5 ± 0.9	7.6 ± 0.8	12.7 ± 2.9	48.9 ± 2.8
				Sawdust	C	7.4 ± 1.2	8.3 ± 0.9	11.5 ± 1.7	45.4 ± 1.7
				WeedMat	C	11.1 ± 1.4	5.6 ± 0.6	7.6 ± 0.6	51.9 ± 2.8
Raised	A								
		29 Feather	B	Comp+Sawd	C	4.9 ± 0.2	13.5 ± 0.4	18.9 ± 2.0	46.5 ± 1.5
				Sawdust	C	5.3 ± 0.6	13.0 ± 1.4	24.7 ± 3.0	41.2 ± 2.7
				WeedMat	C	4.5 ± 0.5	14.8 ± 1.8	16.4 ± 2.5	46.0 ± 1.9
		29 Fish	B	Comp+Sawd	C	6.4 ± 0.7	9.8 ± 1.0	12.6 ± 0.8	47.8 ± 1.4
				Sawdust	C	6.2 ± 1.0	10.3 ± 1.2	14.6 ± 0.9	44.4 ± 1.6
				WeedMat	C	7.9 ± 0.5	7.5 ± 0.6	12.9 ± 1.6	45.2 ± 2.2
		57 Feather	B	Comp+Sawd	C	5.4 ± 0.5	12.7 ± 1.3	16.6 ± 2.0	48.9 ± 1.1
				Sawdust	C	5.5 ± 0.6	12.1 ± 1.5	14.2 ± 2.0	48.7 ± 1.5
				WeedMat	C	5.4 ± 0.5	12.3 ± 1.5	14.5 ± 0.9	48.6 ± 1.7
		57 Fish	B	Comp+Sawd	C	10.0 ± 2.1	10.4 ± 1.9	17.1 ± 1.4	72.5 ± 3.1
				Sawdust	C	7.2 ± 1.1	13.1 ± 1.7	15.8 ± 1.6	71.1 ± 2.4
				WeedMat	C	11.6 ± 2.0	8.9 ± 1.4	17.6 ± 2.7	73.6 ± 2.3
Significance[z]									
Planting method			(A)[y]			n.s.	*	n.s.	n.s.
N fertilizer rate and type			(B)			***	***	***	**
Mulch type			(C)			*	***	***	***
Cultivar			(D)			***	***	n.s.	***
A x B						n.s.	n.s.	n.s.	n.s.
A x C						n.s.	n.s.	n.s.	n.s.
B x C						n.s.	n.s.	n.s.	n.s.
B x D						n.s.	*	n.s.	n.s.
C x D						n.s.	n.s.	n.s.	n.s.

[z]*Significant at $P < 0.05$; **significant at $P < 0.01$; ***significant at $P < 0.001$; ns=not significant.

[y]A = Planting method, B = Nitrogen Fertilizer rate and type, C = Mulch type, D = Cultivar.

Table 2.7 Effect of organic production systems on plant dry weight of 'Liberty' after one growing season, 2 Oct. 2007, NWREC (n=5; mean ± SE).

Planting method		N Fertilizer rate and type (kg·ha^{-1} N)		Mulch type		Proportion of total plant dry weight			
						Shoot:root ratio	Roots (%)	Crown (%)	1-yr & older wood (%)
Flat	A								
		29 Feather	B	Comp+Sawd	C	7.6 ± 0.7	9.0 ± 0.8	19.7 ± 2.4	46.9 ± 2.4
				Sawdust	C	5.6 ± 0.7	12.3 ± 1.6	19.3 ± 3.1	45.3 ± 3.4
				WeedMat	C	6.8 ± 0.6	9.6 ± 0.7	16.4 ± 3.4	47.4 ± 2.1
		29 Fish	B	Comp+Sawd	C	12.9 ± 2.2	5.5 ± 1.0	15.0 ± 1.9	47.6 ± 1.8
				Sawdust	C	10.7 ± 1.7	6.5 ± 1.0	15.8 ± 1.8	46.7 ± 1.5
				WeedMat	C	11.2 ± 1.8	6.1 ± 0.8	11.1 ± 2.0	50.9 ± 2.0
		57 Feather	B	Comp+Sawd	C	6.9 ± 0.6	10.2 ± 1.1	17.5 ± 3.6	50.8 ± 4.9
				Sawdust	C	5.2 ± 0.7	13.0 ± 1.5	22.7 ± 2.4	41.3 ± 1.4
				WeedMat	C	6.5 ± 0.6	10.2 ± 0.8	18.2 ± 2.6	46.2 ± 3.0
		57 Fish	B	Comp+Sawd	C	12.1 ± 1.7	5.4 ± 0.8	9.0 ± 1.6	51.1 ± 2.4
				Sawdust	C	15.7 ± 3.1	4.5 ± 0.8	13.4 ± 0.9	47.8 ± 0.9
				WeedMat	C	13.3 ± 2.4	5.0 ± 0.7	8.5 ± 0.7	52.9 ± 2.2
Raised	A								
		29 Feather	B	Comp+Sawd	C	10.7 ± 3.4	8.1 ± 1.6	19.3 ± 3.4	47.0 ± 2.4
				Sawdust	C	6.8 ± 1.1	10.6 ± 1.5	17.7 ± 2.8	47.7 ± 2.4
				WeedMat	C	9.1 ± 1.6	8.0 ± 1.1	17.9 ± 1.8	47.8 ± 2.5
		29 Fish	B	Comp+Sawd	C	11.7 ± 0.9	5.6 ± 0.4	12.7 ± 1.8	51.2 ± 2.3
				Sawdust	C	10.8 ± 2.7	6.9 ± 1.3	12.7 ± 1.1	48.6 ± 0.6
				WeedMat	C	12.9 ± 1.9	5.4 ± 0.8	11.6 ± 1.5	52.7 ± 1.8
		57 Feather	B	Comp+Sawd	C	9.8 ± 0.7	6.9 ± 0.5	17.9 ± 2.0	48.6 ± 2.0
				Sawdust	C	8.8 ± 0.6	7.7 ± 0.4	18.9 ± 1.4	48.2 ± 1.1
				WeedMat	C	9.8 ± 1.9	8.4 ± 2.4	17.7 ± 1.9	48.2 ± 2.5
		57 Fish	B	Comp+Sawd	C	13.8 ± 2.9	5.2 ± 1.1	10.4 ± 2.4	49.5 ± 3.0
				Sawdust	C	11.3 ± 2.5	6.4 ± 1.3	10.3 ± 2.2	49.1 ± 1.9
				WeedMat	C	15.2 ± 0.9	4.1 ± 0.3	9.0 ± 1.2	52.0 ± 1.0
Significance[z]									
Planting method			(A)[y]			n.s.	*	n.s.	n.s.
N fertilizer rate and type			(B)			***	***	***	**
Mulch type			(C)			*	***	***	***
Cultivar			(D)			***	***	n.s.	***
A x B						n.s.	n.s.	n.s.	n.s.
A x C						n.s.	n.s.	n.s.	n.s.
B x C						n.s.	n.s.	n.s.	n.s.
B x D						n.s.	*	n.s.	n.s.
C x D						n.s.	n.s.	n.s.	n.s.

[z]*Significant at $P < 0.05$; **significant at $P < 0.01$; ***significant at $P < 0.001$; ns=not significant.

[y]A = Planting method, B = Nitrogen Fertilizer rate and type, C = Mulch type, D = Cultivar.

Table 2.8 The effect of organic production systems on yield and fruit quality of 'Duke' in the second growing season, 2008, NWREC (n=5; mean ± SE).

Planting method		N Fertilizer rate and type ($kg \cdot ha^{-1}$ N)		Mulch type		Duke: Yield (g/plant)	Berry weight (g)	Brix (%)	Firmness ($g.mm^{-1}$ of deflection)
Flat	A								
		29 Feather	B	Comp+Sawd	C	135.8 ± 11.4	2.1 ± 0.0	13.7 ± 0.9	191.6 ± 7.2
				Sawdust	C	84.0 ± 36.9	2.2 ± 0.1	13.0 ± 0.3	200.4 ± 5.2
				WeedMat	C	205.2 ± 66.0	2.0 ± 0.1	13.6 ± 0.1	202.1 ± 6.3
		29 Fish	B	Comp+Sawd	C	359.8 ± 80.6	2.1 ± 0.1	13.6 ± 0.2	217.7 ± 5.9
				Sawdust	C	369.2 ± 45.0	2.2 ± 0.1	13.7 ± 0.5	215.5 ± 5.8
				WeedMat	C	456.8 ± 56.0	2.2 ± 0.0	13.8 ± 0.3	221.6 ± 7.5
		57 Feather	B	Comp+Sawd	C	121.6 ± 57.8	2.1 ± 0.1	13.7 ± 0.2	219.5 ± 12.1
				Sawdust	C	61.9 ± 9.8	2.2 ± 0.1	12.7 ± 0.0	198.2 ± 0.0
				WeedMat	C	251.0 ± 54.1	2.0 ± 0.1	14.8 ± 0.7	201.7 ± 3.6
		57 Fish	B	Comp+Sawd	C	271.2 ± 41.3	2.1 ± 0.0	14.0 ± 0.4	238.3 ± 5.9
				Sawdust	C	257.0 ± 41.6	2.0 ± 0.1	15.1 ± 0.5	222.8 ± 2.2
				WeedMat	C	220.0 ± 33.5	1.9 ± 0.0	14.5 ± 0.5	222.7 ± 6.0
Raised	A								
		29 Feather	B	Comp+Sawd	C	198.3 ± 67.8	2.3 ± 0.1	13.1 ± 0.4	204.9 ± 5.7
				Sawdust	C	113.3 ± 30.8	2.4 ± 0.1	13.5 ± 0.2	208.6 ± 3.5
				WeedMat	C	270.1 ± 68.5	2.2 ± 0.0	13.4 ± 0.4	199.0 ± 2.5
		29 Fish	B	Comp+Sawd	C	495.7 ± 57.5	2.3 ± 0.0	13.6 ± 0.3	224.6 ± 4.5
				Sawdust	C	410.4 ± 47.3	2.3 ± 0.0	14.2 ± 0.1	218.9 ± 1.8
				WeedMat	C	556.0 ± 51.9	2.2 ± 0.0	13.9 ± 0.0	219.4 ± 4.4
		57 Feather	B	Comp+Sawd	C	286.1 ± 36.3	2.2 ± 0.1	13.1 ± 0.5	216.3 ± 3.0
				Sawdust	C	207.8 ± 32.3	2.3 ± 0.0	13.5 ± 0.4	221.1 ± 6.8
				WeedMat	C	355.3 ± 93.1	2.1 ± 0.1	13.5 ± 0.4	207.4 ± 3.3
		57 Fish	B	Comp+Sawd	C	406.5 ± 52.3	2.2 ± 0.1	14.2 ± 0.5	225.0 ± 1.6
				Sawdust	C	345.7 ± 40.2	2.1 ± 0.0	13.8 ± 0.3	223.8 ± 3.2
				WeedMat	C	380.5 ± 77.9	2.0 ± 0.0	14.1 ± 0.8	232.1 ± 2.5
Significance[z]									
Planting method		(A)[y]				*	*	**	n.s.
N fertilizer rate and type		(B)				**	*	**	**
Mulch type		(C)				**	n.s.	n.s.	*
Cultivar		(D)				**	**	***	**
A x B						n.s.	n.s.	n.s.	n.s.
A x C						n.s.	n.s.	n.s.	n.s.
B x C						n.s.	*	n.s.	n.s.
B x D						**	*	*	*
C x D						n.s.	**	*	n.s.

[z]*Significant at $P < 0.05$; **significant at $P < 0.01$; ***significant at $P < 0.001$; ns=not significant.

[y]A = Planting method, B = Nitrogen Fertilizer rate and type, C = Mulch type, D = Cultivar.

Table 2.9 The effect of organic production systems on yield and fruit quality of 'Liberty' in the second growing season, 2008, NWREC (n=5; mean ± SE).

Planting method		N Fertilizer rate and type (kg·ha^{-1} N)		Mulch type		Liberty Yield (g/plant)	Berry weight (g)	Brix (%)	Firmness (g.mm^{-1} of deflection)
Flat	A								
		29 Feather	B	Comp+Sawd	C	365.8 ± 49.8	1.9 ± 0.1	16.8 ± 0.2	166.4 ± 1.6
				Sawdust	C	242.3 ± 63.0	2.1 ± 0.1	16.8 ± 0.2	167.9 ± 5.0
				WeedMat	C	376.0 ± 38.6	2.0 ± 0.0	16.5 ± 0.3	157.8 ± 4.5
		29 Fish	B	Comp+Sawd	C	432.3 ± 55.8	1.9 ± 0.1	16.9 ± 0.5	179.9 ± 9.3
				Sawdust	C	389.0 ± 19.3	2.0 ± 0.0	16.7 ± 0.2	181.5 ± 7.8
				WeedMat	C	462.6 ± 37.0	2.1 ± 0.0	15.7 ± 0.3	172.2 ± 4.7
		57 Feather	B	Comp+Sawd	C	331.1 ± 62.6	1.9 ± 0.1	17.3 ± 0.4	174.5 ± 9.5
				Sawdust	C	179.5 ± 53.1	1.9 ± 0.1	16.1 ± 0.5	169.4 ± 3.5
				WeedMat	C	440.6 ± 43.6	2.1 ± 0.0	16.6 ± 0.1	166.2 ± 5.2
		57 Fish	B	Comp+Sawd	C	320.6 ± 38.6	2.0 ± 0.0	16.4 ± 0.1	182.1 ± 4.1
				Sawdust	C	245.3 ± 18.4	1.9 ± 0.1	16.5 ± 0.7	185.0 ± 5.2
				WeedMat	C	365.8 ± 39.3	2.0 ± 0.1	15.4 ± 0.1	177.8 ± 6.5
Raised	A								
		29 Feather	B	Comp+Sawd	C	426.7 ± 84.8	2.0 ± 0.1	14.8 ± 0.3	167.9 ± 5.3
				Sawdust	C	329.6 ± 49.0	2.1 ± 0.1	15.4 ± 0.1	166.7 ± 5.7
				WeedMat	C	439.9 ± 31.3	2.1 ± 0.0	15.4 ± 0.1	160.7 ± 3.6
		29 Fish	B	Comp+Sawd	C	570.8 ± 71.1	2.1 ± 0.1	15.5 ± 0.3	173.8 ± 0.6
				Sawdust	C	439.3 ± 31.1	2.1 ± 0.0	15.2 ± 0.4	176.9 ± 2.0
				WeedMat	C	546.0 ± 61.0	2.3 ± 0.0	15.4 ± 0.4	175.7 ± 1.7
		57 Feather	B	Comp+Sawd	C	546.1 ± 52.8	2.1 ± 0.0	16.1 ± 0.4	169.3 ± 3.3
				Sawdust	C	421.9 ± 42.9	2.1 ± 0.1	15.9 ± 0.2	176.0 ± 0.6
				WeedMat	C	504.9 ± 44.9	2.2 ± 0.1	15.7 ± 0.3	165.6 ± 2.3
		57 Fish	B	Comp+Sawd	C	471.0 ± 19.1	2.1 ± 0.0	16.6 ± 0.3	180.8 ± 4.6
				Sawdust	C	418.0 ± 43.2	2.1 ± 0.0	15.7 ± 0.3	183.7 ± 1.0
				WeedMat	C	438.8 ± 57.3	2.2 ± 0.0	15.3 ± 0.4	173.3 ± 4.1
Significance[z]									
Planting method			(A)[y]			*	*	**	n.s.
N fertilizer rate and type			(B)			**	*	**	**
Mulch type			(C)			**	n.s.	n.s.	*
Cultivar			(D)			**	**	***	**
A x B						n.s.	n.s.	n.s.	n.s.
A x C						n.s.	n.s.	n.s.	n.s.
B x C						n.s.	*	n.s.	n.s.
B x D						**	*	*	*
C x D						n.s.	**	*	n.s.

[z]*Significant at $P < 0.05$; **significant at $P < 0.01$; ***significant at $P < 0.001$; ns=not significant.

[y]A = Planting method, B = Nitrogen Fertilizer rate and type, C = Mulch type, D = Cultivar.

Table 2.10 Effect of organic production systems on plant dry weight of 'Duke' after two growing seasons, 17 Oct. 2008, NWREC (n=5; mean ± SE).

Planting method	N Fertilizer rate and type (kg·ha^{-1} N)	Mulch type	Plant dry weight Roots (g)	Crown (g)	1-yr-old wood (g)	2yr & older wood (g)	Leaves (g)	Total plant (g)
Flat A								
	29 Feather	B Comp+Sawd C	101.4 ± 17.5	104.0 ± 26.3	115.6 ± 19.9	146.8 ± 12.8	180.8 ± 26.0	648.6 ± 82.3
		Sawdust C	114.6 ± 12.7	66.4 ± 4.6	106.0 ± 11.3	146.0 ± 15.5	159.4 ± 16.8	592.4 ± 36.1
		WeedMat C	110.8 ± 17.4	80.4 ± 12.1	92.0 ± 11.0	138.8 ± 10.8	154.4 ± 10.1	576.4 ± 51.4
	29 Fish	B Comp+Sawd C	91.0 ± 14.4	65.2 ± 14.7	89.6 ± 14.7	192.0 ± 25.5	192.4 ± 24.1	630.2 ± 80.9
		Sawdust C	134.4 ± 14.2	113.2 ± 11.1	124.8 ± 6.7	226.8 ± 36.6	262.0 ± 13.6	861.2 ± 47.8
		WeedMat C	86.6 ± 25.4	53.6 ± 16.4	78.8 ± 16.6	222.8 ± 37.0	182.4 ± 28.7	624.2 ± 102.1
	57 Feather	B Comp+Sawd C	112.2 ± 18.7	65.2 ± 10.9	98.0 ± 11.9	166.4 ± 25.5	181.6 ± 17.0	623.4 ± 57.8
		Sawdust C	80.0 ± 11.7	62.8 ± 6.5	93.6 ± 11.4	114.4 ± 4.2	140.4 ± 12.2	491.2 ± 33.4
		WeedMat C	120.8 ± 7.4	68.0 ± 8.9	86.5 ± 10.7	160.0 ± 8.8	171.0 ± 7.9	606.3 ± 22.1
	57 Fish	B Comp+Sawd C	85.0 ± 18.1	78.5 ± 14.8	110.5 ± 31.4	206.0 ± 27.8	246.0 ± 23.9	726 ± 98.5
		Sawdust C	72.0 ± 14.4	44.5 ± 8.4	83.0 ± 17.0	201.0 ± 43.3	242.0 ± 42.9	642.5 ± 122.1
		WeedMat C	32.5 ± 1.0	30.0 ± 2.2	70.0 ± 12.5	171.0 ± 30.9	186.5 ± 25.0	490.0 ± 62.7
Raised A								
	29 Feather	B Comp+Sawd C	97.2 ± 13.7	93.2 ± 10.1	128.4 ± 13.5	146.4 ± 19.8	194.4 ± 21.8	659.6 ± 61.6
		Sawdust C	105.2 ± 16.9	70.0 ± 11.4	138.8 ± 14.9	177.6 ± 33.5	232.8 ± 18.1	724.4 ± 66.2
		WeedMat C	101.2 ± 2.5	76.8 ± 4.6	130.0 ± 12.2	164.0 ± 21.1	193.2 ± 13.7	665.2 ± 44.0
	29 Fish	B Comp+Sawd C	142.0 ± 14.4	100.8 ± 8.9	161.6 ± 23.9	276.4 ± 21.8	297.6 ± 17.5	978.4 ± 60.5
		Sawdust C	156.2 ± 16.0	110.4 ± 7.8	198.0 ± 20.8	278.4 ± 25.9	345.2 ± 20.7	1088.2 ± 64.4
		WeedMat C	79.2 ± 10.1	73.2 ± 14.4	119.6 ± 22.3	220.8 ± 25.8	236.8 ± 31.9	729.6 ± 97.0
	57 Feather	B Comp+Sawd C	103.0 ± 10.5	66.8 ± 11.1	129.6 ± 22.1	232.0 ± 27.5	266.4 ± 23.6	797.8 ± 83.2
		Sawdust C	114.2 ± 22.7	62.0 ± 8.2	143.2 ± 17.8	220.4 ± 31.9	258.8 ± 17.3	798.6 ± 81.9
		WeedMat C	107.2 ± 16.4	86.0 ± 6.0	175.6 ± 20.1	222.0 ± 15.0	246.0 ± 16.2	836.8 ± 48.1
	57 Fish	B Comp+Sawd C	93.8 ± 22.0	59.6 ± 11.0	147.2 ± 21.5	241.6 ± 40.7	299.2 ± 41.7	841.4 ± 121.8
		Sawdust C	81.0 ± 6.7	63.2 ± 7.7	138.0 ± 21.3	212.0 ± 43.5	290.4 ± 29.1	784.6 ± 85.7
		WeedMat C	58.8 ± 11.6	35.2 ± 0.8	102.4 ± 19.4	186.0 ± 24.1	217.6 ± 25.3	600.0 ± 76.0
Significance[z]								
Planting method	(A)[y]		n.s.	n.s.	**	n.s.	***	***
N fertilizer rate and type	(B)		**	**	n.s.	***	***	*
Mulch type	(C)		*	*	*	n.s.	*	n.s.
Cultivar	(D)		n.s.	***	***	***	***	***
A x B			n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
A x C			n.s.	n.s.	n.s.	n.s.	*	n.s.
B x C			***	**	**	n.s.	**	**
B x D			n.s.	n.s.	*	**	n.s.	*
C x D			n.s.	n.s.	n.s.	*	*	n.s.

[z]*Significant at $P < 0.05$; **significant at $P < 0.01$; ***significant at $P < 0.001$; ns=not significant.

[y]A = Planting method, B = Nitrogen Fertilizer rate and type, C = Mulch type, D = Cultivar.

Table 2.11 Effect of organic production systems on plant dry weight of 'Liberty' after two growing seasons, 17 Oct. 2008, NWREC (n=5; mean ± SE).

Planting method	N Fertilizer rate and type (kg·ha⁻¹ N)	Mulch type	Plant dry weight Roots (g)	Crown (g)	1-yr old wood (g)	2yr & older wood (g)	Leaves (g)	Total plant (g)
Flat A								
	29 Feather B	Comp+Sawd C	106.8 ± 19.6	123.6 ± 9.5	131.2 ± 15.2	173.2 ± 9.6	195.2 ± 10.3	730.0 ± 43.9
		Sawdust C	113.6 ± 4.7	100.8 ± 11.9	120.8 ± 14.1	122.4 ± 10.6	160.8 ± 15.7	618.4 ± 28.2
		WeedMat C	100.4 ± 22.9	122.8 ± 6.7	115.2 ± 25.4	182.4 ± 17.2	192.4 ± 24.8	713.2 ± 92.3
	29 Fish B	Comp+Sawd C	130.0 ± 27.9	108.0 ± 8.5	130.8 ± 2.8	282.0 ± 20.3	243.6 ± 17.2	894.4 ± 57.5
		Sawdust C	77.2 ± 7.4	113.6 ± 7.4	142.4 ± 11.3	239.6 ± 19.3	237.2 ± 12.6	810.0 ± 18.0
		WeedMat C	81.0 ± 19.8	95.0 ± 25.4	110.0 ± 23.1	301.5 ± 44.2	244.5 ± 19.8	832.0 ± 116.9
	57 Feather B	Comp+Sawd C	92.2 ± 11.6	89.2 ± 8.1	110.4 ± 11.2	169.6 ± 19.3	204.4 ± 16.6	665.8 ± 51.3
		Sawdust C	82.0 ± 11.6	87.6 ± 9.9	109.0 ± 11.0	118.8 ± 16.5	158.4 ± 13.1	555.8 ± 50.8
		WeedMat C	96.8 ± 19.4	80.0 ± 10.8	126.8 ± 24.7	195.6 ± 12.5	215.6 ± 19.2	714.8 ± 66.6
	57 Fish B	Comp+Sawd C	91.4 ± 14.0	90.0 ± 13.6	160.4 ± 16.5	292.0 ± 30.3	308.0 ± 14.9	941.8 ± 40.4
		Sawdust C	102.5 ± 16.8	106.0 ± 17.3	193.0 ± 15.3	238.5 ± 53.1	322.0 ± 41.3	962.0 ± 88.8
		WeedMat C	100.6 ± 16.5	73.6 ± 19.6	186.4 ± 15.5	340.0 ± 35.5	335.6 ± 24.1	1036.2 ± 101.3
Raised A								
	29 Feather B	Comp+Sawd C	87.8 ± 14.9	101.6 ± 13.9	137.6 ± 22.2	192.8 ± 14.1	202.8 ± 10.9	722.6 ± 44.1
		Sawdust C	149.5 ± 21.3	118.5 ± 18.0	185.0 ± 31.9	174.5 ± 17.0	259.5 ± 26.6	887.0 ± 80.7
		WeedMat C	80.3 ± 17.3	118.0 ± 9.6	147.5 ± 18.8	255.5 ± 26.6	255.0 ± 25.1	856.3 ± 59.4
	29 Fish B	Comp+Sawd C	157.2 ± 47.2	120.4 ± 16.6	236.4 ± 46.6	306.8 ± 78.1	357.2 ± 35.7	1178.0 ± 170.2
		Sawdust C	86.8 ± 18.5	96.0 ± 26.5	139.6 ± 29.1	259.6 ± 44.0	265.2 ± 35.1	847.2 ± 130.0
		WeedMat C	58.7 ± 6.7	82.0 ± 4.2	129.3 ± 28.8	266.7 ± 28.2	259.3 ± 34.1	796.0 ± 92.7
	57 Feather B	Comp+Sawd C	100.4 ± 25.6	116.8 ± 20.8	193.2 ± 26.5	237.2 ± 18.8	279.6 ± 15.0	927.2 ± 60.8
		Sawdust C	82.4 ± 21.9	113.2 ± 17.4	176.8 ± 46.1	183.6 ± 22.0	246.0 ± 38.0	802.0 ± 121.9
		WeedMat C	130.6 ± 15.0	117.6 ± 25.0	219.2 ± 45.5	230.0 ± 28.7	272.4 ± 32.4	969.8 ± 138.2
	57 Fish B	Comp+Sawd C	64.4 ± 7.5	88.8 ± 14.6	136.4 ± 30.7	273.2 ± 40.0	243.2 ± 33.8	806.0 ± 102.1
		Sawdust C	80.7 ± 4.8	131.3 ± 7.0	302.0 ± 74.9	379.3 ± 12.1	414.0 ± 58.6	1307.3 ± 130.0
		WeedMat C	48.6 ± 11.9	66.0 ± 12.1	121.6 ± 23.7	246.4 ± 53.8	250.8 ± 29.3	733.4 ± 110.4
Significance[z]								
Planting method	(A)v		n.s.	n.s.	**	n.s.	***	***
N fertilizer rate and type	(B)		**	**	n.s.	***	***	*
Mulch type	(C)		*	*	*	n.s.	*	n.s.
Cultivar	(D)		n.s.	***	***	***	***	***
A x B			n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
A x C			n.s.	n.s.	n.s.	n.s.	*	n.s.
B x C			***	**	**	n.s.	**	**
B x D			n.s.	n.s.	*	**	n.s.	*
C x D			n.s.	n.s.	n.s.	*	*	n.s.

[z]*Significant at *P* < 0.05; **significant at *P* < 0.01; ***significant at *P* < 0.001; ns=not significant.

[y]A = Planting method, B = Nitrogen Fertilizer rate and type, C = Mulch type, D = Cultivar.

Table 2.12 Soil nutrient analysis sampled 20 cm depth below mulching under 'Duke' plants, Nov. 5 2008, NWREC (n=10; mean).

N Fertilizer rate and type ($Kg \cdot ha^{-1}$)		Mulch type		Macronutrients NH_3-N ($mg \cdot kg^{-1}$)	NH_4-N ($mg \cdot kg^{-1}$)	P ($mg \cdot kg^{-1}$)	K ($mg \cdot kg^{-1}$)	Ca ($mg \cdot kg^{-1}$)	Mg ($mg \cdot kg^{-1}$)	Micronutrients Fe ($mg \cdot kg^{-1}$)	B ($mg \cdot kg^{-1}$)	Cu ($mg \cdot kg^{-1}$)	Mn ($mg \cdot kg^{-1}$)	Zn ($mg \cdot kg^{-1}$)	Al ($mg \cdot kg^{-1}$)	pH	OM ($g \cdot kg^{-1}$)
29 Feather	B	Comp+Sawd	C	1.46	2.65	186.9	352.0	1064.7	189.9	302.8	0.28	0.85	18.9	2.88	1318.2	5.6	4.68
		Sawdust	C	0.80	2.60	168.5	208.7	878.5	167.2	284.7	0.24	0.74	22.7	1.07	1336	5.6	3.74
		WeedMat	C	2.81	3.09	169.8	189.9	722.3	98.6	300.3	0.25	0.70	20.7	1.03	1409.3	5	3.68
29 Fish	B	Comp+Sawd	C	1.96	2.11	194.9	451.8	908.0	174.3	308.5	0.32	0.87	20.9	2.93	1262.8	5.5	4.65
		Sawdust	C	0.91	1.89	167.4	253.6	660.5	112.9	292.1	0.21	0.70	24.1	0.96	1339.8	5.1	3.40
		WeedMat	C	2.84	3.04	183.0	275.7	591.2	102.4	302.5	0.22	0.67	20.9	1.00	1372.2	4.8	3.51
57 Feather	B	Comp+Sawd	C	3.13	3.07	193.5	351.0	1023.0	188.4	298.4	0.25	0.84	18.0	2.82	1311.7	5.6	4.50
		Sawdust	C	1.34	2.73	183.0	195.1	788.2	146.6	292.9	0.22	0.73	22.6	1.02	1354	5.5	3.75
		WeedMat	C	3.21	5.19	174.9	157.2	647.0	97.2	297.5	0.21	0.70	22.6	1.17	1382.5	5	3.77
57 Fish	B	Comp+Sawd	C	13.60	2.31	208.9	447.4	991.3	202.9	311.1	0.25	0.89	25.8	3.36	1278.4	5.2	4.82
		Sawdust	C	6.35	2.60	183.9	293.5	719.5	130.2	299.8	0.21	0.71	30.6	1.15	1372.9	4.9	3.50
		WeedMat	C	37.21	25.44	221.8	347.2	465.8	83.0	316.9	0.22	0.67	33.7	1.35	1429.4	4.3	3.55
Significance[z]																	
N fertilizer rate and type			(B)[y]	***	***	n.s.	***	*	n.s.	n.s.	n.s.	n.s.	***	n.s.	n.s.	***	n.s.
Mulch type			(C)	***	***	***	***	***	***	***	***	***	**	***	***	***	***
B x C				***	***	***	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

[z]*Significant at $P < 0.05$; **significant at $P < 0.01$; ***significant at $P < 0.001$; ns=not significant.

[y]B = Nitrogen Fertilizer rate and type, C = Mulch type

Table 2.13 Effect of organic production systems on plant dry weight of 'Duke' after two growing seasons, 17 Oct. 2008, NWREC (n=5; mean ± SE).

Planting method		N Fertilizer rate and type ($kg \cdot ha^{-1}$ N)		Mulch type		Whip no.	Leaf area (cm^2)	Leaf area index
Flat	A							
		29 Feather	B	Comp+Sawd	C	5.5 ± 1.6	12234.4 ± 2042.1	3.1 ± 0.5
				Sawdust	C	2.2 ± 0.4	9957.6 ± 1147.0	2.6 ± 0.4
				WeedMat	C	2.0 ± 0.6	11071.2 ± 1963.9	3.0 ± 0.7
		29 Fish	B	Comp+Sawd	C	2.5 ± 1.5	14358.2 ± 2454.6	2.7 ± 0.5
				Sawdust	C	4.0 ± 1.1	16895.2 ± 1208.5	3.8 ± 0.6
				WeedMat	C	1.0 ± 0.1	12653.6 ± 2748.9	2.3 ± 0.3
		57 Feather	B	Comp+Sawd	C	3.4 ± 0.9	12999.2 ± 1781.4	2.9 ± 0.4
				Sawdust	C	3.3 ± 0.3	10220.0 ± 789.4	2.3 ± 0.2
				WeedMat	C	4.0 ± 3.0	11890.3 ± 1009.9	3.6 ± 0.6
		57 Fish	B	Comp+Sawd	C	1.3 ± 0.3	18412.5 ± 744.5	3.2 ± 0.3
				Sawdust	C	2.0 ± 0.4	17159.8 ± 3347.3	4.4 ± 1.5
				WeedMat	C	5.0 ± 0.1	12529.3 ± 1550.6	2.8 ± 0.2
Raised	A							
		29 Feather	B	Comp+Sawd	C	5.0 ± 2.7	11951.8 ± 1308.8	2.9 ± 0.4
				Sawdust	C	2.3 ± 0.8	16196.4 ± 1085.3	4.4 ± 0.8
				WeedMat	C	1.7 ± 0.3	11788.8 ± 878.7	2.5 ± 0.3
		29 Fish	B	Comp+Sawd	C	3.0 ± 0.6	20473.4 ± 1756.2	3.0 ± 0.4
				Sawdust	C	2.0 ± 0.4	22758.0 ± 1708.1	3.7 ± 0.9
				WeedMat	C	1.7 ± 0.7	16912.4 ± 2217.7	2.8 ± 0.1
		57 Feather	B	Comp+Sawd	C	3.8 ± 0.8	17816.6 ± 1672.3	2.9 ± 0.2
				Sawdust	C	2.5 ± 0.3	17474.4 ± 1497.9	3.7 ± 0.6
				WeedMat	C	3.2 ± 0.9	17519.6 ± 1258.0	2.6 ± 0.2
		57 Fish	B	Comp+Sawd	C	2.2 ± 0.6	21918.8 ± 2399.3	3.5 ± 0.5
				Sawdust	C	5.0 ± 2.0	20343.8 ± 1714.3	3.3 ± 0.1
				WeedMat	C	2.0 ± 0.0	15438.0 ± 2058.1	3.6 ± 0.3
Significance[z]								
Planting method			(A)[y]			n.s.	**	n.s.
N fertilizer rate and type			(B)			***	***	**
Mulch type			(C)			*	**	n.s.
Cultivar			(D)			***	**	n.s.
A x B						n.s.	n.s.	n.s.
A x C						n.s.	*	n.s.
B x C						n.s.	**	n.s.
B x D						*	n.s.	n.s.
C x D						n.s.	n.s.	n.s.

[z]*Significant at $P < 0.05$; **significant at $P < 0.01$; ***significant at $P < 0.001$; ns=not significant.

[y]A = Planting method, B = Nitrogen Fertilizer rate and type, C = Mulch type, D = Cultivar.

Table 2.14 Effect of organic production systems on plant dry weight of 'Liberty' after two growing seasons, 17 Oct. 2008, NWREC (n=5; mean ± SE).

Planting method		N Fertilizer rate and type (kg·ha⁻¹ N)		Mulch type		Whip no.	Leaf area (cm²)	Leaf area index
Flat	A							
		29 Feather	B	Comp+Sawd	C	13.2 ± 3.5	13932.2 ± 949.5	2.9 ± 0.5
				Sawdust	C	13.2 ± 3.1	10329.4 ± 947.4	2.0 ± 0.3
				WeedMat	C	9.6 ± 3.0	11527.0 ± 1401.0	2.0 ± 0.1
		29 Fish	B	Comp+Sawd	C	5.6 ± 1.5	18263.6 ± 2021.9	4.0 ± 0.5
				Sawdust	C	11.0 ± 0.7	15436.2 ± 902.5	3.5 ± 0.2
				WeedMat	C	6.8 ± 2.5	15762.0 ± 2681.1	2.5 ± 0.5
		57 Feather	B	Comp+Sawd	C	9.0 ± 1.2	13516.0 ± 1094.3	2.7 ± 0.6
				Sawdust	C	9.8 ± 2.5	10235.8 ± 1594.7	1.9 ± 0.2
				WeedMat	C	6.2 ± 1.7	14105.0 ± 1591.4	2.8 ± 0.2
		57 Fish	B	Comp+Sawd	C	3.6 ± 0.7	22870.4 ± 403.1	3.7 ± 0.4
				Sawdust	C	7.8 ± 3.4	20222.5 ± 3155.5	3.9 ± 0.6
				WeedMat	C	3.2 ± 0.9	21710.6 ± 1545.3	4.3 ± 1.0
Raised	A							
		29 Feather	B	Comp+Sawd	C	12.2 ± 1.5	13350.0 ± 1510.2	2.7 ± 0.4
				Sawdust	C	13.6 ± 2.5	17655.8 ± 2256.1	3.2 ± 0.5
				WeedMat	C	8.0 ± 0.9	16248.5 ± 1670.6	3.0 ± 0.2
		29 Fish	B	Comp+Sawd	C	11.6 ± 4.9	25009.4 ± 2961.0	5.3 ± 2.4
				Sawdust	C	8.8 ± 2.3	17836.6 ± 2317.4	3.2 ± 0.6
				WeedMat	C	3.2 ± 0.7	16271.7 ± 1969.7	3.4 ± 0.3
		57 Feather	B	Comp+Sawd	C	14.5 ± 1.6	18764.6 ± 833.0	2.5 ± 0.2
				Sawdust	C	12.2 ± 3.3	16140.8 ± 2548.8	2.9 ± 0.3
				WeedMat	C	11.8 ± 3.0	18615.2 ± 2682.7	3.0 ± 0.3
		57 Fish	B	Comp+Sawd	C	9.8 ± 2.0	17944.2 ± 2056.3	2.5 ± 0.2
				Sawdust	C	5.6 ± 0.5	30052.0 ± 3946.4	4.1 ± 0.3
				WeedMat	C	3.0 ± 1.2	17309.6 ± 2037.3	4.3 ± 0.6
Significance[z]								
Planting method			(A)[y]			n.s.	**	n.s.
N fertilizer rate and type			(B)			***	***	**
Mulch type			(C)			*	**	n.s.
Cultivar			(D)			***	**	n.s.
A x B						n.s.	n.s.	n.s.
A x C						n.s.	*	n.s.
B x C						n.s.	**	n.s.
B x D						*	n.s.	n.s.
C x D						n.s.	n.s.	n.s.

[z]*Significant at $P < 0.05$; **significant at $P < 0.01$; ***significant at $P < 0.001$; ns=not significant.

[y]A = Planting method, B = Nitrogen Fertilizer rate and type, C = Mulch type, D = Cultivar.

Table 2.15 Effect of organic production systems on plant dry weight of 'Duke' after two growing seasons, 17 Oct. 2008, NWREC (n=5; mean ± SE).

Planting method		N Fertilizer rate and type (kg·ha⁻¹ N)		Mulch type		Proportion of total plant dry weight: Shoot:root ratio	Roots (%)	Crown (%)	1yr old wood (%)	2yr & older wood (%)
Flat	A									
		29 Feather	B	Comp+Sawd	C	3.9 ± 0.6	16.0 ± 2.4	15.1 ± 2.2	17.5 ± 1.7	23.7 ± 2.9
				Sawdust	C	2.9 ± 0.3	19.4 ± 2.0	11.4 ± 0.9	18.1 ± 2.1	24.5 ± 1.6
				WeedMat	C	3.0 ± 0.5	19.0 ± 2.0	13.9 ± 1.7	15.9 ± 1.0	24.2 ± 1.2
		29 Fish	B	Comp+Sawd	C	4.0 ± 0.3	14.2 ± 0.9	10.5 ± 1.8	14.2 ± 1.1	30.4 ± 1.4
				Sawdust	C	3.6 ± 0.3	15.6 ± 1.3	13.5 ± 1.9	14.6 ± 0.7	25.7 ± 3.1
				WeedMat	C	4.9 ± 0.8	13.1 ± 2.1	8.9 ± 2.2	12.3 ± 1.5	35.9 ± 2.3
		57 Feather	B	Comp+Sawd	C	3.3 ± 0.8	18.3 ± 2.6	10.5 ± 1.7	15.7 ± 1.4	26.4 ± 2.9
				Sawdust	C	3.7 ± 0.6	16.2 ± 2.1	12.7 ± 0.7	18.9 ± 1.4	23.7 ± 1.6
				WeedMat	C	2.7 ± 0.2	20.0 ± 1.2	11.2 ± 1.2	14.2 ± 1.4	26.5 ± 1.9
		57 Fish	B	Comp+Sawd	C	5.1 ± 0.7	11.2 ± 1.5	10.6 ± 0.8	14.2 ± 3.4	29.3 ± 3.5
				Sawdust	C	4.6 ± 0.1	11.1 ± 0.6	7.1 ± 0.7	12.8 ± 1.3	30.7 ± 1.2
				WeedMat	C	8.3 ± 1.0	6.9 ± 0.6	6.4 ± 0.8	14.4 ± 2.4	34.3 ± 1.9
Raised	A									
		29 Feather	B	Comp+Sawd	C	4.1 ± 0.6	14.8 ± 1.5	14.5 ± 2.0	19.6 ± 1.7	21.9 ± 1.2
				Sawdust	C	4.0 ± 0.5	14.3 ± 1.7	9.7 ± 1.6	19.3 ± 1.5	24.1 ± 3.1
				WeedMat	C	3.7 ± 0.2	15.4 ± 0.8	11.9 ± 1.4	19.8 ± 0.9	24.2 ± 2.0
		29 Fish	B	Comp+Sawd	C	3.9 ± 0.5	14.5 ± 1.2	10.3 ± 0.6	16.2 ± 1.6	28.4 ± 2.0
				Sawdust	C	3.9 ± 0.4	14.4 ± 1.2	10.2 ± 0.9	18.0 ± 1.1	25.5 ± 1.5
				WeedMat	C	5.3 ± 0.5	11.0 ± 0.9	9.8 ± 0.8	15.9 ± 1.3	30.9 ± 2.1
		57 Feather	B	Comp+Sawd	C	4.2 ± 0.2	13.0 ± 0.5	8.2 ± 0.6	15.9 ± 1.6	29.2 ± 1.9
				Sawdust	C	4.4 ± 1.0	13.8 ± 2.0	8.0 ± 1.1	17.9 ± 1.4	27.3 ± 2.0
				WeedMat	C	5.1 ± 1.0	12.7 ± 1.8	10.3 ± 0.6	20.8 ± 1.5	26.8 ± 1.8
		57 Fish	B	Comp+Sawd	C	5.5 ± 0.9	10.7 ± 1.4	7.0 ± 0.5	17.9 ± 2.0	28.6 ± 1.6
				Sawdust	C	5.2 ± 0.8	10.7 ± 1.1	8.2 ± 1.1	17.4 ± 1.6	26.5 ± 3.3
				WeedMat	C	6.1 ± 0.9	9.5 ± 1.2	6.5 ± 1.3	16.4 ± 1.9	30.9 ± 0.3
Significance[z]										
Planting method				(A)[y]		n.s.	n.s.	*	n.s.	n.s.
N fertilizer rate and type				(B)		***	***	***	n.s.	***
Mulch type				(C)		**	*	n.s.	*	***
Cultivar				(D)		***	***	***	**	n.s.
A x B						n.s.	n.s.	n.s.	n.s.	n.s.
A x C						n.s.	n.s.	n.s.	n.s.	n.s.
B x C						*	**	n.s.	n.s.	n.s.
B x D						n.s.	n.s.	n.s.	n.s.	n.s.
C x D						n.s.	n.s.	n.s.	n.s.	n.s.

[z]*Significant at $P < 0.05$; **significant at $P < 0.01$; ***significant at $P < 0.001$; ns=not significant.

[y]A = Planting method, B = Nitrogen Fertilizer rate and type, C = Mulch type, D = Cultivar.

Table 2.16 Effect of organic production systems on plant dry weight of 'Liberty' after two growing seasons, 17 Oct. 2008, NWREC (n=5; mean ± SE).

Planting method		N Fertilizer rate and type (kg·ha⁻¹ N)		Mulch type		Proportion of total plant dry weight: Shoot:root ratio	Roots (%)	Crown (%)	1yr old wood (%)	2yr & older wood (g)
Flat	A									
		29 Feather	B	Comp+Sawd	C	4.5 ± 0.8	14.4 ± 2.0	17.3 ± 1.7	17.8 ± 1.0	23.9 ± 1.1
				Sawdust	C	3.1 ± 0.1	18.5 ± 0.8	16.7 ± 2.5	19.4 ± 1.7	19.7 ± 1.1
				WeedMat	C	4.9 ± 0.9	13.5 ± 1.8	17.9 ± 1.4	15.6 ± 1.4	26.1 ± 1.7
		29 Fish	B	Comp+Sawd	C	5.0 ± 1.2	14.0 ± 2.6	12.2 ± 1.0	14.9 ± 1.3	31.5 ± 0.8
				Sawdust	C	6.7 ± 0.8	9.5 ± 0.9	14.0 ± 0.8	17.6 ± 1.5	29.6 ± 2.3
				WeedMat	C	6.8 ± 0.9	9.4 ± 1.3	11.0 ± 1.9	12.9 ± 1.2	36.4 ± 2.7
		57 Feather	B	Comp+Sawd	C	4.2 ± 0.5	13.7 ± 1.1	13.5 ± 1.0	16.6 ± 1.3	25.5 ± 2.6
				Sawdust	C	4.1 ± 0.5	14.7 ± 1.5	15.9 ± 1.4	19.6 ± 1.1	21.2 ± 1.7
				WeedMat	C	4.7 ± 0.7	13.0 ± 1.8	11.2 ± 1.1	17.4 ± 2.2	28.1 ± 2.4
		57 Fish	B	Comp+Sawd	C	6.9 ± 1.7	9.7 ± 1.3	9.6 ± 1.3	17.4 ± 2.5	30.7 ± 2.4
				Sawdust	C	5.5 ± 0.8	10.5 ± 0.9	11.2 ± 1.9	20.9 ± 3.2	24.1 ± 3.6
				WeedMat	C	6.4 ± 0.7	9.4 ± 0.9	6.8 ± 1.3	18.1 ± 0.4	32.7 ± 0.8
Raised	A									
		29 Feather	B	Comp+Sawd	C	5.3 ± 0.7	12.0 ± 1.7	14.0 ± 1.8	18.6 ± 2.1	26.9 ± 1.9
				Sawdust	C	3.4 ± 0.4	16.7 ± 1.5	13.7 ± 2.2	20.4 ± 1.8	20.0 ± 2.4
				WeedMat	C	7.4 ± 1.5	9.4 ± 2.0	13.8 ± 1.0	17.2 ± 1.6	29.9 ± 2.2
		29 Fish	B	Comp+Sawd	C	5.0 ± 0.8	12.4 ± 1.8	10.3 ± 0.9	20.4 ± 4.4	25.8 ± 6.3
				Sawdust	C	6.0 ± 0.6	10.0 ± 0.8	10.7 ± 1.9	16.3 ± 2.3	31.3 ± 3.3
				WeedMat	C	8.2 ± 0.7	7.4 ± 0.6	10.6 ± 1.4	15.9 ± 2.3	33.7 ± 1.2
		57 Feather	B	Comp+Sawd	C	6.9 ± 1.5	10.7 ± 2.7	12.3 ± 1.4	20.5 ± 1.7	26.2 ± 3.3
				Sawdust	C	7.1 ± 1.6	9.7 ± 1.6	14.4 ± 1.3	20.4 ± 3.3	24.9 ± 3.8
				WeedMat	C	4.3 ± 0.6	13.9 ± 1.1	11.6 ± 1.1	21.7 ± 1.9	24.2 ± 1.1
		57 Fish	B	Comp+Sawd	C	8.2 ± 1.6	8.4 ± 1.3	10.9 ± 0.5	16.7 ± 2.5	33.9 ± 3.2
				Sawdust	C	10.1 ± 0.5	6.3 ± 0.5	10.1 ± 0.5	22.4 ± 3.4	29.8 ± 3.9
				WeedMat	C	11.2 ± 3.1	7.6 ± 2.3	8.8 ± 1.2	16.6 ± 1.8	31.8 ± 4.0
Significance[z]										
Planting method		(A)[y]				n.s.	n.s.	*	n.s.	n.s.
N fertilizer rate and type		(B)				***	***	***	n.s.	***
Mulch type		(C)				**	*	n.s.	*	***
Cultivar		(D)				***	***	***	**	n.s.
A x B						n.s.	n.s.	n.s.	n.s.	n.s.
A x C						n.s.	n.s.	n.s.	n.s.	n.s.
B x C						*	**	n.s.	n.s.	n.s.
B x D						n.s.	n.s.	n.s.	n.s.	n.s.
C x D						n.s.	n.s.	n.s.	n.s.	n.s.

[z]*Significant at $P < 0.05$; **significant at $P < 0.01$; ***significant at $P < 0.001$; ns=not significant.

[y]A = Planting method, B = Nitrogen Fertilizer rate and type, C = Mulch type, D = Cultivar.

Table 2.17 Effect of nitrogen fertilizer on leaf nutrient content, on 'Duke' and 'Liberty' plants, 19 Aug. 2008, NWREC (n=6; mean).

Cultivar	N Fertilizer rate and type (kg·ha⁻¹ N)	Mulch type	Macronutrients N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Micronutrients Fe (ppm)	B (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)	Al (ppm)
Duke D													
	29 Feather B	Comp+Sawd C	1.72	0.14	0.63	0.49	0.18	114.67	23.55	2.82	72.00	16.90	142.78
		Sawdust C	1.66	0.14	0.60	0.44	0.16	113.98	21.55	1.63	83.37	16.30	163.93
		WeedMat C	1.59	0.14	0.60	0.42	0.17	110.40	18.37	1.83	76.12	15.02	132.40
	29 Fish B	Comp+Sawd C	1.99	0.18	0.69	0.45	0.17	111.78	22.95	2.57	110.50	17.58	144.75
		Sawdust C	1.97	0.17	0.67	0.46	0.17	111.40	15.83	3.03	100.43	17.67	131.83
		WeedMat C	1.90	0.17	0.68	0.40	0.15	115.32	15.58	2.03	121.17	14.40	133.30
	57 Feather B	Comp+Sawd C	1.85	0.16	0.65	0.40	0.16	115.53	22.92	1.68	73.05	17.83	115.43
		Sawdust C	1.87	0.17	0.66	0.47	0.17	99.72	21.48	2.37	95.08	19.03	149.58
		WeedMat C	1.78	0.16	0.63	0.43	0.16	114.10	21.18	2.00	94.20	16.07	167.58
	57 Fish B	Comp+Sawd C	2.26	0.20	0.75	0.42	0.14	120.63	21.43	2.25	152.92	16.58	139.55
		Sawdust C	2.25	0.20	0.71	0.46	0.16	126.73	17.08	3.13	164.03	18.83	155.27
		WeedMat C	2.26	0.20	0.77	0.36	0.13	111.62	18.02	2.02	178.32	13.90	126.50
Liberty D													
	29 Feather B	Comp+Sawd C	1.63	0.12	0.54	0.47	0.15	140.57	33.53	1.28	102.63	10.72	166.45
		Sawdust C	1.50	0.11	0.49	0.48	0.16	137.18	26.13	1.35	109.55	9.52	165.07
		WeedMat C	1.46	0.11	0.53	0.46	0.16	138.95	27.07	1.90	96.22	9.58	187.68
	29 Fish B	Comp+Sawd C	1.80	0.12	0.61	0.41	0.14	132.33	24.48	1.13	117.18	9.13	134.83
		Sawdust C	1.77	0.13	0.63	0.44	0.14	147.82	19.65	2.02	138.93	11.72	170.97
		WeedMat C	1.76	0.13	0.66	0.40	0.14	145.05	18.33	2.07	132.50	10.03	156.65
	57 Feather B	Comp+Sawd C	1.76	0.12	0.58	0.46	0.15	135.57	31.80	1.43	102.43	11.05	155.00
		Sawdust C	1.74	0.12	0.55	0.46	0.14	141.52	25.45	1.33	133.17	10.57	165.73
		WeedMat C	1.59	0.11	0.56	0.41	0.14	144.85	20.92	1.53	124.28	9.28	154.37
	57 Fish B	Comp+Sawd C	2.13	0.15	0.74	0.41	0.13	151.82	24.78	1.32	166.90	10.60	163.93
		Sawdust C	2.16	0.14	0.72	0.41	0.13	156.73	18.92	2.23	192.90	13.18	162.97
		WeedMat C	2.03	0.14	0.72	0.40	0.14	148.03	17.32	2.60	157.00	11.63	168.23
Significance[z]													
Planting method	(A)[y]		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
N fertilizer rate and type	(B)		***	***	***	n.s.	**	n.s.	***	n.s.	***	n.s.	n.s.
Mulch type	(C)		***	n.s.	n.s.	***	*	n.s.	***	n.s.	*	***	n.s.
Cultivar	(D)		***	***	***	n.s.	***	***	***	***	***	***	***
B x C			n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*	n.s.
B x D			n.s.	**	**	n.s.	n.s.	n.s.	**	n.s.	n.s.	n.s.	n.s.
C x D			n.s.	n.s.	n.s.	n.s.	**	n.s.	n.s.	**	n.s.	*	n.s.

[z]*Significant at $P < 0.05$; **significant at $P < 0.01$; ***significant at $P < 0.001$; ns=not significant.

[y]A = Planting method, B = Nitrogen Fertilizer rate and type, C = Mulch type, D = Cultivar.

Chapter 3: Impact of production system on weed management, plant water status, and soil properties.

Abstract

A 0.4 ha planting of blueberry (*Vaccinium corymbosum* L.) was established in Oct. 2006 to evaluate the effects of cultivar (Duke and Liberty), planting method (flat versus raised beds), weed management (sawdust mulch and hand-weed control; compost plus sawdust mulch with acetic acid, flaming, and hand-weeding used as needed; and weed mat plus hand-weeding as needed), and type and rate of fertilizer (feather meal and liquid fish emulsion at 29 and 57 $kg \cdot ha^{-1}$ N) on plant growth, yield, fruit quality, irrigation requirements, and weed presence. Weed presence increased from 2007 to 2008. Hand-weeding was required in all treatments in both years. Weed mat plots had the fewest weeds, whereas compost plus sawdust mulched plots had the highest weed coverage. In weed mat plots, the only weeds that emerged were in the area of the planting hole. In the compost plus sawdust mulched treatment, acetic acid applied at a 20% concentration on hot days, provided acceptable control of annual weeds, but was moderately effective on perennial weeds. Flaming was somewhat effective when used on small weeds on hot days. Soil water content was lower through the growing season on raised beds than on flat ground, especially under weed mat; this system thus required 148% more irrigation water than did plots mulched with sawdust, and compost plus sawdust to maintain an adequate percent soil water content for blueberry plant growth. Soil temperature at 5 cm depth was higher under weed mat and more variable through the year than in the organic mulched treatments. The extra irrigation water required in weed mat mulched treatments may have been

associated with increased soil and canopy temperatures and soil water evaporation, and greater plant evapotranspiration. In overall, regardless of mulching type, weed coverage was maintained but required additional inputs to be more efficient in all treatments. Water consumption issues should be considered when selecting the type of mulch to be used due to its markedly differences in water application requirements, which were highly affected during the growing season by soil temperature.

Introduction

Weeds are considered a major pest in highbush blueberry (*Vaccinium corymbosum* L.) production systems. The costs associated with managing weeds are considered a significant expense in conventional and organic blueberry farms. Mulches are commonly used as a cultural method of weed control. While inorganic and organic mulches may control weeds, the impact of various mulches on irrigation requirement, blueberry plant water status, and soil properties has not been well studied in organic production systems.

Planting method. Planting on raised beds is a common production system in blueberry fields (Strik, 2007) to improve drainage and help protect plants from standing water (Scherm and Krewer, 2008). It has been reported that raised beds do not mitigate high soil temperatures during the summer (White, 2006), but improve soil conditions by lowering compaction and providing greater internal drainage (Magdoff and Van Es, 2000). Raised beds thus help prevent saturated soils and pest problems like phytophthora root rot (Bryla and Linderman, 2007). In contrast, planting on flat ground is considered to increase soil moisture and reduce soil temperature during the fruiting season, which is beneficial for the root growth of southern highbush blueberries (Spiers, 1995). Growers have found that weed control by hand or mechanical methods is more difficult or expensive in raised bed production system than in flat ground systems (Strik, personal communication).

Adequate soil moisture is important to improve or maintain availability of N from fertilizers or mineralization and to obtain optimum plant growth and yield. Maintaining soil moisture to about 50 to 70 % of water holding capacity (WHC) maximizes aerobic microbial activity by oxygen diffusion (Linn and Doran, 1984), although this response varies with fertilizer source. An incubation study using Granby sandy clay loam (sandy, mixed, mesic Typic Endoaquolls) soil with partially composted chicken manure and alfalfa pellets, showed that the mineralization process was significantly reduced at 90% WHC compared to 50 and 70% WHC after two weeks of application. Nevertheless the amount of N mineralized was enhanced by soil moisture from 50 to 90% WHC from week 2 to 12, up to 11 $mg \cdot kg^{-1}$ (Agehara and Warncke, 2005). Conversely, low soil moisture reduces the microbial activity of nitrifying bacteria by decreasing ammonium (NH_4^+) diffusion and intracellular water potential (Agehara and Warncke, 2005). Stark and Firestone (1995), stated that plant cell dehydration as a result of reduced enzymatic activity, diffusional limitation of substrate supply, and less nitrifying soil bacteria activity can occur when soil water potentials are less than -0.6 MPa (more than 50% WHC).

Drip irrigation has been shown to require up to 66 and 250% less water than microspray and sprinkler systems, respectively, in a two-year study conducted on young highbush blueberry plants (cv. ‘Elliott’), in Corvallis, OR (Bryla et al., 2009). The authors concluded that plants drip irrigated at either 50, 100, or 150% of the crop evaporation requirement (ET_c) had the highest yield compared to microspray (only at 50 and 100% ET_c) and sprinkler. However, drip irrigated plants at 150 % ET_c had a reduction in berry weight, percent soluble solids, and juice pH than those irrigated with drip at 50 and 100 ET_c (Bryla et al., 2009).

Percent of soil water content and plant water potentials can also be used to monitor water available to the plants, and plant water status, respectively. In Willamette silt loam (fine-silty mixed superactive mesic Pachic Ultic Argixeroll), acidic soils found in Oregon, highbush blueberry cultivars have produced acceptable growth and yield when percent of soil water content ranged from 12 to 22%, at a 0 to 0.6 m depth in cultivars spaced 0.45 m apart (Bryla and Strik, 2007). A percent soil water content above 30% (at 0 to 0.3 m depth) can have negative effects on growth and production due to soil water saturation (Bryla and Linderman, 2007).

Blueberry plants with stem water potentials from -0.6 to -0.8 MPa show a rapid decline in photosynthetic rate and stomatal conductance (Bryla and Strik, 2006). When water potentials are less than -1.2 MPa, there is an increased embolism in the xylem vessels and 50% loss of hydraulic conductance at -1.4 MPa (Améglio et al., 2000).

Mulching. Douglas-fir (*Pseudotsuga menziesii* M.) when used as sawdust mulch has a positive impact on plant growth, yield (Clark and Moore, 1991; Karp et al., 2006; Kozinski, 2006; White, 2006), root distribution (Spiers, 2000), number of whips (White, 2006), number of one-year-old shoots (Kozinski, 2006; White, 2006), and reduces extreme temperature fluctuations (Cox, 2009; White, 2006). Furthermore, sawdust mulch reduces seed germination of non-desirable plants. There are successful blueberry plantings with no mulch of any kind in the Pacific Northwest (Strik, 2007). In Georgia, rabbiteye blueberries are grown in un-mulched sandy loam soils with only 1.5% organic matter (Williamson et al., 2006).

Organic mulches derived from wood chip materials can increase soil moisture from 15 to 20% (primarily in the top 0.10 m), reducing irrigation requirement by 20 to 30% compared to un-mulched soil (Granatstein and Mullinix, 2008). The temperature of mulched soils measured at a depth of 5 cm can be 4.7 C° cooler on a warm day in spring (Granatstein and Mullinix, 2008) and 8.9 C° cooler on a hot day in the summer (Krewer et al., 1997). However, White (2006) found no cooling effect of sawdust mulch compared to bare soil at a soil depth of 0.02, 0.15, and 0.30 m during the growing season. In winter, sawdust mulch reduced soil temperature (White, 2006).

The most common compost being trialed by blueberry growers is developed from yard debris. One of the major concerns with using this and other composts is their relatively high pH (7 or above) and EC or salt content. If compost mulch increases soil pH at the mulch-soil interface, there might be a negative impact on the growth of blueberry roots (Li et al., 2006).

Weed mat or landscape fabric is considered an inert mulch in orchard production (Granatstein and Mullinix, 2008) and is approved for use as a weed barrier by the USDA Organic National Program (NOP, 2006). In orchards, weed mat has been widely used mainly due to its effective weed control, although weeds appear in the planting hole and removal by hand may be required in commercial crops (Runham et al., 2000). Sciarappa (2008) reported almost complete control of hairy crabgrass (*Digitaria sanguinallis* L.), foxtail species, (*Setaria* spp.), and broadleaf weeds, when using weed mat plus a mulch of coffee grinds around the planting area in an organic blueberry study in New Jersey over two growing seasons. However, concerns have been expressed about possible negative impacts of weed mat on plant growth due to increased soil temperature (Williamson et al., 2006). Magee and Spiers (1995) found that white-on-black plastic polyethylene based mulches led to greater plant growth and yield than did black plastic or black woven fabric mulches in southern highbush cultivars due to a decreased soil temperature in the more reflective mulches. Similarly, black plastic mulch produced higher soil temperatures (15.1 C° to 26.2 C°) than paper mulch (14.9 C° to 22.5 C°) at 0.10 m depth, during one growing season in courgettes (*Curbita pepo* L.) and celery (*Apium graveolens* L.) in the U.K. (Runham et al., 2000). In Oregon, black plastic had no significant effect on red raspberry plant growth, even though black plastic mulch increased soil temperature at 0.15 m depth compared to bare soil or straw mulch (Strik et al., 2006).

Weed management. Sawdust mulch and weed mat have been shown to reduce weed presence in many crops (Cox, 2009; Sciarappa et al., 2008). Many organic growers have relied on hand-weeding, hoeing, and use of mulches to manage weeds in blueberry fields. However, as organic production becomes more common, various products are being trialed for their effectiveness as a contact herbicide. Acetic acid (vinegar) at a concentration of 20% was an effective post-emergence herbicide (Garrett and Beck 1999; Webber et al., 2005) controlling at least 79% of annual weeds and from 35 to 65% of broadleaf and grass weeds

(Fausey, 2003). However, acetic acid used at 9% was not effective at controlling hairy vetch (*Vicia villosa* R.), black oats (*Avena strigosa* S.), winter palmer amaranth (*Amaranthus palmeri* W.), and common purslane (*Portulaca oleraceae* L.; Moran and Greenberg, 2008).

Use of intense heat to fully control weeds organically can be done by exposing weeds to a temperature of about 190°C for 2.3 seconds or 500°C for 0.3 seconds, causing the rupture of cell walls due to affections in the cortex region of the stem and depletion of proteins allocated in the leaves (Lalor and Buchele, 1968). Parish (1990) also suggested that temperature must be increased to 100°C for at least 0.1 second to burst cell membranes; however, coagulation of proteins occurs between 50°C and 70°C. “Flame weeding” with a propane flamer has some additional benefits to weed control such as avoiding chemical residues in the soil and eliminating the risk of development of weed resistance.

Diver (2002) suggested that flaming can be more effective on broadleaf weeds when they are up to 5 cm tall and in grasses before they develop a protective sheath (usually before they reach 2.5 cm in height), otherwise a second pass might be required.

Infrared weed control can be used to do in-row selective flaming to avoid risk of igniting dry vegetation. The infrared devices use a propane tank to heat a ceramic or a steel plate, which radiates temperatures up to 1,093 °C (Diver, 2002); such a tool might be of more use than a direct flame in sensitive crops such as blueberries.

The objectives of this study were to evaluate the efficiency of organic production systems on weed presence or control, irrigation requirement, plant water status, and soil properties.

Materials and Methods

Experimental location. The 0.43 ha research trial was established 9 Oct. 2006 on a site in transition to organic production at the North Willamette Research and Extension Center (NWREC; 45°16' 47.55" N and 122°45' 21.90" W), Aurora, OR. Plant spacing was 0.76 m by 3 m (4,385 plants per ha). Prior to planting, the site was in wheat. The soil was a Willamette silt loam (fine-silty mixed superactive mesic Pachic Ultic Argixeroll) with an organic matter content of 3.7% and pH of 4.9 prior to planting. The research planting was certified as organic in May 2008 by Oregon Tilth (OTCO; Salem, OR).

Site preparation. As part of a cultural method, buckwheat (*Fagopyrun esculentum* M.) was seeded at a rate of 30 $kg \cdot ha^{-1}$ on 30 May 2006, as a pre-plant cover crop and was incorporated into the soil, prior to seed head formation, on 26 July 2006. Rows were marked and were sub-soiled once using a 3-shank ripper (0.41 m) followed by three passes of a single shank ripper (0.51 m). Rows were then power spaded in early September while the soil was still dry. The site was irrigated until the wetting front was about 0.3 m deep. A few days later, when the soil was dry, the rows were roto-tilled to a depth of 0.15 m before using a bed shaper (depending on treatment). Raised beds were 0.31 m high, 0.38 m wide at the top, and 1.5 m wide at the base when established, but had settled to 0.25 m high by fall, 2007. Certified organic grass seed (*Festulolium braunii* K. Richt.)

was established between rows at a rate of 28 kg·ha^{-1} on 14 Oct. 2006. The grass of the between row cover crop was kept from encroaching in the rows by maintaining the edges with a 20% vinegar (acetic acid) solution directed spray, as required, generally every 3 weeks during the growing season. The between row grass was dense enough to prevent weed emergence and required minimal mowing during the dry summer.

Treatments. The treatments compared in years 1 and 2 (2007 and 2008) were: i) planting into “raised beds” or on "flat ground"; ii) the cultivars Duke and Liberty (*Vaccinium corymbosum* L.); iii) the weed management treatments a) Douglas-fir (*Pseudotsuga menziesii* M.) sawdust mulch (9 cm deep) and pulling weeds by hand, as required, b) compost (yard debris; 4 cm deep) plus sawdust (5 cm) mulch on top and weed management using vinegar (20% acetic acid), propane flaming, and hand pulling as needed; and c) landscape fabric (weed mat) with sawdust mulch (5 cm) in the 20 cm diameter planting hole and hand-weeding; and iv) method and rate of fertilization: feather meal (Nature Safe, Cold Spring, KY) and fish emulsion (“Fish Agra”, Northeast Organics Inc., Manchester-by-the-Sea, MA) at a rate of 29 and 57 kg of N·ha^{-1}. Fertilizer formulations, application dates, and experimental design are provided in Chapter 2.

The compost (Rexius, Eugene, OR) and sawdust (Decorative Bark, Lyons, OR) mulches were applied on 12 Oct., 2006. Weed mat was folded from 0.15 m to 0.13 m (Baycor, TenCate Protective Fabrics, Union City, GA) and applied on 1 Feb., 2007. The sawdust mulch and yard debris compost were analyzed at the beginning of the study (Soil Control Lab, Watsonville, CA) (Table 3.1).

Weed measurement. Visual evaluations were conducted to determine the percentage of weed coverage per plot, an assessment of weed population. Weeds were evaluated every three weeks, starting 7 May, 2007, with weed management done after each evaluation, if necessary. No weed coverage data were recorded in Oct., Nov., and Dec. of each year. The visual ratings used were: 0 = 0%; 1 = 1-20% weed coverage/plot; 2 = 21 - 40%; 3 = 41 - 60%; 4 = 61 - 80%; and 5 = 81 - 100%. All product inputs, where applicable, and labor time required to manage weeds were recorded to help provide a final cost analysis per treatment.

Weed management methods. In all mulching treatments, the complementary weed management treatments were applied if the visual evaluation of weed coverage per treatment was greater than 20% in several plots.

In the sawdust mulch and weed mat treatments, weeds were only pulled by hand, when necessary. In the sawdust plus compost treatment, hand-pulling was used in combination with acetic acid (vinegar) or propane flaming, depending on the year.

Applications of vinegar (20%, mixed with water; Garrett and Beck 1999; Webber et al., 2005) were done preferably after 10 am on days when no rain and minimal wind were present. The use of vinegar was preferred over flaming in the driest months when use of flaming may increase risk of fire in treatments with dry surface mulches. Two people were required for vinegar applications – a tractor operator and one applicator walking behind the tractor to spot spray weeds, as required. The 100 L sprayer tank was connected to the hand-held shielded applicator by a hose. The tank had a 12-volt electric pump, which at 69 kPa, had a discharge capacity of about 159 L·hr^{-1}. The nozzle used was a flat fan type with a delivery rate of 37 L·hr^{-1}.

A hand-held propane flamer was constructed with a 0.20 m diameter head and a 8,000-14,000 BTU small gas heater, attached to a rod to facilitate spot burning. Only one person was required to carry the 40 L propane tank on a cart and the heat device.

Irrigation and soil moisture. Plants were irrigated by a single lateral of drip tubing, with 2 L·h^{-1} in-line emitters spaced every 0.3 m, positioned near the center of the planting bed at the base of the plants. The system was designed so that raised beds and flat ground rows could be irrigated independently to adjust for differences in water use if needed. A second lateral (0.45 m between the two lines) was also installed to allow for differences in irrigation requirement with use of weed mat mulch. Irrigation was controlled with a timer.

Volumetric water content was measured using TDR (time domain reflectometry, Trase System, Soil Moisture Equipment Corp., Santa Barbara, CA). In 2007, 0.3 m long, un-coated stainless steel TDR rods (Soil Moisture Equipment Corp., Santa Barbara, CA) were used in three randomly selected replications of all treatment combinations of planting method, cultivar, and weed management, but only those receiving the high rate of fish emulsion (36 plots). In 2008, un-coated stainless steel TDR rods, 0.15 m in length were added to the same plots and were placed on the opposite side of the plant base from the installed 0.3 m un-coated stainless steel TDR rods. Un-coated stainless steel TDR rods were placed about 0.1 m from the crown. The second plant from the end of the plot was selected for measurement. Data were collected weekly and analyzed to determine further changes in irrigation needed to achieve a relatively uniform percentage of soil moisture in all treatments with a target range of 25 to 30%. The frequency of irrigation required increased progressively during the growing season, from two days a week (once a day for 15 min.) in May to four days a week (once a day for 15 min.) in June, and seven days a week (three times a day from 3 to 20 min.) in July, August, and September, 2007. In 2008, the irrigation schedule progressed from three days a week (twice a day from 3 to 20 min.) in May and June, to everyday in July – September (six times a day from 2 to 6 min. in July and August, and two and three times a day from 2 to 8 min., respectively, in September).

Plant water potential was measured using a pressure chamber (model 600; PMS Instrument Co., Corvallis, OR). Plastic bags laminated with aluminium foil were used to cover fully expanded leaves from the upper shoots of the plants. Leaves were covered starting at 11am with measurements beginning at 12pm. Data were collected from three replications, the same plots used to obtain TDR readings, once a month in June, July, and August in each year.

Soil temperature. Data on soil temperature were collected using HOBOS 8K (Onset Corporation, Bourne, MA). The HOBOS were installed randomly in treatments receiving the high rate of fish emulsion, mulched with weed mat and sawdust, and planted on raised beds and flat ground in two randomly selected replications (8 plots). Each soil temperature probe was installed 0.1 m from the plant crown at a depth of 5 cm below the soil-mulch interface. Average hourly temperature readings were taken every day from June 2007 through Dec. 2008 with data summarized as maximum and average day and night time temperature. Data were compared to bare soil (5 cm; un-irrigated) temperatures from a nearby

(< 0.5 km) weather station located at the NWREC (http://www.usbr.gov/pn/agrimet/).

Results and Discussion

Weed presence in this newly established field was not as high as has been observed in many grower fields (personal observation). Several commercially-accepted practices were followed to try to minimize weeds in this planting. The five years prior to the planting year, this planting site was used for wheat production. The last year of non-OMRI-approved herbicide and fertilizer use was 2004 thus meeting requirements for organic certification in spring, 2008. The buckwheat (*Fagopyrun esculentum* M.) cover crop, seeded and incorporated the summer before planting, helped reduce weed populations and improved soil conditions. The immediate area surrounding this research site was planted to wheat, clover, or grass, depending on the season, and the row middles were planted to a grass cover crop thus helping minimize blow-in of weed seeds. Finally, the planting was irrigated using drip, reducing water presence in non-crop areas and thus weed seed germination.

<u>Weed population</u>

In 2007, percent weed population was significantly affected by mulch through the season, planting method in May and June, and cultivar in July and September. Fertilizer type and rate did not affect weed population (Table 3.2). In 2008, weed population was significantly affected only by mulch in most months (Table 3.3). In both years, the highest level of weed incidence was observed in May and June. In 2008, there was a higher percent weed population in April than June. No weed management labor or material inputs were required in February or March when weed presence was low. The mulch treatments and the relatively low weed pressure helped keep weed presence below the threshold of 20% coverage; however in the months with the highest presence of weeds, greater than 20% weed coverage was observed, on average in May and in some plots in April, May, and June.

Classification of the weeds found in each treatment was not possible due to time constraints. A list of weeds observed at various times through each season is presented in Table 3.4. In both years, the same weed species seemed to reappear in specific treatments (visual observation). For example, curly dock (*Rumex crispus* L.), quackgrass (*Elytrigia repens* L.), and prostrate knotweed (Polygonum aviculare L.) were repeatedly observed in the organic mulches, while annual bluegrass (*Poa annua* L.) was mostly observed in the planting hole area of weed mat treatments. Burkhard et al. (2009), suggested the predominant proliferation of weed species under certain treatments may be caused by factors such as variations in soil pH, which can determine the preference of weed species and its re-appearance in oncoming growing seasons.

Weed mat was more effective at reducing weed presence than the organic mulches (compost plus sawdust and sawdust), based on visual ratings (Tables 3.1 and 3.2). Weed mat likely reduced light exposure on any existing weed seeds in the soil, thus impeding the process of germination (Bond and Grundy, 2001; Cox, 2009). In contrast to the organic mulches, weed mat was not a favorable substrate for the germination of any weed seeds that landed in plots by wind, birds, or vertebrates. Nevertheless, weeds did grow in the open areas of the weed mat, around the plants.

In the second growing season, the visual rating of weed presence in the planting hole area increased in the weed mat treatment. It was difficult, however, to visually rate weed presence in weed mat plots, as weeds were only present directly around the plant and weeds were generally small. Even if there were few and small weeds only in the planting hole around one plant per plot, the entire plot would be rated with a “1”, representing a range of 1% to 20% coverage. For example, on 30 May, 2007, the highest visual rating of weed presence (0.4), representing 8% of the plot being covered by weeds, was observed in weed mat plots. In contrast, weed mat plots averaged a visual rating of 1.0 (20% coverage) on 20 May, 2008. The increase in weed presence from the first year to the second year was in part due to the depletion of sawdust around the plant, reducing its effectiveness as a mulch and allowing smaller weeds, such as Annual Bluegrass (*Poa annua* L.) to grow more aggressively in the planting hole area; some of these weeds may also have produced seeds further aggravating the problem in this area. Similarly, an organic experiment done in five-year-old highbush blueberry plants (cv. Duke) in Nova Scotia, Canada, Burkhard et al. (2009) found that weed proliferation in organic mulches more rapidly increased after the first year due to the germination of annual weeds, perennial weeds being more established, and a reduction in mulch depth. In our experiment, the weed mat fabric was still sound at the end of the second year and thus no weeds grew through the fabric.

All treatments were weeded by hand (HW) on 14 Mar. and 18 Apr. 2007 and 31 Jan., 20 May, and 14 Aug., 2008. However, weed mat plots required three extra HW in 2007 and five in 2008. In the first growing season, 2007, plots could be hand weeded faster, particularly in weed mat treatments, than in 2008. The total seasonal requirement for hand-weeding in weed mat plots was 6.8 labor hours per ha in 2007 and 29.6 $hr \cdot ha^{-1}$ in 2008.

There was no significant difference between sawdust and weed mat mulches in the percent weed population even though weed mat had fewer and smaller weeds than sawdust in the months of May, June, July, August, September, October, and November 2008 (Table 3.3). The rating system used may not have been accurate enough to evaluate weed presence at such relatively low populations. Although sawdust mulch may also have controlled weeds relative to bare ground (not part of this study), weeds rapidly started to grow in Mar. 2007 (data not recorded), reaching their highest coverage in late May, 2007 (Table 3.2). Use of sawdust mulch and HW was effective at controlling weed growth. Maximum weed coverage occurred in late May of both years, averaging a visual rating of 0.9 to 1.0 or 18 to 20% weed coverage. Weed populations decreased by late summer, due to natural growth cycles in the case of winter annual weeds and dry soil conditions in un-irrigation regions of the plot. Some perennial weeds remained small during the dry summer months, but started to re-grow once fall rains began to be more frequent and surpassed 12.4 mm of rain on 28 Sept. 2007 and 3 Nov. 2008 (Agrimet, 2007 and 2008). In 2007, sawdust plots required HW on six occasions and a total seasonal labor requirement of 18.2 $hr \cdot ha^{-1}$ to maintain the weed population below 20%, whereas HW was done on five occasions in 2008 for a total of 46.9 $hr \cdot ha^{-1}$.

Sawdust plus compost mulch was the least effective treatment for weed control in both years (Tables 3.1 and 3.2). Similarly to the other mulch treatments, weed presence was highest in late spring and lowest in late summer. The sawdust plus compost mulch may have had higher weed populations because weed seeds that landed in these plots had a favorable environment for establishment. While the compost was covered with a 5 cm deep layer of sawdust that might make this treatment superficially similar to the sawdust mulch treatment, deeper-rooted weeds might have benefited from the higher nutrient content found in the compost. Also, by the second season, the compost mulch was exposed in some areas of the plot where sawdust had either been displaced by hand-weeding or wind. Weed seeds might germinate more easily in compost than in a drier pure sawdust material. The yard debris compost used in our experiment did not have any weed seeds present, because of the heating processes used during the composting procedure to ensure weed seed sterilization. Mulches such as manure and sawdust compost, and seafood waste compost were found to provide an ideal texture and nutrient rich growing media, increasing the percentage surface area covered by weeds from 61% to 70% and 91% to 100%, respectively, by the second growing season in a newly established blueberry field in Nova Scotia, Canada (Burkhard et al., 2009). Nevertheless, compost based mulches could be effective depending upon their thickness (Abouziena et al., 2008; Gregg and Schutzki, 2009) and bulk density (Burkhard et al., 2009).

The additional weed control methods used in compost plus sawdust treatments were vinegar (VN) application, which was used in June, July (twice), and August (twice) and HW in 2007; these methods were effective at maintaining weeds below the rating of 1 (Tables 3.1 and 3.2). By observation, targeted applications of vinegar subsequently required about five hours of intense sunlight to be effective. Because the mode of action of vinegar is comparable to that of a contact herbicide

(Sullivan, 2003), only annual weeds were generally controlled and perennial weeds eventually recovered. In late summer (7 Sept. 2007), HW was required due to the relative ineffectiveness of vinegar with lower sun intensity (Garret and Beck, 1999) and the start of rain events that promoted perennial weed growth. Quackgrass (*Elytrigia repens* L.) continued to grow in the second year despite HW efforts.

In 2007, the five VN applications had a total product cost of $164 per ha and required 61 $hr \cdot ha^{-1}$ labor in addition to the 7.4 $hr \cdot ha^{-1}$ labor needed for HW. In 2008, VN application was required only once in late June and the VN treatment was effective until mid-August when HW was used instead of VN, mostly because weeds were larger in size thus likely leading to insufficient vinegar contact (Young, 2004). In the compost plus sawdust mulch in 2008, $79 of product and 4.8 $hr \cdot ha^{-1}$ to apply VN and 15 $hr \cdot ha^{-1}$ for HW were required. For this study, the VN-dedicated tank and wand mounted to a tractor allowed for fast spot application. No blueberry phytotoxicity was observed from any application of VN.

In 2008, the use of a propane flamer was added to the sawdust plus compost weed management treatment. The sawdust plus compost mulched plots received two passes of a propane flamer (FL; spot treatments only) in the spring. However, the use of FL in early and late April was relatively ineffective at controlling weed growth, even when the FL treatments were done three weeks apart. Granatstein and Mullinix (2008) found no difference between yard waste wood chip mulch and dwarf New Zealand white clover (*Trifolium repens* L.) plus flaming for percent weed cover, although weed presence tended to increase in the flaming treatment by the third year. In our study, while the FL treatment was intended to act as a contact herbicide, there were weeds that appeared to be more tolerant to heat either due to larger plant size or to a higher water content, such as dandelion (*Taraxacum officinale* W.). Dandelion is a perennial weed with a milky sap, a large taproot, and leaves clustered at the top of the root crown (Whitson et al., 2004). While longer exposure to FL may have been possible (Lanini, 2004), it was important to minimize risk of the mulch catching fire (Rifai et al., 2003) and blueberry plant injury from excessive heat.

The FL system used in this study was tedious to use, because the propane tank had to be carried in the field. Attempts at improving effectiveness of FL by increasing exposure time to the heat source for the weeds present, required more labor time than did application of VN. Similarly to what was found with VN application, use of FL was more effective when there were several warm sunny days after treatment. A commercial grower would be able to attach a propane tank to a tractor and use a long wand to get the FL head near the weeds; however, several passes and stops would be required during the growing season. In the compost plus sawdust mulch 24.7 $hr \cdot ha^{-1}$ of labor were required for FL. There may also be better flaming devices available on the market.

Results from our first two growing seasons showed that weed control using organic mulches and some additional hand or chemical weed management maintained weeds below 20% coverage even during high pressure months. The use of vinegar at 20% did not seem to compromise the growth of young blueberry plants, when a plastic protective shield was used in spot spraying. However, to maximize effectiveness of vinegar and flaming, use was limited to climatic conditions where several dry, hot days were expected after weed control. Hand-weeding was the most common method used to control weeds in this study, and was required in all weed management treatments. Weed mat mulch was the most effective weed control system.

Water requirements

Soil water content was significantly affected by planting method ($P < 0.001$) on 20 June, 6 July, and 2 Aug., 2007. Mulch affected soil water content ($P < 0.001$) on 6 and 13 July, 2007. Soil water content was not affected by cultivar, even though 'Duke' and 'Liberty' differed in size of the root system and top growth in both years (Chapter 2). In 2008, there was no effect of treatment on soil water content throughout the season.

Irrigation was applied from 17 May to 21 Sep. in 2007 and from 14 May to 1 Oct. 2008. Irrigation scheduling was more efficient in 2008, with a 161% and 19% reduction in the total amount of water applied in flat ground and raised beds compared to 2007, respectively (Fig. 3.1). Raised beds required greater amounts of water than flat ground to maintain similar levels of soil water content. In 2007, one-year-old highbush blueberry plants grown on raised beds mulched with weed mat required 202 $L \cdot y^{-1}$ more irrigation water than did plants on flat ground with weed mat. Similarly, in 2008, two-year-old plants grown on raised beds with weed mat required an additional 267 $L \cdot y^{-1}$ of irrigation water than did plants on flat ground with weed mat. At the end of the two growing seasons the weed mat mulched plots required 106% and 148% more water than did plots mulched with sawdust and sawdust plus compost in flat ground and raised beds, respectively (Fig. 3.1). In an experiment with organic mulches in 'Red Delicious' apples in Wenatchee WA, yard waste wood chip mulch reduced cumulative irrigation by

20% to 30% compared to un-mulched plots (Granatstein and Mullinix, 2008). Organic mulches tended to increase soil moisture and reduce plant stress (Gregg and Schutzki, 2009).

Irrigation scheduling was adjusted based on percent soil water content data collected using TDR (at 0.30 m in 2007 and 0.15 m and 0.30 m in 2008) with the goal of maintaining a desirable percent soil water content for blueberry growth. For example, during the warmest weeks in 2007 (July 7, 13, 27) plots were irrigated on 7 days/week, for up to three, 20 min. sets/day. In 2008, during the warmer weeks of July 16, 23, and 30 and Aug. 6, 13, and 20, irrigation was applied 7 days/week with three to six, 2 – 5 min. sets/day. In the second growing season, although we increased the frequency of irrigation, the amount of water applied was reduced. Thus irrigation water was applied more uniformly and TDR readings at 0.15 and 0.30 m were less variable in 2008 than in 2007 in this young planting. The installation of an additional 0.15 m long soil probe for TDR readings in 2008 was useful for improving irrigation scheduling. The average volumetric soil water content readings obtained at a depth of 0 to 0.30 m with the 0.30 m probes was found to be a less effective indicator of plant available soil water content for these shallow-rooted (Eck and Childers, 1966) one- and two-year-old highbush blueberry plants. We confirmed, using soil core samplers that the soil was drying faster in the top 0.10 m of the soil profile than at greater depths, particularly in raised beds. In 2007, soil water content was above 30% in the months of July, August, and part of September, indicating the field was being over irrigated, soil was saturated and exceeded field capacity (Fig. 3.2). White (2006) noted that young ‘Elliott’ highbush blueberry grown on raised beds previously amended with sawdust required more frequent irrigation than did un-amended soils; water percolating through these amended raised beds increased plant drought stress. In our study, the soil was not amended with sawdust prior to planting.

In 2007, plant water potential varied from -0.3 to -1.1 MPa, on average, compared to -0.3 to -0.7 MPa in 2008, due to a more efficient irrigation. Symptoms of drought stress were observed in late June, 2007, particularly on fast-growing whips of 'Liberty' (up to -1.4 MPa); the amount of irrigation water applied was increased in response (Fig. 3.1). During the second growing season, plant water potential was significantly lower ($P < 0.05$) early in the season, on 24 June and 31 July (-0.4 to -0.6 MPa), than later in the season (27 Aug., -0.3 to -0.4 MPa; data not shown) in both cultivars. Similarly, Bryla and Strik (2007) found that plant water potential declined towards the end of the fruiting season. Changes in plant water potential during the growing season may be a reflection of differences in plant water use after fruit filling, ripening, and to cultivar differences (Bryla and Strik, 2007). Except for June 2007, in both years, plant water potential readings indicated that plants were not stressed for water. Typically water stressed blueberries have water potentials less than -1.2 MPa (Améglio et al., 2000).

The irrigation water applied maintained soil water content within desirable levels for blueberries below 30% (Bryla and Linderman, 2007), especially during the second year 24% to 30% (Fig. 3.2). As a result of adequate irrigation and proper soil water content management, plants produced expected growth and yield by the end of the second growing season (0.5 $kg \cdot plant^{-1}$; Chapter 2). While plants growing on flat ground were less vigorous than those on raised beds (Chapter 2) and a small percentage of 'Duke' plants started dying in 2008, particularly in weed mat plots, no phytophthora root rot was isolated (OSU Plant Disease Clinic, Corvallis, OR). Phytophthora root rot has been observed in fields that are excessively irrigated (Bryla and Linderman, 2007).

Soil temperature

Variations in soil temperature among treatments likely affected volumetric soil water content and the irrigation water applied. The effect of mulch on soil temperature measured at a 5 cm depth was similar in both years. However in 2008, the soil temperature at 5 cm decreased due to weather conditions, more uniform irrigation management, and greater shading of the mulch from the plant canopy, compared to 2007 (Fig. 3.3).

The presence of weed mat led to an increase in soil temperature compared to sawdust mulched plots, especially in the warmer and drier months of July and August. In both years, weed mat behaved much like bare soil with regard to impact on soil temperature, whereas use of an organic mulch decreased soil temperature (Fig. 3.4). Similar results were found by Cox (2009) when comparing plastic weed mat and woodchip mulch in southern highbush blueberries in Australia. Similarly, Granatstein and Mullinix (2003) found that bare soil was up to 6.7°C and 4.7°C warmer at a 5 cm depth than shredded paper mulch and wood chips. Thus, to compensate for the effect of increased soil temperature, faster evaporation of irrigation water near the soil surface, and possible faster plant transpiration rate (Agehara and Warncke, 2005), plantings grown on raised beds with weed mat required as much as 369 and 295 $L \cdot plant^{-1}$ more water than did the organic mulches in 2007 and 2008, respectively. Total plant dry weight was not significantly affected by mulch treatments by the end of the second growing season

(Chapter 2). Raised beds covered with weed mat had a slightly higher maximum soil temperature than did flat ground with weed mat (Fig. 3.5). Therefore the increase in water requirements was more likely related to soil temperature determined by mulch treatment than by an increase in canopy size. In an irrigation experiment performed in Oregon, Bryla and Strik (2007) found that even though percent canopy cover increased by 246% in highbush blueberry plants at a planting distance of 0.45 m relative to 1.2 m, water use was only increased by 10% at the most.

The warmest day recorded during the two growing seasons was on 10 July 2007, when recorded soil temperatures averaged 27.1 °C and 24.2 °C in flat ground weed mat and sawdust mulched treatments, respectively. Raised bed plantings had much warmer soil temperatures when covered with weed mat (30.5 °C), whereas those covered with sawdust mulch had a similar soil temperature (24.0 °C) to flat ground plantings (Fig. 3.6). Temperatures of bare, non-irrigated soil on the same day at an Agrimet meteorological station located less than 1 km from the field trial were 38.7 °C and 30.4 °C at 5 cm and 20 cm depth, respectively (data not shown). The sawdust mulches thus moderated soil temperatures more than did the weed mat. In summer-bearing red raspberries, black plastic mulch increased soil temperature at 15 cm compared to bare soil and soil mulched with straw (Strik et al., 2006). In young cherries (*Prunus avium* L.), the use of polypropylene cover increased soil moisture content and soil temperature compared to un-mulched trees (Yin et al., 2007). On 10 July 2007, the warmest day, symptoms of wilting were observed on vigorous shoots of ‘Duke’ and ‘Liberty’ plants by 12 pm; by 4 pm, some plants showed symptoms of drought stress, including leaf-edge necrosis, particularly in

‘Liberty’ and those grown on weed mat. Although there was likely sufficient water applied through the drip irrigation system, such injury at these temperatures (39 °C max. and 28.6 °C avg., Agrimet) may have been avoided if an overhead irrigation system could have been used for conductive cooling. In our study, ‘Liberty’ plants were more sensitive to high air (> 39 °C) and soil (> 30 °C) temperatures, particularly in young plants, compared to ‘Duke’.

Raised beds required greater amounts of irrigation water than did flat ground to maintain similar levels of soil water content. On warmer days, raised beds had slightly warmer soil temperature than did flat ground. Adequate soil moisture was maintained in all treatments, especially in the second growing season when soil moisture data were recorded at a shallower depth. Use of weed mat as a mulch required greater amounts of irrigation water to maintain the same soil water content more likely due to higher canopy temperature and increased soil temperatures. Weed mat tended to behave more like a bare soil, not being able to buffer variations in temperature extremes, as occurred in sawdust and compost plus sawdust mulch.

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Table 3.1 Analysis for total nutrient content and respiratory activity of sawdust and yard debris compost. May 9, 2007. Watsonville, CA. No replication.

Nutrients	Sawdust	Compost
N (%)	0.11	1.1
NH_4-N ($mg \cdot kg^{-1}$)	3.7	5
NH_3-N ($mg \cdot kg^{-1}$)	1.6	16
P ($mg \cdot kg^{-1}$)	255	2356
K ($mg \cdot kg^{-1}$)	46	562
Ca ($g \cdot kg^{-1}$)	0.2	1.7
Mg ($g \cdot kg^{-1}$)	0.03	0.54
B ($mg \cdot kg^{-1}$)	2.1	7.8
Mn ($mg \cdot kg^{-1}$)	61	540
pH	4.2	7.3
EC (mmhos/cm) -wet	0.313	0.143
O.M. ($g \cdot kg^{-1}$)	37.4	23.4
C:N	441	21
bulk density (kg/m3) - wet	352	673
respiration (mg CO2-C/g		
optimal water & temp	0.69	0.68
optimal water & temp & N	2.2	1.3

Table 3.2 Mean rating of weed population, 2007. NWREC (n=20; mean ± SE).

Planting method	Cultivar	Mulch type	14 Mar.	18 Apr.	7 May	30 May	18 June	18 June	5 July	6 July	25 July	3 Aug.	3 Aug.	10 Aug.	23 Aug.	23 Aug	7 Sep.	12 Sep.
			Treatment applications and weed rating															
Flat A																		
	Duke B	Comp+Sawd C	HW[1]	HW	0.7[2] ± 0.1	0.9 ± 0.1	0.9 ± 0.1	VN	0.5 ± 0.1	VN	VN	0.6 ± 0.1		VN	0.7 ± 0.1	VN	HW	0.8 ± 0.1
		Sawdust C	HW	HW	0.3 ± 0.1	0.7 ± 0.1	0.4 ± 0.1	HW	0.3 ± 0.1	HW		0.4 ± 0.1	HW		0.1 ± 0.1	HW		0.1 ± 0.1
		WeedMat C			0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	HW	0.0 ± 0.0	HW		0.0 ± 0.0			0.1 ± 0.1	HW		0.1 ± 0.1
	Liberty B	Comp+Sawd C	HW	HW	0.4 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	VN	0.4 ± 0.1	VN	VN	0.3 ± 0.1		VN	0.2 ± 0.1	VN	HW	0.4 ± 0.1
		Sawdust C	HW	HW	0.3 ± 0.1	0.8 ± 0.1	0.5 ± 0.1	HW	0.2 ± 0.1	HW		0.4 ± 0.1	HW		0.2 ± 0.1	HW		0.0 ± 0.0
		WeedMat C			0.2 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	HW	0.0 ± 0.0	HW		0.0 ± 0.0			0.1 ± 0.1	HW		0.0 ± 0.0
Raised A																		
	Duke B	Comp+Sawd C	HW	HW	0.5 ± 0.1	1.1 ± 0.1	1.0 ± 0.2	VN	0.7 ± 0.1	VN	VN	0.6 ± 0.1		VN	0.7 ± 0.1	VN	HW	0.7 ± 0.1
		Sawdust C	HW	HW	0.3 ± 0.1	0.9 ± 0.1	0.7 ± 0.1	HW	0.3 ± 0.1	HW		0.3 ± 0.1	HW		0.1 ± 0.1	HW		0.1 ± 0.1
		WeedMat C			0.2 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	HW	0.1 ± 0.1	HW		0.0 ± 0.0			0.0 ± 0.0	HW		0.0 ± 0.0
	Liberty B	Comp+Sawd C	HW	HW	0.6 ± 0.1	1.0 ± 0.1	1.1 ± 0.1	VN	0.5 ± 0.1	VN	VN	0.7 ± 0.1		VN	0.7 ± 0.1	VN	HW	0.7 ± 0.1
		Sawdust C	HW	HW	0.4 ± 0.1	0.9 ± 0.1	0.8 ± 0.1	HW	0.2 ± 0.1	HW		0.4 ± 0.1	HW		0.1 ± 0.1	HW		0.1 ± 0.1
		WeedMat C			0.2 ± 0.1	0.4 ± 0.1	0.1 ± 0.1	HW	0.0 ± 0.0	HW		0.0 ± 0.0			0.0 ± 0.0	HW		0.0 ± 0.0
Significance[3]																		
Planting method		(A)			n.s.	*	*		n.s.			n.s.			n.s.			n.s.
N fertilizer rate and type		(B)			n.s.	n.s.	n.s.		n.s.			n.s.			n.s.			n.s.
Mulch type		(C)			***	***	***		***			***			***			***
Cultivar		(D)			n.s.	n.s.	n.s.		*			n.s.			n.s.			**
A x C					n.s.	n.s.	**		n.s.			n.s.			*			n.s.
A x D					n.s.	n.s.	n.s.		n.s.			n.s.			n.s.			*
C x D					n.s.	n.s.	n.s.		n.s.			n.s.			*			n.s.

[1] HW= Hand weeding, VN= Vinegar application.

[2] Visual mean rating: 0= 0%; 1 = 1- 20%; 2 = 21 - 40%; 3 = 41 - 60%; 4 = 61 - 80%; 5 = 81 - 100% weed coverage per plot.

[3] *Significant at P < 0.05; **significant at P < 0.01; ***significant at P < 0.001; n.s.=not significant.

Table 3.3 Main effects of mulch as affected by date in 2008, NWREC (n=80; mean).

Weed coverage by mulch type	Weed coverage and management by dates 31 Jan.	22 Feb.	13 Mar.	8 Apr.	29 Apr.	20 May	11 June	30 June	21 July	14 Aug.	3 Sep.	25 Sep.	14 Oct.	4 Nov.
Comp+Sawd	0.5[1] a[2] HW[3]	0.1 a	0.2 a	1.0 a FL	1.1 a FL	1.2 a HW	0.8 a	0.9 a VN	0.4 a	0.7 a HW	0.3 a	0.5 a	0.5 a	0.7 a
Sawdust	0.3 b HW	0.0 a	0.1 b	0.9 a HW	0.8 c -	1.0 b HW	0.6 b	0.7 b HW	0.1 b	0.3 b HW	0.1 b	0.2 b	0.1 b	0.4 b
WeedMat	0.7 a HW	0.1 a	0.3 a	1.0 a HW	0.9 b -	1.0 b HW	0.5 b	0.7 b HW	0.0 b	0.1 c HW	0.1 b	0.2 b	0.2 b	0.3 b
Significance[4]														
Mulch type	**	n.s.	*	n.s.	***	**	**	**	***	***	***	***	***	***

[1] Visual mean rating:0 = 0%; 1 = 1- 20%; 2 = 21 - 40%; 3 = 41 - 60%; 4 = 61 - 80%; 5 = 81 - 100% weed coverage per plot.

[2] Percent maximun weed population with different letters are significantly different at $P < 0.05$.

[3] HW= Hand weeding, FL= Flamer, VN= Vinegar application.

[4] *Significant at P < 0.05; **significant at P < 0.01; ***significant at P < 0.001; n.s.=not significant.

Table 3.4 Weeds observed in all mulch treatments, 2007 - 2008.

Annual weeds	Perennial weeds
Annual bluegrass '*Poa annua* L.'	Curly Dock '*Rumex crispus* L. '
Barnyardgrass '*Echinochloa crus-galli* L.'	Canada thistle '*Circusium arvense* L.'
Common groundsel '*Senecio vulgaris* L.'	Dandelion '*Taraxacum officinale* W.'
Hairy vetch '*Vicia villosa* R.'	Field bindweed '*Convolvulus arvensis* L
Ladysthumb '*Polygonum persicaria* L.'	Quackgrass '*Elytrigia repens* L.'
Large crabgrass '*Digitatia sanguinalis* L.'	Red sorrel 'Rumex acetosella L.'
Palmer amaranth '*Amaranthus palmeri* S.'	
Prostrate knotweed '*Polygonum aviculare* L.'	
hepherd's-purse '*Capsella bursa-pastoris* L.'	

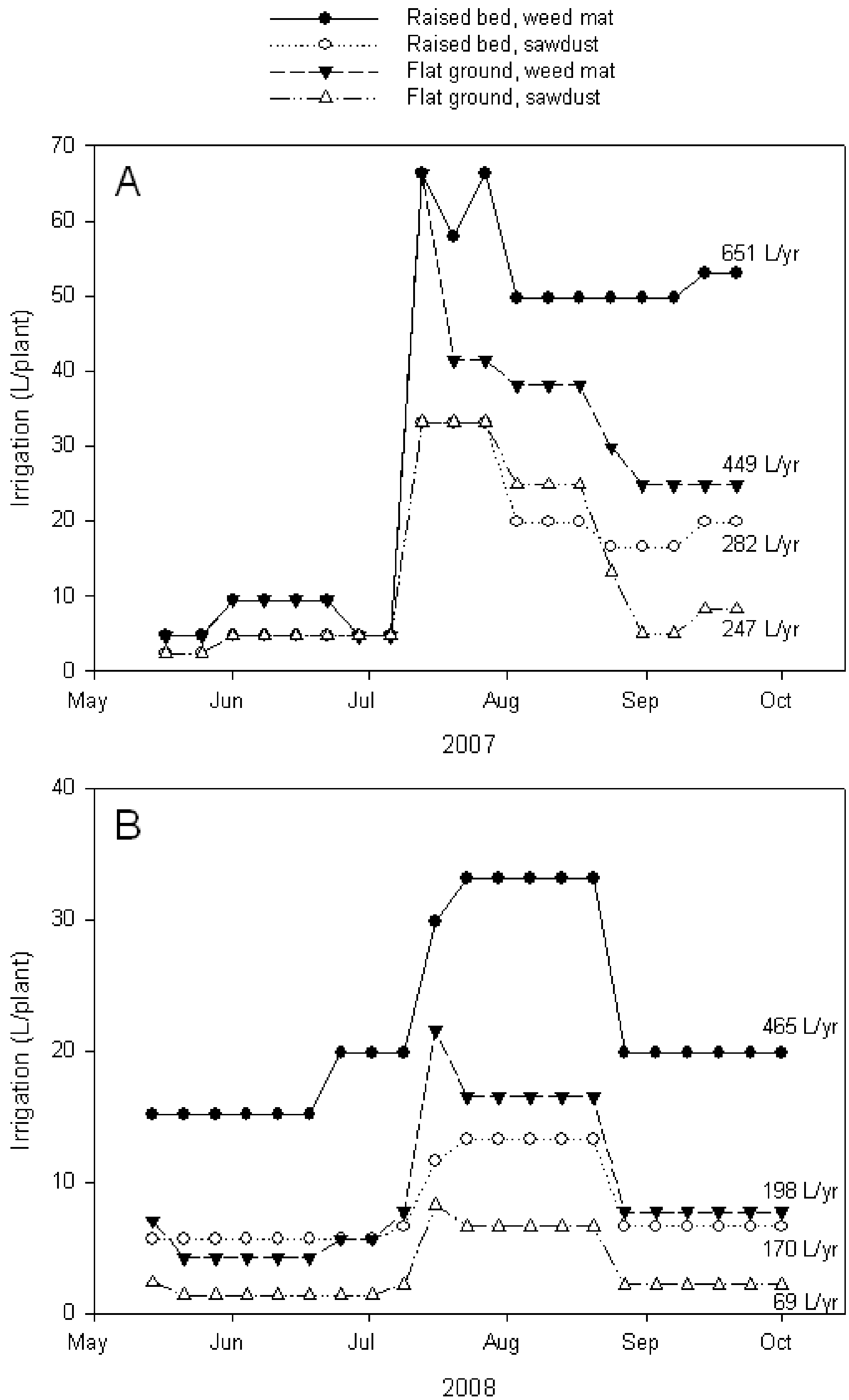

Fig. 3.1 Irrigation water applied on raised beds and flat ground having weed mat, and sawdust and sawdust plus compost, (A) 2007 and (B) 2008.

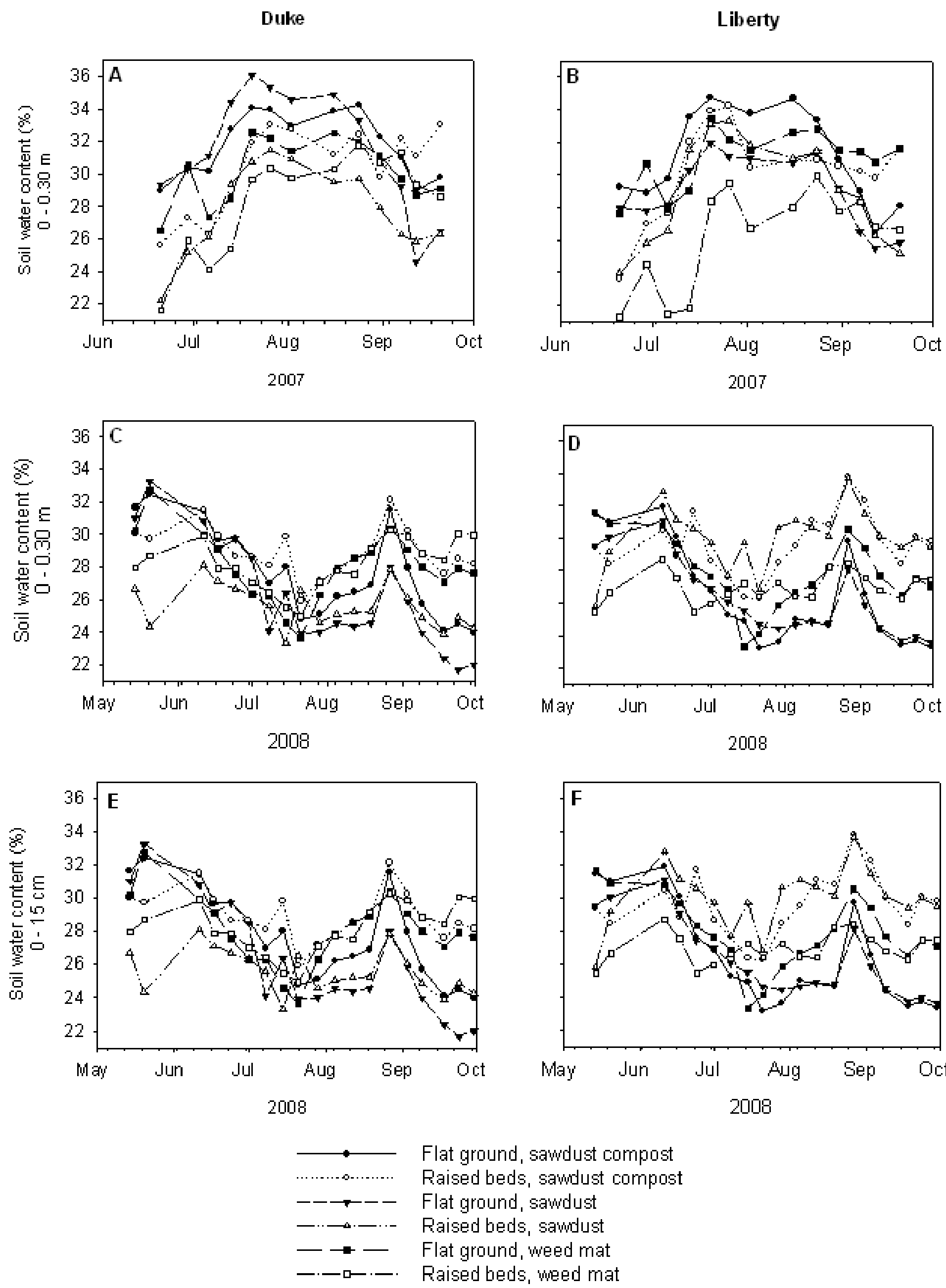

Fig. 3.2 Soil water content of (A) 'Duke' and (B) 'Liberty' at 0.30 m depth in 2007 and (C) (D) 2008 respectively; and at 15 cm depth in 2008 (E) 'Duke' and (F) 'Liberty'.

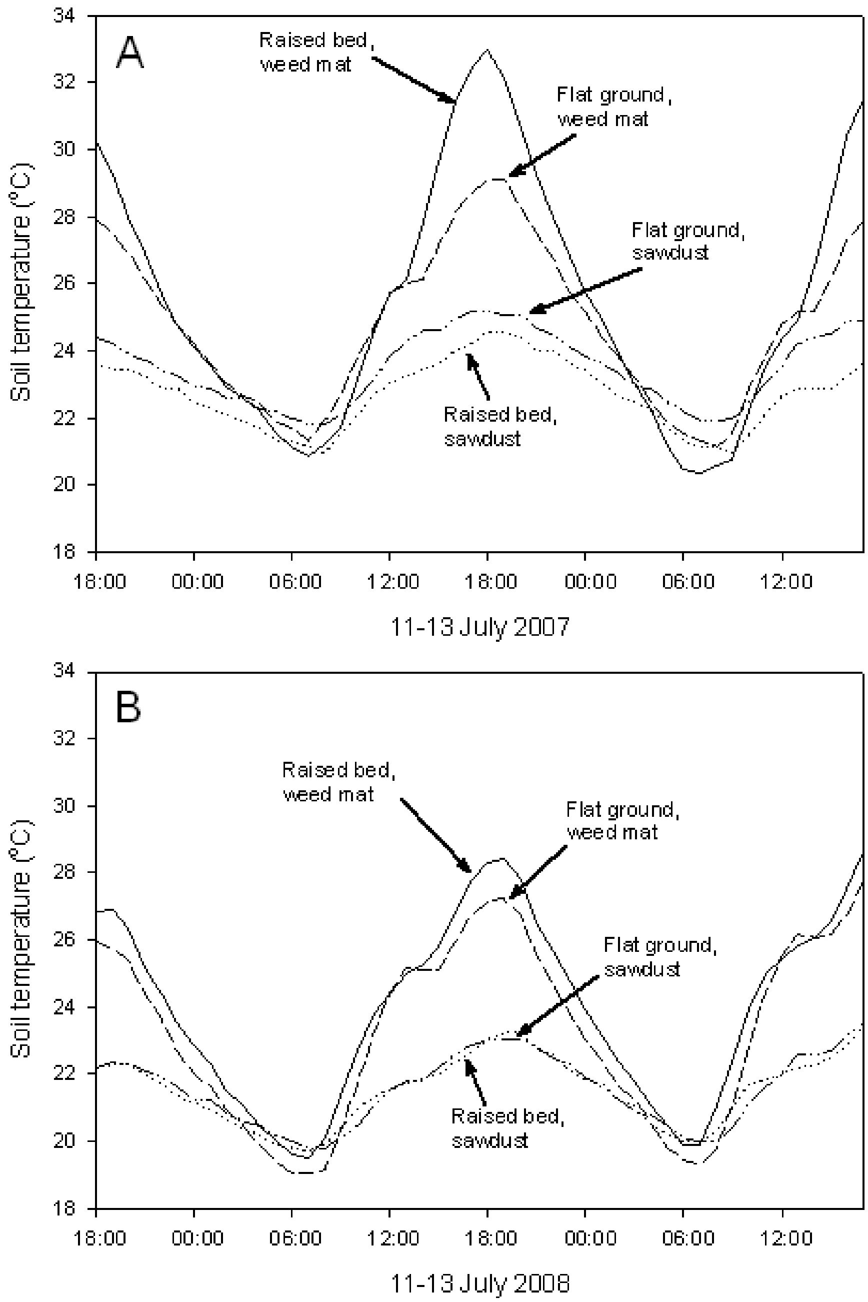

Fig. 3.3 Diurnal changes in soil temperature in raised beds and flat ground covered with weed mat or sawdust. The patterns are illustrated for temperatures measured in mid-July in (**A**) 2007 and (B) 2008.

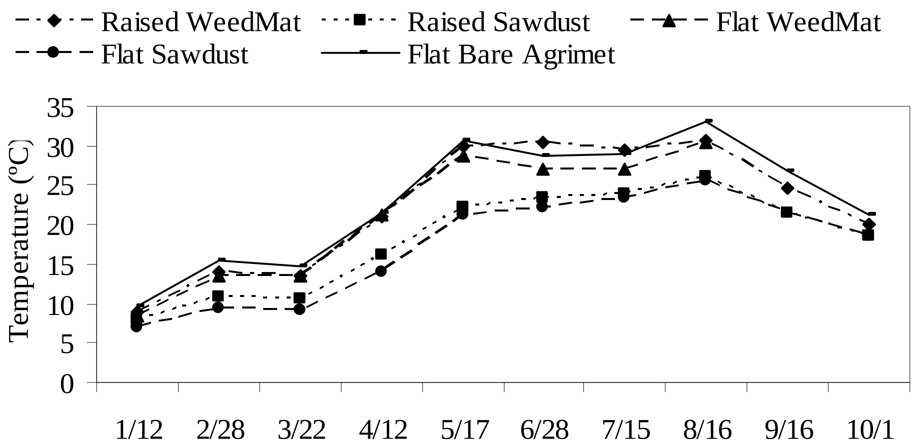

Fig. 3.4 Soil temperature at 5 cm depth and compared to Agrimet weather station, 2008.

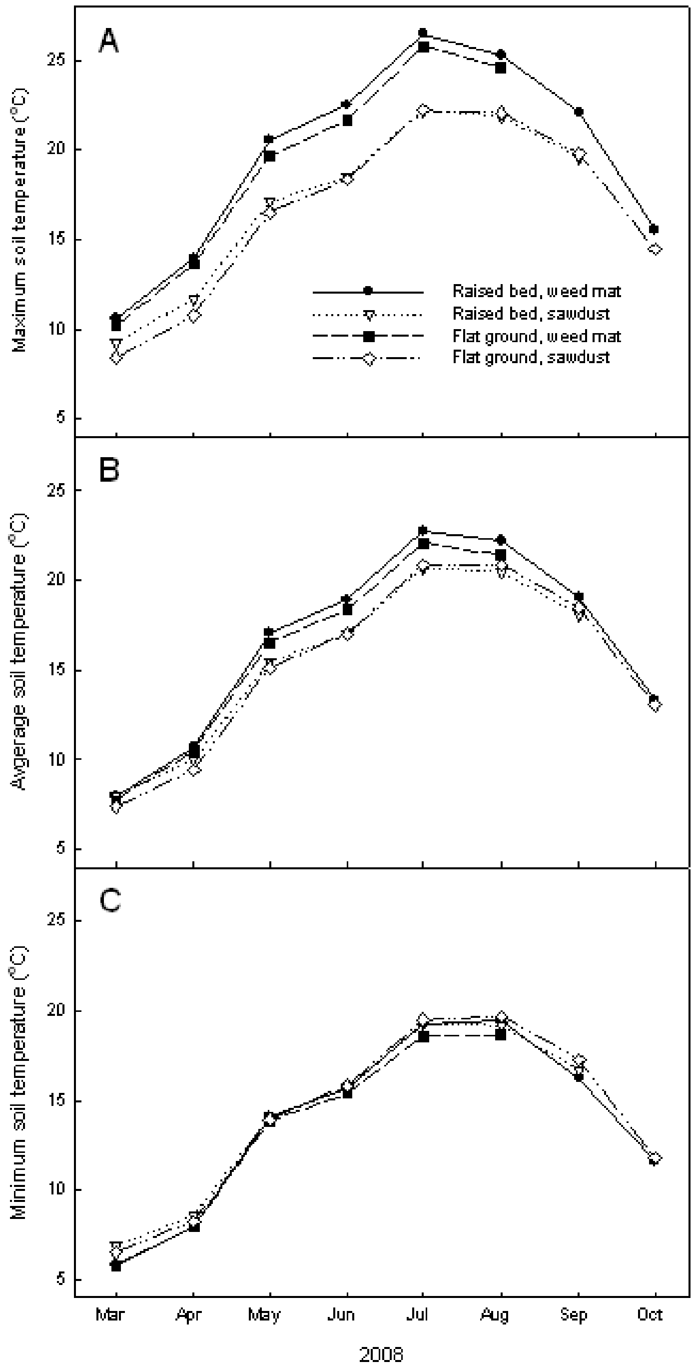

Fig. 3.5 Monthly (A) maximum, (B) average, and (C) minimum soil temperature in raised and flat blueberry beds covered with weed mat or sawdust.

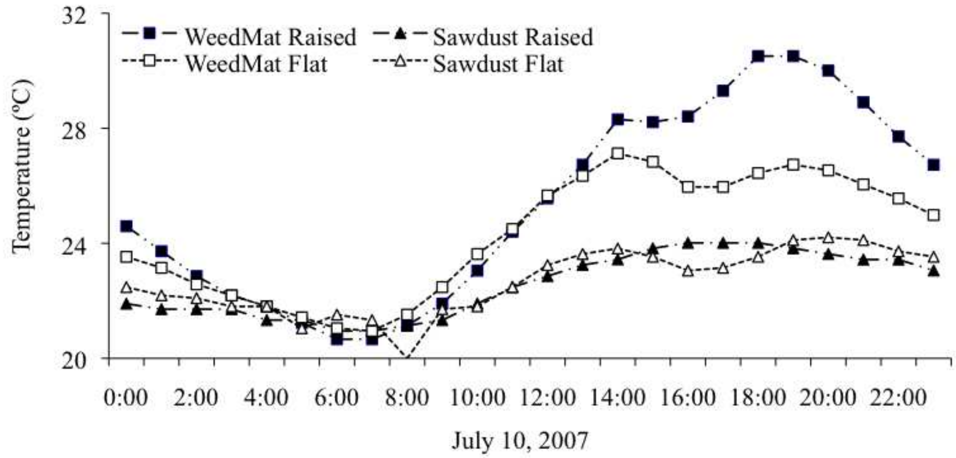

Fig. 3.6 Representation of the warmest day, July 10, 2007.

Chapter 4: Conclusions

Our research in a newly established organic blueberry field has revealed that planting method, organic fertilizer type and rate, and mulch treatment affected plant growth of 'Duke' and 'Liberty' and fruit yield and fruit quality. Weeds were controlled within organic certification standards with no apparent negative effect on blueberry plant growth or production. Irrigation requirement was affected by planting method and mulch type and seemed to be associated with variations in soil temperature.

Planting method. Raised beds improved plant growth, increasing total plant dry weight by 27% and 14% in 'Duke' and 'Liberty', respectively, after two growing seasons. While biomass accumulation of one-year-old wood and leaves were positively affected by raised beds, the biomass of roots, crown, whips, and two-year and older wood, and the number of flower buds per lateral were not affected by planting method.

Raised beds required greater amounts of irrigation water to reach a similar percent soil water content as for flat ground systems. We have attributed the greater plant biomass accumulation on raised beds to the additional water received and the faster water drainage in raised than flat systems, rather than on other soil property factors i.e., soil compaction; this may require further research.

Due to the larger plant canopy found on raised beds, yield was also increased by 44% and 34% in 'Duke' and 'Liberty', respectively. Berries from plants grown on flat ground, had 10% lesser weight than berries from plants grown on raised beds.

Organic fertilizers. In this study, plants fertilized with fish emulsion had better growth and yield than those fertilized with feather meal, in both cultivars. Fertilization at the low rate of fish emulsion led to a 23% increase in total plant dry weight in 'Duke' compared to the high rate, but fish fertilizer rate had little effect in 'Liberty'. When feather meal was applied earlier in the spring in the second season, it had a positive effect on total plant dry weight especially in 'Liberty' when grown on weed mat. The high rate of feather meal led to a greater total plant dry weight and yield than the low rate.

The high rates of fertilizer had a negative impact on young plants (first growing season), primarily on root and crown development, especially in 'Duke'. In contrast, 'Liberty' plants were more vigorous, producing more whips and shoot growth; this cultivar thus seemed to positively respond to higher rates of fertilizer, especially during the second growing season.

Overall, by the end of the second growing season, the combination of sawdust mulch with the low and the high rate of fish fertilizer resulted in greater total plant DW for 'Duke' and 'Liberty', respectively. However, in 'Liberty', plants grown with weed mat and fertilized with the high rate of feather meal had a greater total plant DW than with either rate of fish fertilizer. Similarly, when 'Duke' was grown with weed mat mulch, fertilization with the high rate of feather meal produced greater total plant DW than fertilization with the high rate of fish emulsion.

Plants fertilized with the high rate of fish fertilizer had an above normal leaf tissue %N in the second growing season, probably as a result of carryover of excessive amounts of nitrogen applied in the first season. In contrast, fertilization with the low rate of feather meal led to below normal leaf tissue %N in the second year; however, plants did not show any N deficiency symptoms as occurred during the first growing season.

Yield and berry size was greatest with the low rate of fish emulsion in both cultivars, followed by the high rate of fish emulsion in ‘Duke’ and the high rate of feather meal in ‘Liberty’. Treatment combinations producing the highest yields where the low rate of fish emulsion and weed mat in ‘Duke’ and the low rate of fish emulsion with compost plus sawdust mulch in ‘Liberty’.

Plants fertilized with the high rate of fish emulsion produced fruit with greater percent soluble solids than any other fertilizer treatment, except in ‘Liberty’ plants grown on flat ground. Fertilization with fish emulsion led to firmer fruit than in plants fertilized with feather meal in both cultivars. Fish fertilizer could have been transporting sap with more substrate through the xylem and accumulate it in the fruit increasing its firmness. Future research should be conducted to clearly identify the constituents that were causing these differences due to fertilizer type. Fruit from weed mat plots were less firm than from any of the organic mulches. Fruit firmness and percent soluble solids decreased as water regimes were increased. ‘Duke’ and ‘Liberty’ thus responded differently to the organic fertilizers applied in this study.

Mulching. Use of sawdust and compost plus sawdust mulch produced greater root, crown, one-year-old wood DW, and leaf DW, than weed mat mulch by the end of the second season. Weed mat reduced root growth, especially in plants fertilized with the high rate of fish emulsion. The number of whips in

'Liberty' was three times more than in 'Duke'; however, 'Liberty' plants had the fewest whips when grown with weed mat.

Plants grow with weed mat and compost plus sawdust mulch had greater yield than those having sawdust mulch after the second growing season. Fruit from weed mat plots had less firmness than that from sawdust and compost plus sawdust mulches.

Weed management. Weed mat was the most effective mulch for suppressing weeds; however, hand weeding around the planting hole was required to maintain weed levels below the threshold of 20% weed coverage. Sawdust mulched treatments required 12 and 17 additional hours per hectare of hand weeding in 2007 and 2008, respectively, than weed mat treatments to maintain weeds below thresholds. Compost plus sawdust was the least effective mulch for controlling weeds, as weed populations were highest in this treatment. The germination of weed seeds appeared to be higher in compost plus sawdust mulches perhaps due to the compost being a more desirable substrate for germination and a source of nutrients. Vinegar was an acceptable contact herbicide when used at a concentration of 20% acetic acid. It was efficient in controlling annual weeds and retarding growth of some small perennial weeds. In our experiment, flaming was the least used method for controlling weeds due to its difficulty to use in the field and the associated fire risks, particularly on hot, sunny days in May and June, when weed populations were relatively high. On colder days, such as in early spring, late fall or winter, flaming was found to be ineffective, as weeds would require more extended exposure to heat and the intense sunlight necessary for greater control, similar to what was observed with use of vinegar, is less prevalent.

Water requirements and soil temperature. Percent soil water content was similar among mulching treatments during the second year due to the monitoring done at 0.15 and 0.30 m depth of the soil surface. On average, raised beds required 25% and 58% more irrigation water in 2007 and 2008, respectively, compared to flat ground. At the end of the two growing seasons, the weed mat mulched plots required 106% and 148% more water than did treatments with an organic mulch in flat ground and raised beds, respectively, mainly due to warmer soil temperatures under the weed mat.

In both years, soil temperatures under weed mat were comparable to what was observed in bare soil, whereas organic mulches were able to buffer variations in different seasonal soil temperatures. The increase in water requirement found in weed mat mulched plots was mostly due to increased soil temperature, rather than canopy size. The warmer soil temperatures in weed mat could have altered the transpiration rate of the young blueberry plants without increasing total plant dry weight.

Further research will be required to consistently identify in a longer term the leading production systems analyzed in this experiment, and its sustainability while minimizing the inputs used. Cultivar selection, mulching type, and irrigation amount and frequency, should be highly considered with the type, rate and date of fertilizer that will be applied to avoid affecting i.e., water requirements and fruit quality, among others. The effect on roots due to the use the different mulching methods, will also require an extended research, due to the continue mineralization process when using compost, which might affect nutrient uptake if pH is altered, or plant growth even if minimal amounts of N and micronutrients are released.

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