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Establishing peach trees for organic production in Utah and the Intermountain West

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Abstract. Adequate weed control and nutrient supply are critical for successful establishment of fruit trees. This is of particular concern in organic orchard establishment. In order to determine the best approach for establishing peach trees (*Prunus persica* L.) organically in climates characterized by hot dry summers and cold winters such as the North American Intermountain West, seven organic and three integrated and conventional treatment combinations were established in two first leaf orchards at the USU Kaysville Research Farm, Utah, in 2008 and 2009. Treatments consisted of different tree-row and alleyway mulch and fertilizer combinations. Compost or conventional fertilizer (16-16-16 and urea) were applied at a baseline rate of 4.9, 9.6, 19 g and 114 g of available nitrogen (N) per 1st , 2nd, 3rd and 4th leaf tree respectively and adjusted up or down on a plot basis based on tree growth. Compost was supplemented with a feather meal 13-0-0 fertilizer starting in year three to avoid over application of phosphorus (P) and potassium (K). Organic experiment tree growth was initially slowed by living and straw mulches present in the tree-row. By 2011, 3rd leaf trees were largest in treatments with Birdsfoot trefoil alleyways, despite considerable tree-row weed/living mulch pressure. In the integrated experiment, trees were larger in the compost plus conventional herbicide compared to conventional fertilizer and herbicide treatment. Paper mulch depressed tree growth in combination with both compost and conventional N sources, but more so in combination with compost and organic herbicide where weed control was moderate. Weed pressure not lack of N was determined to limit organic tree growth in this study. A trefoil alleyway may alleviate the need for intensive weed control when establishing organic peach orchards.

1 Introduction

The United States (US) market for organic produce continues to grow despite the recent economic downturn (Dimitri and Oberholtzer, 2009; Slattery et al., 2011). Growth in tree fruits and berries has been particularly strong with organic peach production increasing by 116 percent between 2008 and 2011 (Perez and Plattner, 2013). Organic production in the US has largely failed to keep pace, and meeting consumer demand continues to be a challenge (Dimitri and Oberholtzer, 2009). Utah and the Intermountain Western US are traditional producers of high quality tree fruit with high elevations, warm daytime temperatures and cool nights during the summer, resulting in fruit that is exceptionally sweet and flavorful. Overall fruit production has dwindled in recent years due to urbanization and changing markets, although the planted area of tart cherries and peaches has remained stable (Ernst et al., 2012; Utah Fruit and Berry Survey, 2006). The arid climate of the Intermountain West with relatively low disease pressure confers considerable advantages for organic production and growing urban centers provide access to markets. Currently, certified organic tree fruit in Utah is limited to a few very small producers, however. Challenges include a lack of local expertise, short growing seasons with cold winters and shallow alkaline soils low in organic matter. Strengthening an organic tree fruit industry in the region will require locally adapted best management strategies, something that is currently lacking.

A major challenge to establishing new organic orchards is the transition process. Successful organic production requires growers manage soil reserves of readily available nutrients as most organic fertilizers mineralize slowly in the short-term. Building sufficient soil nutrient reserves can take time, especially in soils with very low native organic matter and high pH. Young fruit trees are particularly susceptible to competition from weeds which compete for water and nutrients and often provide a refuge for pests (Skroch and Shribbs, 1986; Hoagland et al., 2008, Tworkoski and Glenn, 2008). Bare soil or maintenance of an herbicide or tillage strip is generally preferred during the orchard establishment phase in both organic and conventional production (Welker and Glenn, 1991; Layne et al., 1994; Neilsen and Hogue, 2000; Tworkoski and Glenn, 2008). Tillage along with applications of compost is a commonly used organic orchard floor management system in the US (Hoagland et al., 2008). Adequate quantities of high quality compost can be difficult and expensive to obtain, however, while frequent tillage has been shown to disrupt surface roots and tree stability, and reduce soil quality over the long term (Skroch and Shribbs, 1986; Hoagland et al., 2008).

An alternative or complement to compost and other expensive organic inputs is to grow legumes in the orchard (Granatstein and Sánchez, 2009; Rowley et al., 2011). Legumes are capable of supplying significant N to fruit trees. Subterranean clover is used in coastal orchard regions in the US because of its low growth habit. In a California study, subterranean clover grown in the tree-row was found as effective as high 90 kg N ha^{-1} applications of compost + native vegetation for establishment of young peach trees at only a fraction of the cost of compost (Meyer et al., 2006). Many growers in Colorado and Utah plant orchards into established alfalfa and manage weeds by mowing. However, this practice has not been formally evaluated and has generally been discouraged in peach orchards due to the potential for problems with pests, particularly cat-facing insects (Killian and Meyer, 1984).

Legumes can also strongly inhibit tree growth through competition (Skroch and Shribbs, 1986; Hoagland et al., 2008; TerAvest et al., 2011). An Italian study showed that subterranean clover inhibited early growth of peach trees compared to a tillage control (Antonelli et al., 1997). Merwin and Stiles (1994) showed a similar competition problem with crown vetch planted in the tree- row of establishing apple trees. In tart cherry, Sánchez et al. (2003) showed that legumes incorporated into tree-row cover crop mixes did not increase yield relative to mixes with fewer or no legumes. Although fertigation + living mulches reduced yield discrepancies in this Michigan study. Stasiak and Rom (1991) indicated that competition effects may be short lived in establishing peach orchards, however. In addition, locating the legumes in the alleyway versus the tree-row may be critical to reducing competition and optimizing benefits (Granatstein and Sánchez, 2009; Mullinix and Granatstein, 2011).

There is also considerable interest in mulch, made from various organic and inorganic materials, for weed control in organic orchards (Granatstein and Mullinix, 2008; Tworkoski and Glenn, 2008: Cline et al., 2011; TerAvest et al., 2011). Hoagland et al. (2008) demonstrated good weed control with wood chip mulch, although tree nutritional problems were observed and soil quality was somewhat impaired. Use of woven fabric mulch was used successfully in sweet cherry establishment (Nunez-Elisea et al., 2005) although Neilsen and Hogue (1992) showed dramatic reductions in soil and leaf K in apple. Yield was highest in tart cherry systems receiving supplemental grass legume mulch combined with glyphosate as needed (Sanchez, 2003). And paper mulch significantly increased growth of apple (Hogue et al., 2010). Straw is effective for weed control during raspberry establishment (Bushway et al., 2008) and may sufficiently cool soil temperatures in the early spring to prevent premature bud break (Walsh et al. 1996; Wang et al. 2015), an increasing problem in a changing climate. Mulches may also hold additional benefits in terms of conserving soil moisture (Walsh et al. 1996; Wang et al. 2015). Increased rodent activity is of potential concern, however (Sullivan et al. 1998).

The goal of this study was to evaluate orchard floor management practices for establishing organic peach trees in environments characterized by hot dry summers, cold winters and shallow alkaline soils such as the Intermountain Western US. Two orchards were established in 2008 at the USU Kaysville Research Farm, Utah. A certified organic orchard was planted to test the effects of living and straw mulches as weed management strategies in the tree-row in combination with grass or legumes grown in the alleyway. These treatments were compared to common organic methods of maintaining weed free tree-rows, tillage and fabric mulch, with grass alleyways. A second orchard was established to investigate the interaction between nutrient availability from organic fertilizers and weed competition.

2 Materials and Methods

2.1 *Site history, experimental design and management.*

Two peach orchards (*Prunus persica* L.) were established in neighboring fields at the USU Horticulture Research Station in Kaysville, UT (41° 1'16.73"N, 111°55'43.37"W, 1336 m elevation). The fields were fallow prior to 2005 and were then planted to a succession of summer and winter cover crops to facilitate weed control. The soil type was a Kidman fine sandy loam. In April 2008, the two sites were clear cultivated and the orchards planted. The organic experiment was planted in twelve rows of 30 trees with 2.44 m in-row and 4.88 m between-row spacing, in a randomized complete block design with four blocks. The integrated experiment was planted in twelve rows of 25 trees with the same spacing and design described above. The blocking factor represented cultivar (‘Starfire’ and ‘Coralstar’ on ‘Lovell’ rootstock) and location within each orchard. Cultivars were planted in alternating blocks of three rows each resulting in plots of 3 x 5 trees in size with six (organic) or five (integrated) treatments per block. The three central trees in each 15 tree plot were designated as data trees; the surrounding trees served as guard trees to protect the data trees from edge effects. This layout resulted in two guard rows between data rows and two guard trees between data trees in a row.

Treatments were established in each experimental orchard in June of 2008. Organic experiment: straw mulch with a grass alleyway **(StGr)**, straw mulch and a Birdsfoot trefoil (*Lotus corniculatus*) alleyway **(StTr),** living mulch (low-growing shallow rooted allysum, *Lobularia maritima*) with grass alleyway **(LmGr)**, living mulch and legume alleyway **(LmTr)**, woven plastic mulch (5oz. Dewitt, Sikeston, MI) with a grass alleyway **(WfGr)** and tillage with grass alleyway **(TiGr)**. Treatments assigned to the integrated experiment were: conventional fertilizer plus herbicide **(CfH)**, compost as organic fertilizer plus herbicide **(OfH),** conventional fertilizer with paper mulch and reduced herbicide **(CfM)** and compost with paper mulch and organic herbicide **(OfM)**. All alleyways in the integrated experiment were planted to grass. Treatments **StGr**, **StTr, LmGr,** and **LmTr** were managed according to the sandwich system (Hoagland et al., 2008) with a narrow 0.3 m tilled strip maintained between the tree-row and alleyway using a tractor mounted rototiller. In the organic experiment a significant number of data trees failed to grow above the graft during the first season so all data-row trees were replanted in April 2009.

Chicken manure compost was applied to all treatments in the organic experiment and treatment **OfH** and **OfM** in the integrated experiment in 2008, and compost made of steer manure, steer stomach contents upon slaughter and wood chips was applied in 2009-2011. Compost was applied around the drip line of the tree within the tree-row in tillage, weed fabric, herbicide and paper mulch treatments, and to the tillage strips in the straw and living mulch treatments. Compost had a total N content of 1.89, 1.46, 2.25, and 2.10 % and a C:N ratio of 7:1, 13:1, 12:1 and 10.9 in 2008-2011 respectively (Table 1). Application rates in the organic experiment were calculated to supply 17, 24, 32 and 51 g total N from 2008 to 2011 respectively, assuming available N of 20 % in 2008 and 2009, 30 % in 2010 and 25 % in 2011. Application rates in the integrated orchard were higher (17, 48, 63 and 51g N from 2008 to 2011 respectively) due to the fact that the trees were one year older. Individual compost rates were adjusted up or down on a plot basis relative to the base rate based on tree growth (Table 2). Due to rapidly rising soil P, the baseline rate of compost was limited to 2.26 kg per tree in 2011 and the additional N provided through the application of an organically approved feather meal product (NatureSafe 13-0-0, Irving, TX) in late May. Conventionally fertilized trees (**CfH** and **CfM)** received 4.8, 9.6, 19.2g and 19.2g N in the form of 16-16-16, from 2008-2011 and an extra 95 g N in the form of urea (46-0-0) in 2011. Elemental sulfur (S) was applied to the soil at a rate of 90 g per tree in early December 2010 due to low soil and leaf test S values. Tissue tests also revealed trace element deficiencies so foliar applications of trace elements were applied equally to all treatments as needed starting in 2009. An organic approved pest management program for the control for peach twig borer, greater peach tree borer (pheromone-based mating disruption and a microbial insecticide) and coryneum blight (copper) was instigated across both orchards in 2008. Horticultural oil for peach aphid control was applied in 2010 and 2011.

Fresh straw was added at a rate of ~4 kg per tree to the straw treatments (**StGr** and **StTr**) in March 2008 and 2009. This rate was reduced to 2 kg per tree in 2010 and 2011. The straw applied was either wheat (*Triticum aestivum*) or barley (*Hordeum vulgare*). Spray-on paper mulch (Nature’s Own organic hydro-seeding mulch, Hamilton Manufacturing Inc. Twin Falls, ID) was mixed with water and applied with a hydro-seeder to treatments **CfM** and **OfM** in March. The fabric mulch (**WfGr**) was rolled back each fall to prevent rodent damage to tree trunks and replaced each March after fertilizers were applied. The alyssum planted in the living mulch plots (**LmGr** and **LmTr)** failed to re-establish following the winter of 2008, most probably due to a late frost that killed the emerging seedlings. It was reseeded in 2009 and 2010, however, stands in those years were poor due to increasing perennial weed pressure, and in 2011 the living mulch treatment was allowed to generate spontaneously from weeds already present. The alleyways were mowed approximately monthly and in the trefoil treatments (**StTr** and **LmTr**) the clippings were blown into the tree-row and allowed to remain on the surface. Living mulches and weeds in tree-rows were mowed as needed approximately monthly. The tillage treatment (**TiGr**) was maintained by hand using a stirrup hoe approximately once per month. Glyphosate herbicide was applied twice per year to the conventional and compost herbicide treatments (**CfH** and **OfH**) and once per year to the paper mulch treatment (**CfM**) at rate of 1.5% in spray volumes of 234 to 281 L ha^{-1}. A single application of a clove oil organic herbicide (Matran, Ecosmart Technologies Inc, Ames, IA) was applied to the organic treatment with paper mulch (**OfM**) according to label recommendations in 2009 and 2010. Acetic acid (Weed Pharm) was applied to this treatment two times at a rate of 280 L ha^{-1} in 2011. Each plot was irrigated independently using micro sprinklers. We previously found that orchard water use differed by the species of orchard floor vegetation (Rowley et al. 2011). For this study, irrigation needs were determined for each plot. Irrigation volumes to be applied were calculated based on soil volumetric water content, measured each week per plot prior to irrigation, using a capacitance probe (Diviner 2000, Sentek Technologies, Stepney, Australia). Hence soil moisture was returned to field capacity each week to reflect actual water use by treatment.

2.2 *Tree growth, nutrition and soil fertility.*

Trunk cross sectional area was calculated each winter using trunk diameters measured with a forestry tape measure 30 cm above ground level, and canopy diameter, shoot elongation and pruning weights determined each spring. Tree nutritional status was determined by analyzing a random sample of the 3rd fully expanded leaves in late July or early August. Leaf samples were rinsed in ddH_2O and dried at 70° C for 72 hours, ground to < 0.2µm with a UDY mill (UDY corp, Fort Collings, CO). The leaf samples were analyzed for total N, P, K, Ca, Mg and trace elements at the USU Analytical Lab (Logan, UT) in 2010 and Albion Laboratories (Clearfield, UT) in 2011.

Soil nitrate (NO_3^-) and ammonium (NH_4^+) were determined during the growing season at monthly intervals from May through August. Six random soil samples per plot were collected from the tree-row (0-30 cm) with a 1.6 cm probe, combined, passed through a 2-mm sieve, extracted immediately in 1M KCl and measured on a QuickChem Lachat (Latchat Instruments, Loveland, CO) using the sulfanilamide and phenate methods according to manufacturer's instructions. Soil pH, electrical conductivity (EC) and macro and micro elements were measured yearly on air-dried soils in June according to Gavlak et al. (2003). Organic carbon (C) and nitrogen (N) were measured by dry combustion with PrimacsSNC total C and N analyzers (Skalara, Inc, Buford, GA) on finely ground (<0.2 µm) soil samples collected as above from 0-10 cm depth. Inorganic C was found present in trace quantities only in the top 10 cm so total C was assumed to equal organic C.

2.3 *Statistical analyses.*

Tree growth, nutrient status and soil fertility in response to treatment were analyzed using an incomplete randomized block design with two factors in PROC GLIMMIX in the SAS System for Windows (SAS Institute, Cary, NC). In the organic experiment, the factors were alleyway and tree-row with time as repeated measures. Main effects were compared to weed-free control treatments using contrast statements. In the integrated experiment, the two factors were fertilizer type and method of weed control. When a significant tree-row x alleyway interaction was detected all treatments within each experiment were analyzed as a one-way design with repeated measures. In all cases experimental factors and time were modelled as fixed effects while block was modelled as a random effect.

3 Results and Discussion

3.1 *Tree Growth.*

Weed fabric and tillage treatments initially increased tree trunk cross sectional area relative to the living mulch treatments in the organic orchard (Figure 1). However, by 2011 trees grown with trefoil alleyways (**LmTr** and **StTr**) were as large as the weed free control treatments (**TiGr** and **WfTr**) while trees grown with grass alleyways (**LmGr** and **StTr**) were significantly smaller. This suggests that trees grown with trefoil in the alleyway were able to access more resources (nutrients and water) than trees grown with a grass alleyway despite considerable weed pressure in the tree-row (Table 3). In addition to N supplied by the compost and feather meal, trefoil biomass blown into the tree-row generated an additional 0.1 kg / tree or 73 kg total N ha^{-1} (Table 2). This more than doubled the total N applied to the trefoil treatments per year which could possibly account for the additional tree growth. However, the amount of this surface deposited N available for tree uptake is unclear (Ferreira et al., 2015). And increased tree growth could also be associated with increased tree root growth and improved access to soil resources (Parker and Mayer, 1996). Straw mulch helped to suppress weeds, and this was reflected in a modest increase in tree trunk cross sectional area (Figure 1, Table 3), overall however, tree growth was dominated by legume alleyway effects.

Trials in New Zealand, Utah and Portugal showed orchard-grown legumes have the potential to generate 80-194 kg total N ha^{-1} (Goh et al., 1995; Rowley et al., 2011; Ferreira et al., 2015). Legumes have also been shown to strongly inhibit tree growth through competition, however (Skroch and Shribbs, 1986; Merwin and Stiles, 1994; Antonelli et al., 1997; Hoagland et al., 2008; TerAvest et al., 2011). Effects of ground cover competition is known to be species specific, with alfalfa less competitive with peach than many grasses (Parker et al., 1993; Parker and Meyer, 1996). The reasons are unclear, but could relate to root morphology, specifically the tap-rooted structure of alfalfa and other legumes such as Birdsfoot trefoil. Black et al., (2010) showed that root growth of tart cherry in orchards managed with a grass alleyway was primarily constrained to the area below the herbicide strip, confirming the need for weed control in orchards managed with grass alleyways. Locating legumes in the alleyway versus the tree-row, as in this study, may be critical to reducing competition in the alleyway, hence optimizing the benefits of orchard-grown legumes and reducing tree susceptibility to weed pressure (Granatstein and Sánchez, 2009; Mullinix and Granatstein, 2011).

In the integrated experiment, there were initially few differences between treatments in tree trunk cross sectional area (Figure 2). By 2011, however, tree trunk cross sectional area in the **OfM** treatment was lowest. No difference in trunk cross sectional area between the **OfH** treatment and the conventional treatment suggests that reduced tree growth in the **OfM** treatment was caused by inadequate weed control rather than lack of N (Table 4). There were no differences between the **CfM** treatment and the conventional control indicating that paper mulch was not immobilizing N, at least with conventional fertilizer. Conventional trees in the integrated experiment transitioned to organic management beginning in 2011, quickly became chlorotic and stunted compared to other conventionally managed trees (data not shown). This illustrates the challenges associated with transitioning mature trees to organic production on soils that are naturally low in organic matter with poor nutrient reserves.

3.2 *Soil Properties.*

Soil properties in the tree-row responded positively to compost additions, cover crops, and organic mulches in both experiments. Similar results have been demonstrated in response to orchard ground cover and mulch in a range of climates and soil types (Sanchez et al., 2003; Hoagland et al., 2008; Tworkoski and Glenn, 2008; Ramos et al., 2011; TerAvest et al., 2011). In the organic experiment in Utah, total organic soil C significantly increased in the top 10 cm in the trefoil treatment two years after establishment, while increased total organic N was seen in response to trefoil by the third year (Figure 3 and 4). Weed fabric also appeared to improve soil C but only in one year out of four. While both straw and living mulch increased soil C and N compared to tillage and weed fabric, there were no differences between straw and living mulch. Compost consistently increased soil total C and N compared to conventional fertilizer beginning from orchard establishment (Figure 5). Significant effects of paper mulch on total C were not apparent until year three, however, with no differences measured in total N (data not shown).

Available N (NO_3^- and NH_4^+) in the tree-row varied considerably between treatments and year, although trefoil increased soil NO_3^- in three out of four years (data not shown). These findings are in contrast to Ferreira et al. (2015), who found no increase in soil N as a result of surface deposited legume residue. Compost increased soil NO_3^- relative to conventional fertilizer in 2009 with the opposite effect in 2011. In general soil NO_3^- levels were low (below 15 mg kg^{-1}) suggesting a tight coupling between N mineralization and tree uptake in the tree-row. Nutrient status in the alleyway was not measured in this study.

Available soil P and K increased dramatically (2-3x baseline levels) within one year of compost application (Figures 6 and 7) well above the recommended levels of 10-30 and 75-400 mg kg^{-1} for P and K respectively (Cardon et al., 2008). For this reason, compost rates were reduced in 2011 with supplemental N supplied through additions of feather meal. Elevated soil P is associated with inhibition of trace element uptake as well as surface water eutrophication (Marschner, 1995; Alloway, 2009). Elevated soil K can compete with Ca and Mg uptake and reduce fruit quality, particularly in apple (Marschner, 1995; Mercelle, 1995). This reflects the challenge of relying on compost alone for soil fertility, even if adequate quantities are cheaply available. Once compost applications were reduced to meet projected orchard P as opposed to N needs, soil available P and K returned to more acceptable levels. Alleyway treatment effects on soil P were non-significant, and tree-row effects highly variable by year, although there was a tendency for straw mulch to increase soil available P. Both straw and trefoil had a tendency to increase soil available K, although again, year to year variability was high thus making interpretation difficult.

Other soil macro and micro elements were highly variable by year with few clear treatment patterns emerging. Living mulch increased soil Ca and Mg relative to straw mulch in two out of four years while trefoil increased available soil Mn. In the integrated experiment, compost increased soil Ca, Mg, Na, and S in 2009 and 2010, and Cu and Zn in 2010. When compost rates were reduced in 2011, differences largely disappeared, however (data not shown). Soil pH at this site remained at 8.0 throughout with no treatment effects noted in any of the treatments in either orchard.

3.3 *Tree leaf nutrients.*

Tree leaf nutrients also varied chiefly by year as opposed to treatment. In the organic experiment there were no treatment effects on tree leaf N. Legumes have been associated with excessive late season N uptake which can contribute to winter bud kill and fruit quality problems (Tworkoski and Glenn, 2008). This was not observed in our study, perhaps because of low native soil organic matter. Growers in Utah frequently apply N in the fall to increase tree growth in the spring due to low native soil reserves. Leaf P was significantly greater in grass and weed fabric treatments compared to trefoil, with tillage intermediate. Trefoil treatments had greater leaf K than grass and weed fabric in 2010 and greater leaf K than tillage and weed fabric in 2011. In the integrated experiment, paper much reduced tree leaf N in 2009, although not to deficiency levels, and conventional fertilizer increased tree leaf N over compost in 2011. Compost increased tree leaf P in all years, K in 2009 and 2010 and Zn in 2011. Paper mulch increased tree leaf P in 2011 but there were no other treatment effects on tree leaf nutrients (data not shown). The tendency for both compost and mulch to increase leaf K was also documented by Marsh et al. (1996) in organic apple. Although Toselli et al. (2012) and de Melo et al. (2016) found no effect of compost on the nutrient content of peach leaves despite increased yields.

Leaf tissue S, Ca, and Mn frequently tested low in all treatments in this study (Mills and Jones, 1996) and so all trees were amended with foliar applications of Ca and trace elements. Low leaf tissue S was resolved after soil applications of S in 2010. In 2010 and 2011, leaf tissue P tested above normal, although this fell back to within normal levels after compost was reduced (data not shown). Low leaf tissue Ca is attributed to competition with K as well as dry and sandy soil conditions, all of which were present at this site. Low leaf tissue Mn can be explained by low soil availability at high soil pH. Trefoil increased the availability of soil Mn in this study and compost increased the availability of soil Zn in 2011, although this was not reflected in increased tree leaf Mn or Zn. Hashemimajd and Jamaati-e-Somarin (2011) showed use of compost increased the availability and tree leaf status of Zn and Fe in peach grown on calcareous soil. And Sorrenti et al. (2012) showed similar findings in pear. Peck et al. (2006) found organic apple grown on calcareous soil deficient in Zn, however. Further monitoring is needed to determine whether long-term changes in soil nutrient availability translates into improved peach tree nutritional status in calcareous soils.

This study design was unusual in that each treatment was treated as a discrete system with respect to N and water inputs. The goal was to manage each system optimally by decreasing fertilizer N inputs in treatments receiving legume N inputs and increasing N inputs when tree growth was reduced (Table 2). Similarly, irrigation was targeted based on soil water drawdown in each plot, ensuring water was applied optimally to each treatment. In spite of treatment specific N and water management, we were unable to overcome the negative effects of weed competition in treatments with a grass alleyway. Despite reduced external N inputs, trees with a trefoil alleyway were largest even with significant living mulch/weed pressure in the tree-row.

Research is ongoing to determine the extent to which external N sources can be reduced further in treatments with a trefoil alleyway.

4 Conclusions

Improved methods for transition to organic production are needed to assist growers in meeting the increasing demand for organic fruit. Trunk cross sectional area of newly planted peach trees was initially reduced when established with living mulch as opposed to active weed management in the tree-row. By the third leaf, however, trees planted with trefoil alleyways were significantly larger than trees planted with grass alleyways, with no difference between trees managed with tillage or weed fabric. Trunk cross sectional area in trees grown with legume alleyways was also equivalent to trees of similar age managed conventionally. This suggests that trees with trefoil alleyways were able to access more resources than trees with grass alleyways, despite considerable weed pressure in the tree-row and reduced external inputs. Conversely, trees established with grass alleyways were shown to be highly dependent on weed management in the tree-row, with no difference found between trees managed with organic fertilizers and herbicide and those managed conventionally. Total tree growth as indexed by trunk cross sectional area was reduced substantially when paper mulch with organic vs. conventional herbicide was used, allowing for the buildup of weeds over time. Increased N inputs did not overcome this competition effect. Surface deposited legume mulch and compost positively affected soil C and N status. Compost when used alone to meet tree N needs, increased soil P and K levels to unacceptable levels which necessitated the replacement of some compost applied N with feather meal. Greater tree growth in legume treatments may be associated with greater soil N although the potential for reduced tree root competition with trefoil vs. grass in the alleyways deserves further study. More research is also needed to replicate these results in a range of soil types and climates. In the meantime, these findings strongly suggest that growing legumes such as Birdsfoot trefoil in the alleyways could be a successful approach to establishing organic peach orchards with the potential to significantly improve soil health and reduce costs associated with intensive weed control and expensive external inputs.

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Table 1. Compost characteristics from 2008 to 2011.

Compost characteristic	**Chicken manure 2008**	**Steer manure 2009**	**Steer manure 2010**	**Steer manure 2011**
Total N%	1.89	1.46	2.25	2.10
C:N Ratio	7:1	13:1	12:1	10.9
P %	-	0.15	0.44	1.00
K %	-	0.53	1.35	1.79

Table 2. Average nitrogen inputs for compost, feather meal, and alley way biomass amendments for six different orchard floor treatments: living mulch tree-row with grass (LmGr) and trefoil (LmTr) alley way, straw mulch tree-row with grass (StGr) and trefoil (StTr) alley way, tillage tree-row with grass alleyway (TiGr) and weed fabric with grass alley way (WfGr). Different letters indicate significant differences at $p \leq 0.05$.

Orchard floor treatment	**Compost applied per tree (kg DW)**	**Compost total N per tree (kg)**	**Feather meal total N per tree (kg)**	**Biomass total N per tree (kg)**	**total average N inputs per tree (kg)**
2008					
LmGr	0.91	0.017	-	-	0.017
LmTr	0.91	0.017	-	-	0.017
StGr	0.91	0.017	-	-	0.017
StTr	0.91	0.017	-	-	0.017
TiGr	0.91	0.017	-	-	0.017
WfGr	0.91	0.017	-	-	0.017
2009					
LmGr	1.67	0.024	-	-	0.024
LmTr	1.67	0.024	-	-	0.024
StGr	1.67	0.024	-	-	0.024
StTr	1.67	0.024	-	-	0.024
TiGr	1.67	0.024	-	-	0.024
WfGr	1.67	0.024	-	-	0.024
2010					
LmGr	2.55	0.055	-	-	0.055
LmTr	2.54	0.055	-	-	0.055
StGr	2.45	0.057	-	-	0.057
StTr	2.46	0.057	-	-	0.057
TiGr	2.17	0.049	-	-	0.049
WfGr	1.67	0.037	-	-	0.037
2011					
LmGr	2.28	0.051	0.077a	0	0.129 b
LmTr	2.28	0.051	0.066b	0.104	0.318 a
StGr	2.28	0.051	0.069ab	0	0.119 b
StTr	2.28	0.051	0.064b	0.108	0.333 a
TiGr	2.28	0.051	0.045c	0	0.096 c
WfGr	2.28	0.051	0.050c	0	0.101 c

Note: trefoil biomass was mown and blown into the treerow from 2009 on, however residue quantity was only collected in 2011.

Table 3. The effectiveness of tree-row organic weed management strategies (n = 4), evaluated based on weed density (plants/m^2) and a visual evaluation of bare ground (% cover) in 2010 in the organic experiment. Densities were determined from two 0.25 m^2 quadrants in each plot. Percent bare ground was visually estimated between the three center data trees.

Treatment		Weed densities (no./m^2)			Bare ground (%)	
Tree-row	Alleyway	4-May	27-Jul	29-Aug	29-Jun	27-Jul
Straw	Grass	20.5 d	37.5 c	29.5 b	52.7 b	42.3 b
Straw	Legume	56.5 bc	72.5 b	72.5 a	32.1 c	22.3 c
Alyssum	Grass	78.0 ab	119.0 a	41.0 b	18.4 c	13.3 c
Alyssum	Legume	46.5 cd	86.0 b	25.5 b	25.3 c	12.2 c
Tillage	Grass	92.5 a	8.0 d	85.5 a	62.0 b	96.2 a
Weed fabric	Grass	-	-	-	97.2 a	92.8 a
Analysis of variance				(*P*)		
Block		0.47	0.49	0.28	0.70	0.74
Treatment		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Factorial						
Tree-row		0.03	0.0001	0.08	0.010	0.010
Alley		0.84	0.90	0.16	0.34	0.14
Tree-row x alley		0.002	0.0003	0.0053	0.08	0.18

Table 4. The effect of conventional and organic tree-row management (n = 4) on weed control during the 2010 growing season, as evaluated by weed density and a visual evaluation of bare ground in the integrated experiment. Weed density was determined from two 0.25 m^2 quadrants in each plot. Percent bare ground was visually estimated between the three center data trees.

Treatment		Weed density (no./m^2)				Bare ground (%)	
Weed management	Fertility	4-May	29-Jun	27-Jul	29-Aug	29-Jun	27-Jul
Bare-ground	NPK	56.5 a	29.0 bc	22.0 b	9.0 bc	89.6 a	95.1 a
Bare-ground	Compost	66.5 a	82.5 a	20.0 b	15.5 b	89.9 a	93.9 a
Paper mulch	NPK	6.0 b	5.0 c	8.0 c	7.0 c	88.5 a	95.3 a
Paper mulch	Compost	9.5 b	34.0 b	39.0 a	30.5 a	76.8 b	78.9 b
<u>Analysis of variance</u>					(*P*)		
Block		0.15	0.23	0.08	0.69	0.57	0.55
Treatment		<0.0001	0.0004	<0.0001	<0.0001	0.0074	<0.0001
Factorial							
weed management		<0.0001	0.003	0.58	0.02	0.02	0.001
Fertility		0.33	0.0008	0.003	<0.0001	0.048	0.0003
Weed x fertility		0.64	0.27	0.001	0.004	0.04	0.0009

Figure Captions:

Figure 1: Trunk cross sectional area over time (n = 4) for organic peach trees established in 2009 under different orchard floor management systems: straw mulch grass alleyway (StGr), straw mulch trefoil alleyway (StTr), living mulch grass alleyway (LmGr), living mulch trefoil alleyway (LmTr), tilled tree-row grass alleyway (TiGr) and weed fabric tree-row grass alleyway (WfGr). Different letters indicate significant differences among treatments within a year at the level of $p < 0.05$.

Figure 2: Trunk cross sectional area over time (n = 4) for peach trees established in 2008 under different integrated orchard floor management systems: organic fertilizer conventional herbicide (OFH), conventional fertilizer conventional herbicide (CFH), conventional fertilizer conventional herbicide to start transition to organic in 2011 (CFHT), organic fertilizer paper mulch (OFM), conventional fertilizer paper mulch (CFM). Different letters indicate significant differences at the level of $p < 0.05$.

Figure 3: Total organic soil carbon (0-10cm depth) in the organic experiment for alleyway main effect over time (n = 4) contrasted with organic weed free standards tillage and weed fabric. Different letters indicate significant differences at the level of $p < 0.05$.

Figure 4: Total soil nitrogen (0-10cm depth) in the organic experiment for alleyway main effect over time (n = 4) contrasted with organic weed free standards tillage and weed fabric. Different letters indicate significant differences at the level of $p < 0.05$.

Figure 5: Main effect of fertilizer and interaction of weed control method with time in the integrated experiment on soil organic carbon (n = 4). Different letters indicate significant differences at the level of $p < 0.05$.

Figure 6: Available (Olsen) soil phosphorus for tree-row main effect over time (n = 4) in the organic experiment contrasted with organic weed free standards tillage and weed fabric. Different letters indicate significant differences at the level of $p < 0.05$.

Figure 7: Available (Olsen) soil potassium for tree-row and alleyway main effect over time (n = 4) in the organic experiment contrasted with organic weed free standards tillage and weed fabric. Different letters indicate significant differences at the level of $p < 0.05$.

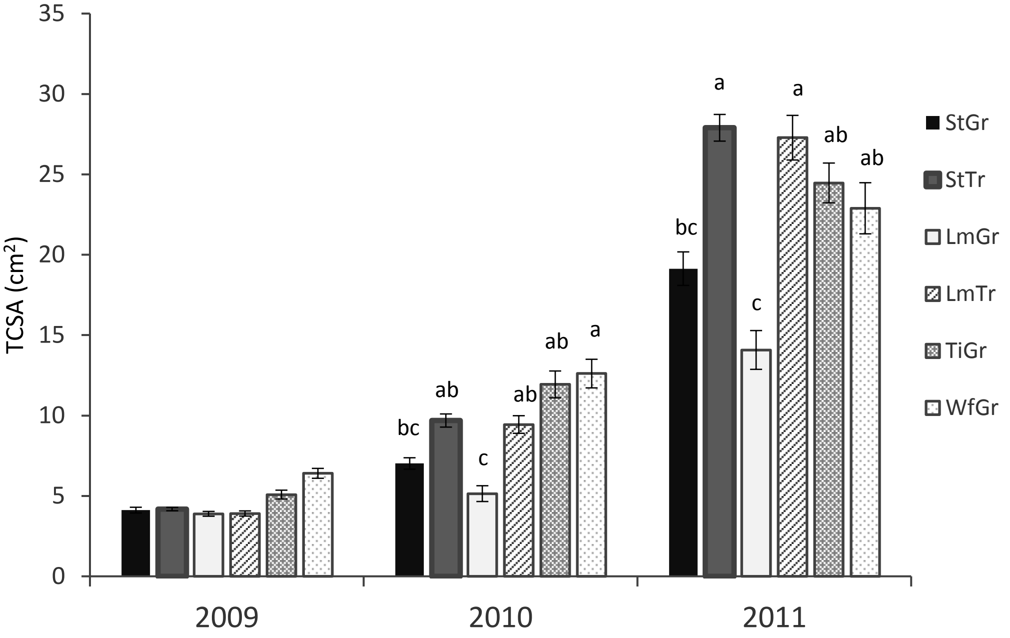
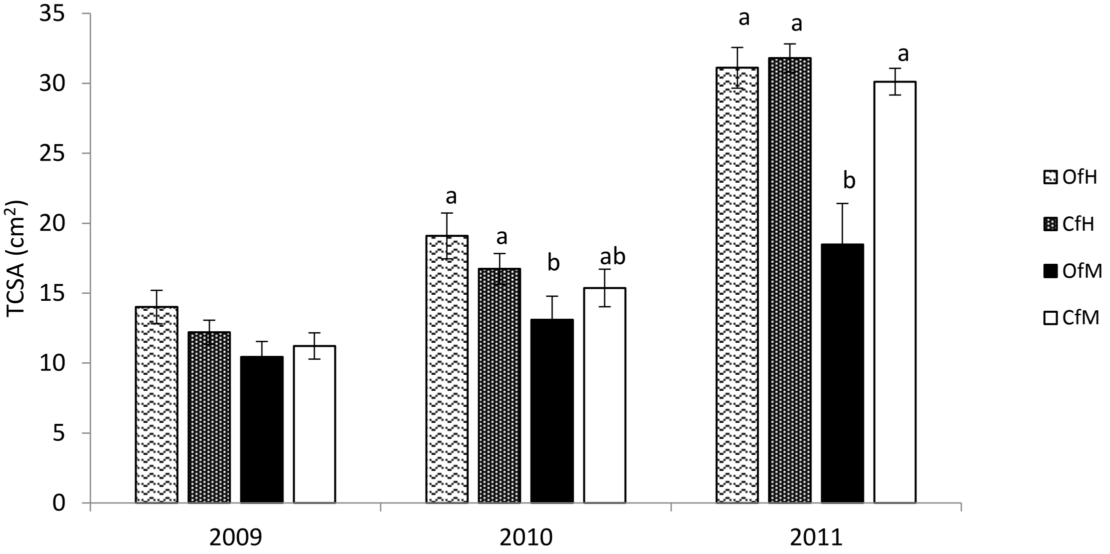

35
30
25
20
15
10
5
0
TCSA (cm²)
2009
2010
2011
bc
ab
c
ab
ab
a
bc
a
c
a
ab
ab
StGr
StTr
LmGr
LmTr
TiGr
WfGr

Figure 1.

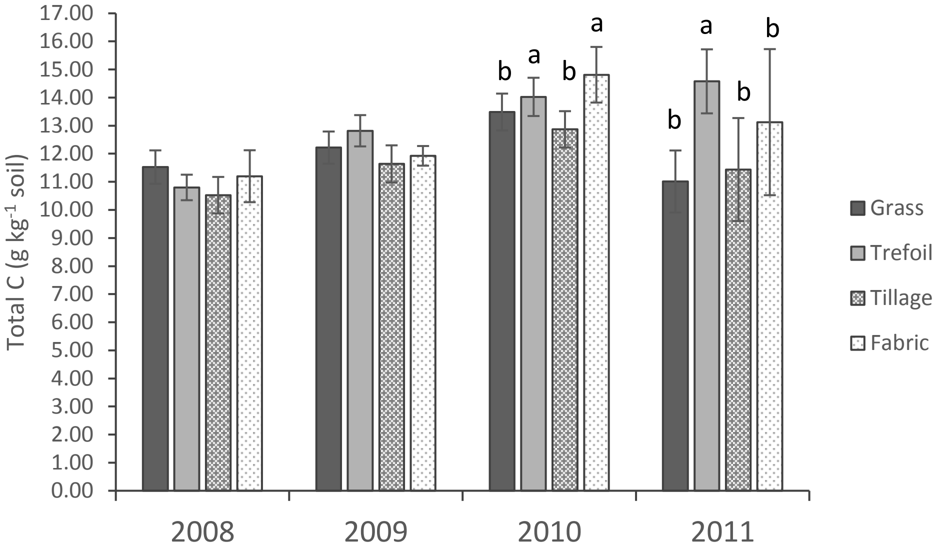
598



599

600 Figure 2.

601



Total C (g kg^{-1} soil)
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
2008
2009
2010
2011
b
a
b
a
b
a
b
b
Grass
Trefoil
Tillage
Fabric

Figure 3.

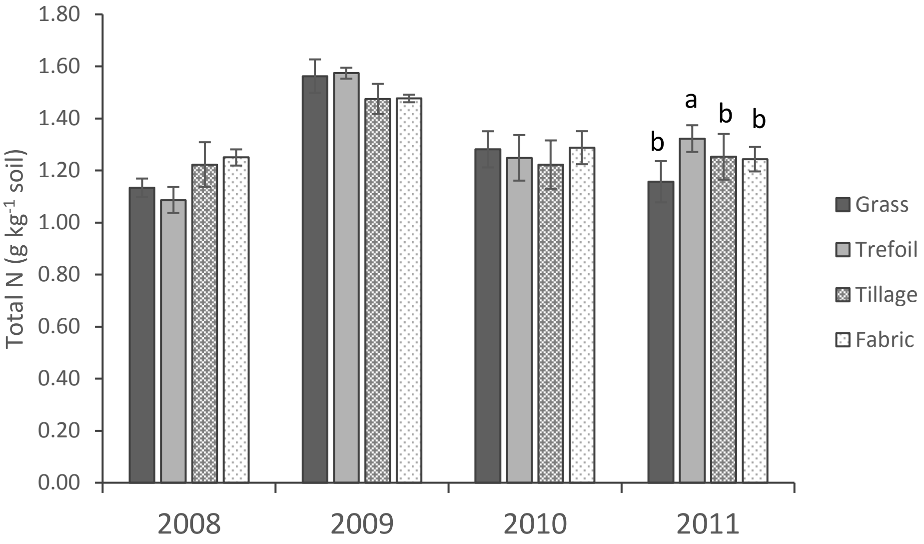
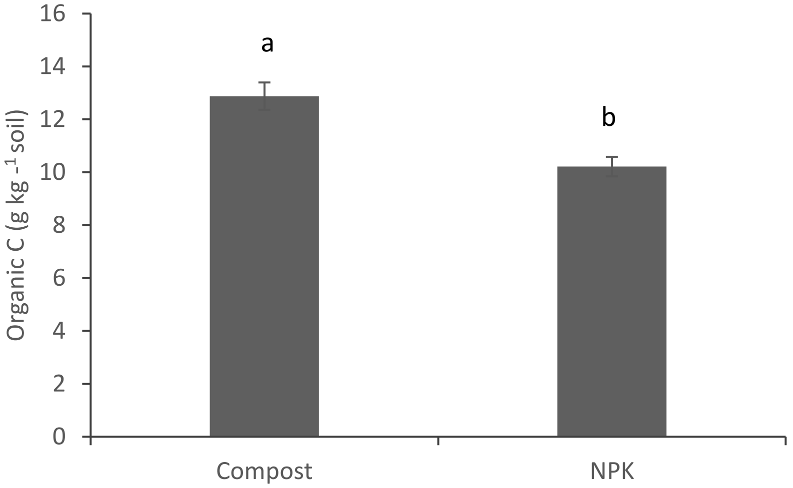

1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Total N (g kg-1 soil)
2008
2009
2010
2011
b
a
b
b
Grass
Trefoil
Tillage
Fabric

Figure 4


Organic C (g kg -1 soil)
0
2
4
6
8
10
12
14
16
a
b
Compost
NPK

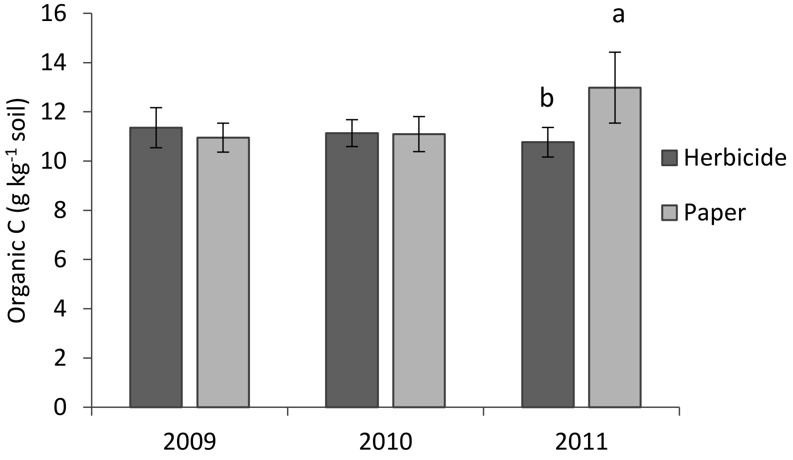

Organic C (g kg-1 soil)
0
2
4
6
8
10
12
14
16
b
a
2009
2010
2011
Herbicide
Paper

Figure 5.

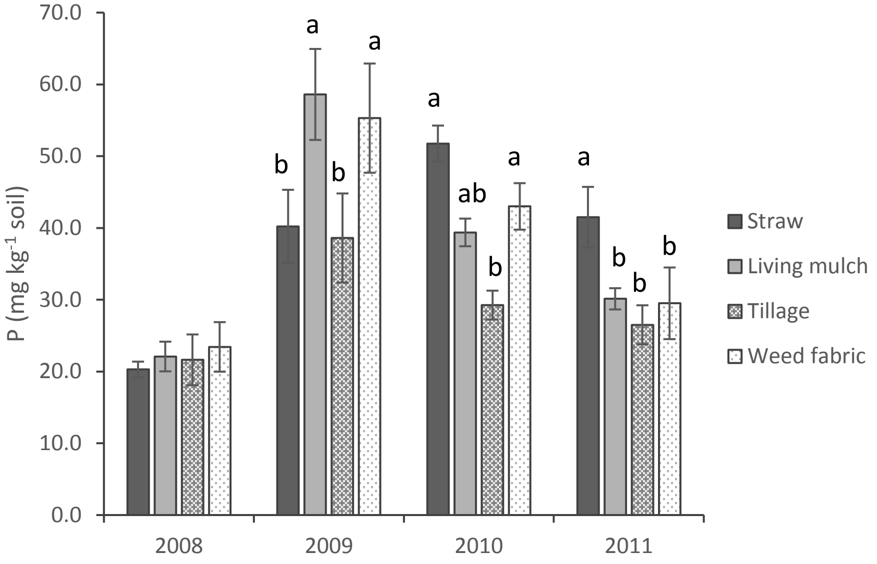

70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
P (mg kg^{-1} soil)
2008
2009
2010
2011
b
a
b
a
a
ab
b
a
a
b
b
b
Straw
Living mulch
Tillage
Weed fabric

Figure 6.

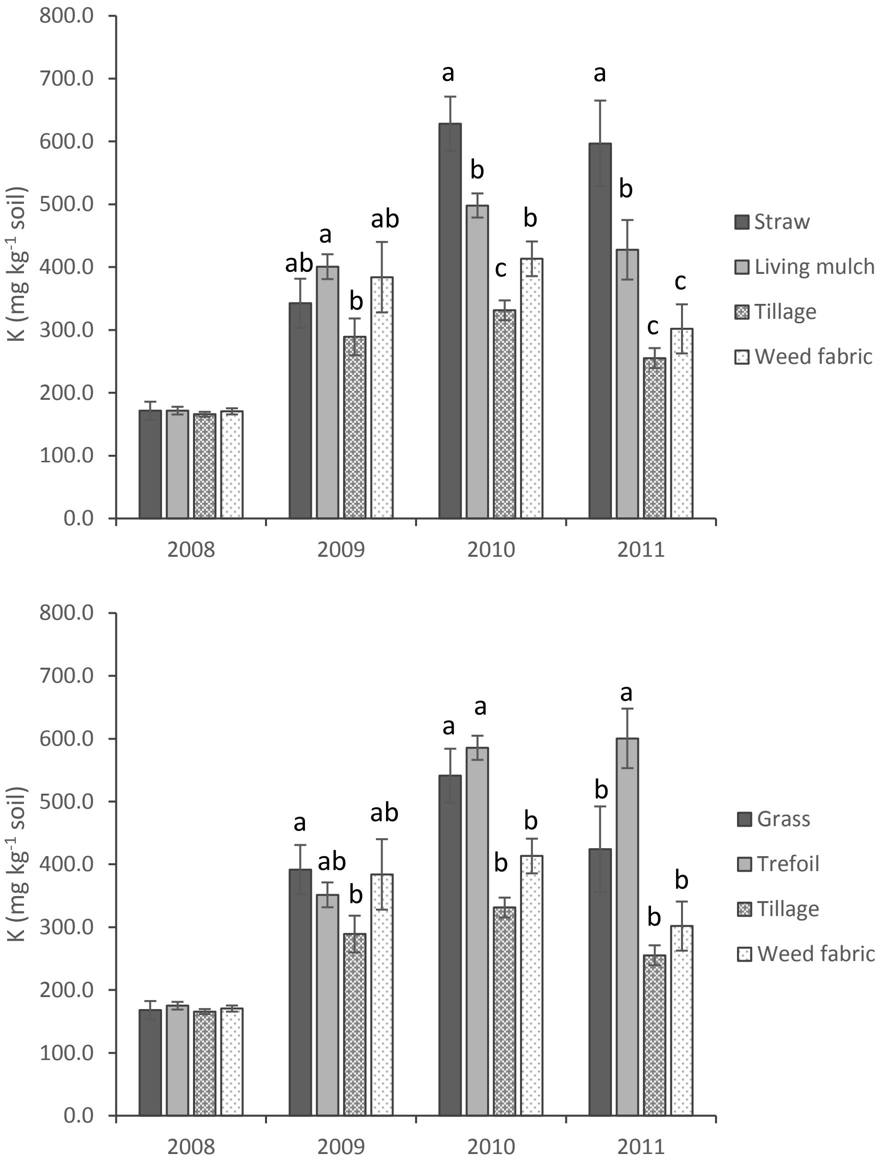

800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
K (mg kg^{-1} soil)
2008
2009
2010
2011
ab
a
b
ab
a
b
c
b
a
b
c
c
Straw
Living mulch
Tillage
Weed fabric
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
K (mg kg^{-1} soil)
2008
2009
2010
2011
a
ab
b
ab
a
a
b
b
b
a
b
b
Grass
Trefoil
Tillage
Weed fabric

Figure 7.