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# Establishment of birdsfoot trefoil (*Lotus corniculatus*) pastures on organic dairy farms in the Mountain West USA

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**Abstract** Birdsfoot trefoil (BFT, *Lotus corniculatus* L.) is a nonbloating perennial forage legume well suited to ruminant production on pastures. It is persistent under irrigation in cool, dry western US climates, and has been found to increase meat and milk production compared with other forages. The establishment of BFT pastures was evaluated on five commercial organic dairy farms in southern Idaho and northern Utah. Participating producers broadcast seeded 4-ha BFT pastures between 26 July and 8 September 2011 at a rate of 25 kg pure live seed ha$^{-1}$. Birdsfoot trefoil and weed densities were systematically sampled 17 to 23 days after first BFT emergence in autumn 2011 and again in spring 2012. On all farms, BFT seedling density was high, averaging 690 plants m$^{-2}$ in the autumn after planting and 340 plants m$^{-2}$ the following spring. However, weed density varied between 130 and 750 plants m$^{-2}$ in the autumn of 2011 and 240 and 410 plants m$^{-2}$ in the spring of 2012. On the three farms where weed density was equal to or greater than BFT density in the spring of 2012, spring BFT cover averaged less than 10 %. On the two farms where spring weed density was less than BFT density, spring BFT cover was 48 and 66 %. These two pastures produced 6000 to 7600 kg of dry matter ha$^{-1}$ by 20 June 2012 and were well enough established to support grazing for the remainder of the summer. Birdsfoot trefoil establishment was enhanced under sprinkler compared with flood irrigation.

**Keywords** Germination · Irrigation · Legume · Seedling · Weed competition

## Introduction

There is growing interest in grass-fed and organic livestock production in the USA. Grazing-based beef and dairy systems have the potential to lessen environmental impacts through lower energy expenditures and reduced acidification of soil and water (Arsenault et al. 2009; Koknaroglu et al. 2007; O'Brien et al. 2012), improve the fatty acid composition of meat and milk (Clancy 2006; Kay et al. 2005; Nuernberg et al. 2005; Realini et al. 2004; Schroeder et al. 2005), reduce dairy cow mortality (Burow et al. 2011), and increase profitability through reduced feed costs and niche marketing (Brock and Barham 2008; White et al. 2002).

Feed costs are a major determinant of profitability in livestock agriculture. McBride and Greene (2009) demonstrated that feed costs were 25 % lower for the quartile of US organic dairies that used the most pasture than for the quartile of organic dairies that was most concentrate-based. For the most pasture-based quartile, however, milk yield averaged 30 % less than that of the most concentrate-based quartile of organic dairies.

The environmental sustainability of grazing-based dairy systems has been questioned in comparison with the high productivity of ruminants fed concentrates in

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drylot systems, which has lower land area requirements for animal production and lower waste generation per unit of milk or meat produced (Capper et al. 2009; Meeh et al. 2013; Pimentel et al. 1980). The forage legume birdsfoot trefoil (BFT) supports high levels of ruminant production under grazing while minimizing environmental impacts and, therefore, has the potential to improve the productivity of grazing-based systems while retaining their social, economic, and environmental benefits (MacAdam et al. 2006).

Birdsfoot trefoil has positive environmental effects and benefits for ruminant nutrition that make it well suited for grazing-based ruminant production. Birdsfoot trefoil fixes the nitrogen it requires for growth, and unlike more commonly cultivated legumes such as alfalfa (*Medicago sativa* L.) and most true clovers (*Trifolium* sp.), the tannin content of BFT allows it to be grazed, even in pure stands, without risk of bloat. The beneficial tannins produced by BFT reduce enteric methane production (Woodward et al. 2004) and increase milk yield in dairy cows (Turner et al. 2005; Woodward et al. 1999, 2009). Birdsfoot trefoil has reduced dairy manure ammonia emissions compared with alfalfa (Misselbrook et al. 2005), reduced urine nitrogen content (Woodward et al. 2009), and decreased mineralization of nitrogen from faeces compared with white clover (*Trifolium repens* L.) (Crush and Keogh 1998), which lowers the potential for nitrate leaching. Tannin-containing forages, including BFT, suppress internal parasites (Hoste et al. 2006; Marley et al. 2003). Compared with other tannin-containing forages, BFT supports high weight gain in cattle (MacAdam et al. 2011; Marten et al. 1987; Wen et al. 2002) and lambs (Douglas et al. 1995; Marten and Jordan 1979). Despite these advantages, adoption of this legume is limited due to slow establishment and poor persistence in some climates (Ahlgren 1956; Beuselinck et al. 1984; Seaney and Henson 1970).

In the cool, dry climate and moderately alkaline soils of mountain valleys in the western USA, BFT grown under irrigation is productive and persistent (Beuselinck et al. 2005; MacAdam and Griggs 2006), but small seed size and low seedling vigor mean that weed competition can interfere with establishment of BFT pastures (Chapman et al. 2008; Henson and Taymon 1961). It is recommended that clipping or grazing be limited to that needed to control weeds during the planting year (Ahlgren 1956). Chemical weed control has been demonstrated to improve first year yields, but by the second year, BFT can yield equally well when established with no weed control (Scholl and Brunk 1962; Wakefield and Skaland 1965). Limited first year productivity and concern about weeds may dissuade organic producers from planting BFT despite the advantages the crop offers once established. A transient loss of sequestered carbon will occur when perennial grass pastures are cultivated (Vellinga et al. 2004), so a further consideration is that the potential carbon sequestration over the lifetime of the new pasture should more than offset the short-term carbon dioxide equivalent losses associated with cultivation.

A number of studies have addressed BFT establishment under conventional management including the use of soil fertility amendments and pre- and/or post-establishment herbicides (e.g., Buxton and Wedin 1970a; Fribourg and Strand 1973; Wakefield and Skaland 1965), but none was carried out under organic management. The pasture establishment study reported here was conducted on-farm, working within the constraints of producers' schedules and existing infrastructure. The five cooperating dairy producers are members of the Organic Valley® Cooperative who farm in southern Idaho and northern Utah. The objectives of this study were to evaluate the planting of BFT under irrigation on commercial organic dairy farms in the Mountain West and relate management practices such as planting date and irrigation type to differences in weed competition and the rate of BFT establishment. This is the first phase of a larger project that seeks to address the production deficit experienced by grazing-intensive organic dairies, comparing milk production of dairy cows grazing BFT pastures with that of dairy cows grazing grass pastures; those milk production data will be reported separately.

## Materials and methods

### Autumn planting

Producers at three organic dairy farms in southern Idaho (ID-1, ID-2, ID-3) and two in northern Utah (UT-1 and UT-2) participated in this study. All farms were located within the Cache Valley, a remnant bed of Lake Bonneville that covered 51,000 km$^2$ in the Great Basin 32,000–14,500 years ago (Utah Geological Survey 2013). Irrigation is from rivers and reservoirs fed by autumn, winter, and spring precipitation. In preparation for late summer-early autumn 2011 planting of BFT, producers at all but two farms, ID-2 and ID-3, deep-ploughed long-established grass pastures each totalling at least 4 ha in autumn of 2010. An advising producer suggested a small grain crop be planted to provide summer feed and allow additional soil cultivation before establishing BFT. In the autumn of 2010, winter barley (*Hordeum vulgare* L.) was planted on farm UT-2, and in spring of 2011, spring oats (*Avena sative* L.) was planted on farms ID-1, ID-3, and UT-1. On farm ID-2, the 4-ha field where BFT was to be planted had been cropped for alfalfa hay for 3 years, preceded by an annual crop of barley, so no grain crop was planted prior to BFT (Table 1).

Beginning in July 2011, all producers planted BFT using a Brillion "Sure Stand" Seeder (Brillion Farm Equipment, Brillion, WI). Two farms (ID-1 and ID-2) were sprinkler irrigated, and on those BFT was planted into a prepared seedbed and irrigated immediately. Producers on the three flood-irrigated farms (ID-3, UT-1, and UT-2) prepared a seedbed, irrigated, and then planted BFT after the soil had dried sufficiently to be crossed with a tractor. On all farms, the same seed lot of 'Norcen' BFT seed (Norfarm Seeds Inc., Bemidji, MN) coated with OMRI-certified Apex™ Green (Summit Seed Coatings LLC, Boise, ID) containing Nitragin K rhizobium inoculant for BFT (Novozymes BioAg Inc., Brookfield, WI) was broadcast planted at a rate of 25 kg pure live seed (PLS) ha$^{-1}$, including 3 kg ha$^{-1}$ hard seed. Planting dates were as follows (in chronological order): 26 July at ID-1, 10 August at ID-2, 17–18 August at UT-1, 5 September at ID-3, and 7–8 September at UT-2.

Farms ID-1 and ID-2 applied sprinkler irrigation after planting through the end of September; ID-1 was equipped with a lateral roll sprinkler system and reported applying approximately 50 mm of water every 8–9 days. ID-2 was equipped with an all-terrain vehicle-towed pod sprinkler system, and approximately 25 mm was applied every 7 days. ID-3 and UT-2 flood irrigated once in the autumn after seedling emergence. UT-1 irrigated only the east 2-ha BFT field once after planting; an autumn rain occurred before the second field could be irrigated. It is difficult to estimate the application rate of water with flood irrigation because the differential between water applied to the head and tail ends of the field depends on the soil infiltration rate. Farms UT-1 and UT-2 could not report how much water they applied; farm ID-3 applied approximately 75 mm. No farms resumed irrigation prior to spring sampling of plant densities. ID-1 and ID-2 clipped weeds that had grown taller than BFT once in the autumn by greenchopping (ID-1) or swathing (ID-2).

## Climate data

Average monthly minimum and maximum temperatures and total monthly precipitation and evapotranspiration were calculated from data gathered at three weather stations (Preston, ID; Trenton, UT; and Cutler Dam UP&L, UT) with a similar geographical distribution in Cache Valley as the five farms. Data were provided by the Utah State University Climate Center, Climate Database Server, which gives daily evapotranspiration estimated by the ASCE-standardized Penman-Monteith method (ASCE-EWRI 2005). Thirty-year averages were calculated from data gathered by the same three weather stations, provided by Western Regional Climate Center reports of National Climatic Data Center 1981–2010 monthly mean temperatures. Figure 1 shows monthly temperature (a), precipitation and evapotranspiration data (b) for 2011 and 2012 as well as 30-year mean data at these three weather stations.

## Soil tests

Soil tests were carried out on all BFT pastures prior to planting. Soils were sampled to a depth of 30 cm and a composite of 20 subsamples was taken systematically along a "W" pattern encompassing each field. Soil samples were passed through a 2-mm sieve and stored at 4 °C until analysis, which occurred within 2 weeks. The following properties were measured according to Gavlak et al. (2003): nitrate-nitrogen ($NO_3$-N) by the chromotropic acid method (method 16S3.30); Olsen extractable P and K (method S4.10); water-extractable calcium, magnesium, sodium, and sulfur were measured using the saturation paste method (method S1.60); and soil pH (method S2.20) and electrical conductivity, a measure of salinity (EC; method S2.30), were measured in a 1:1 *w*/*v* water-saturated paste. Sodium absorption ratio (SAR) was calculated for farm ID-3 as the proportion of sodium to calcium plus magnesium in the soil according to the formula given in Davis et al. (2012).

## Stand assessment

Birdsfoot trefoil and weed plant densities were sampled on each farm in the autumn of 2011 and again in the

**Table 1** Birdsfoot trefoil field management, irrigation infrastructure, and soil descriptions

| Farm | Previous crops | Crop, autumn 2010/spring 2011 | BFT seeding date 2011 | Irrigation method | Major soil type(s)[a] | Soil | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Texture | pH | EC (dS $m^{-1}$) | Na | $NO_3$ | P | K | Ca | Mg | S |
| | | | | | | | | | mg $kg^{-1}$ | | | | | | |
| ID-1 | Grass pasture (5+ years) | Summer oats | 26 July | Sprinkler | Kidman (coarse-loamy, mixed, mesic Calcic Haploxerolls); Maplecreek-Layton (coarse-loamy, mixed, mesic Oxyaquic Calcixerolls) | Sandy loam | 8.28 | 0.26 | 36 | 24 | 36 | 535 | 44 | 19 | 8 |
| ID-2 | Barley, alfalfa (3 years) | Alfalfa | 10 August | Sprinkler | Kidman (coarse-loamy, mixed, mesic Calcic Haploxerolls) | Sandy loam | 8.29 | 0.12 | 12 | 4 | 24 | 300 | 33 | 7 | 3 |
| ID-3 | Grass pasture (5+ years) | Summer oats | 5 September | Flood | Windernot-Lewnot-Stinkcreek (sandy-skeletal, mixed, mesic Pachic Calcixerolls) | Sandy loam | 9.04 | 0.41 | 105 | 3 | 59 | 489 | 35 | 19 | 57 |
| UT-1 | Grass pasture (10+ years) | Summer oats | 18 August | Flood | Greenson (fine-silty, mixed, mesic Aquic Calciustolls) | Silty loam | 8.25[b]<br>8.28[c] | 0.24<br>0.21 | 10<br>34 | 6<br>17 | 14<br>18 | 709<br>842 | 65<br>67 | 11<br>12 | 9<br>13 |
| UT-2 | Grass pasture (10+ years) | Winter barley | 8 September | Flood | Collett (fine, mixed, mesic Aquic Calciustolls); Nibley (fine, mixed, mesic Aquic Argiustolls) | Clay | 8.21 | 0.26 | 19 | 6 | 44 | >900 | 58 | 20 | 10 |

[a] Major soil types provided by NRCS Web Soil Survey

[b] West field

[c] East field

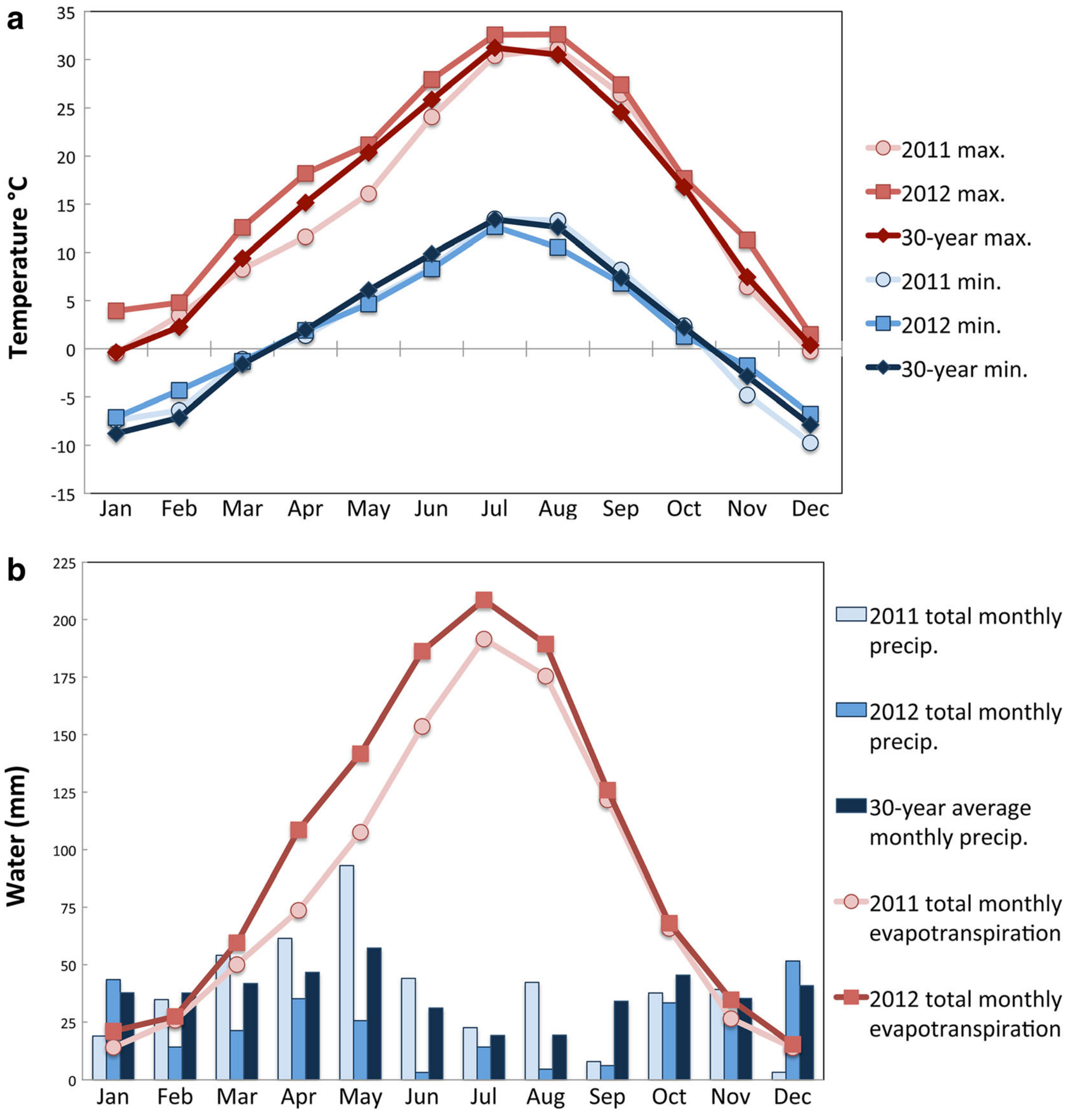

**Fig. 1** Average monthly minimum and maximum temperatures for Cache Valley in 2011 and 2012 with 30-year average for comparison (**a**). Total monthly precipitation and evapotranspiration in 2011 and 2012 and 30-year average monthly precipitation for comparison (**b**)

spring of 2012. Each BFT field was divided into a grid of 30.5-×30.5-m rectangular subdivisions. Maps of the fields with grids superimposed and a sampling point in the center of each subdivision were created using ArcGIS (ESRI, Redlands, CA 92373). These maps were uploaded to a handheld Archer GPS unit (Juniper Systems, Logan, UT 84321) so that the central point of each subdivision could easily be located in the field. Across each BFT field, every second subdivision was sampled. Satellite images with sampling subdivisions superimposed on each farm's BFT field can be seen in Fig. 2a. BFT fields were not identical in shape or area, leading to minor differences in the number of subdivisions sampled in each field (ID-1 $n$=20; ID-2 $n$=21; ID-3 $n$=30; UT-1 $n$=19; UT-2 $n$=24).

A 0.5-×0.5-m quadrat divided into 25 10-×10-cm cells was located at five random sampling points within each subdivision. At each location, 2 of the 25 cells were randomly selected, and weed and BFT seedlings rooted within these two cells were counted. In addition, in spring 2012, the same sampling scheme was used to estimate percent cover of BFT, weeds, and bare ground to the nearest 5 %. The dominant weed species in each pasture were noted.

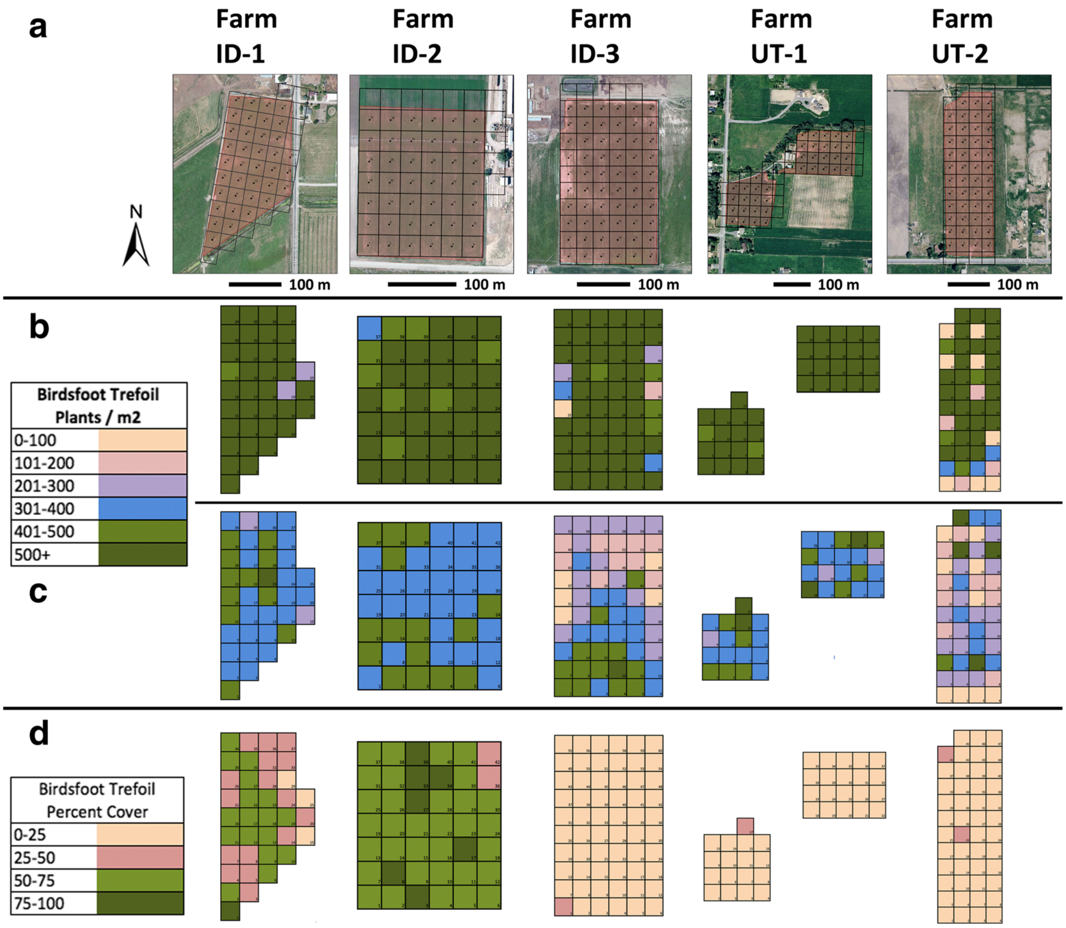

**Fig. 2** Satellite images of farms with field subdivisions superimposed (**a**), schematics of BFT plant density in autumn 2011 (**b**) and spring 2012 (**c**), and percent BFT cover in spring 2012 (**d**). Plant density and cover maps are not drawn to scale

In the autumn of 2011 following planting, plant density sampling occurred 17–23 days after first BFT emergence. Sampling dates were as follows (in chronological order): 16 August at ID-1, 3 September at ID-2, 25 September (east half) and 8 October (west half) at UT-1, 9 October at ID-3, and 10 October at UT-2. Farm UT-1 was sampled on two dates because emergence was earlier on the east half of the field, which was irrigated prior to seedling emergence. In the spring of 2012, plant density and cover sampling occurred after the first observation of new BFT seedling emergence from hard seed. Dates of sampling were as follows: 24 April at UT-1, 28 April at UT-2, 29 April at ID-3, 6 May at ID-1, and 8 May at ID-2.

Birdsfoot trefoil and grass pasture dry matter production was measured on farms ID-1 and ID-2 on 6, 13, and 20 June 2012 using a nondestructive FarmWorks F100 electronic rising plate meter (RPM; FarmWorks Systems, Fielding, New Zealand) calibrated for each BFT and grass field. On each sampling date, RPM measurements were taken within four quadrants of ungrazed paddocks by walking in a 'W' pattern and taking one reading every 12 steps. Calibration samples were cut to 1 cm above the soil surface from the area under the RPM after taking a single reading and dried in a forced-air oven at 60 °C for 48 h. More than 70 calibration samples of each pasture type were taken from each farm during the summer of 2012.

## Statistical analysis

The mean of five quadrat measurements, randomly located within each subdivision, was the experimental unit for BFT and weed plant density and BFT and weed cover. Farm was treated as a random effect, and subdivisions within farm were the subjects of repeated measures of BFT and weed density over two seasons. Birdsfoot trefoil and weed densities were modeled using the Poisson distribution and a log link function. Since BFT and weed had different variability, covariance parameters were estimated for BFT and weed separately. To examine the effects of plant density on cover, four covariates (2011 and 2012 BFT density and 2011 and 2012 weed density) were regressed on 2012 BFT and weed cover. Irrigation and soil type of the farms were also included in this model to test their effects on BFT cover. To assess the impact of autumn BFT plant density on BFT winter mortality, autumn BFT plant density was regressed on the proportion of BFT plant density lost over winter. The above analyses were performed using PROC GLIMMIX in SAS/STAT 13.2 (SAS Institute Inc. 2014, Cary, NC USA). Two-sample *t* tests (SAS PROC T-TEST) were used to compare autumn 2011 and spring 2012 BFT and weed densities as well as spring 2012 BFT and weed cover within each farm. Mean values for spring 2012 BFT and weed cover for each farm ($n=5$) were regressed on planting date (day of year), soil pH, EC, and inorganic nutrient values for those farms using SAS PROC REG.

## Results

To illustrate the distribution of BFT across each field, BFT plant density data for autumn 2011 and spring 2012 and BFT cover data for spring 2012 were color-coded and displayed on the field grids used for sampling (Fig. 2a). For these grids, values for unsampled subdivisions were calculated as the mean of all adjacent subdivisions sharing a full side. Farms ID-1, ID-2, and UT-1 exhibited even distribution of high BFT plant densities across their fields following autumn planting (Fig. 2b) and the following spring (Fig. 2c). Despite overall high field averages, some subdivisions on farms ID-3 and UT-2 showed BFT densities below 100 plants m$^{-2}$ in the autumn of 2011, and by spring of 2012, BFT density had become more varied on these two farms (Fig. 2c). Foliar cover of BFT was uniformly low across these fields in the spring of 2012 (Fig. 2d). Although farm UT-1 had high, evenly distributed BFT seedling density at both sampling dates (Fig. 2b, c), in the spring of 2012, BFT cover was low; only farms ID-1 and ID-2 had more than 25 % BFT cover on most or all BFT pasture subdivisions in the spring of 2012 (Fig. 2d).

Mean BFT seedling density across farms was 665 plants m$^{-2}$ after planting in autumn 2011 and 328 plants m$^{-2}$ the following spring, and autumn and spring BFT densities were significantly different ($P<0.01$). Autumn BFT seedling density was greater than 500 plants m$^{-2}$ on all farms, and spring BFT seeding density was greater than 200 plants m$^{-2}$ on all farms (Fig. 3). Birdsfoot trefoil density was higher than weed density on all three Idaho farms in the autumn after planting ($P\leq0.01$), but on only two (ID-1 and ID-2) the following spring ($P\leq 0.01$; Fig. 3). Regardless of high BFT plant densities, mean BFT cover in spring of 2012 was only 19 % and was less than 10 % on three of the five farms (Fig. 4). On the three farms where BFT density was less than or equal to weed density in the spring of 2012 (Fig. 3, ID-3, UT-1, UT-2), mean BFT cover was 10 % or less on the same date (Fig. 4). While autumn BFT and weed densities evaluated across farms did not influence spring BFT cover, autumn weed density did affect spring weed cover ($P=0.03$). Spring BFT plant density had a highly significant effect on spring BFT cover ($P<0.\ 01$), and spring weed density also affected spring weed cover ($P<0.01$); spring weed cover increased as spring weed density increased ($r=0.88$; $P=0.05$). Data for BFT plant density and weed density were not correlated except for a positive correlation ($r=0.55$; $P=0.01$) on UT-2 in the autumn of 2011.

The most commonly observed weeds were *Malva neglecta* Wallr. (dwarf mallow), *Chenopodium album* L. (fat hen), *Amaranthus retroflexus* L. (common amaranth), *Brassica* spp. (annual mustards), *Lactuca serriola* L. (prickly lettuce), *Rumex crispus* L. (curled dock), *Trifolium* spp. (clovers), and a number of annual and perennial grasses (Poaceae), including volunteer oats at ID-3 and volunteer barley at UT-2 in autumn 2011. At farm ID-1, dwarf mallow was observed across most of the pasture, showing a strong presence in spring on the north end of the field (Fig. 2d). The weed population at ID-2 was mixed, with no single species appearing more often than others, although annuals were more commonly observed than perennials. Grasses were the most common weeds at ID-3 and UT-2, although a mixture of annual and perennial forbs was also present. The weed population at UT-1 was dominated by annual mustards, fat hen, and prickly lettuce in both autumn and spring, although dwarf mallow was also present,

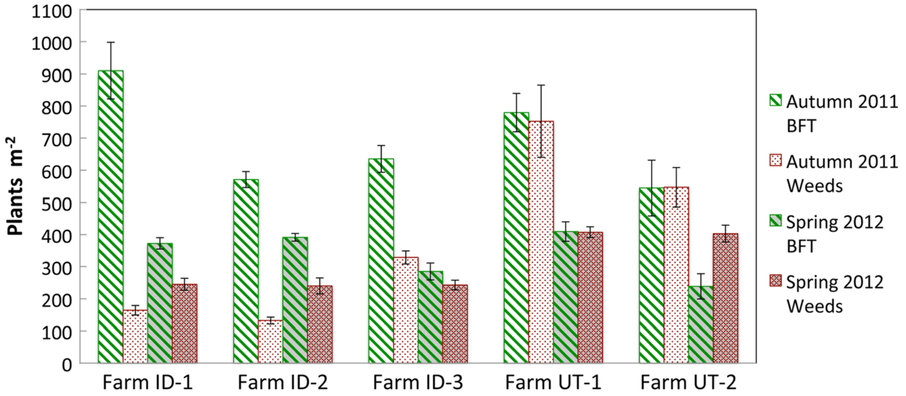

**Fig. 3** Birdsfoot trefoil (BFT) and weed plant density following planting in autumn 2011 and in spring 2012 (±SEM) on five organic dairy farms, $n$=19–30, depending on land area

and curled dock was the dominant broadleaf weed at UT-2.

BFT stands on farms ID-1 and ID-2 were well enough established to begin grazing in 2012, and by 20 June, forage dry matter (DM) in BFT pastures was greater than in grass pastures. Before the first grazing on 20 June 2012, ID-1 had approximately 7600 kg ha$^{-1}$ BFT DM and 5500 kg ha$^{-1}$ grass DM ($P$=0.02) and ID-02 had approximately 6000 kg ha$^{-1}$ BFT and 4800 kg ha$^{-1}$ grass ($P$<0.01) (Fig. 5). Rising plate meter calibration equations were developed for each farm and pasture type; linear regressions of pasture dry matter on rising plate meter measurements were all highly significant ($P$<0.01). Grass pastures on these farms were mixtures of *Lolium perenne* L. (perennial ryegrass), *Dactylis glomerata* L. (cock's foot), *Schedonorus arundinaceus* (Schreb.) Dumort. (tall fescue), and *Elymus repens* (L.) Gould (couch grass) and also contained considerable *T. repens* L. (white clover).

Previous crop history, BFT planting date, irrigation method, major soil type, soil texture, and details of nutrient status of the BFT pastures on all farms are summarized in Table 1. Across farms ($n$=5), BFT spring cover was greater with sprinkler irrigation ($r$=0.97; $P$=0.01), and there was an increase in weed cover as soil potassium ($r$=0.87; $P$=0.06) and calcium ($r$=0.87; $P$=0.06) increased.

## Discussion

This establishment study was carried out as part of an on-farm research project necessitating the creation of a seedbed for BFT establishment on the site of established pastures. Cultivation of long-established grass pastures inevitably resulted in the emission of carbon dioxide and nitrous oxide gases from microbial oxidation of soil organic matter, although quantifying these losses was beyond the scope of the study. This on-farm research project will be subjected to economic analysis to determine the level of milk production needed to justify establishment costs, and the length of time required to

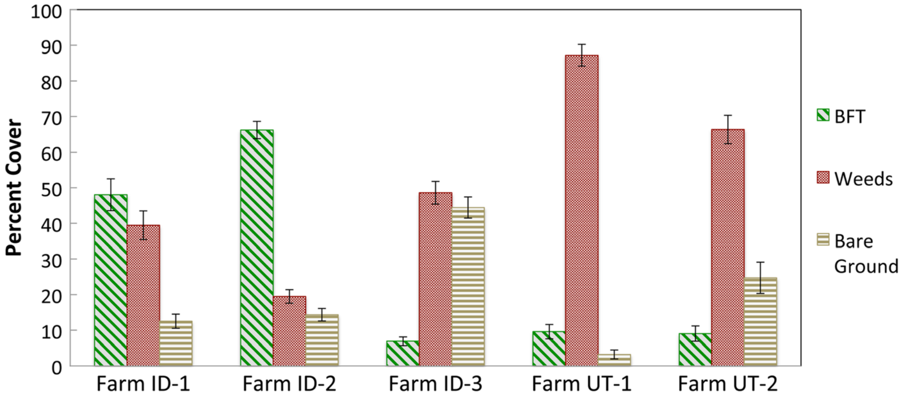

**Fig. 4** Percent cover of BFT and weed foliar cover and bare ground evaluated in spring 2012 (±SEM), $n$=19–30, depending on land area

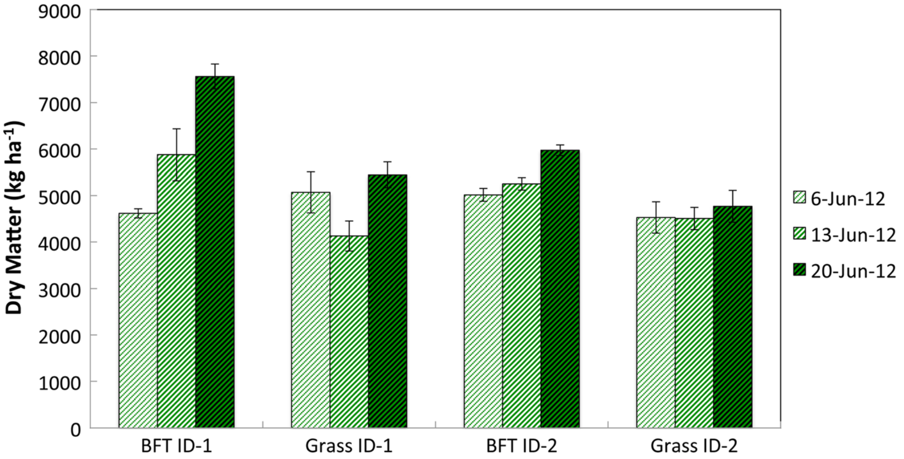

**Fig. 5** Herbage dry matter accumulation in BFT and grass pastures on the two farms with the highest BFT and lowest weed cover evaluated at three dates prior to grazing in 2012; *n*=4

recover soil organic matter losses should also be considered before pasture renovation is undertaken. Pastures with a high proportion of deep-rooted nitrogen-fixing forage legumes that result in elevated ruminant productivity without nitrogen fertilization have the potential to restore lost soil carbon and nitrogen relatively quickly and increase long-term soil carbon storage (Fornara and Tilman 2008; Gilmanov et al. 2014). This particular legume also contains condensed tannins that reduce enteric methane emissions, urine nitrogen content, and slow organic matter mineralization, further contributing to a rapid restoration of soil carbon and nitrogen storage.

Producers participating in this study employed recommended strategies to promote rapid establishment and mitigate weed competition. Two of the five farms participating in this study (ID-1 and ID-2) were able to establish pastures with sufficient BFT density, cover, and distribution to be grazed in 2012, after harvesting crops in the late summer of 2011 and planting BFT in early autumn of 2011. These two newly established BFT fields had accumulated significantly more DM than the adjacent grass pastures by June 20. These results from farms ID-1 and ID-2, which were both sprinkler irrigated, indicate that it is possible to establish a productive BFT stand without sacrificing a full growing season.

The remaining three farms had uniformly low BFT cover in the spring of 2012 due to aggressive weed competition, but BFT plant density was more than 200 plants m$^{-2}$ in the majority of pasture subdivisions in all three of these BFT pastures in spring of 2012. The management recommended to support continued BFT stand establishment (e.g., Ahlgren 1956) is to suppress weed competition while maintaining a high ratio of BFT leaf area to land area (leaf area index) by clipping or lightly grazing during the growing season following autumn planting. Although studies have shown that early weed competition does not necessarily affect yields of BFT in the second year after planting (Scholl and Brunk 1962; Wakefield and Skaland 1965), the rapid establishment achieved on farms ID-1 and ID-2 was advantageous by quickly returning the pastures to productivity.

## Seeding rate and method

Producers participating in this study broadcast seeded BFT at a high rate. The commonly recommended seeding rate for BFT is 6 to 11 kg ha$^{-1}$ PLS (Hall and Cherney 2007; Rhykerd et al. 1981; Undersander et al. 1993), but higher seeding rates may be warranted in some cases. In north central Alberta, Canada, Chapman et al. (2008) found that BFT seeded in spring at a rate of 12 kg ha$^{-1}$ competed poorly against weeds and experienced significant winterkill, resulting in poor stands. Wakefield and Skaland (1965) demonstrated that increasing BFT spring seeding rate from 3.4 to 13.4 kg ha$^{-1}$ increased second year plant density from 95 to 385 plants m$^{-2}$ and DM production from 5826 to 6741 kg ha$^{-1}$ without the use of herbicides. For alfalfa in the same study, increasing the seeding rate from 5.6 to 22.4 kg ha$^{-1}$ increased plant density from 86 to 269 plants m$^{-2}$ and DM production from 5399 to 6050 kg ha$^{-1}$. Broadcast planting provides better distribution of seed across the soil than drilling, reducing intraspecific competition, and can be more successful than band seeding (Fribourg and Strand 1973). Soil-to-seed contact is variable in broadcast seeding, increasing seedling mortality (Barker et al. 2012). The BFT seeding rate of 25 kg ha$^{-1}$ used in this study, along with OMRI-certified seed coating, was selected to insure against establishment failure across a range of soil types and irrigation methods under broadcast seeding and without soil fertility amendments or herbicides.

### Plant density, cover, and mortality

The minimum density of BFT seedlings necessary to establish a productive stand has been defined in several studies: in Minnesota, mature BFT plants were transplanted into the field and the optimal plant density for maximum BFT forage yield was found to be 30 plants m$^{-2}$ (McGraw et al. 1986); Ayres et al. (2006) considered BFT pastures with 57 plants m$^{-2}$ successfully established; and Taylor et al. (1973) judged BFT hay plots with a density of 102 plants m$^{-2}$ to have excellent stands. In our study, whole field averages were well above 100 plants m$^{-2}$ on all farms by the spring of 2012, and only small patches on two farms (ID-3 and UT-2) had BFT plant densities lower than 100 plants m$^{-2}$. These two farms, and farm UT-1, had uniformly low BFT cover despite high BFT seedling densities.

Concern that poor BFT establishment might result from an excessively high seeding rate and intraspecific competition can be addressed by noting that elevated spring BFT plant density had a positive effect on BFT cover. The poor competitiveness of BFT was underscored by the lack of a negative correlation between BFT plant density and weed density in spring 2012, 10 months after planting; the only significant correlation between these factors was a *positive* correlation on one farm in autumn of 2011. Poor BFT cover (i.e., leaf area) in spite of relatively high BFT seedling density suggests a physiological basis for slow establishment and poor competition with weeds, such as low photosynthetic rate, high respiration rate, or assimilate partitioning that favors root growth over shoot growth. Gist and Mott (1957) found that after 45 days of growth under a range of moisture conditions, shoot dry matter of BFT seedling was approximately half that of alfalfa, while the dry matter of BFT seedling roots was only about one-third that of alfalfa. In Iowa, Buxton and Wedin (1970b) found that while BFT root dry weights were no more than one-quarter those of alfalfa in the seeding year, by the end of the year following seeding, root dry weights of BFT were nearly equal to those of alfalfa. Low shoot growth rate in BFT seedlings accompanied by low initial root dry matter further suggests that BFT seedlings have a lower rate of photosynthesis or a higher rate of respiration than alfalfa seedlings.

### Irrigation, soil moisture, and climate effects

While organic BFT establishment has not been studied previously, extensive work under conventional management identified planting date, air temperature, and moisture availability as influential in BFT establishment. Low soil moisture was found to be a limiting factor in the success of BFT emergence and establishment in a number of studies. Ayres et al. (2006) found that BFT was well adapted to a wide variety of Australian soil conditions, but that drought at the time of planting caused BFT establishment to fail. Douglas and Foote (1994) assessed spring establishment of BFT at Palmerston North, New Zealand, where rainfall was less than evapotranspiration at the start of the study and no rain fell for 3 weeks prior to planting. They measured 8.2 % BFT emergence, occurring between 8 and 15 days after planting, and 50 % survival of emerged seedlings after 10 weeks. In the present study, the only management factor that was correlated with BFT cover in spring 2012 was irrigation method. Sprinkler irrigation can be applied more frequently and consistently than flood irrigation, facilitating seedling development.

Hur and Nelson (1985) demonstrated that optimal BFT germination occurs at 20 °C when temperature is constant, and relative humidity is maintained at 90 to 100 %. Germination percentages of more than 50 % occurred in their study in less than 20 days at temperatures ranging from 12 to 30 °C. In July and August of 2011, when BFT was planted on farms ID-1, ID-2, and UT-1, maximum air temperatures averaged 30 °C and minimum air temperatures averaged 13 °C. Evapotranspiration in August was high (175 mm) compared with total monthly precipitation (23 mm in July, 42 mm in August). In September, when ID-3 and UT-2 pastures were seeded, maximum air temperatures averaged 26 °C and minimum air temperatures averaged 8 °C. Evapotranspiration in September was 122 mm and total monthly precipitation was 8 mm. During the planting period of this study, relative humidity averaged 44 % (MesoWest Data, http://mesowest.utah.edu/).

These conditions indicate the difficulty of maintaining adequate moisture close to the soil surface during seedling establishment in the Mountain West, under sprinkler irrigation much less under flood irrigation, which saturates the soil and can therefore only be applied at longer intervals. Flood irrigation precedes sprinkler technology historically and is still widely used due to its simplicity and low cost, although flood irrigation is more prone to cause erosion and more difficult to control. The producer at farm UT-2 reported that his BFT field may not have been adequately leveled prior to planting due to time constraints. This could have contributed to the patchy establishment we observed, as less water would reach unevenly elevated areas of the field.

### Planting date and seedling mortality

Because high initial plant densities were achieved on each farm regardless of irrigation method, this study can provide useful information on the interaction of planting date, soil characteristics, and management prior to planting with differences in establishment success. After evaluating a wide range of planting dates in Tennessee, Fribourg and Strand (1973) concluded that good establishment occurred for BFT planted mid- to late April in the spring and mid-July to early August in the autumn; supplemental irrigation improved the success of autumn plantings. In Iowa, Buxton and Wedin (1970a) determined that a late summer planting following the harvest of an oat crop yielded more forage in the year following seeding than planting BFT in the spring with an oat companion crop. Late summer-early autumn planting was chosen over spring planting for the present study for these and other reasons: spring moisture commonly delays cultivation and planting and can result in the establishment of perennial seedlings under high summer temperatures; feed from winter or spring annual grain crops can be harvested prior to an autumn planting and allow further cultivation of sod-bound soils; and competition from annual weeds is shorter lived in autumn than in spring (Vough et al. 1995).

Autumn planting can fail if an early frost occurs before BFT seedlings have matured sufficiently. In a greenhouse experiment, Rachie and Schmid (1955) showed that 14 days of growth is not sufficient for BFT to survive 12 h at −10 °C, but after 19 days of growth, 76 % of seedlings with four to five true leaves and a height of 5 to 10 cm from a range of BFT cultivars survived the same subfreezing temperatures. In the study reported here, temperatures decreased rapidly in September and October, and by the end of October, minimum nighttime temperatures began to drop below 0 °C. All seedlings had more than 20 days of growth prior to the first frost, which occurred on 19 October. Average minimum temperatures for December 2011, January 2012, and February 2012 were −7.9, −8.8, and −7.1 °C, respectively.

### Soil conditions

Soil properties such as texture and fertility can influence crop establishment and growth. The soils on the three Idaho farms were sandy loams while the soils on the two Utah farms were higher in silt or clay, but none of the soils were considered limiting in texture or fertility for the establishment of legumes (Cardon et al. 2008) and there was no statistical relationship between spring BFT cover and soil texture. Water-extractable soil sulfur was somewhat low on farm ID-2; however, no plant sulfur deficiency symptoms were observed. Soil phosphorus ranged from 14 to 59 mg $kg^{-1}$ (marginal to very high) and soil potassium ranged from 300 to more than 900 mg $kg^{-1}$ (all very high). Adequate phosphorus, potassium, and sulfur concentrations for a deep-rooted perennial legume such as alfalfa are 15–30, 150–250, and >8 mg $kg^{-1}$, respectively (Cardon et al. 2008). While BFT cover was not affected by soil nutrient levels, weed cover increased as calcium and potassium increased. These nutrients were most elevated on the oldest sods, so the joint increase in nutrients and weed seeds may simply be a result of long-term grazing.

Birdsfoot trefoil is reported to tolerate soil pH ranging from 4.5 to 8.2 (Duke 1981) and to be moderately tolerant of soil salinity, reaching a threshold EC at 5.0 dS $m^{-1}$ before yield declines (Maas and Hoffman 1977). Soil pH was moderately to strongly alkaline and soil salinity (EC) was low on all farms (Table I). High sodium levels relative to other salts negatively impact soil structure and drainage, and farm ID-3 had a higher concentration of sodium than other farms in this study. Sodium concentration on ID-3 was not high enough to classify it as a sodic soil (farm ID-3 SAR=8.3; sodic soil SAR>13; Davis et al. 2012); however, the soil was observed to form a hard crust when dry despite its sandy loam texture, a characteristic of sodic soils. The ID-3 field where BFT was planted was flood irrigated, and the producer reported a history of poor drainage and a seasonally high water table. Although weed cover in spring 2012 was similar to farm ID-1, BFT cover was lower and percent of bare ground was higher on ID-3 than ID-1. Therefore, we suspect that the unusually patchy distribution of BFT we observed on ID-3 resulted from these unfavorable soil conditions.

### Crop rotation

Differences in previous field management are likely to have influenced BFT establishment and weed competition in this study. On farm ID-2, alfalfa hay had been cultivated for 3 years preceded by an annual crop of barley, while the fields planted with BFT on all other farms had been managed under grazing rather than cropping. The use of crop rotations can reduce the weed seed bank (Liebman and Davis 2000), and this may have provided a competitive edge for BFT establishment on farm ID-2, which had the lowest autumn weed density, lowest spring weed cover, and highest spring BFT cover. Farm ID-1 also had low weed densities, but BFT cover was less than on ID-2 and weed cover was higher. Weed populations were also different on these two farms; the predominant weed at ID-1 was the perennial dwarf mallow, which has large horizontally oriented leaves, while more upright annual weeds were dominant at ID-2.

### Mixtures vs. monocultures

Planting mixtures of forage species rather than monocultures can reduce weed competition in pastures (Sanderson et al. 2005). MacAdam and Griggs (2006) evaluated the performance of BFT in binary grass-legume mixtures under irrigation in the Intermountain West, finding that it was as productive in mixtures with grasses as alfalfa and white clover. However, voluntary intake is higher for legumes than grasses (Van Soest 1965), and many of the advantages BFT provides for ruminant production, such as increased nitrogen use efficiency and reduced enteric methane emissions, have been attributed to the condensed tannins produced by the BFT (Mueller-Harvey 2006; Waghorn 2008). Growing BFT in mixtures reduces the overall concentration of condensed tannins in the forage consumed by grazing animals, diluting potentially beneficial effects (Woodward et al. 2009). Birdsfoot trefoil monoculture pastures were employed in the multiyear organic milk production research, which includes this establishment study, to evaluate the effect of the tannin-containing legume BFT on milk production from pastures in comparison with grass pastures.

## Conclusions

A high seeding rate of BFT was used in the broadcast planting of pastures on five organic dairies, with the goal of grazing as soon as establishment was achieved. Birdsfoot trefoil was planted as a monoculture so that the full benefit for milk production of this highly digestible tannin-containing legume could be assessed. Planting dates that ranged over 6 weeks at the end of summer did not have a significant effect on establishment because all planting dates were early enough for sufficient seedling development, and excellent germination and initial establishment was achieved on all five farms. Sprinkler irrigation positively influenced spring 2012 BFT cover, and we observed that the farm on which crop rotation had occurred preceding planting (ID-2) had the highest BFT density and cover at the end of the seedling establishment period. Because this study was conducted as on-farm research with a relatively small sample size of five farms and management that inevitably varied from farm to farm, the influence of some factors on BFT establishment, such as cropping history, could not be statistically assessed, but sprinkler irrigation was strongly associated with the successful establishment of BFT. Domination of foliar cover by weeds was the main factor associated with slow establishment of BFT, although the level of competition varied with weed species. Investigation of traits that could improve the competitiveness of BFT seedlings and hasten establishment, such as higher seedling photosynthetic rate or lower seedling respiration rate, can be used to refine plant breeding efforts to increase the value of BFT as a forage crop, especially for pasture-based and organic ruminant production.

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