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REGULAR ARTICLE

Alfalfa-grass biomass, soil organic carbon, and total nitrogen under different management approaches in an irrigated agroecosystem

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Abstract
Background and aims Management approach may influence forage production as well as soil organic carbon (SOC) and soil total nitrogen (STN) accrued beneath perennial grass-legume components of irrigated crop rotations. This study aimed to evaluate effects of conventional, certified organic, and reduced-tillage management approaches on above- and belowground biomass production and C and N content in alfalfa-grass mixture, and their relationships with SOC and STN.
Methods An alfalfa-grass mixture was established in 2009 on four replications under a sprinkler irrigation system. Soil characteristics were analyzed at planting time in 2009. Aboveground biomass production, coarse and fine roots, SOC, STN, aboveground biomass C and N, and coarse- and fine-root C and N were quantified in samples collected during 2009–2011.
Results Conventional management produced more aboveground biomass than reduced-tillage and organic, but production under organic matched conventional and exceeded reduced-tillage in the last two harvests of the study. Root production was constant under the three approaches, but resulted in more SOC accrued under reduced-tillage than under the other two approaches.
Conclusions Biomass production was favored by conventional seedbed preparation and soil fertility management while SOC accrual was favored by minimum soil disturbance. In addition, aboveground biomass was influenced by seasonal air temperature, precipitation, and nutrient mineralization from the previous season, so above-/belowground allocation changed seasonally.

Keywords Aboveground biomass · Root biomass · Alfalfa-grasses cropping · Soil organic carbon · Biomass allocation

Introduction

Perennial forages in long-term rotations can be an important component of sustainable cropping systems as above- and belowground biomass contributes to SOM accrual in agroecosytems (Norton et al. 2012). However, many studies show that management approaches that increase belowground biomass production generally decrease aboveground biomass production in grasses and legumes grown for forage (Acharya et al. 2012; Anderson 1988; Monks et al. 2012; Qin et al. 2004), suggesting that management

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approaches that support both optional forage production and root biomass should be adopted. One reason for the dichotomy between above- and belowground biomass production is limited N supply that results in reduced aboveground biomass production but increased root biomass (Anderson 1988; Monks et al. 2012). Also, tillage increases root proliferation by increasing soil volume compared to no-tillage (Qin et al. 2004). In soils under reduced- and no-tillage management, roots are more concentrated in the top few centimeters due to increased soil water availability and organic matter (Baker et al. 2007; Franzluebbers and Stuedemann 2008; Qin et al. 2004). Comparing no tillage with conventional tillage, Chassot et al. (2001) demonstrated that minimum soil disturbance led to increased root proliferation in surface soils. Other studies suggest that aboveground biomass production is not affected by management approach (Allen and Entz 1994; Halvorson et al. 2002).

In forage production systems, perennial grasses increase soil organic matter (SOM) by increasing root biomass and minimizing soil disturbance compared to annual cropping systems (Paustian et al. 1997). In such systems where aboveground biomass is removed through mowing or grazing, roots and rhizodeposit C are primary sources of SOC (Van der Krift and Berendse 2002). Active-fraction SOM (turnover time <1 year) is dominated by dead roots, root residues and rhizodeposits. Roots constitute up to 30 % of total SOM (Stevenson and Cole 1999). From long-term plots under corn cropping, Allmaras et al. (2004) reported that, together with root exudates, mucilages, and sloughed tissues, root biomass contributes 1.7 to 3.5 times more C to SOC than stover.

Root turnover and biogeochemical cycling of root derived C and N strongly influence SOM (Baker et al. 2007; Einsmann et al. 1999; Fageria and Moreira 2011). Organic and reduced-tillage management systems accumulate more SOM, possibly due to accumulation of more root biomass C and N than under conventional management systems (Chassot et al. 2001; Marriott and Wander 2006; Pulleman et al. 2000). Fageria (2002) and Fageria and Moreira (2011) reported that higher SOM in organic and reduced-tillage management compared to conventional management was partly due to more root biomass inputs and partly due to slower rates of root turnover. Evaluation of belowground biomass, biomass C and N content and contributions to SOC and STN is relatively uncommon, due perhaps to the difficulty and expense of isolating roots from soil. In many cases, shoot: root ratio is used to estimate belowground biomass C and N contributions from crops (Bolinder et al. 1997, 2002, 2007), which might not truly represent the seasonal dynamics of root biomass production and contribution of root biomass C and N. Very few studies have reported the seasonal or interannual variation in root biomass and belowground biomass C and N contributions (Bolinder et al. 2002; Pietola and Smucker 1995; Teixeira et al. 2009). We evaluated effects of conventional, organic, and reduced-tillage management approaches on seasonal growth of above- and belowground biomass, biomass C and N at the final sampling and their relation with SOC and STN. We hypothesized that belowground biomass production, and SOC and STN would be greater in organic and reduced-tillage management than in conventional management.

Materials and methods

Study site

The study was conducted at the James C. Hageman Sustainable Agriculture Research and Extension Center (SAREC) near Lingle, Wyoming (42°7′15.03″N and 104°23′13.46″W). The study site is characterized by cool temperature and short growing seasons, with an average frost-free period of about 125 days and average annual precipitation of 300–400 mm (Western Regional Climate Center 2012). Average maximum and minimum temperatures and annual precipitation of the study area for the last 60 years were 17.8 °C, 0.06 °C, and 332 mm respectively. In addition, maximum and minimum air temperature and precipitation were monitored at the SAREC weather station within 1 km of the research plots during the study period. Monthly average maximum and minimum air temperature and monthly average precipitation throughout the study period are presented in Fig. 1. The soil at the study site was a Mitchell loam (coarse-silty, mixed [calcareous] mesic Ustic Torriorthent) (Soil Survey Staff 2012) with slightly alkaline pH, and low SOM content (≤ 1 %; Table 1).

Experimental design and sampling

In 2009, A mixture of alfalfa (*Medicago sativa* L.), meadow brome (*Bromus riparius* Rehmann), orchard grass (*Dactylis glomerata* L.), and oats (*Avena sativa* L.) as a nurse crop was planted under three management approaches: conventional, reduced-tillage, and organic,

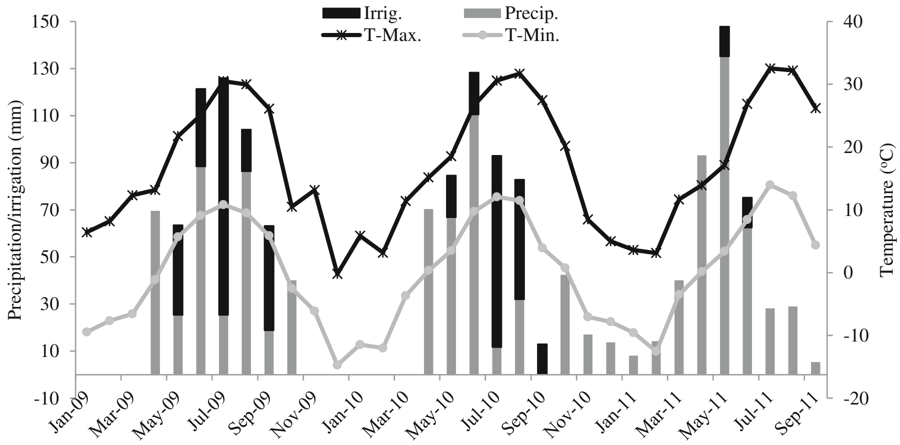

Fig. 1 Monthly average maximum and minimum temperature, and monthly total precipitation and irrigation at SAREC, Lingle (March 2009 to September 2011) (T-Max. = maximum temperature, T-Min. = minimum temperature, Precip. = precipitation, Irrig. = irrigation)

with four replications on 0.81 ha plots. The seed rate for alfalfa-grass mixture was 22 kg ha^{-1} (50 % alfalfa, 10 % meadow brome, 10 % oat, and 30 % orchard grass). The experimental field was under a center pivot irrigation system and had been in conventionally tilled continuous corn for at least 6 years prior to the establishment of the experiment. At the beginning of the experiment, conventional and organic plots were moldboard ploughed, disked and cultivated to a depth of 20 cm (total five tillage passes), which incorporated residues into soils, leaving <15 % on the soil surface. Plots under reduced-tillage management were tilled once with a Landstar (Kuhn Krause, Inc., Hutchinson, KS), a five-step tillage system that discs, cultivates, and uniformly distributes residues in the seedbed (0–20 cm) and on the soil surface before planting. Conventional and reduced-tillage plots received chemical fertilizers, whereas organic plots received composted cattle manure at ~4.5 Mg ha^{-1} $year^{-1}$ (Table 1). Only the conventional plots were fertilized in the establishment year (2009). All plots were maintained for three consecutive years. Plots were not tilled after initial establishment of the forage crops. Since alfalfa-grass established well in all plots, weed management was not an issue.

Soil samples were collected at the beginning of the study for basic characterization, and four times (spring, early and late summer, and fall) each in 2010 and 2011 for analysis of roots. Roots were not quantified during

Table 1 Soil physical and chemical conditions at the beginning of experiment and soil fertility management strategies for alternative management approaches of alfalfa-grass cropping, 2009–2011

Management approach	pH	EC (dS m^{-1})	Particle size (%)			Soil texture	Db (g cm^{-3})	SOC	STN	Fertility management		
			Sand	Silt	Clay			(g kg^{-1})		2009	2010	2011
Conventional	7.51	0.44	42.3	39.3	18.5	Loamy	1.49	8.96	0.77	25:50:0	157:56:22	135:56:22
Organic	7.53	0.40	39.5	42.0	18.5	Loamy	1.54	9.27	0.77	–	40:10:11	50:12:14
Reduced-tillage	7.52	0.42	31.3	46.5	22.3	Loamy	1.43	8.13	0.86	–	157:56:22	135:56:22
LSD	0.10	0.12	21.5	13.9	7.92	–	0.16	3.12	0.36	–	–	–

EC electrical conductivity, *Db* bulk density, *SOC* soil organic carbon, *STN* total soil nitrogen, *LSD* least significant difference (p=0.05). Conventional and reduced-tillage plots received nitrogen: phosphorus: sulfur (kg ha-1) through chemical fertilizer and organic plots received the nutrients through composted cattle manure the establishment year (2009). Samples were collected following the method described by Cleary et al. (2010). Sixteen soil cores were collected from 0 to 15 cm soil depth (2.1 cm × 15 cm) along 50 m permanent transects set in each plot, composited, thoroughly homogenized, and ~500 g subsamples were transported to the laboratory in sterile sample bags. In the laboratory, soil samples were stored in −20 °C freezer until fine- and coarse-roots were separated and cleaned for the further analysis. A separate set of subsamples was taken for total C, STN and inorganic C analysis.

Aboveground biomass samples were collected at the time of alfalfa-grass harvest for hay, typically done at 10 % flowering of alfalfa, which was done two times in 2009 (July and September) and three times in 2010 and 2011 (June, August and September). Biomass samples were collected from 50 m^2 areas (50 m transects × 1 m width) using a Hege 212 forage plot harvester. Alfalfa-grass mixed hay from all cuttings was field dried to ~12 % moisture, bailed and stored. Approximately 500 g subsamples of hay at the time of hay harvest were brought to the laboratory, weighed for moist biomass, then oven dried at 70 °C for 48 h and weighed again for dry matter content. The last harvest of each season was made before October 1st to ensure an adequate buildup of energy reserves for winter survival and re-growth in the following growing season. Approximately 100 g oven-dried subsamples from the third cutting of 2011 samples were saved for aboveground biomass C and N analysis.

Sample preparation and analysis

For basic soil analyses, standard procedures were used, including particle-size distribution by the hydrometer method (Gee and Bauder 1986), bulk density by the core method (Blake and Hartge 1986), pH and electrical conductivity (EC) by electrode (Thomas 1996).

Aboveground biomass samples collected from the last cutting were processed for laboratory analysis. Subsamples were oven dried for 48 h at 72 °C, finely ground, and analyzed for C and N concentrations by combustion on a NC1100 soil C/N analyzer (Carlo Erba Instruments, Milan, Italy). Sample preparation and laboratory analysis of belowground root biomass samples were done by a procedure modified by Cleary et al. (2010). Root samples stored in −20 °C freezer were thawed, soaked for an hour in tap water, and then passed through a nest of 2 mm and 250 μm sieves for 20 min. Materials in the sieves were gently swirled to separate the roots from soil, litter materials, and crop residues. Materials that did not pass through the 2 mm sieve were considered to be coarse roots. Roots passing through 2 mm sieves but not passing through 250 μm sieves were considered to be fine roots. Materials on the sieves included significant amounts of light fraction SOM and litter materials. Therefore, the materials on the sieve were resuspended in water to separate the roots from light fraction SOM (<1 g cm^{-3}). Light fraction SOM on the surface of water was removed, and SOM mixed with roots was picked with forceps and discarded. Live and dead roots were not separated from coarse- or fine-root fractions. Roots were then washed in tap water, dried for 24 h at 72 °C and weighed to determine the coarse- and fine-root biomass. Root biomass samples from the last sampling were ground in a Brinkman Retsch Mortar Grinder (Brinkman Instruments Inc.) after drying, and total C and N in fine- and coarse-roots were measured by dry combustion (NC1100 Carlo Erba Instruments, Milan, Italy). Similarly, total C, STN and inorganic C contents were analyzed on a second set of subsamples from all plots. Total C and STN were measured by dry combustion and inorganic carbon by modified pressure-calcimeter (Sherrod et al. 2002). Soil organic C was determined by subtracting inorganic C from the total C.

Belowground biomass was determined as follows:

$$\text{Belowground biomass} \left(\text{g m}^{-2}\right) = \text{Fine root biomass} + \text{Coarse root biomass} \quad \text{(a)}$$

$$\text{Root biomass}\left(\text{g m}^{-2}\right) = \text{RDM} \times \text{Db} \times \text{D} \times 10 \quad \text{(b)}$$

Where, RDM is root dry mass (g kg^{-1} soils), Db is dry bulk density (g cm^{-3} soil), D is sampling depth (cm) and 10 is conversion factor for mass and area.

Above- and belowground biomass C and N and SOC and STN in g m^{-2} were determined as follows:

$$\text{Above ground biomass C} = \frac{\text{biomass C}\left(\text{g kg}^{-1}\right) \times \text{aboveground biomass}\left(\text{g m}^{-2}\right)}{10} \quad \text{(c)}$$

$$\text{Aboveground biomass N} = \frac{\text{biomass N}\left(\text{g kg}^{-1}\right) \times \text{aboveground biomass}\left(\text{g m}^{-2}\right)}{10} \quad \text{(d)}$$

$$\text{Belowground biomass C} = \frac{[\text{biomass C}(\text{g kg}^{-1}) \times \text{fine root biomass}(\text{g m}^{-2}) + \text{biomass C}(\text{g kg}^{-1}) \times \text{coarse root biomass}(\text{g m}^{-2})]}{10} \tag{e}$$

$$\text{Belowground biomass N} = \frac{[\text{biomass N}(\text{g kg}^{-1}) \times \text{fine root biomass}(\text{g m}^{-2}) + \text{biomass N}(\text{g kg}^{-1}) \times \text{coarse root biomass}(\text{g m}^{-2})]}{10} \tag{f}$$

$$\text{Soil organic C} = \text{SOC} \times \text{Db} \times \text{D} \times 10 \tag{g}$$

$$\text{Soil Total N} = \text{STN} \times \text{Db} \times \text{D} \times 10 \tag{h}$$

Where, SOC is soil organic carbon (g kg^{-1}), STN is soil total nitrogen (g kg^{-1}), Db is bulk density (g cm^{-3}) and D is sampling depth (cm) and 10 is conversion factor for mass and area.

Statistical analysis

The analysis of above and belowground biomass that were measured multiple times in a year were compared using a mixed model analysis of variance (Proc. Mixed) with repeated observation terms of the Statistical Analysis System (SAS ver. 9.3, SAS Institute, Cary, NC) as described in Littell et al. (2002). Effect of management approach across sampling dates within a year (2009, 2010, and 2011) were analyzed by using management approach (M), sampling date (S), and M X S interaction as sources of variance. Sampling date was considered as a repeated observation term in this analysis. In addition, for evaluating the effect of management approach across years, total aboveground biomass for various sampling dates in a year and average root biomass for various sampling dates in a year were analyzed using management approach (A), year (Y), and A × Y interaction as sources of variance and effects of year as repeated observation term in the model. Means were separated by using the Fisher's protected least significant difference (LSD) test. Least significant difference was calculated based on the PDIFF test in the LSMEANS procedure (α=0.05). Analysis of parameters that were measured once at the beginning and at the end of the study was done using one-way analysis of variance (Proc. ANOVA) set in randomized complete block design. Mean separations were conducted using Fisher's protected LSD (α=0.05), when significant effects of treatments were observed. Relationships of belowground biomass C and N with SOC in 2011 were evaluated using a Pearson correlation (Proc. CORR.) procedure in SAS ver. 9.3.

Results

Air temperature and precipitation

Monthly average maximum and minimum temperature were higher than 60 years average maximum and minimum temperature, respectively, during May to September throughout the study (Fig. 1). The minimum temperature dropped to its lowest average in December 2009 and February 2011. Average precipitation was lower in 2009 and 2010 compared to that in 2011. Therefore, more water was applied as irrigation during 2009 and 2010 than in 2011 to meet the crop water requirement for the season. Maximum and minimum temperature and precipitation may influence the above and belowground biomass production in alfalfa-grass cropping as described below.

Above and belowground biomass

Analysis of variance indicated that aboveground biomass was significantly influenced by management approach in 2010, sampling date throughout the study and management approach × sampling date interaction in 2011 (Table 2 and Fig. 2). Aboveground biomass was consistent among

Table 2 Analysis of variance table for above- and belowground biomass parameters (repeated observation parameters) under alternative management approaches of alfalfa-grass cropping

Year	Source of variance	Aboveground biomass			Root biomass						
					Total			Coarse		Fine	
		DF	F	*P* value	DF	F	*P* value	F	*P* value	F	*P* value
2009	Approach (A)	2	0.04	0.96	–	–	–	–	–	–	–
	Sampling dates (S)	1	331	<0.01	–	–	–	–	–	–	–
	A × S	2	1.16	0.36	–	–	–	–	–	–	–
2010	A	2	4.10	0.05	2	4.93	0.04	3.52	0.04	3.81	0.03
	S	2	141	<0.01	3	61.2	<0.01	1.76	0.17	58.4	<0.01
	A × S	4	0.84	0.52	6	0.68	0.66	0.57	0.75	0.70	0.65
2011	A	2	4.65	0.06	2	1.79	0.22	0.48	0.63	4.08	0.03
	S	2	132	<0.01	3	22.6	<0.01	10.2	<0.01	23.4	<0.01
	A × S	4	2.77	0.05	6	2.76	0.03	0.74	0.63	3.44	0.01
Yearly total/ average[a]	A	2	1.78	0.25	2	1.45	0.24	1.79	0.22	1.34	0.27
	Year (Y)	2	72.3	<0.01	1	1.63	0.20	0.40	0.53	2.56	0.11
	A × Y	4	3.47	0.03	2	0.83	0.44	0.19	0.83	0.91	0.41

[a] Yearly total of aboveground biomass and average of fine and coarse root biomass was analyzed

management approaches in 2009 but significantly greater in conventional management than in organic (p=0.04) and reduced-tillage (p=0.03) management approaches in 2010, and greater than in reduced-tillage management (p=0.02) in 2011. In addition, aboveground biomass was greatest in the first harvest each year and decreased considerably in subsequent harvests (Table 2 and Fig. 2). Total aboveground biomass production (sum of all harvests within a year) was significantly influenced by year and a management approach × year interaction (Table 2 and Fig. 3).

Coarse-root biomass was significantly influenced by management approach in 2010 and by sampling dates in 2011. Fine root biomass was significantly influenced by management approach and sampling dates throughout the study and by interaction of sampling date × management approach in 2011 (Table 2

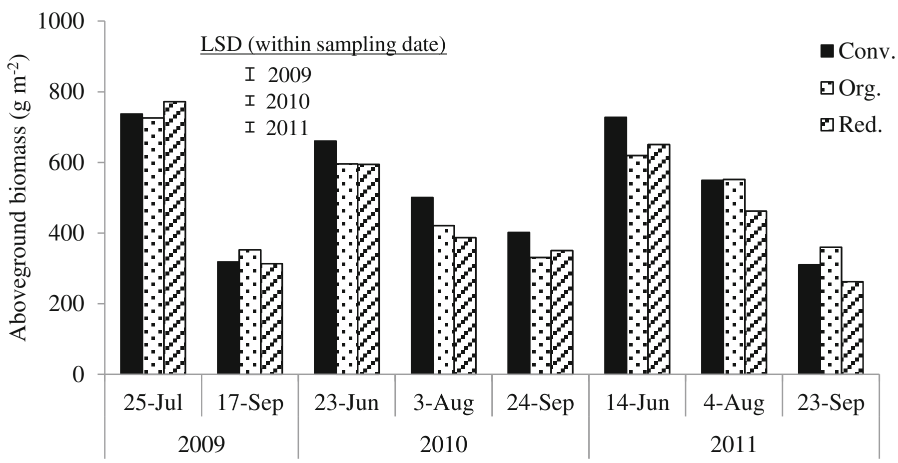

Fig. 2 Aboveground biomass during different cuttings within a year under alternative management approaches of alfalfa-grass cropping (Conv. = Conventional management, Org. = Organic management, and Red. = reduced-tillage management). LSD = Least significant difference between management approaches within a sampling (p=0.05)

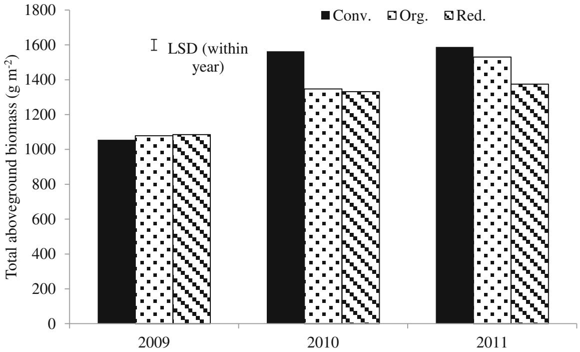

Fig. 3 Annual total aboveground biomass as influenced by management approaches in alfalfa-grass cropping (Conv. = Conventional management, Org. = Organic management, and Red. = reduced-tillage management). LSD = Least significant difference between management approaches within a year (p=0.05)

and Fig. 4). The seasonal trend shows that the amount of belowground biomass, mainly fine root biomass, increased consistently toward subsequent sampling dates in 2010 across all treatments and was significantly lower under organic management than under the other two management approaches in the first harvest of 2011. Fine-root biomass decreased consequently from second to the fourth sampling in 2011. The ratio of fine-root biomass to coarse-root biomass (F:C ratio), averaged across years and seasons, was 4.1 in conventional management, which was significantly higher than F:C ratio in soils under organic (3.1) management. The F:C root ratio in soils under reduced-tillage management (3.4) was intermediate between the other two management approaches and was not significantly

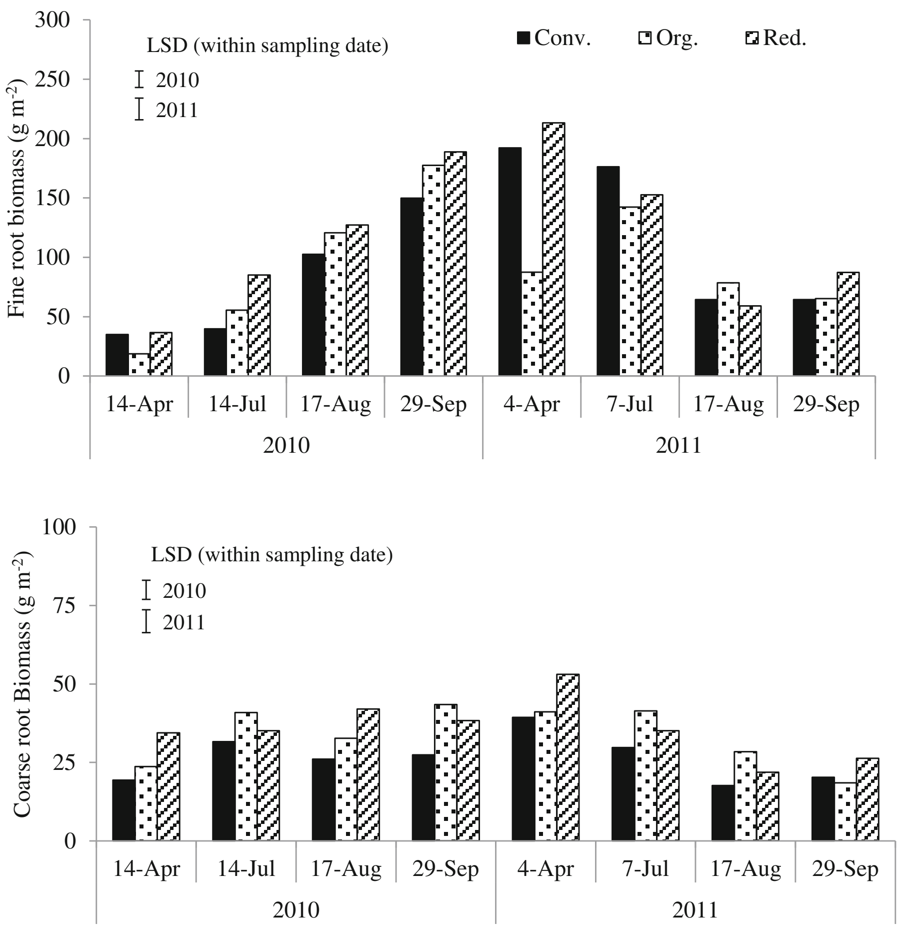

Fig. 4 Fine- and coarse-root biomass in soils under alternative management approaches of alfalfa-grass cropping (Conv. = Conventional management, Org. = Organic management, and Red. = reduced-tillage management). Error bars indicate standard error, n=4. Root-biomass was measured at 0–15 cm soil depth. Same letter within a sampling date indicate no significant difference among management approaches. LSD = Least significant difference between management approaches within a sampling (p=0.05)

different from either. The interaction of management approach × growing season did not have significant effects on F:C ratio, although there was considerable decrease in fine root biomass in the first sampling of the second year under organic management. Total belowground biomass production (sum of coarse and fine root biomass) was significantly influenced by sampling date and management approach in 2010 and was influenced by sampling date in 2011 (Table 2). Average fine and coarse root biomass (average of four sampling dates within a year) was not significantly different among management approaches, years and management approach × year interaction (Fig. 5).

Biomass and soil carbon and nitrogen

Biomass C and N contents were significantly affected by management approaches. One-way analysis of variance for parameters measured once at the end of the study, including root and aboveground biomass C and N, SOC, STN, and their stoichiometric relations, indicated significant effects of the management approaches on total root biomass C and N, fine-root biomass C and N, and C: N ratio for coarse roots. Total soil N, coarse-root biomass C and N, and aboveground biomass N, on the other hand, were not affected by management approaches (Table 3).

Root biomass C and N contents were significantly higher under reduced-tillage than conventional and organic management (Table 3). Similarly, SOC contents under reduced-tillage were significantly higher than under conventional and organic management.

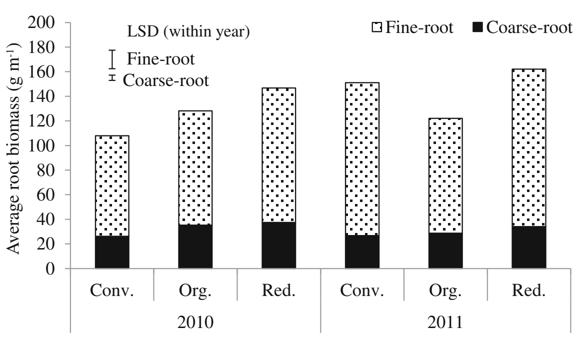

Fig. 5 Average fine- and coarse-root biomass in 2010 and 2011 as influenced by management approaches in alfalfa-grass cropping (Conv. = Conventional management, Org. = Organic management, and Red. = reduced-tillage management). LSD = Least significant difference between management approaches within a year (*p*=0.05)

Total soil N content followed a similar trend, although the effect was not significant. Coarse-root biomass C and N were not affected by management approaches, but fine-root biomass C and N were significantly higher in soils under reduced-tillage management than under conventional and organic management. Similarly, aboveground biomass C was significantly affected but the biomass N was not affected by the management approaches (Table 3). Organic C to N ratios (C:N) in root biomass and soils were affected by management approaches. For both fine- and coarse-root fractions, C:N ratios were higher in soils under organic management than in soils under reduced-tillage and conventional management. Root C:N ratio in fine-roots followed a similar trend, although it was not significantly different among management approaches. Correlation coefficients for SOC and STN contents as functions of root biomass C and N (Table 4) were significant for all treatments combined, strongly significant under organic management, and not significant under conventional or reduced tillage management.

Discussion

Management approach affects biomass allocation

Statistically equivalent root production across the three approaches, both seasonally (Fig. 4) and annually (Fig. 5), but higher aboveground biomass under conventional management (Fig. 3) indicates that conventional management produced more aboveground biomass per unit root biomass than the two alternative approaches. This suggests that the effects of seedbed preparation, including SOM mineralization and porosity enhanced by tillage, along with synthetic fertilizer application, under conventional management facilitated relatively more biomass allocation aboveground. Lower nutrient conditions under reduced-tillage and organic management, which did not receive fertilizer or compost at planting (Table 1) apparently slowed overall initial growth but led to relatively larger biomass allocation to roots. Analyzed by the three cuttings (Fig. 2), yields did not vary statistically among the management approaches until the third year, when organic management yielded more biomass from the 2nd to 3rd cuttings than the other two approaches, and significantly more than reduced tillage. This suggests that benefits of annual compost additions may have

Table 3 Above- and belowground biomass (BM), biomass carbon (C) and nitrogen (N), soil organic carbon (SOC), soil total nitrogen (STN) and carbon to nitrogen (C:N) ratio for September 2011 sampling

Management approach	Aboveground biomass				Coarse-roots				Fine-roots				Total (roots)				Soil		
	BM g m^{-2}	C	N	C: N	BM g m^{-2}	C	N	C: N	BM g m^{-2}	C	N	C: N	BM g m^{-2}	C	N	C: N	SOC g m^{-2}	STN	C: N
Conventional	311	148	9.03	16.6	20.3	8.73	0.55	17.3	64.4	22.1	2.02	11.0	84.7	30.8	2.57	12.0	1909	217	8.80
Organic	360	171	9.98	18.8	18.5	8.41	0.33	26.2	65.2	24.6	2.04	12.0	83.7	33.0	2.37	13.9	2018	214	9.43
Reduced-tillage	262	108	8.67	12.7	26.3	12.7	0.65	20.0	87.3	33.0	3.01	10.9	114	45.7	3.66	12.5	2453	256	9.58
LSD	–	21.6	3.12	6.24	–	6.23	0.30	5.25	–	8.25	0.68	1.11	–	9.70	0.84	1.67	188	48.5	2.18

LSD indicates least significant difference among management approach (p=0.05). BM values are taken from the last column of Figs. 2 and 4

begun to pay off at the end of the study as mineralization released nutrients and possibly improved water holding capacity (Delate and Cambardella 2004).

The difference in management between conventional and reduced-tillage was the initial tillage, whereas the difference between conventional and organic was nutrient management. Multiple tillage passes in conventional management probably facilitated mineralization of SOM, created a more favorable soil environment, and enabled good seed-to-soil contact, promoting early root establishment, and ultimately allowed early establishment of crops leading to higher aboveground biomass yield. Chemical fertilizer might have additive effects to the effects of soil cultivation. Good seed-to-soil contact might not have been achieved under reduced-tillage (Franzluebbers and Stuedemann 2007). In agreement with our results, Rasse and Smucker (1999) reported that plots under no-tillage corn-alfalfa rotation had significantly lower aboveground biomass yield than plots under conventional corn-alfalfa rotation. Lower aboveground biomass production may not support short-term agronomic goals, but in the longer term, root turnover would build SOM, improving soil condition and crop production (Qin et al. 2004; Tisdale et al. 2007). This is because more SOM and nutrients accumulate in surface soils of no-tillage plots than SOM and nutrients in surface soils of conventional tillage plots (Franzluebbers 2002).

The seasonal trend in aboveground biomass across all management approaches was influenced by air temperature and irrigation water supply. The highest biomass production in the first harvest of each year is likely due to combined effects of optimum temperature for the crop growth, soil water content, and nutrient mineralization from the previous season. Toward the second and third harvests, air temperatures gradually decreased (Fig. 1) and soil nutrients are gradually depleted.

Fine root biomass (Fig. 4a) tapered off during 2011, while aboveground biomass remained consistent (Fig. 2), suggesting that the stands were beginning to decline. In organic plots, fine-root biomass was surprisingly low in the first sampling of 2011 (Fig. 4). We interpreted this as a possible effect of lower availability of soil N in organic plots than in other management approaches. These seasonal changes and differences in relative biomass allocation above and below ground suggest that estimation of root biomass based on one-time observation or on aboveground biomass production, which is common in root systems studies (Bolinder et al. 1997, 2002; Pietola and

Table 4 Correlation coefficients for total root biomass C and N versus SOC and STN under all treatments and the three management approaches

Management approach	SOC *R* value	STN *R* value
All treatments	0.75 *	0.59 *
Conventional	−0.56	−0.02
Organic	0.86 *	0.98 *
Reduced tillage	0.18	0.001

Based on analyses of C, N, and roots in 0–15 cm depth soil samples collected in 2011. Mean root biomass C and N, SOC and STN are presented in Table 3

* Significant correlation at $P<0.05$

Smucker 1995; Teixeira et al. 2009), should consider management- and season-related dynamics of biomass partitioning and biomass C and N contributions. Only a few studies report seasonal or interannual variation in root biomass and biomass C and N contribution (Bolinder et al. 2002; Pietola and Smucker 1995; Teixeira et al. 2009). Evaluation of above- and belowground biomass production in closer sampling intervals and belowground biomass in deeper depths will help to understand the differences in biomass production among different management approaches and growing seasons.

Seasonal and interannual trends of root biomass similar to the trend we observed from this experiment have been documented previously (Bolinder et al. 2002; Meyer and Helm 1994; Pietola and Smucker 1995; Teixeira et al. 2009); however, not in enough detail to elucidate the effects of alternative management approaches. In a wheat-fallow cropping system, Qin et al. (2004) found no significant difference in root biomass under no-tillage and conventional systems. Based on a study in wheat-sorghum rotations, Sainju et al. (2005), on the other hand, reported significantly higher root biomass in surface soils under no-tillage management than root biomass in soils under conventional tillage. Both the systems discussed, however, were rotations involving annual crops, which have shorter growth periods and faster root turnover than perennial crops (DuPont et al. 2010). This study provides important information regarding root biomass production in perennial crops as influenced by management differences. Two years of root observation in perennial crops such as alfalfa-grass mixture, however, might not be sufficient to evaluate effects of alternative management approaches. In addition, the systems transitioned from continuous corn for several years might be adjusting to the changed crops and alternative soil management practices. However, a common practice in crop-livestock operations in central and northern Great Plains is to cultivate alfalfa-grass for 3 years and convert the field into other crops because alfalfa and grass yield and quality gradually decrease in consecutive years (Anonymous 1998; Ghimire et al. 2013; Meyer and Helm 1994).

Belowground carbon and nitrogen storage

Growing plants tend to maintain SOC levels by continuously supplying C from roots and stimulating microbial growth in the rhizosphere, compared with bare soil, which tends to decrease SOC (Sanchez et al. 2002). In our study, different management approaches drove differences in C and N contents of roots in the surface 15 cm of soil 3 years after establishment of alfalfa-grass forage (Table 3). Reduced-tillage before planting resulted in more root biomass throughout the study period (Fig. 4) and at the final harvest, apparently supporting higher SOC and STN contents than those under the other management approaches (Table 3). Since SOC content is influenced not only by root biomass but also by soil microbial biomass, other particulate SOM, rhizodeposit materials, and soil disturbances (Franzluebbers and Stuedemann 2007; Ghimire 2013; Rasse et al. 2005; Stevenson and Cole 1999), root biomass C and N measured at the last sampling does not reflect the total belowground C and N inputs during the study period. A portion of the SOC and STN is likely derived from rhizodeposits, root turnover, soil microbial biomass, and aboveground residue turnover that were not measured in our study. Previous studies indicate that root biomass C represents 1.5-30 % of total SOC with positive correlation between root C amount and SOC content (Baker et al. 2007; Fageria and Moreira 2011; Rasse et al. 2005; Stevenson and Cole 1999). Root biomass C in our study (1.6–1.9 % of SOC) falls on the lower end of this range. In fact, root C and N content at the end of the study were related to SOC and STN, respectively, only under organic management (Table 4), likely reflecting that compost contributed to both SOM accrual and root growth. In the other approaches, synthetic fertilizers contributed to root growth but not directly to SOM. Nonetheless, our results indicate an important contribution of root biomass C and N to SOC and STN, respectively.

Perennial legume-grass forage crops are an important component of irrigated crop rotations of the western U.S. from standpoints of both forage production and soil productivity maintenance. Producers of this region are increasingly adopting alternative management approaches, including reducing tillage and other inputs, and certified organic production. The research reported here indicates that management approach influences both the productivity and SOM contributions of alfalfa-grass stands, with conventional management producing more forage but reduced-tillage accruing more SOC by the end of the 3-year study. The results also suggest that assumptions about root biomass quantities based on one-time observations or relationships to aboveground biomass may be flawed. Longer-term monitoring will reveal how these management-root-SOM relationships impact nutrient cycling, C sequestration, and productivity of subsequent crops in rotation.

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