African Journal of Biotechnology Vol. 7 (22), pp. 4056-4067, 19 November, 2008
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB08.525
ISSN 1684–5315 © 2008 Academic Journals

Full Length Research Paper

Evaluation of switchgrass and sainfoin intercropping under 2:1 row-replacement in semiarid region, northwest China

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Accepted 12 September, 2008

Field experiments were carried out under natural conditions to compare the aboveground biomass, root growth and distribution, and topsoil nutrition contents of switchgrass (*Panicum virgatum*) and sainfoin (*Onobrychis viciaefolia*) grown in sole cropping and 2:1 row-replacement intercropping in semiarid loess region on Loess Plateau of northwest China. The sole and intercropping was compared based on the aboveground biomass, water use efficiency (WUE), soil organic matter (SOM) and total nitrogen (TN), and root biomass and distribution. The aboveground biomass production was measured every year at the end of growth seasons in 2001 - 2005. Root biomass and vertical distribution were studied only in 2005. Topsoil SOM and TN contents were measured discontinuously during the study period. Results showed that intercropping reduced the aboveground biomass production of sainfoin significantly compared with its pure stand. The WUE of sole switchgrass was significantly the highest in each year among the three stands, while the intercropped stand was significantly higher than sole sainfoin on five-year averaged. The aggressivity of sainfoin to swichgrass decreased along with the growth years. Before 2005, the land equivalent ratio (LER) was bigger than 1.0 and actual yield loss (AYL) was positive. Under intercropping, root biomass input and root: shoot ratio in switchgrass reduced, while sainfoin inputs more photosynthate to root growth. Switchgrass had high root biomass and wide distribution vertically and horizontally indicates a higher belowground competitive ability in the mixture. It indicated a flexible distribution strategy of switchgrass tending to increase soil exploitation and space sequestration efficiency in soil layers. SOM and TN increased significantly for the three stands at the end of the fourth growth year, especially for the mixture. Switchgrass and sainfoin intercropped under 2:1 row-replacement can be a short-term rotation tillage choice with respect to soil management in the area.

Key words: aboveground biomass, competition, intercropping, root distribution, sainfoin, switchgrass.

INTRODUCTION

Drought and soil degradation are the two major restricts for plants growth in semiarid regions on Loess Plateau of China (Shan and Chen, 1993). To seek and adopt sustainable cropping systems with high water use efficiency and soil environment-friendly are the main attempts for developing agriculture in this region (Shan and Chen, 1993). Some efforts were made to find appropriate combination and intercropping of different forage species to improve resources use efficiency and soil quality (Zhang and Li, 2003). Farming practice such as tillage and rotation are the main management factors causing changes in soil main nutrition elements, and it is possible to improve soil quality through rational cropping instead of chemical fertilization (Wu et al., 2004; Huang et al., 2007; Jagadamma et al., 2007).

Switchgrass (*Panicum virgatum* L.) is a native warm-season grass in the central and northern America, it can

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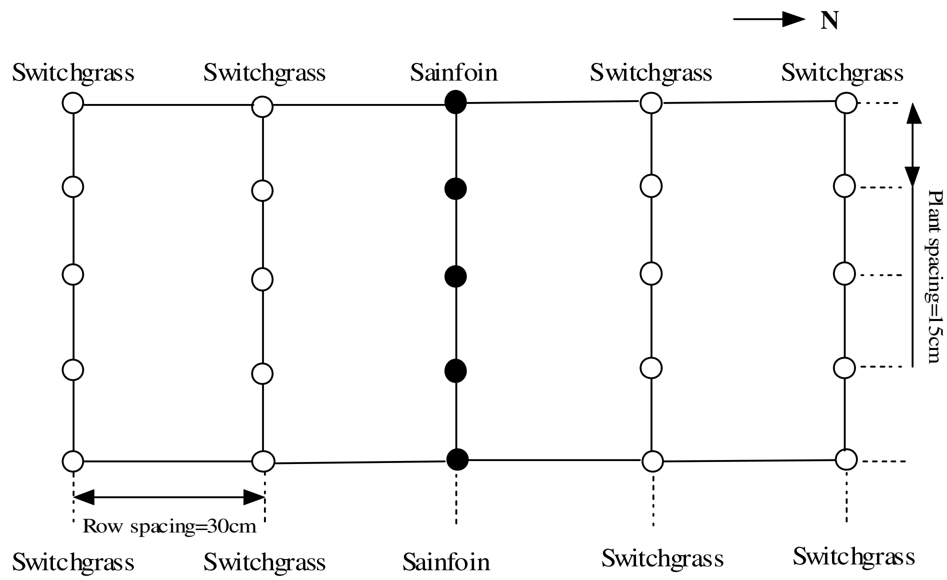

Figure 1. Planting pattern of switchgrass and sainfoin in row intercropping.

be used as forage and hay crop and for soil and water conservation (McLaughlin and Kszos, 2005). Switchgrass showed significant performance ecologically and biologically in loess hilly-gully region on Loess Plateau of China after introduction. Sainfoin (*Onobrychis viciaefolia* L.) has been used in China as a palatable forage crop in arid and semiarid areas of northern China (Xu et al., 2007). Considerable research has been conducted in switchgrass and sainfoin for biomass production and water use characteristics in pure stands (Shan and Chen, 1993; Xu et al., 2006). However, little quantitative information on the aboveground biomass production and root growth in sainfoin and switchgrass under intercropping has been documented.

Intercropping of two or more crops especially cereals with legumes is popular in many countries because yields are often higher than in sole cropping systems (Anil et al., 1998; Li et al., 2001; Lithourgidis et al., 2006). The reasons are mainly that resources such as water, light and nutrients can be utilized more effectively than in the respective solecropping systems (Li et al., 2001; Wilson and Tilman, 1993). Some other studies showed that intercropping reduced the yields of component crops (Park et al., 2002; Zhang and Li, 2003). This yield reduction occurs because of lower component crop density and interspecific shoot and root competitions (Thorsted et al., 2006; Wang et al., 2007). In the current study, the yearly aboveground biomass in 2001 - 2005, seasonal root biomass and distribution in 2005 and the top soil SOM and STN content during the experiment were compared of the three stands. Our objectives were to (1) to examine the competitive relationships of switchgrass and sainfoin under intercropping in consecutive growth years, (2) to characterize seasonal root distribution pattern of the five-year old established stands, and (3) to evaluate the intercropping with respect to soil water use, shoot and root biomass production and two soil quality parameters.

MATERIALS AND METHODS

Study site description

Field experiments were conducted at the research farmland of Ansai Research Station (ARS) of Chinese Academy of Science (CAS) in Shaanxi Province (36° 51´30"N; 109°19´23"E; elev. 1068 m). It is located in the semiarid region of northwest China with mean annual rainfall of 540 mm. The average annual temperature is 8.8ºC, with extremes of -6.9ºC in January and 22.6ºC in July. The loessial soil is characterized as silt loam, highly calcareous in nature (pH 8.4), deep (50 – 80 m), low organic carbon, low available N, low available P, and high in available K (Shan and Chen, 1993).

Experimental culture

The field was previously planted with apple trees (*Malus domestica*) between 1992 and 1997. Apple trees were cut down in October 1997 and the field was prepared for this experiment in late autumn of 2000. Twelve experimental plots of 7 × 6 m were arranged in a randomized complete block design with a 15 cm distance between every two plots. Fertilizers N, P and K were applied prior to plowing at a rate of 60 kg N ha^{-1}, 45 kg P ha^{-1}, and 45 kg K ha^{-1}. Switchgrass and sainfoin were grown as monoculture and intercropped in 2:1 row ratio. Row spacing was 30 cm, and plant space within one row was 15 cm (Figure 1). Each plot contains 11 rows of sainfoin and 22 rows of switchgrass.

Aboveground biomass sampling

Aboveground biomass samples were taken each year in 2001 –

2005 at the end of growth season and were determined by cutting the plants with hand-held shears to ground level from 50 × 50 cm quadrant. Each species of the mixed cultures were harvested separately from the whole plot. Each measurement was replicated for three times. The selection of the plot for sampling was random. To reduce the edge effect, samples were taken about three rows from the plot border. Total aboveground biomass of each species either sole cropped or intercropped was considered the sum of dry litter and standing parts. Plant samples were dried in a forced draft oven at 65°C for 24 h and weighed.

Competition indices

Actual yield loss (AYL) is the proportionate yield loss or gain of intercrops in comparison to the respective sole crop, i.e. it takes into account the actual sown proportion of the component crops with its pure stand. AYL was calculated as:

$$\text{AYL} = (\text{AYLa}+\text{AYLb}) = \left\{\left[\frac{\left(Yab/Zab\right)}{\left(Yaa/Zaa\right)}\right]-1\right\}+\left\{\left[\frac{\left(Yba/Zba\right)}{\left(Ybb/Zbb\right)}\right]-1\right\} \quad (1)$$

where Y is the yield per unit area and Z is the sown proportion, subscripts aa and bb refer to pure stands (sole crops) of species A and B, and ab and ba refer to intercrops. Partial actual yield loss AYLa and AYLb represent the proportionate yield loss or gain of species A and B when grown as intercrops, relative to their yield in pure stands. AYL is therefore the sum of the two partials AYLa and AYLb. The sign (positive or negative) of the AYL score gives a quantitative assessment of advantage/disadvantage accrued under any intercrop situation when the main objective is to compare yield on a per plant basis (Banik et al., 2000).

Land equivalent ratio (LER) was calculated as follows:

$$\text{LER} = (\text{LERa}+\text{LERb}) = \left\{\left(\frac{Yab}{Yaa}\right)+\left(\frac{Yba}{Ybb}\right)\right\} \quad (2)$$

where LERa and LERb are the partial LER of the two species respectively.

Aggressivity (A) measures the interspecies competition in intercropping by relating the yield changes of the two component crops. In this paper, we employed the aggressivity concept to evaluate the difference between the extent to which intercropped species a' and 'b' vary from their respective sole cropping aboveground biomass:

$$Aab = \frac{Yia}{YsaFa} - \frac{Yib}{YsbFb} \quad (3)$$

where *Yia* and *Yib* are yields of crops 'a' (sainfoin) and 'b' (switchgrass) in intercropping, *Ysa* and *Ysb* are yields of crops 'a' and 'b' in sole cropping. *Fa* and *Fb* are the proportion of area occupied by crops 'a' and 'b' in the intercropping. When *Aab* is bigger than zero, competitive ability of crop 'a' exceeds that of crop 'b' under intercropping (Li et al., 2001).

Soil water sampling

Soil water samplings were made using soil core sampler (Ø4 cm) before and after growth seasons every year from 2001 - 2005. Sampling sites were at the center of two rows, and for intercropping it was at the center of switchgrass and sainfoin rows. It (ω %) was determined from the analysis of soil gravimetric water content where soil sample was dried at 105°C for 24 h, and which was calculated as follows:

$$\omega\ (\%) = \frac{(Ww - Wd)}{Wd} \times 100\% \quad (4)$$

where *Ww* and *Wd* were the wet and dry weight mass of soil samples. The soil water content was measured down to 3 m in 2001 and 2002 but extended to 5 m from 2003 to 2005.

Soil bulk density (ρ) is 1.1 g cm^{-3} for 0 - 20cm layer and 1.3 g cm^{-3} for below 20 cm respectively. Soil water storage (W) at each measured time was calculated as: W = 10×*H* (soil depth)(cm) × ρ (g cm^{-3}) × ω (%) (Xu et al., 2006), because there were no runoff and subsurface drainage in the lowland farmland (Shan and Chen, 1993), evapo-transpiration (ET) was calculated as the rainfall during growth season plus soil water difference between two measurements. Rainfall was recorded at a weather station about 100 m from the experimental fields. Water-use efficiency (WUE) was defined as the amount of biomass produced per unit volume of water evapotranspired.

Soil sampling and analysis

Top soil SOM and TN content were determined three times which were April 20, 2001 (before sowing), November 4, 2004 (the end of the fourth growth season) and April 5, 2006 (before the sprouting in the sixth growth season). Soil samples were taken using auger method (Ø 4 cm). Soil samples were taken at the center of two rows. Each time nine samples taken randomly were mixed to form a composite soil sample for each stand. Under intercropping, six subsamples were taken between rows of switchgrass and three from the center of switchgrass and sainfoin rows. Samples were taken from the 0 – 20 cm soil depth. Soil total nitrogen (TN) content was measured by the Semimicro-Kjeldahl method (Bremner and Mulvaney, 1982). Soil organic matter (SOM) was determined by dichromate wet combustion method (Nelson and Sommers, 1982).

Root biomass sampling

Root sampling was only taken in 2005 and were sampled by auger method (Ø 9cm) within each species stand for three times. The sampling on the 4th September and 4th November were done together with aboveground biomass measurements. The root mass had also been sampled on the 4th April before sprouting. The core samples were taken down to 150 cm deep and divided into 6 segments (0 - 20, 20 - 40, 40 - 60, 60 - 90, 90 - 120, and 120 – 150 cm). Three replicate samples systematically distributed over each plot were taken between rows, at the center of plant, and between plants in the row, respectively. The samples were brought to laboratory and rinsed free of soil on two sieves (1 and 0.5 mm mesh). After washing, the roots were separated into switchgrass or sainfoin according to their color and surface characteristics, but no attempt was made to distinguish between live and dead roots of each species.

According to the planting pattern (Figure 1), it was assumed that root coverage of each plant underground was a 30 × 15 cm rectangle, and the root biomass (RB) production per unit ground area (g m^{-2}) would be:

$$\text{RB} = \frac{0.3\times 0.15\times\sqrt{(a+b)^2+(a+c)^2}}{4\pi R^2} \quad (5)$$

where *a*, *b* and *c* were root biomass measured at the center of plant, between rows and between plants in the row of each species respectively, and *R* was the soil auger radius (Figure 2).

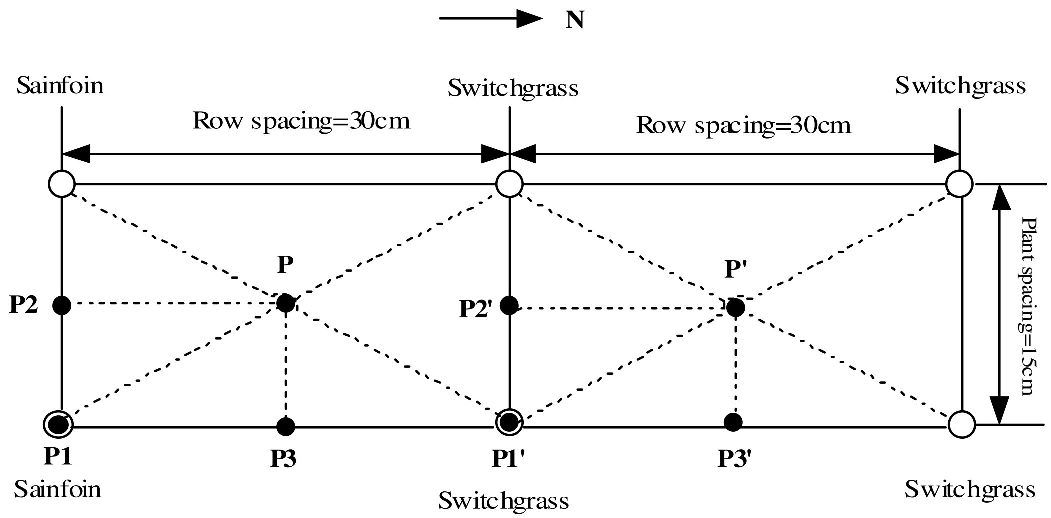

Figure 2. Root sampling scheme for the core method (P1 and P1' = center of the plant, P2 and P2' = center of the rows and P3 and P3' = midway between two plants). P and P' are the corresponding representatives for the calculation of root biomass. Open circle represents individual plant of each species.

P and P' are the corresponding representatives for root biomass between rows of switchgrass and sainfoin, and rows of switchgrass respectively. P was calculated as:

$$P = \frac{\sqrt{(P1+P2)^2+(P1+P3)^2}}{4} \quad (6)$$

and P' was calculated as:

$$P' = \frac{\sqrt{(P'1+P'2)^2+(P'1+P'3)^2}}{4} \quad (7)$$

The total root biomass of each species in 150 cm profile was the sum of root biomass in all the soil segments. The root biomass of switchgrass or sainfoin under intercropping was calculated as: (P×2+P')/3 based on the basal area occupied by the two species. The whole root biomass of intercropped stand was the sum of root biomass of switchgrass and sainfoin.

Statistical analysis

The data obtained were analyzed by standard ANOVA using SPSS 11.0. The Paired-Samples T test was used for comparison between years or treatments. The significant differences between treatments were compared at 5% level of probability.

RESULTS

Rainfall during 2001 - 2005

The 50 year (1951 - 2000) average annual rainfall for the site is 537.7 mm, while annual rainfall recorded during 2001, 2002, 2003, 2004 and 2005 was 515.2, 541.1, 577.8, 509.1 and 541.1 mm, respectively. In the area, rainfall of the growing season from April to October accounts for 85 - 95%, and July to September accounts for 60 - 80%, which is considered the rainy season. During the growing season from 2001 to 2005, rainfall accounted for 93.0, 94.2, 89.3, 97.2 and 99.2% of yearly total and rainfall from July to September accounted for 68.2, 40.88, 59.5, 72.9, and 69.2%, respectively (Figure 3).

Soil water content dynamics

Figure 4 showed the seasonal soil gravimetric water content of the three stands during the experimented years 2001 - 2005. Since established in 2001 to the fallow season between 2003 and 2004, the soil water content change trends of the three stands were similar, and sole switchgrass had the highest, especially in late 2002. Since the start season of 2004, the soil water content of the intercropping stand was significantly the highest, but there were no significant difference between sole switchgrass and sole sainfoin (Figure 4).

Aboveground biomass

The equivalent biomass production of sainfoin under intercropping was significantly higher than sole cropping only in 2001, but adversely in latter years (Table 1). The contribution of sainfoin to biomass production under intercropping was the highest in 2001 and decreased rapidly since 2002. The equivalent biomass production of switchgrass under intercropping was significantly lower than sole cropping except in 2003 and 2004. The contribution

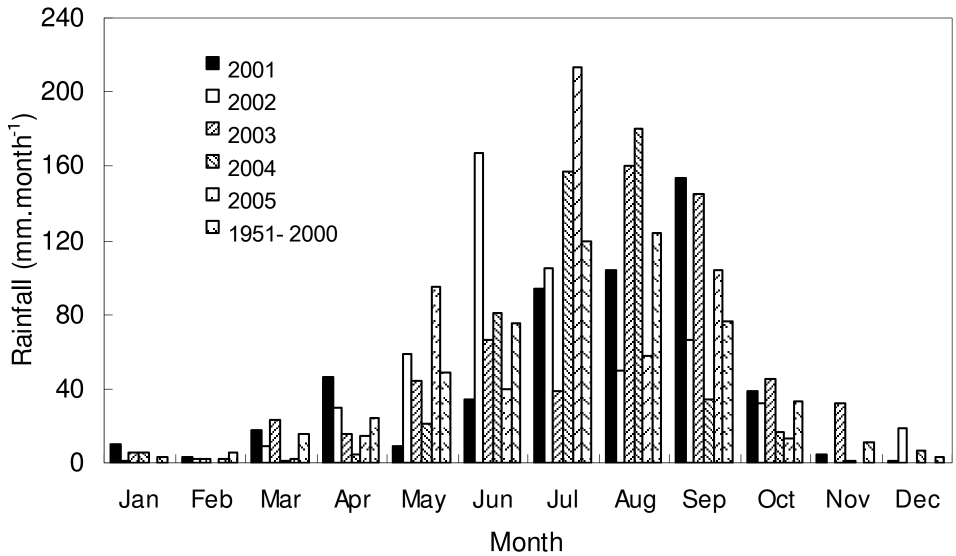

Figure 3. Monthly rainfall in each experimented year and 50 year (1951 - 2000) mean.

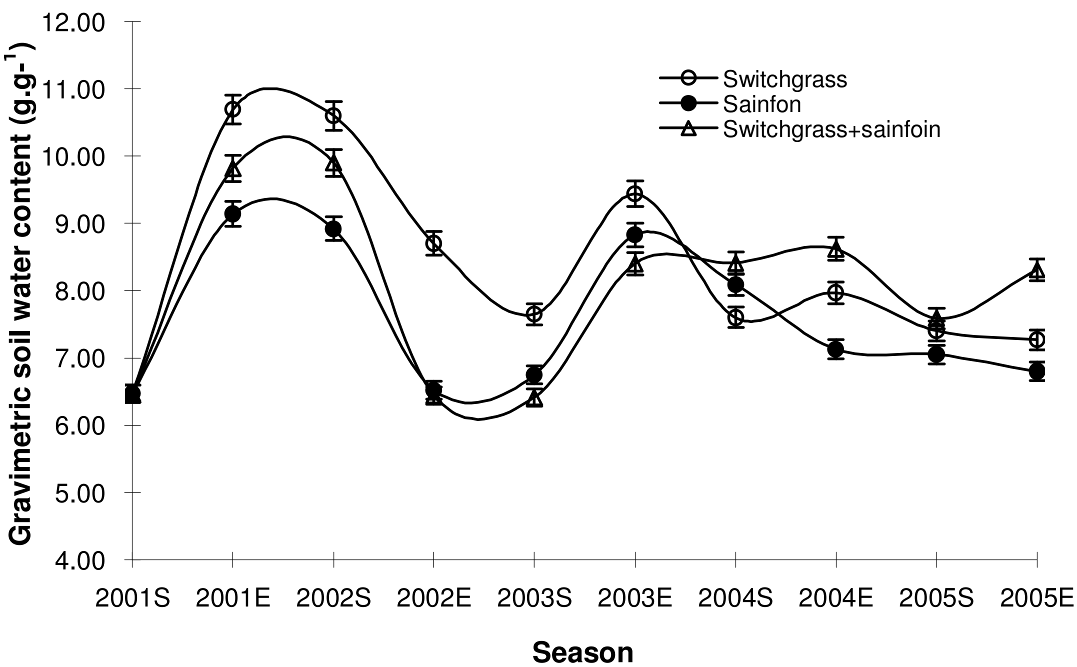

Figure 4. Seasonal mean soil water content change in 2001 - 2005 (S and E in abscissa referenced to start and end of growth seasons in each year; the value was the average of 0 – 300 cm in 2001 and 2002, and it was the average of 0 – 500 cm for 2003 - 2005).

of swichgrass increased gradually under intercropping and in 2005 sainfoin only occupied 3.2% of total dry aboveground biomass for the mixture.

Water use efficiency

Water use efficiency (WUE) in 2001 was the lowest for all the three stands (Table 2). Sole switchgrass had the highest WUE in each year. The intercropping had similar WUE in the first two years with sole sainfoin, but in the latter three years its WUE was significantly higher. The five-year averaged WUE was ranked as sole switchgrass > switchgrass and sainfoin intercropping > sole sainfoin, and it was significantly different between each other (Table 2).

Table 1. Yearly biomass production (g m^{-2}) of switchgrass and sainfoin in solecropping and intercropping*.

Year	2001	2002	2003	2004	2005	Mean ± S.E.
Switchgrass (solecropped)	305.7d(c)	1655.4a(a)	1252.4c(a)	1342.5c(a)	1460.3 b(a)	1203.3 ± 18.6(a)
Switchgrass (intercropped)†	233.3c(d)	913.1b(c)	1113.6a(a)	1239.4a(a)	910 b (b)	881.9 ± 11.8(c)
Sainfoin (solecropped)	332.8d(b)	1368.4a(b)	874.9b(b)	923.6b(c)	745.1 c(c)	848.9 ± 7.2(b)
Sainfoin (intercropped)†	504.4c(a)	719.6a(e)	535.3b(c)	396.7d(d)	60.3 e(e)	443.2 ± 2.9(e)
Switchgrass + sainfoin (2:1)‡	323.7d(b)	848.6c(d)	920.8b(b)	958.5a(c)	626.8 b(d)	735.7 ± 7.4(d)
Switchgass contribution in mixture (%)	48.05	71.73	80.62	86.20	96.79	76.68
Sainfoin contribution in mixture (%)	51.95	28.27	19.38	13.80	3.21	23.32

*Values within a row followed by different letters are significantly different ($P < 0.05$), and values within a column with different small letters in bracket are also significantly different ($P < 0.05$). S.E means standard error of mean.
† Equivalent biomass production under intercropping.
‡ Biomass production of switchgrass and sainfoin under intercropping was calculated as: switchgrass equivalent biomass production under intercropping × 2/3 + sainfoin equivalent biomass production under intercropping × 1/3.

Table 2. Yearly WUE (g m^{-2} mm^{-1}) of switchgrass and sainfoin in sole cropping and intercropping.

Year	2001	2002	2003	2004	2005	Mean ± S.E.
Sole switchgrass	1.12c(a)	2.76ab(a)	2.89a(a)	2.60b(a)	2.67b(a)	2.41 ± 0.07(a)
Sole sainfoin	0.97e(b)	2.26a(b)	1.87b(c)	1.70c(c)	1.27d(c)	1.61 ± 0.01(c)
Switchgrass + sainfoin (2:1)	1.01d(b)	2.28a(b)	2.19b(b)	2.09b(b)	1.38c(b)	1.79 ± 0.01(b)

*Values within a row followed by different letters are significantly different ($P < 0.05$), and values within a column with different small letters in bracket are also significantly different ($P < 0.05$). S.E means standard error of mean.

Table 3. Competition indices of sainfoin (crop a) and switchgrass (crop b) based on yearly biomass.

Year	2001	2002	2003	2004	2005	Mean ± S.E.
AYLa	+3.5516	+0.5971	+0.8360	+0.2884	-0.7574	+0.9000 ± 0.0428
AYLb	+0.1453	-0.1717	+0.3334	+0.3855	-0.0652	+0.1255 ± 0.0250
AYL	+3.6969	+0.4074	+1.1693	+0.6739	-0.8226	+1.0250 ± 0.0676
LER	+2.2808	+1.0786	+1.5009	+1.3531	+0.7041	+1.3835 ± 0.0308
Aab	+3.4063	+0.7508	+0.5026	-0.0971	-0.6921	+0.7741 ± 0.0186

Competition index

The partial AYLa of sainfoin during 2001 - 2004 gave positive values, indicating yield gain, while the partial AYLb of switchgrass was negative in 2002 and 2005, showing yield loss (Table 3). The higher value of AYLa than AYLb in the first four consecutive years (2001 - 2004) was consistent with the positive Aab. This revealed that sainfoin was the dominant species whereas switchgrass was the dominated species before 2005. LER was bigger than 1.0 during 2001 - 2004. The aggressivity of sainfoin (crop 'a') to switchgrass (crop 'b') (Aab) decreased gradually as the growth year was postponed.

Root biomass and distribution

Sole cropping

Roots were found throughout the 0 – 150 cm soil profiles and root biomass (RB) decreased with sampling depth for all stands (Figures 5 - 8). The total RB in the 150 cm soil profile increased gradually from April to November, reaching the highest for the two species under sole- or intercropping (Table 4). The seasonal increase in RB of sole sainfoin was mainly due to the contribution of the RB distributed in the 0 - 20 soil layer (Figure 5). However the increase in RB of each soil layer of switchgrass led to faster RB accumulation (Figure 5). For the two intervals between measurements, RB accumulations of sole sainfoin in 0 – 150 cm soil profiles were same (27.9 and 28.0 g m^{-2} respectively). But switchgrass increased much more at the later growth season, and which were about 3.2 and 43.1 g m^{-2} respectively (Table 5). Unlike sole switchgrass, root growth of sole sainfoin are mainly concentrated in 0 – 60 cm stratum seasonally, and RB decreased after September in the profile down from 60cm.

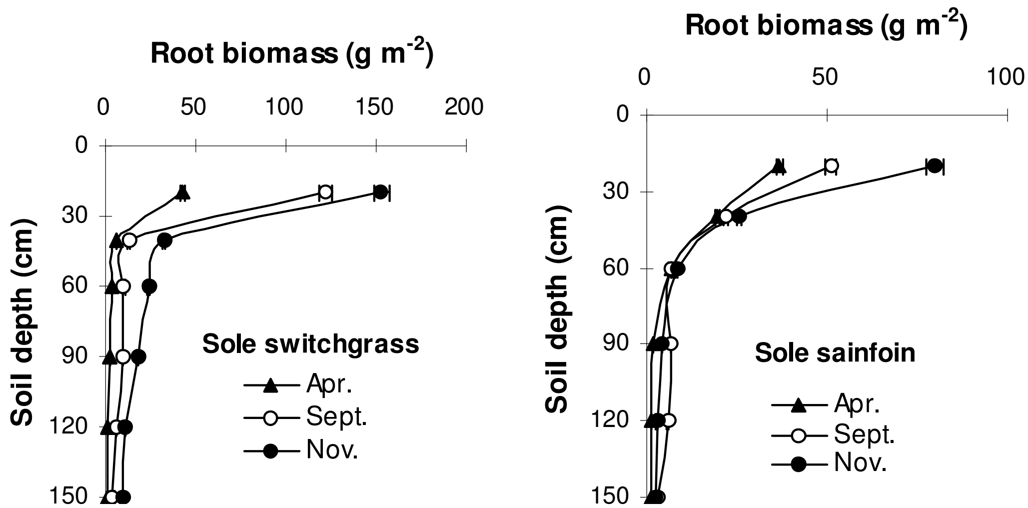

Figure 5. Root biomass distributions in 0 – 150 cm soil profiles of sole switchgrass and sole sainfoin, for the three sampling dates in 2005.

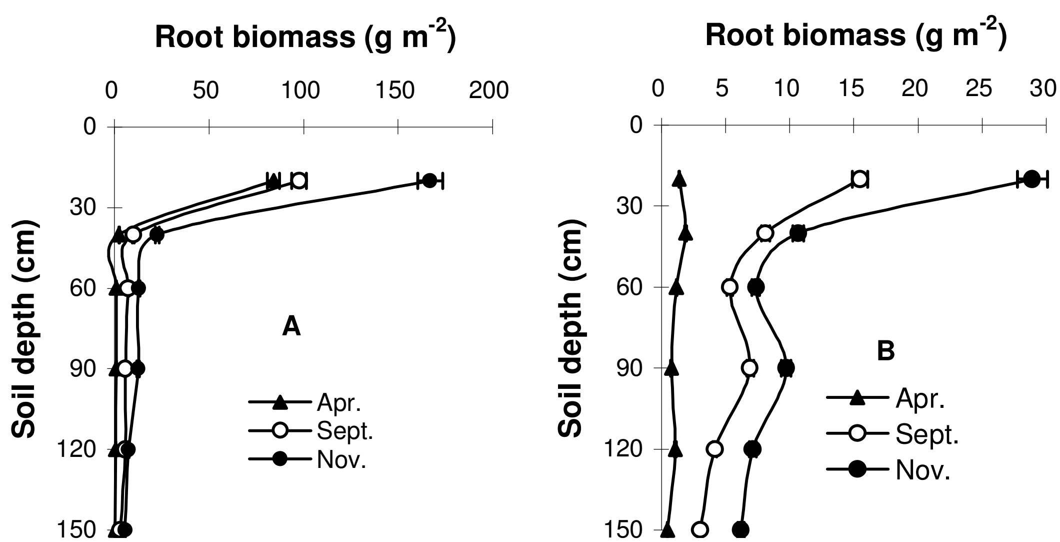

Figure 6. Root biomass distribution in 0 – 150 cm soil profile of switchgrass under intercropping for the three sampling dates in 2005 growing period (A represented root biomass of switchgrass measured from P1', P2' and P3'; B represented root biomass of switchgrass measured from P1, P2 and P3; see Figure 2).

Switchgrass in intercropping

RB was measured for swichgrass under intercropping separately from switchgrass and sainfoin sides under intercropping (Figure 1). The RB in all the soil layers kept increasing from April until November (Figure 6). For measured from switchgrass side, the RB in 0 – 150 cm soil layer increased from April to September, and the net addition decreased as root deepened (Figure 6A). For RB measured from sainfoin side (Figure 6B), although the RB in 0 – 150 cm soil profile increased gradually from April to November, the changing trend was significantly different from that of switchgrass side (Figure 6B). The root distribution patterns from sainfoin side in September and November were similar, and in April root distributed vertically from the top downwards (Figure 6B).

Sainfoin in intercropping

RB of sainfoin under intercropping was measured with the same steps as switchgrass under intercropping (Figure 2). For RB measured from sainfoin side, roots were also found in a high density on the top and de-

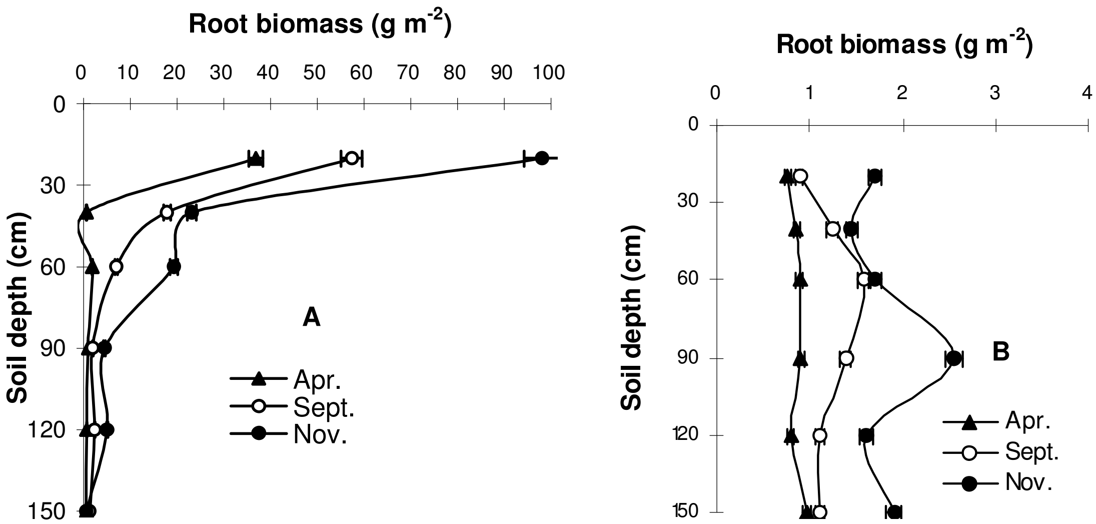

Figure 7. Root biomass distribution in 0 - 150 cm soil profile of s under intercropping for the three sampling dates in 2005 growing period (A represented root biomass of sainfoin measured from P1, P2 and P3; B represented root biomass of sainfoin measured from P1', P2' and P3'; see Figure 2).

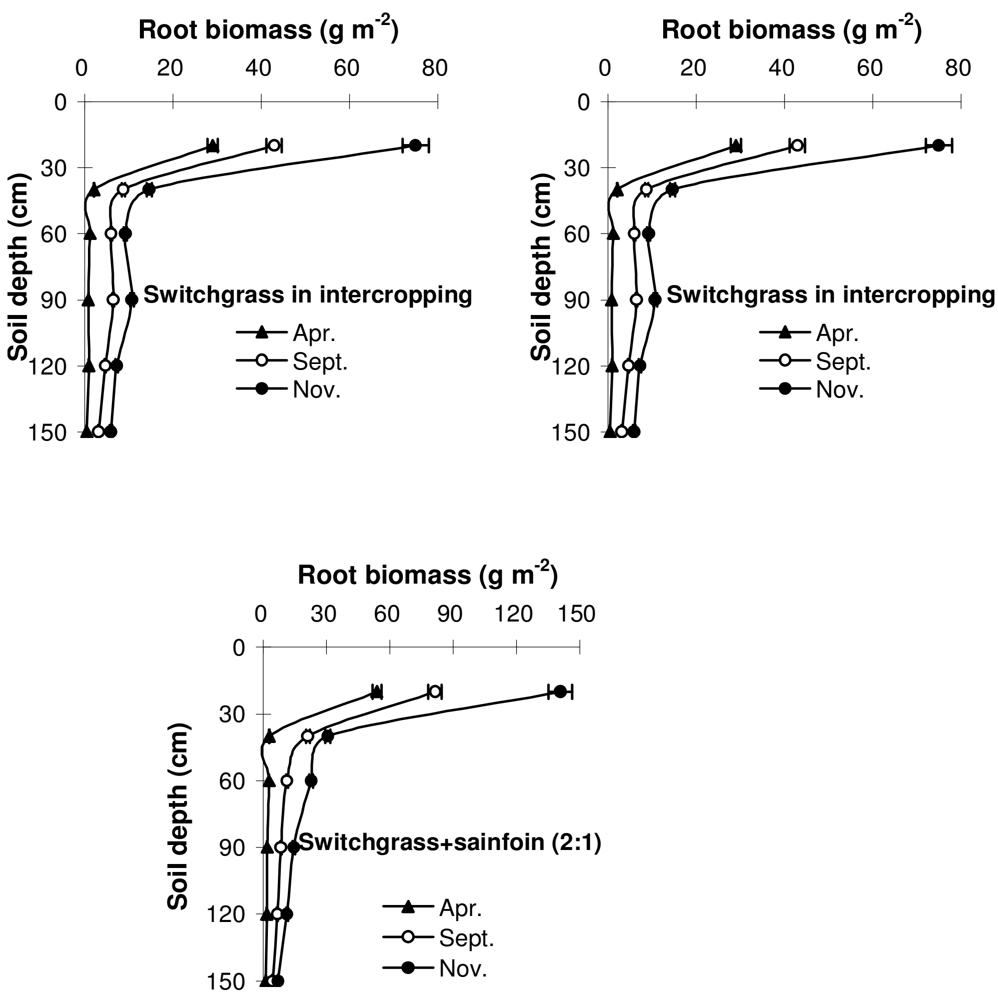

Figure 8. Root biomass distributions in 0-150cm soil profile of switchgrass and sainfoin under intercropping for the three sampling dates in 2005.

Table 4. Aboveground and root dry biomass (g m^{-2}) of each sampling in 2005 (.ean ± SE).

Plant	Sole sainfoin			Sole switchgrass			Intercropped sainfoin		
	Apr.	Sept.	Nov.	Apr.	Sept.	Nov.	Apr.	Sept.	Nov.
Shoot	-	815.9 ± 21.3	745.1 ± 22.4	-	1387.6 ± 19.1	1460.3 ± 20.1	-	124.6 ± 10.5	60.3 ± 8.3
Root	67.4 ± 1.1	95.3 ± 2.1	123.3 ± 3.6	58.0 ± 5.3	165.0 ± 9.1	248.0 ± 7.8	29.6 ± 0.9	61.2 ± 1.7	104.3 ± 2.2
Total	67.4 ± 1.1	911.2 ± 16.8	868.4 ± 26.7	58.0 ± 5.3	1552.6 ± 13.9	1708.6 ± 20.8	29.6 ± 0.9	185.8 ± 11.9	164.6 ± 10.6

Table 4. Contd.

Plant	Intercropped switchgrass			Switchgass + sainfoin (2:1)		
	Apr.	Sept.	Nov.	Apr.	Sept.	Nov.
Shoot	-	1083.2 ± 20.3	910.2 ± 18.3	-	723 ± 21.3	626.8 ± 18.7
Root	34.3 ± 1.5	71.8 ± 2.0	122.6 ± 2.9	63.9 ± 1.1	133 ± 7.9	226.8 ± 6.8
Total	34.3 ± 1.5	1155 ± 19.6	1032.8 ± 17.8	63.9 ± 1.1	856 ± 14.8	853.6 ± 18.5

Table 5. Soil organic matter (SOM) and total nitrogen (TN) content in 0 – 20 cm soils.

Distribution	Soil organic matter (%)			Total nitrogen (%)		
	20 Apr., 2001	4 Nov., 2004	5 Apr., 2006	20 Apr., 2001	4 Nov., 2004	5 Apr., 2006
Sole switchgrass	0.56a (b)	0.81c (a)	0.81c (a)	0.042a (b)	0.050b (a)	0.052b (a)
Sole sainfoin	0.56a (b)	0.88b (a)	0.86b (a)	0.042a (c)	0.055a (a)	0.052b(b)
Switchgrass + sainfoin (2:1)	0.56a (b)	0.93a (a)	0.92a (a)	0.042a (b)	0.057a (a)	0.058a (a)

*Values within a column followed by different letters are significantly different ($P < 0.05$), and values within a column with different small letters in bracket are also significantly different ($P < 0.05$).

creased with depth (Figure 7A). For RB measured from switchgrass side, it increased from April to November especially in the lower soil depth (Figure 7B).

Switchgrass and sainfoin intercropping

The respective RB of switchgrass and sainfoin under intercropping and the RB of intercropped stand were calculated separately according to the equation (5). The RB distributions of them were showed in Figure 8.

The total RB in 0 – 150 cm soil profile of intercropped switchgrass increased from 34.3 g m^{-2} in April to 71.8 g m^{-2} in September, and then to 122.6 g m^{-2} in November. The main increase in RB was in 0 - 40 cm soil layer. The RB of sainfoin also increased from April to September and then November, which were 29.6, 61.2 and 104.3 g m^{-2} respectively. The RB, sum of respective switchgrass and sainfoin under 2:1 row intercropping, had similar seasonal trend with switchgrass (Figure 8).

Seasonal aboveground and root biomass in 2005

In April, 2005, the RB in the 0 – 150 cm soil profile were not significantly different between switchgrass and sainfoin under sole- or intercropping, but for each species RB was significantly lower under intercropping compared with sole cropped (Table 4). From April to September and then November, the root biomass increased significantly for each species under sole or intercropping. Aboveground biomass increased from September to November, but it was not significantly different except for intercropped sainfoin between September and November (Table 4). The root biomass increased faster than aboveground biomass from September to November under both sole- and intercropping. The root: shoot ratio of sainfoin under intercropping was significantly higher than under solecropping, while swithcgrass had significantly higher root: shoot in sole cropping than intercropping (Table 4). The whole root: shoot ratio of switchgrass and sainfoin (2:1) was significantly higher than each under sole cropping.

SOM and TN dynamics

Soil organic matter (SOM) and total nitrogen (TN) increased significantly in the 0 – 20 cm layer after four years growth (Table 5). SOM in Switchgrass and sainfoin mixture increased more than respective sole cropping, and was significant the highest of the three stands. TN also increased significantly, and at the end of the fourth growth year sole sainfoin and intercropping were higher than sole switchgrass, but there was no significant difference between the former two (Table 5). At the start season in 2006, switchgras and sainfoin intercropping was significant the highest, and there was no difference between sole switchgrass and sole sainfoin in topsoil TN.

DISCUSSION

Aboveground biomass and biomass equivalent

Although aboveground biomass production of the component species in the mixture were lower than their respective sole cropping, the total land productivity was improved in mixed cultures as supported by higher total LERs especially during 2001 - 2004 (Tables 1 and 3). The four-year mean LER was 1.55 ranged from 1.08 in 2002 to 2.28 in 2004 (Table 3). This means the sole culture of switchgrass or sainfoin requires 55% more land to produce equal biomass indicating greater land-use efficiency than sole cropping (Agegnehu et al., 2006). Higher aboveground biomass production of sole switchgrass or sainfoin as compared to their mixture was due to the fewer disturbances in the habitat and homogeneous environment of solecropping (Table 4) (Banik et al., 2006; Wang et al., 2007), while the lower equivalent yield under intercropping was due to competition between the two species in the mixture (Table 4) (Thorsted et al, 2006). Fluctuations in weather parameters especially seasonal rainfall affected the biomass production over years (O'Connor et al., 2001; Xu et al., 2006). The adverse responses in equivalent aboveground biomass production of switchgrass and sainfoin in mixture suggested that these two species were not appropriate under 2:1 row repalcement intercropping for long time if the biomass production is the primary target (Table 4) (Connolly et al., 2001).

Root biomass and distribution

The root distribution for both species within the mixed stand was different from that of the pure stand of each species (Figure 5 - 8) (Xu et al., 2007). Intercropped switchgrass occupied a larger soil volume and extended high portion of root system under sainfoin (Figure 6). This is likely to be the main cause of the greater success of switchgrass, compared with sainfoin, in terms of growth and competitive ability (Schmid and Kazda, 2001). Switchgrass had high tillering ability, and such an extensive rooting system enabled it to take up nutrients and water from the subsoil of sainfoin and thereby overcome periods of low nutrient and water available in the topsoil (Neukirchen et al., 1999). Grieu et al. (2001) pointed out that to extract water from deep soil is more advantageous to plant growth than to develop a larger root biomass or root density. Under intercropping, switchgrass and sainfoin all input bigger proportion of RB to deep soil than pure stands (Figure 5 - 8), while the total RB was smaller under intercropping (Table 4). Higher roots penetration depth of intercropping system may be due to the spatial complementarity in which the component crops avoid the area of resources that is already depleted or being depleted by other crops (Banik et al., 2006).

Competition functions

Higher LER in intercropping treatment indicated yield advantage over monocropping due to better land utilization during 2001 - 2004 (Table 3). Advantage from non legume–legume intercropping systems have been reported previously in crops such as wheat and legume (Banik, 1996), pea and barley (Chen et al., 2004), field bean and wheat (Bulson et al., 1997) and maize and faba bean (Li et al., 1999), and grasses and legumes (Sengul, 2003).

The total LER decreased as growth year postponed, indicating that the proportion of sainfoin decreased and higher competition between the two species (Table 1). Actual yield loss and aggressivity values indicated sainfoin as dominant species in the mixture during 2001 - 2003, while in 2004 - 2005 it was the dominated species (Table 3). Greater competitive abilities of switchgrass to exploit resources in association with legumes or grasses have been reported (Knee and Thomas, 2002; Xu et al., 2008). Plant competitive strategies can be classified as tolerance or avoidance of competition (Wilson and Tilman, 1993). Plants tolerate competition by exploiting available water and soil nutrients (Gersani et al., 2001), while plants avoid competition by growing into soil horizons or soil patches where competitors do not grow or before competitors can respond to changing soil conditions (Brisson and Reynolds, 1994). Our results showed that switchgrass allotted more root biomass vertically and horizontally under intercropping (Table 4 and Figure 6), which suggested that switchgrass had the capacity to tolerant and avoid competition, while sainfoin only had the capacity to tolerate competition. These combined with shoot competition would make switchgrass to substitute sainfoin gradually because of higher WUE on the fluctuating soil water conditions (Lopez-Zamora et al., 2004).

Soil SOM and TN

In semiarid Loess Plateau of nonwestern China, the soils are lack of soil organic matter (Wu et al., 2004). Maintenance and improvement of soil quality is critical to sustaining agricultural productivity and environmental quality in this region especially for the continuous cropping system (Reeves, 1997). In agricultural production system, soil organic matter (SOM) and total nitrogen (TN) are the two major determinants and indicators of soil fertility and quality, and are closely related to soil productivity (Huang et al., 2007). According to soil quality standard of Zhen et al. (2006), the soil OM level of the three stands increased from very poor level (<0.6%) to fair level (0.8 - 1.0%). The SOM and TN were the highest in intercropping after five years planting, which was partially because of root death caused by soil dry-wet cycling induced by seasonal rainfall change and competition between the two species (Lopez-Zamora et al., 2004).

Conclusion

In this study, despite the reduction of aboveground biomass under intercropping, the mixed culture exhibited higher WUE than sole sainfoin, and its LERs were bigger than 1.0 in the first four years. The results also showed that the highest SOC and TN storage in topsoil of the mixture although WUE and biomass production were lower than sole switchgrass. In the context of developing environmentally sustainable agricultural systems in semi-arid northwestern China, the results from this study suggested that 2:1 row intercropping of switchgrass and sainfoin can be taken as a short-term rotation cropping pattern in the region.

ACKNOWLEDGMENTS

This work was financially supported by the Project of Knowledge Innovation Engineering of CAS (No. KZCX3-SW-444), the Second Phase Action-plan for Western China Development (No. KZCX2-XB2-05), and Talent Training Project in Western China of CAS (No. 2006YB01).

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