International Journal of Agronomy and Agricultural Research (IJAAR)
ISSN: 2223-7054 (Print) 2225-3610 (Online)
http://www.innspub.net
Vol. 7, No. 2, p. 130-141, 2015

INNSPUB

RESEARCH PAPER OPEN ACCESS

Effect of switchgrass plantation on soil moisture and nitrogen availability and microbial biomass carbon in a semi-arid ecosystem

R.L. Molatudi[1,2,4], Y. Steinberger[3], F.Y. Meng[1,4], G.H. Xie[1,4,*]

[1]*College of Agronomy and Biotechnology, China Agricultural University, Beijing, P. R. China*

[2]*School of Agricultural and Environmental Sciences, University of Limpopo, Limpopo, South Africa*

[3]*The Mina and Everard Goodman Faculty of Life Sciences, Bar-Ilan University, Ramat-Gan, Israel*

[4]*National Energy R&D Center for Biomass, China Agricultural University, Beijing, P. R. China*

Article published on August 16, 2015

Key words: *Panicum virgatum* L., Energy plants, Mineral nitrogen

Abstract

The crop canopy was reported to have a strong influence on soil moisture and nutrient availability. The aim of this study was to determine the effect of switchgrass (*Panicum virgatum* L.) plantations on soil moisture and the levels of mineral nitrogen and microbial biomass carbon. Soil samples were collected from six soil layers to a depth of 90 cm under switchgrass stands established in 2006 (SG2006), 2008 (SG2008), and 2009 (SG2009), and under native grasses as a control, during 2012 and 2013. Soil moisture was significantly higher (P < 0.05) under native grasses than under all switchgrass stands. Soil ammonium nitrogen (NH_4^+-N) levels were significantly higher under all switchgrass stands than under native grasses. The nitrate nitrogen (NO_3^- -N) concentration was significantly lower in soil under native grasses than under all switchgrass stands and averaged 2.74 mg kg^{-1} for the two seasons. Among all the treatments, the 2009 switchgrass plantation soil had a significantly lower (P < 0.05) microbial biomass carbon (MBC) (160 mg kg^{-1} and 121 mg kg^{-1} in 2012 and 2013, respectively) during both growing seasons. Ammonium-nitrogen, NO_3^- -N and MBC were significantly higher in the upper soil layers than in deeper layers in all treatments studied. Soil moisture was significantly higher in the deeper layers than in the upper layers, regardless of treatment. These findings confirm that switchgrass plantations exhibit beneficial impacts on soil fertility in semi-arid regions, through alleviation of NO_3^--N leaching and enhancement of soil microbial carbon.

* **Corresponding Author:** G.H. Xie ✉ lraisibe@gmail.com

Introduction

Nitrogen is one of the most important elements in nature, and it plays a key role in plant growth and productivity (Fan *et al.*, 2014). Ammonium (NH_4^+-N) and nitrate (NO_3^--N) are the main forms of nitrogen absorbed by plants. Plants could increase soil organic matter through accumulation of organic residues and acceleration in soil water-holding capacity (Garcia *et al.*, 1994) to improve nitrogen availability. Crop canopy has a strong positive influence on soil moisture and nutrient availability in many arid and semi-arid ecosystems (Schade and Hobbie, 2005; Su *et al.*, 2005). It is established that crop plantations can significantly influence the spatial distribution of soil nutrients (Cao *et al.*, 2011).

Due to the concerns regarding negative environmental consequences and declining energy supplies of fossil fuels, there has been a worldwide increase in interest to develop biomass crops which will be grown in marginal lands for biofuel production. Switchgrass (*Panicum virgatum* L.), a perennial warm-season grass, is one of the sources of lignocellulose that is currently being considered as the second generation for production of ethanol (McLaughlin *et al.*, 2002). The crop was chosen on the basis of its widespread adaptation, fast growth cycle, high biomass production, low ash content and ability to produce well even in the driest years (Lewandowski and Kauter, 2003; Parrish and Fike, 2005; Wright and Turhollow, 2010). It was introduced in China and regarded as a potential energy crop (Xiong *et al.*, 2008) since it can be grown on marginal land and will not compete with food crops for arable land.

Numerous studies carried out on switchgrass as a bioenergy crop support the notion that crops that grow well on marginal and less productive soils improve soil conservation and increase energy production compared with row-crop production on the same land (Vogel, 1996; McLaughlin and Kszos, 2005; Lee *et al.*, 2007). Additional studies on switchgrass are necessary in order to compare and evaluate the ecological consequences after energy cropping on marginal land. Thus the main aim of this study was to compare the soil moisture, mineral nitrogen and microbial biomass carbon under different switchgrass plantations on a sandy waste land in semi-arid regions of China.

Materials and methods

Study site

A field experiment was set up in a marginal land in Ganqika (42°58'N, 122°21'E), Inner Mongolia, China. Switchgrass has been introduced and planted as a potential energy crop at this site since 2006 (Xiong *et al.*, 2008). The land was not cultivated and was populated primarily with short, native grasses prior to the switchgrass. The soil at the site was classified as a loamy sand. The area has a temperate continental monsoon-type climate, with an annual average sunshine period of 2888.9 hours per year and an average annual temperature of 5.8 °C. The annual mean precipitation is 451 mm, falling mostly between June and August. The monthly precipitation and temperature at the study site, as well as the main soil properties (0–90 cm layer) during the study period, are presented in Fig. 1 and Table 1.

Experimental design, treatments and crop cultivation

The study was conducted between May and October of 2012 and 2013. Switchgrass plant stands were established at the site in 2006 (SG2006), 2008 (SG2008), and 2009 (SG2009) and were arranged as treatments, respectively. A plot of native grasses adjacent to the switchgrass field was set up as a control. According to local herdsmen, the land of the native plot had never been changed artificially. Five 6 x 6 m replicates were randomly placed in each of the switchgrass stands and in the native grass control site. Amounts of 84 kg N ha^{-1} as urea, 99 kg P_2O_5 ha^{-1} as diammonium phosphate, and 45 kg K_2O ha^{-1} as potassium sulfate were applied to each switchgrass plot as topdressing before the plant regrowth in both years. Amounts of 30 kg N ha^{-1} and 15 kg N ha^{-1} as urea were also applied at 40 and 80 days after regrowth, respectively.

In the control plot, native perennial rhizomatous grasses constituted the most dominant population (i.e., 96% of the total plant population) according to our field survey on October 4, 2013. Chinese leymus (*Leymus chinensis* (Trin.) Tzvel.) was the most dominant perennial grass species and accounted for 78% of stems and plants. The other grasses included perennial Chee reedgrass (*Calamagrostis epigejos* (L.) Roth.), small reed (*Deyeuxia angusitifolia* (Kom.) Y. L. Chang) and annual green bristle grass (*Setaria viridis* (L.) Beauv.). Non-grass plants, including perennial capillary wormwood herb (*Artemisia capillaris* Thunb) and argy wormwood (*Artemisia argyi* Lévl. &Vant.), were also found in the plot. The native plot exhibited an aboveground biomass yield of 3.6 t ha^{-1}, which was composed of 65% Chinese leymus, 30% of the other grasses, and 5% of non-grass plants. Because grasses were the most dominant species, mainly fine fibrous root systems were found belowground in the native (control) plot.

Soil sampling and chemical analysis

Soil samples were collected with a soil auger before switchgrass emergence and at 40-day intervals until harvesting. In each of the five plots, soil subsamples were collected from five randomly selected points, mixed thoroughly, composited, stored in insulated plastic bags and transferred to a temperature of 4 °C. The soil samples were collected from a 0–90 cm depth and divided into six units according to the following soil layers: 0–15, 15–30, 30–45, 45–60, 60–75 and 75–90 cm. Each composited soil sample was divided into two parts. One part of each sample was used to determine the soil moisture, and content of ammonium nitrogen ($NH4^+$-N), nitrate nitrogen (NO_3^--N), and microbial biomass carbon (MBC). Soil microbial biomass carbon was determined from the 0–45 cm layers. The second part of each sample was air-dried at room temperature, hand ground to a fine powder and passed through a 0.25-mm sieve. Ground samples were used for pH, electric conductivity (EC), and soil texture determination.

Soil chemical analysis

The pH and EC of the soil samples were determined in a soil slurry made by using a 1:1 soil/water ratio (B-212 Twin Compact pH meter-HORIBA) and a 1:5 soil/water ratio (Conductivity Meter DDS-307) for pH and EC, respectively. The soil moisture content in each sample was measured gravimetrically at 105 °C to a constant weight and was expressed as a percentage on an oven-dried basis. The NO_3^--N content was determined as previously described by Norman *et al.* (1985) by utilizing the dual-wavelength spectrophotometer method and the NH_4^+-N content was determined using a 2 mol/L KCl extraction indophenols blue colorimetric method (Keeney and Nelson, 1982).

Soil microbial biomass carbon was measured by a fumigation-extraction procedure described by Vance *et al.* (1987), where one portion of composited field moist samples was fumigated by exposing the soil to alcohol-free $CHCL_3$ vapor for 24 h in vacuum desiccators (Jenkinson and Powlson, 1976). After the $CHCL_3$ was removed by vacuum extraction, the fumigated portion was extracted with 0.15 mol l^{-1} K_2SO_4 by shaking for 30 min (25 °C; 200 r/min), and the suspension was filtered using Whatman No. 2 filter paper (Pandey *et al.*, 2009; Pandey and Begum, 2010). Another portion of unfumigated soil was extracted with K_2SO_4 by a procedure similar to that performed for the fumigated portion. Organic carbon in the extracts was analyzed using the digestion-titration method. Specifically, after transferring 5 ml of the extract to a test tube, 5 ml of 0.1018 mol l^{-1} $K_2Cr_2O_7$ and 5 ml of concentrated H_2SO_4 were added. The samples were digested for 10 min at 175 °C and titrated using 0.105 mol l^{-1} $FeSO_4$ with the phenanthroline indicator. All analyses were carried out in duplicate. Microbial biomass carbon was estimated from the following equation:

MBC = 2.64Ec

Where Ec is the difference between estimates from fumigated and unfumigated soils, both expressed as mg/kg on an oven-dried basis; and 2.64 is the proportionality factor of MBC released by the fumigation extraction (Vance *et al.*, 1987).

Data analysis

Analysis of variance (ANOVA) was conducted using the General Linear Model procedure of the SPSS 20.0 analytical software package (IBM SPSS Inc., Chicago, IL, US). The difference between the means exhibiting significant differences were separated using the Least Significance Difference (LSD) test at a $P < 0.05$ level.

Results

Soil moisture

Significant differences in soil moisture, NH_4^+-N, NO_3^--N, and MBC were found between samples collected under switchgrass and native grass during the 2012 and 2013 growing seasons (Fig. 2). Soil moisture levels of 9.8 and 10.4% were recorded in 2012 and 2013, respectively, and were significantly higher ($P < 0.05$) under native grass than under all switchgrass plantations. Soil moisture under switchgrass planted in 2008 was significantly higher ($P < 0.05$) than under all other switchgrass plantations in both seasons. Soil under switchgrass planted in 2009 had the lowest soil moisture ($P < 0.05$) during the two seasons, with 4.6 and 6.4% in 2012 and 2013, respectively.

Table 1. Main soil chemical and physical properties of different layers at a depth of 90 cm at the study site during the growing season.

Soil layer (cm)	pH (H_2O)	Electrical conductivity (μS cm^{-1})	Sand (%)	Silt (%)	Clay (%)	Total nitrogen (g kg^{-1})	Soil organic carbon (g kg^{-1})
0–15	8.6	141	76.8	11.4	11.8	0.46	10.4
15–30	8.7	148	85.5	6.6	7.9	0.35	8.4
30–45	8.8	147	82.6	6.9	10.5	0.28	7.0
45–60	8.8	153	83.9	4.9	11.3	0.24	6.5
60–75	8.8	143	84.0	7.5	8.6	0.21	5.8
75–90	8.8	142	85.0	6.6	8.4	0.26	6.0

Soil texture was classified as follows: sand between 0.01–1.0 mm, silt between 0.002–0.05 mm, and clay less than 0.002 mm (Gee and Bauder, 1986).

Overall, soil moisture was significantly higher ($P < 0.05$) under native grass than under the switchgrass plantations. Moreover, soil moisture was significantly higher ($P < 0.05$) in the deeper soil layers compared to the upper soil layer during the 2012 and 2013 growing seasons, irrespective of switchgrass plantation age (Fig. 3).

Ammonium nitrogen and nitrate nitrogen content

No significant differences in NH_4^+-N content were found under all switchgrass plantations during both growing seasons (Fig. 4A). In 2012, the soil under native grass exhibited the lowest NH_4^+-N content, but it was only significantly lower than under the 2008 plantation. Nitrate nitrogen levels (4.5 mg kg^{-1}) were significantly higher ($P < 0.05$) under the 2008 switchgrass plantations than under all other treatments in the 2012 growing season. There were no significant differences in NO_3^--N levels between switchgrass plantations in the 2013 growing season. Significantly lower ($P < 0.05$) NO_3^--N levels were measured under native grass in the two seasons, with 3.2 mg kg^{-1} and 2.3 mg kg^{-1} in 2012 and 2013, respectively (Fig. 4B). However, there was no significant difference between soil NO_3^--N levels under switchgrass planted in 2009 and soil under native grass in the 2012 season.

Soil NH_4^+-N concentrations were not impacted by switchgrass plantations at all soil depths investigated in this study during the 2012 growing season. Ammonium nitrogen values under native grass were significantly lower ($P < 0.05$) compared to that in soil under switchgrass plantations at all soil depths during the 2012 and 2013 growing seasons (Figs. 5A, 5B). However, there were no significant differences in soil ammonium nitrogen values between all treatments at the 0–15 cm depth during the 2013 growing season.

There were significant differences in soil NO_3^--N concentration in all treatments (Figs. 5C, 5D). Nitrate nitrogen levels were significantly higher ($P < 0.05$) under the 2006 switchgrass plantations at all soil depths than those in soil subjected to all other treatments in the 2012 growing season. There were no significant differences in NO_3^--N concentrations between SG2008 and SG2009 at all soil depths during the 2012 growing season. However, an exception was found in the 30–45 cm soil depth samples, where the NO_3^--N concentration in SG2008 was significantly higher than that in SG2009. The soil under native grass exhibited significantly lower values of NO_3^--N than all other treatments during the 2013 growing season.

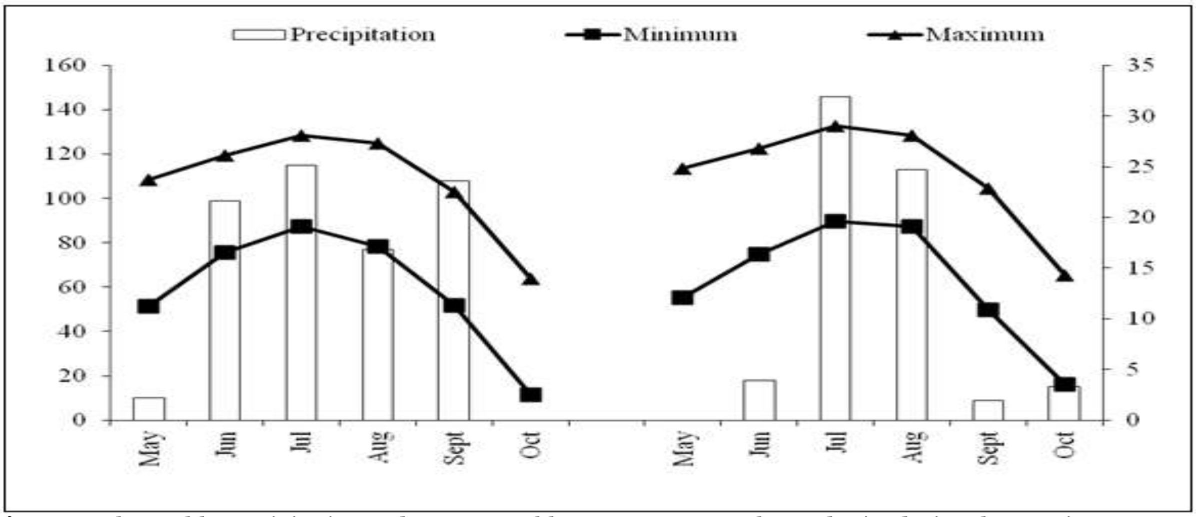

Fig. 1. Total monthly precipitation and mean monthly temperatures at the study site during the growing seasons.

Soil Microbial biomass carbon

Soil MBC followed the same trend as soil moisture, and was significantly higher ($P < 0.05$) in soil under native grass than under all switchgrass plantations (Fig. 6). Among all the treatments, the soil under the 2009 switchgrass plantation had the lowest MBC ($P < 0.05$) during both growing seasons, with 160 mg kg^{-1} and 121 mg kg^{-1} in 2012 and 2013, respectively. However, there were no significant differences in MBC under all switchgrass plantations in the 2012 growing season.

The MBC did not demonstrate any significant differences under all switchgrass plantations at all soil depths during the 2012 and 2013 growing seasons (Fig. 7).

However, a significantly higher ($P < 0.05$) MBC was measured in soil under native grass at the 0–15 cm depth than in soil under all switchgrass plantations in both seasons. Although no significant differences in MBC were found under all switchgrass plantations at all soil depths during the 2012 growing season, the 0–15 cm soil depth showed a slightly higher MBC of 204 mg kg^{-1}, 174 mg kg^{-1}, 176 mg kg^{-1} than that of the 15–30 cm soil depth (which exhibited 191 mg kg^{-1}, 158 mg kg^{-1}, 153 mg kg^{-1}) and the 30–45 cm soil depth (which demonstrated 187 mg kg^{-1}, 126 mg kg^{-1}, 120 mg kg^{-1} in 2006, 2008 and 2009 switchgrass plantations, respectively).

During the 2013 growing season, the 0–15 cm soil depth samples had a significantly higher MBC than that of the 15–30 cm and 30–45 cm soil depth samples under all switchgrass plantations.

The soil under switchgrass planted in 2006 also exhibited significantly higher MBC ($P < 0.05$) than that of the soil under switchgrass planted in 2008 and 2009 at the 30–45 cm soil depth. No significant differences in MBC were found in the soil between 2008 and 2009 under switchgrass plantations at all soil depths (Fig. 7).

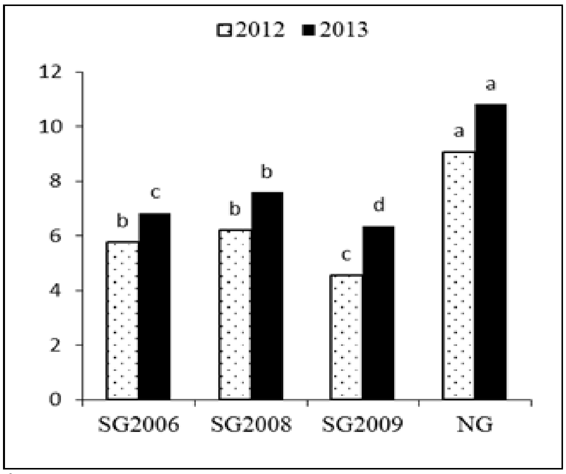

Fig. 2. Dynamics of soil moisture under switchgrass planted in 2006 (SG2006), 2008 (SG2008) and 2009 (SG2009) and under native grasses (NG) during the 2012 and 2013 growing seasons. The different small letters above the bars indicate significant differences at $P < 0.05$ within each year.

Discussion

Soil moisture content

In the present study, switchgrass stands showed a significant effect on soil moisture and nutrients, particularly in the upper soil layers. Soil moisture under the native grasses was significantly higher than that under the switchgrass plantations. Soil moisture decreased with increasing depth in all soil treatments establishing the depth dependency of soil moisture dynamics. A higher soil moisture in the deeper than upper depths may be due to root water uptake (Hupet and Vanclooster, 2002). No significant differences in soil moisture were recorded between switchgrass plantations. However, the moisture content in soil under switchgrass planted in 2008 was significantly higher than that in soil under switchgrass planted in the 2006 and 2009 plantations for both seasons.

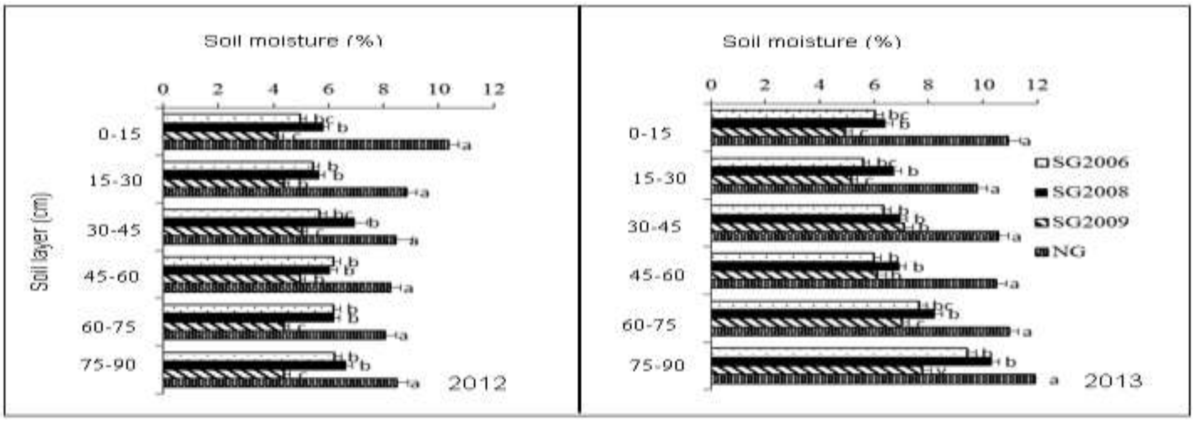

Fig. 3. Dynamics of moisture of soil layers at a depth of 90 cm under switchgrass planted in 2006 (SG2006), 2008 (SG2008) and 2009 (SG2009) and under native grasses (NG) during the 2012 and 2013 growing seasons. The different small letters to the right of the bars indicate significant differences at $P < 0.05$ within each year.

The moisture content in soil under switchgrass planted in 2009 was significantly the lowest during both seasons. The lower soil moisture in these plantations compared to that in the soil under native grasses may be due to higher evapotranspiration in switchgrass plantations (which have a higher leaf canopy) than in native grasses. The results of this study are consistent with those reported by Yang *et al.* (2012), who found that introduced vegetation usually consumes more moisture than native grasses. Furthermore, the significantly lower soil moisture under the 2009 switchgrass plantation than under the 2006 and 2008 plantations may be due to the low organic matter in this plantation. Organic matter has been reported as one of the main factors affecting soil moisture content (Wang *et al.*, 2013). Hudson (1994) also reported that organic matter increases the available water capacity in all soil textural groups. An increase in switchgrass plantation duration has been reported to increase the organic matter in the soil (Schmer *et al.*, 2011).

High organic matter under switchgrass planted in 2006 and 2008 could have led to the higher soil moisture in these plantations than that in soil of the 2009 plantation.

Soil mineral nitrogen content

The NH_4^+-N and NO_3^--N levels were higher in soil under the 2006 switchgrass plantation than that in soil under the 2008 and 2009 plantations and the native grasses, regardless of soil depth. Higher NH_4^+-N and NO_3^--N levels were also observed in the upper soil depths than in the lower soil depths in all of the treatments.

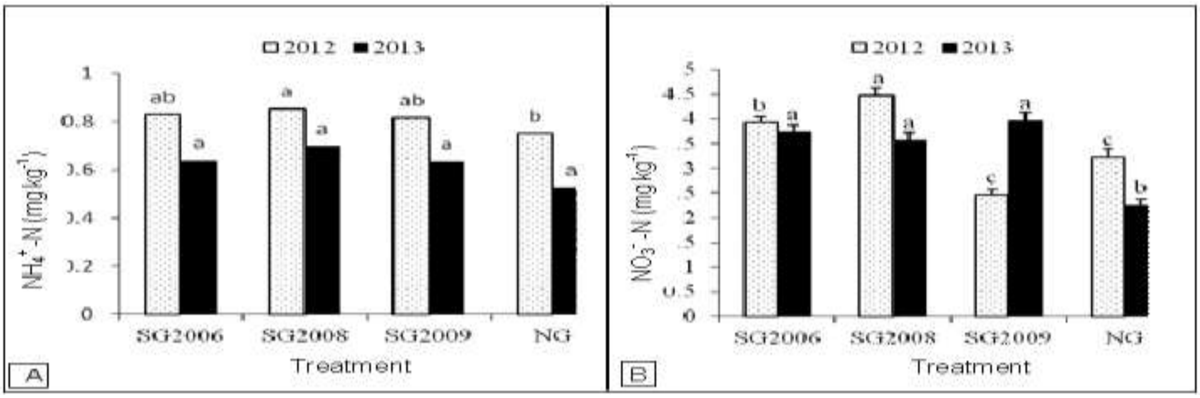

Fig. 4. Dynamics of soil ammonium nitrogen (NH_4^+-N) (A) and nitrate nitrogen (NO_3^--N) (B) under switchgrass planted in 2006 (SG2006), 2008 (SG2008) and 2009 (SG2009) and under native grasses (NG) during the 2012 and 2013 growing seasons. The different small letters above the bars indicate significant differences at $P < 0.05$ within each year.

The higher NH_4^+-N and NO_3^--N levels in soil under switchgrass plantations than in soil under native grass in the present study could be due to the lower moisture recorded under switchgrass plantations. The NH_4^+-N and NO_3^--N levels have been reported to be lower in moist soils than in dry soils (Roberts *et al.*, 2010). Parker and Schimel (2011) also reported lower NH_4^+-N and NO_3^--N levels in soils with a high moisture level than in soil with a low moisture content. Although the NH_4^+-N and NO_3^--N levels were higher in the soils under the switchgrass plantations than in the soil under native grass, the NO_3^--N content represented the dominant form of inorganic N in all treatments. A similar observation was reported by Parker and Schimel (2011). Yu *et al.* (2008) also reported NO_3^--N as the dominant form of inorganic N in soil under Mongolian plantations. The small amount of NH_4^+-N in the soil relative to NO_3^--N can be explained by the preferential uptake of NH_4^+-N, which has also been observed in some grass species (Atkinson, 1985). Nitrate predominance, as the mineral N form, may be related to the soil salinity that was observed in this study, which tends to encourage nitrification. Nitrogen in plant residues adds to the organic nitrogen in the soil, which will be further mineralized into mineral nitrogen by microorganisms. Switchgrass has been reported to have a high biomass and organic matter accumulation with crop plantation duration (Dou *et al.*, 2013). This could have led to the higher NH_4^+-N and NO_3^--N concentrations in the soil under switchgrass planted in 2006 than in the soil under the 2008 and 2009 switchgrass plantations.

Soil microbial biomass carbon

The soil microflora and the vegetation of an ecosystem are closely interrelated. Plants influence soil biotic processes by delivering organic compounds (Yadav, 2012). The soil microbial biomass represents a small but important labile pool of nutrients in soils, and its activity exerts a key controlling influence on the rate at which C, N and other nutrients cycle through ecosystems (Lovell *et al.*, 1995). The soil microbial biomass is the active component of the organic pool, which is responsible for organic matter decomposition thereby affecting the soil nutrient content (Franzluebbers *et al.*, 1999). It is also used as an important indicator of soil fertility (Moore *et al.*, 2000; Insam, 2001).

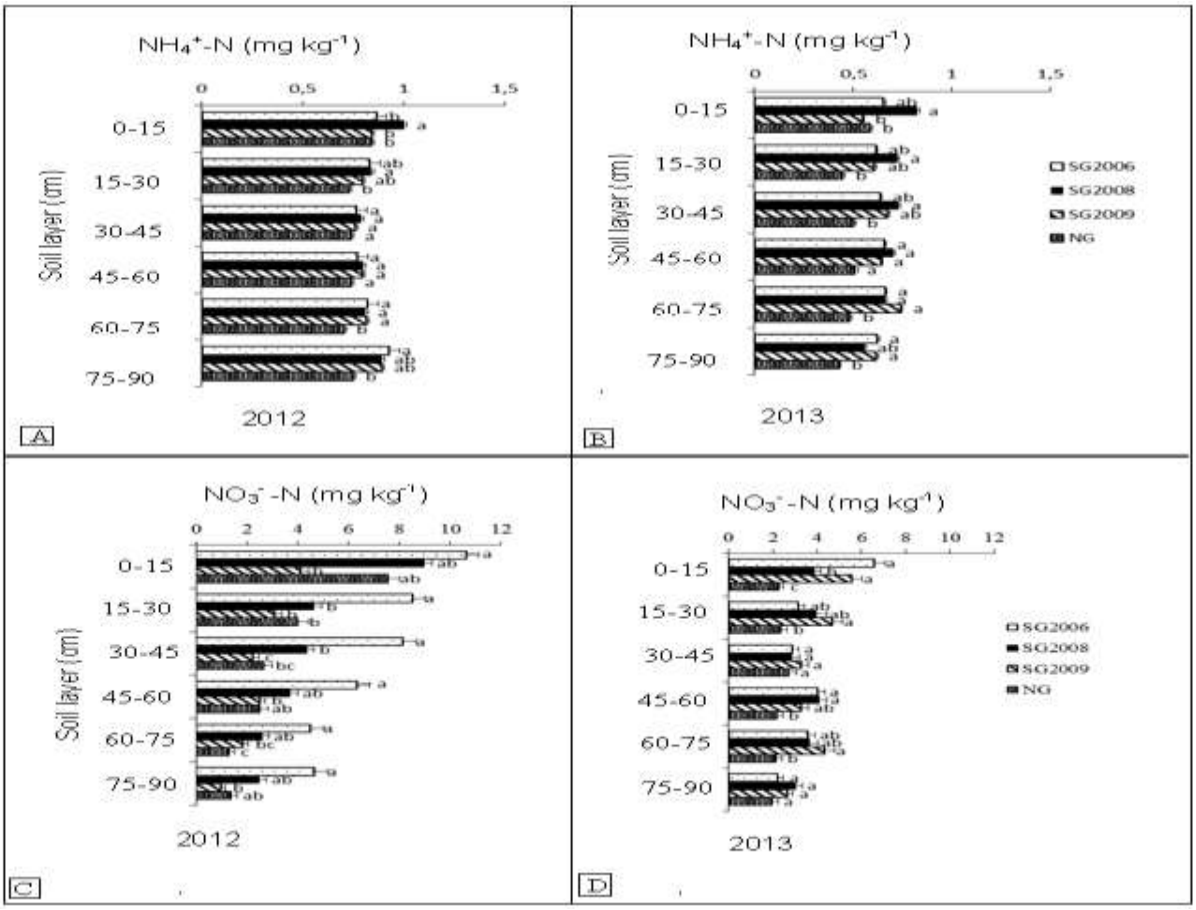

Fig. 5. Dynamics of soil ammonium nitrogen (NH_4^+-N) (A and B) and nitrate nitrogen (NO_3^--N) (C and D) values in the 0 to 90 cm-depth in the 2012 and 2013 growing seasons. The different small letters to the right of the bars indicate significant differences at $P < 0.05$ within each year.

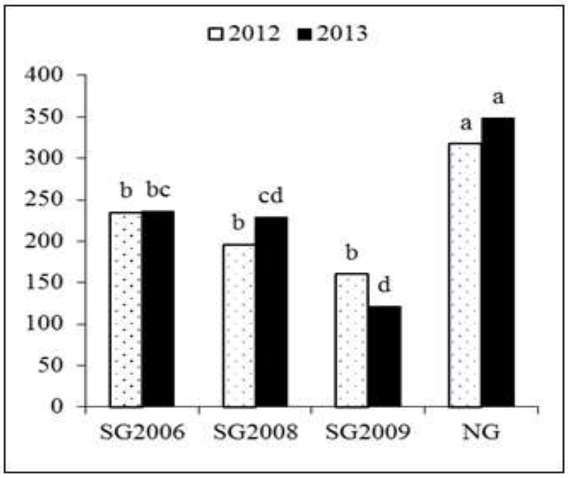

Fig. 6. Dynamics of soil microbial biomass carbon (MBC) under switchgrass planted in 2006 (SG2006), 2008 (SG2008) and 2009 (SG2009) and under native grasses (NG) during the 2012 and 2013 growing seasons. The different small letters above the bars indicate significant differences at $P < 0.05$ within each year.

Soil physicochemical characteristics influence the microbial biomass and the activity of microorganisms. Changes in soil moisture, carbon input from crop roots and crop residues are also known to have an effect on the soil microbial biomass and activity (Ross, 1987), which also affect the soil's ability to supply nutrients to plants through organic matter turnover (Bonde and Roswall, 1987; Yu *et al.*, 2008).

The results from this study indicated a higher MBC in the soil under native grasses than that in the soil under switchgrass plantations at the 0–15 cm depth. Soil under switchgrass planted in 2006 also contained a higher MBC than soil under the 2008 and 2009 plantations. The higher amount of MBC present in soil under native grass than under switchgrass plantations could be due to high moisture and soil aggregates in the soil under native grasses. The results of this study are consistent with those of Diaz-Ravina *et al.* (1995) and Devi and Yadava (2006) who demonstrated that a lack of soil moisture limits the microbial biomass. Griffiths *et al.* (2003), Tu *et al.* (2006) and Zhou *et al.* (2012) reported that water availability affects the physiological status of bacteria and can indirectly regulate substrate availability, while water stress reduces the microbial biomass and activity through induced osmotic stress, resource competition and starvation. Fierer and Schimel (2002) also confirmed higher microbial activity under moist conditions in grassland soils. The higher MBC in the soil under the 2006 switchgrass plantations than in the soil under the 2008 and 2009 plantations could be due to its higher organic matter content. Longer crop plantations have been reported to have high organic matter input via leaf and root litters and root exudates over a long period (El Titi, 2003). The high MBC at the 0–15 cm soil depth in all treatments is attributed to the improved soil environment and increased organic and inorganic materials released from plants, which provide the energy source and nutrients for microorganisms that largely enter the soil through the surface, as reported by Cao *et al.* (2011).

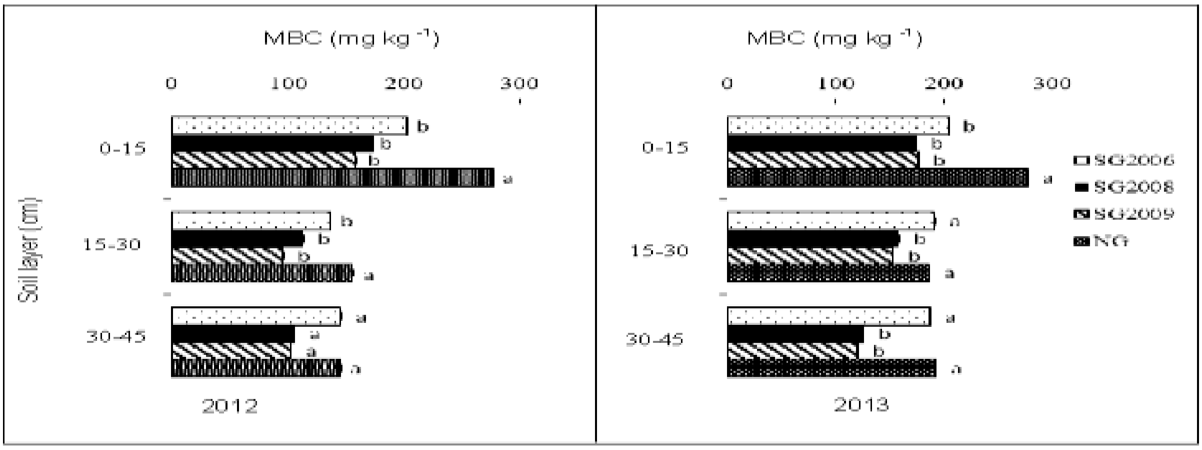

Fig. 7. Dynamics of soil microbial biomass carbon (MBC) values in the 0 to 45 cm soil layers in the 2012 and 2013 growing seasons. The different small letters to the right of the bars indicate significant differences at $P < 0.05$ within each year.

Conclusion

There were no significant differences in soil NH_4^+-N levels between all treatments analyzed in this study. However, the upper soil layer contained a slightly higher NH_4^+-N concentration than that of the deeper layers, regardless of the switchgrass plantation. Nitrate-N was found to be higher in the soil under the switchgrass plantations than in the soil under native grasses. The NO_3^--N concentrations increased with increasing age of the switchgrass plantation, irrespective of soil depth and a decrease with increasing soil depth, irrespective of switchgrass plantation. Soil microbial biomass carbon and organic carbon increased in the soil under the switchgrass plantations, regardless of the soil depth. Soil microbial biomass carbon and organic carbon contents were also greater in the surface layer and decreased with an increase in soil depth, irrespective of the switchgrass plantation. In summary, our results confirm that switchgrass plantations have a beneficial impact on soil fertility in semi-arid land, through alleviation of NO_3^--N leaching and enhancement of soil microbial carbon.

Acknowledgement

This study was financially supported by the National Natural Science Foundation of China (31470555). The authors thank Allen McBride and Anthony Turhollow Jr. from the Oak Ridge National Laboratory (ORNL), USA, for their comments on the experimental design, and Aiguo Pang and Zhihui Chen for their assistance in the field and lab work.

References

Atkinson C. 1985. Nitrogen acquisition in four coexisting species from an upland acidic grassland. Plant Physiology **63,** 375–387.

Bonde TA, Roswall T. 1987. Seasonal variation of potentially mineralizable nitrogen in four cropping systems. Soil Science Society of American Journal **51,** 1508–1541.

Cao C, Jiang SY, Ying Z, Zhang FX, Han XS. 2011. Spatial variability of soil nutrients and microbiological properties after the establishment of leguminous shrub *Caragana microphylla* Lam. plantation on sand dune in the Horqin sandy land of Northeast China. Ecological Engineering **37,** 1467–1475.

Devi NB, Yadava PS. 2006. Seasonal dynamics in soil microbial biomass C, N and P in a mixed-oak forest ecosystem of Manipur, North-east India. Applied Soil Ecology **31,** 220–227.

Diaz-Ravina M, Acea MJ, Carballas T. 1995: Seasonal changes in microbial biomass and nutrient flush in forest soils. Biology and Fertility of Soils **19**, 220–226.

Dou FG, Hons F M, Ocumpaugh W R, Read J C, Hussey MA, Muir JP. 2013. Soil organic carbon pools under switchgrass grown as a bioenergy crop compared to other conventional crops. Pedosphere **23(4),** 409–416.

El Titi A. 2003. Implication of soil tillage for weed communities. In El Titi A (Ed.): Soil tillage in Agroecosystems. CRC Press, Boca Raton, FL, USA. 147–186 p.

Fan XR, Xie D, Chen JG, Lu HY, XU YL, Ma C, XU GH. 2014. Over-expression of OsPTR6 in rice increased plant growth at different nitrogen supplies but decreased nitrogen use efficiency at high ammonium supply. Plant Science **227,** 1–11.

Fierer N, Schimel JP. 2002. Effects of drying-rewetting frequency on soil carbon and nitrogen transformations. Soil Biology and Biochemistry **34,** 777–787.

Franzluebbers AJ, Haney RL, Hons FM. 1999. Relationships of chloroform fumigation–incubation to soil organic matter pools. Soil Biology and Biochemistry **31,** 395–405.

Garcia C, Hernandez T, Costa F, Ceccanti B. 1994. Biochemical parameters in soils regenerated by the addition of organic wastes. Waste Management Research **12,** 457–466.

Gee GW, Bauder JW. 1986. Particle-size analysis. In: A. Klute, editor, Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.p. 383–411.

Griffiths RI, Whiteley AS, O'Donnell AG, Bailey MJ. 2003. Physiological and community responses of established grassland bacterial populations to water stress. Applied and Environmental Microbiology **69,** 6961–6968.

Insam H. 2001. Development in soil microbiology since the mid. Goderma **100,** 389–402.

Jenkinson DS, Powlson DS. 1976. The effects of biocidal treatments on metabolism in soil. V. A method for measuring soil biomass. Soil Biology and Biochemistry **8,** 209–213.

Keeney DR, Nelson DW. 1982. Nitrogen - inorganic forms. In A.L. Page (eds.) Methods of soil analysis, part 2. Agronomy Monograph 9, 2nd ed. ASA and SSSA, Madison, WI. 643-698 p.

Lee DK, Doolittle JJ, Owens VN. 2007. Soil carbon dioxide fluxes in established switchgrass land managed for biomass production. Soil Biology and Biochemistry **39,** 178–186.

Lewandowski I, Kauter D. 2003. The influence of nitrogen fertilizer on the yield and combustion quality of whole-grain crops for solid fuel use. Industrial Crops and Products **17(2),** 103–117.

Lovell, RD, Jarvis SC, Bardgett RD. 1995. Soil microbial biomass and activity in long-term grassland: effects of management changes. Soil Biology and Biochemistry **27,** 969–975.

McLaughlin SB, de la Torre Ugarte DG, Garten Jr CT, Lynd LR, Sanderso MA, Tolbert VR, Wolf DD. 2002. High-value renewable energy from prairie grasses. Environmental Science and Technology **36,** 2122–2129.

McLaughlin SB, Kszos AL. 2005. Development of switchgrass (*Panicum virgatum*) as a bioenergy feedstock in the United States. Biomass Bioenergy **28,** 515–535.

Moore JM, Klose S, Tabatabai MA. 2000. Soil microbial biomass carbon and nitrogen as affected by cropping system. Biology and Fertility of Soils **31,** 200–210.

Norman RJ, Edberg JC, Stucki JW. 1985. Determination of nitrate in soil extracts by dual-wavelength ultraviolet spectrophotometry. Soil Science Society of America Journal **49,** 1182–1185.

Pandey CB, Begum M. 2010. The effect of a perennial cover crop on net soil N mineralization and microbial biomass carbon in coconut plantations in the humid tropics. Soil Use and Management **26,** 158–166.

Pandey CB, Srivastava RC, Singh RK. 2009. Soil nitrogen mineralization and microbial biomass relation, and nitrogen conservation in humid-tropics. Soil Science Society of American Journal **73,** 1142–1149.

Parker SS, Schimel JP. 2011. Soil nitrogen availability and transformations differ between the summer and the growing season in California grassland. Applied Soil Ecology **48,** 185-192.

Parrish D, Fike J. 2005. The biology and agronomy of switchgrass for biofuels. Critical Reviews in Plant Science **24,** 423–459.

Roberts G, Penwell A, Peurou F, Sharpe A. 2010. The effect of soil moisture content on nitrogen transformation using OECD test guideline 216. Applied Soil Ecology **46,** 478–482.

Ross DJ. 1987. Soil microbial biomass estimated by the fumigation-incubation procedure: seasonal fluctuation and influence of soil moisture content. Soil Biology and Biochemistry **19,** 397–404.

Schade JD, Hobbie SE. 2005. Spatial and temporal variation in islands of fertility in the Sonoran Desert. Biogeochemistry **73,** 541–553.

Schmer MR, Liebig MA, Vogel KP, Mitchell RB. 2011. Field-scale soil property changes under switchgrass managed for bioenergy. Global Change Biology and Bioenergy **3,** 439–448.

Su YZ, Zhang TH, Li YL, Wang F. 2005. Changes in soil properties after establishment of *Artemisia halodendron* and *Caragana microphylla* on shifting sand dunes in semiarid Horqin Sandy Land, Northern China. Environmental Management **36,** 272–281.

Tu C, Ristaino JB, Hu S. 2006. Soil microbial biomass and activity in organic tomato farming systems: Effects of organic inputs and straw mulching. Soil Biology and Biochemistry **38,** 247–255.

Vance ED, Brookes PC, Jenkinson DS. 1987. An extraction method for measuring soil microbial biomass C. Soil Biology and Biochemistry **19,** 703–707.

Vogel KP. 1996. Energy production form forages (or American agriculture—back to the future). Journal of Soil and Water Conservation **51,** 137–139.

Wright L, Turhollow A. 2010. Switchgrass selection as a “model” bioenergy crop: A history of the process. Biomass Bioenergy **34,** 851–868.

Xiong SJ, Zhang QG, Zhang DY, Olsson R. 2008. Influence of harvest time on fuel characteristics of five potential energy crops in northern China. Bioresource Technology **99,** 479–485.

Yadav R. 2012. Soil organic carbon and soil microbial biomass as affected by restoration measures after 26 years of restoration in mined areas of Doon Valley. International Journal of Environmental Sciences **2(3),** 1380–1385.

Yang L, Wei W, Chen L, Jia F, Mo B. 2012. Spatial variation of shallow and deep moisture in semi-arid Loess Plateau, China. Hydrology and Earth System Sciences **16,** 3199–3217.

Zhou Y, Pei Z, Su J, Zhang J, Zheng Y, Ni J, Xiao C, Wang R. 2012. Comparing soil organic carbon dynamics in perennial grasses and shrubs in a saline-alkaline arid region, Northwestern China. PLoS ONE **7(8),** e42927.