JEB
Journal of Environmental Biology

Journal Website : www.jeb.co.in
E-mail : editor@jeb.co.in
ISSN: 0254-8704 (Print)
ISSN: 2394-0379 (Online)
CODEN: JEBIDP

Effects of stocking rates on functional group diversity and forage quality in rangeland of Qilian Mountain, China

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Abstract

The present study aimed at investigating a balance between environment and livestock grazing, through identifying appropriate stocking rate in rangeland with highest biodiversity and forage quality. The experiment was carried out to determine the effects of six stocking rates on Shannon Weiner index of functional group diversity and nutritive value and relationship between them in the edge of the Tibetan plateau of China. The results showed that abundance of functional group diversity indices were significantly influenced by stocking rates ($p<0.05$) and the highest appeared in 2.5 and 2.6 animal month unit (AMU) ha^{-1}. There were significant differences in forage content of nitrogen (N), water-soluble carbohydrate (WSC), neutral detergent fiber (NDF) and acid detergent fiber (ADF) under stocking rates ($p<0.05$). There were higher N and WSC content but lower NDF and ADF content under 2.5 and 2.6 AMU ha-1 than other stocking rates. Positive relationship was found between all functional group diversity indices and N and WSC content of community but negative relationship between all functional group diversity indices and NDF and ADF content of community. All the results represented that moderate control of stocking rates was an effective management measure to protect functional diversity, improve forage quality and sustain rangeland health.

Publication Info

Paper received:
01 June 2014

Revised received:
30 September 2014

Re-revised received:
01 January 2015

Accepted:
07 February 2015

Key words

Functional group diversity, Grassland, Nutritive value, Stocking rate

Introduction

Overgrazing in grassland leads to many negative environmental effects including soil erosion, desertification, rampant of rodent damage and reduction of biodiversity (Deng *et al.*, 2014). It is necessary to prevent environmental degradation in pasture and perform many management practices such as controlling stocking rate. Lack of attention for monitoring biodiversity under stocking rates has been a major cause of environmental deterioration in rangeland. In recent years, many studies have evaluated the relationship between ecosystem functioning and functional group diversity. An increasing number of research have addressed that diversity of plant functional group is more crucial than plant species diversity to ecosystem functioning. By increasing resource use, greater functional group diversity plays a key role in providing high community stability and productivity in rangeland.

In variable grazing environments, many factors affect the choices made by browsing herbivores such as nutrition quality of food, flavor, plant secondary metabolite and spatial distribution of plant species (Bedoya-Pérez *et al.*, 2014; Lande *et al.*, 2014), in which nutrients play a significant role for diet selection of herbivores (Eby *et al.*, 2014). Herbivores meet nutrient requirements from diverse plant species during foraging. It is important for herbivores to keep dietary diversity as a result of detoxification limitation and nutritional balance especially in species rich rangeland environments. The nutrient balance hypothesis considers that diversity of diet provides livestock various balanced nutritional content, so increasing the quantity of different high nutrient functional groups in rangeland would be the best way to meet energy and nutrient requirements.

On comparing diet composition of herbivores between plant functional groups in seasonal environments it was found that plant species selection was connected with plant quality and available biomass (Di Stefano and Newell, 2008; Zweifel-Schielly *et al.*, 2012). High quality grass has high nitrogen (N), high water-soluble carbohydrate (WSC), low neutral detergent fiber (NDF) and low acid detergent fiber (ADF). In such grazing systems, plant functional group diversity could affect livestock's ability to be selective thereby influencing the forage nutrients. And in turn, the effects of forage nutrients on diet selection have the capability to impact plant functional group diversity. However, previous studies, including most conducted in alpine meadow, so far have ignored the relationship between functional group diversity and forage nutrients. In order to understand the complicated net of livestock-environment interaction between biodiversity and forage nutrition in regional rangeland and seek the most suitable stocking rate in this system, the effect of deer grazing in Sunan alpine meadow was investigated in the present study.

Materials and Methods

Study site : The experiment was carried out on alpine meadow in the middle of Qilian Mountain, which is located on the edge of eastern region of Tibetan Plateau in China (38°80'N, 99°60'E) at an altitude of 2700 m. The site called Sunan Deer Farm was established in 1958 having largest number of wapiti (red deer) (*Cexvas elaphus kansuensis*) in China. The average annual daily temperature was 3.6°C. The highest and lowest annual month temperature was noted in July and January ranging from 15.9°C to -10.4°C. The multi-year average precipitation was 253.0 mm and 86.4% precipitation occurred between May to September. The maximum and minimum rainfall occurred in July and December ranging from 60.6mm to 1.3mm. The main plant species included of *Stipa breviflora, Leymus secalinus, Achnatherum inebrians, Artemisia frigida*, *Agropyron cristatum*, *Convolvulus ammannii* and some other species.

Stocking rate : Stocking rate was calculated by multiplying the total number of animals (animal unit equivalent) by total grazing time (month) in a unit area. Animal unit refers to the consumption of standard quantity feed by a 1000 pound cow or a lactating cow with a six month calf. The following formulas were used to calculate stocking rates at every 300 m, from 0 m of farm door to 1500 m distance.

$$L_i = \sum_{i=1}^{n} P\,(N \geq 1) \quad \text{(Eq. 1)}$$

$$L' = \frac{\sum_{i=1}^{6} L'}{6} \quad \text{(Eq. 2)}$$

$$ST_j = ST \times \frac{L_j}{6L'} \quad \text{(Eq. 3)}$$

Where, L_i is frequency of animal appeared in i paddock. L is average frequency of livestock in each paddock. "P"=head×time. ST_j represents stocking rate (animal month unit) of the whole grazing land. ST_j is the stocking rate of j paddock. From these formulas stocking rates corresponding to distance to entrance of rangeland was calculated. 0 m, 300 m, 600 m, 900 m, 1200 m and 1500 m to entrance representing the stocking rate was 6.9, 4.9, 3.5, 2.5, 1.5 and 1 animal month unit (AMU) ha^{-1} respectively in 1999 and 7.3, 5.1, 3.7, 2.6, 1.5 and 1.1 AMU ha^{-1} respectively in 2012.

Plant functional group diversity : The plant community in grazing pasture was classified into functional groups representing their characteristics based on 5 kinds of criteria: nutrition type, nitrogen fixation type, life form type, family type and tillering type (Grime, 1979) (Table 1). The value of plant functional group diversity was calculated by Shannon-Weiner index. Shannon-Wiener diversity index (H) of each functional group was calculated by the following formula : $H = -\sum P_i \ln(P_i)$ (Eq. 4), where, P_i is the importance value of i functional group.

Determination of nitrogen, water-soluble carbohydrate, neutral detergent fiber and acid detergent fiber : The herbaceous vegetation in each stocking rate was clipped at ground level using hand-scissors in six random 1m^2 quadrats in July 1999 and 2012. The plant samples were dried at 65°C for 72 hr and then ground to pass through a 1mm pore size mesh. Subsamples were submitted for nutrient analyses of N, WSC, NDF and ADF. Herbage nitrogen content was determined by phenol sulphuric acid method (Dubois *et al.*, 1956). WSC was determined by anthrone-based method (Yemm and Willis, 1954).

Table 1 : Plant functional group and definition of attribute classes

Type	Functional group diversity	Components	Meaning	References
I	Nutrition functional diversity	High quality, medium quality, low quality, non-ingestion	Difference of crude protein and crude fiber	(Ren, 1998)
II	Nitrogen fixation diversity	Grasses, legumes, forbs, sedges	Growth form and N-fixing capacity	(Leishman and Westoby, 1992)
III	Life type diversity	Annual, biennial, perennial	Longevity of lifeform	(McIntyre and Lavorel, 2001)
IV	Family compositional diversity	According to family of plant, 12 families in winter pasture	Taxonomic of plant families in Sunan herbaceous communities.	(Hadar *et al.,* 1999)
V	Tillering type diversity	Rhizome type, bunched type, thick bunched type, Rhizome-bunched type, root-tillering type, prostrate type, bulb type	Root system: root propagation by root crown and root distribution	(Grime, 2001)

NDF and ADF were analyzed by ANKOM 200 Fiber Analyzer (Ankom Technology, USA).

Data analysis : All analyses were conducted with SPSS software (SPSS 17.0 for Windows, Chicago, IL, USA), including Oneway analysis of variance (ANOVA), LSD test and linear regression analysis. Significant differences for all statistical tests were evaluated at the level of $P \leq 0.05$.

Results and Discussion

Oneway analysis of variance showed that abundance of functional group diversity indices were significantly influenced by stocking rates ($p<0.05$).There was a higher functional group diversity in 2.5 AMU ha^{-1} in 1999 and 2.6 AMU ha^{-1} in 2012 for all the functional group diversity as compared with other stocking rates and the trend was found to increase from 1 to 2.5 AMU ha^{-1} and then decreased from 2.5 to 7.1 AMU ha^{-1} (Table 2, 3). Tillering type diversity index was the highest functional group diversity and life type diversity index was the lowest in both the years. Tillering type diversity was 144.1% and 178.3% higher than life type diversity in 1999 and 2012, respectively, under medium stocking rate (2.5 AMU ha^{-1} in 1999 and 2.6 AMU ha^{-1} in 2012).

Moderate grazing intensity enhanced or at least maintained plant diversity because it had created an intermediate level of disturbance (Scimone *et al.*, 2007). Overgrazing leads to ecological destabilization in rangeland environments, which allows invasive species to become established, but moderate level of grazing can maintain diversity of ecosystem over long period of time (Fleischer, 1994; Wu *et al.*, 2011). A key management variable is stocking rate affecting the composition and structure of pastures. When grazing livestock are controlled at low stocking rates in grassland environments, biodiversity increases but high level of stocking rates can significantly decrease plant diversity (Dumont *et al.*, 2009; Deng *et al.*, 2014). It appears that both high and low stocking rates would reduce the biodiversity of permanent grassland, as under these two management strategies small number of plant species were able to grow.

Communities form certain edible forage ratio, nutritional components, plant height type, vegetation characteristics, tillering type and life form type under different grazing pressure, representing more diversity in plant community or more evenness in different functional type allocation. Significant difference in functional group diversity can be related to difference in dietary choice, more probably to maximize energy supply. Grassland community may have sustainable development when all types of functional group diversity values are modified by medium grazing intensity, because there are more kinds of high quality forage in dominant but less poisonous weeds.

Oneway analysis of variance showed that stocking rates had significant effect on N, WSC, NDF and ADF content of community ($p<0.05$). Medium stocking rate (2.5 AMU ha^{-1} in 1999 and 2.6 AMU ha^{-1} in 2012) had highest N and WSC content and lowest NDF and ADF content (Table 4, 5). N and WSC content were 17.6% and 13.1% higher in moderate stocking rate (2.5 AMU ha^{-1}) than 1.5 AMU ha^{-1} in 1999 and were 18.3% and 12.2% higher in moderate stocking rate (2.6 AMU ha^{-1}) than 1.5 AMU ha^{-1}

Table 2 : Effect of stocking rate on functional group diversity in 1999

Stocking rate (AMU ha^{-1})	Nutrition functional diversity (H)	Nitrogen fixation diversity (H)	Life type diversity (H)	Family compositional diversity (H)	Tillering type diversity (H)
1	0.949±0.013^{d}	0.667±0.01^{d}	0.297±0.014^{c}	1.041±0.015^{d}	1.145±0.01^{d}
1.5	1.054±0.011^{c}	0.732±0.012^{c}	0.477±0.013^{b}	1.248±0.010^{c}	1.392±0.012^{b}
2.5	1.264±0.013^{a}	0.925±0.014^{a}	0.636±0.015^{a}	1.444±0.012^{a}	1.552±0.012^{a}
3.5	1.161±0.014^{b}	0.807±0.011^{b}	0.463±0.012^{b}	1.355±0.010^{b}	1.361±0.012^{b}
4.9	1.034±0.016^{c}	0.742±0.014^{c}	0.445±0.013^{b}	1.23±0.011^{c}	1.287±0.012^{c}
6.9	0.941±0.017^{d}	0.658±0.012^{d}	0.264±0.012^{c}	1.054±0.013^{d}	1.155±0.011^{d}

Data followed by different letter in a column are significantly different at $P \leq 0.05$, using Fisher's LSD test

Table 3 : Effect of stocking rate on functional group diversity in 2012

Stocking rate (AMU ha^{-1})	Nutrition functional diversity (H)	Nitrogen fixation diversity (H)	Life type diversity (H)	Family compositional diversity (H)	Tillering type diversity (H)
1.1	1.136±0.013^{d}	0.751±0.013^{c}	0.359±0.017^{c}	1.253±0.015^{d}	1.545±0.012^{c}
1.5	1.271±0.018^{c}	0.85±0.017^{b}	0.556±0.017^{b}	1.451±0.016^{b}	1.652±0.011^{b}
2.6	1.441±0.012^{a}	1.03±0.013^{a}	0.659±0.014^{a}	1.649±0.014^{a}	1.843±0.012^{a}
3.7	1.352±0.013^{b}	0.887±0.017^{b}	0.548±0.013^{b}	1.49±0.013^{b}	1.714±0.011^{b}
5.1	1.241±0.018^{c}	0.802±0.016^{b}	0.522±0.014^{b}	1.36±0.014^{c}	1.563±0.014^{c}
7.3	1.147±0.012^{d}	0.756±0.014^{c}	0.364±0.014^{c}	1.25±0.017^{d}	1.465±0.011^{c}

Table 4 : N, WSC, NDF and ADF content of plant community under 6 stocking rates in 1999

Stocking rate (AMU ha^{-1})	N (g kg^{-1})	WSC (g kg^{-1})	NDF (g kg^{-1})	ADF (g kg^{-1})
1	18.5±0.1^{c}	158.3±1.4^{b}	600.5±5.3^{a}	408.9±4.6^{a}
1.5	18.1±0.5^{c}	152.7±2.5^{b}	595.5±4.1^{a}	399.7±5.2^{a}
2.5	21.3±0.3^{a}	172.7±2.1^{a}	504.5±4.9^{c}	320.1±4.9^{c}
3.5	20.1±0.3^{b}	160.0±2.3^{b}	542.9±4.2^{b}	378.6±5.0^{b}
4.9	19.9±0.1^{b}	153.7±3.5^{b}	557.2±4.2^{b}	380.7±5.3^{b}
6.9	18.7±0.6^{c}	155.7±1.1^{b}	552.6±4.9^{b}	378.6±4.6^{b}

Data followed by different letter in a column are significantly different at $P \leq 0.05$ using Fisher's LSD test

Table 5 : N, WSC, NDF and ADF content of plant community under 6 stocking rates in 2012

Stocking rate (AMU ha^{-1})	N (g kg^{-1})	WSC (g kg^{-1})	NDF (g kg^{-1})	ADF (g kg^{-1})
1.1	18.5±0.1^{c}	159.6±1.4^{b}	621.3±4.8^{a}	418.2±5.4^{a}
1.5	18.0±0.5^{c}	152.9±2.5^{b}	592.2±4.9^{a}	352.4±4.5^{c}
2.6	21.3±0.3^{a}	171.5±2.1^{a}	511.4±5.9^{c}	303.2±6.0^{d}
3.7	20.1±0.3^{b}	159.7±2.3^{b}	561.9±5.2^{b}	354.6±5.3^{c}
5.1	18.4±0.1^{c}	154.7±3.5^{b}	567.5±6.9^{b}	372.4±5.3^{b}
7.3	18.3±0.6^{c}	157.4±1.1^{b}	558.8±6.2^{b}	342.4±4.9^{c}

Data followed by different letter in a column are significantly different at $P \leq 0.05$ using Fisher's LSD test

in 2012. NDF and ADF contents were 16% and 21.7% lower in moderate stocking rate (2.5 AMU ha^{-1}) than 1 AMU ha^{-1} in 1999 and were 17.7% and 27.5% lower in moderate stocking rate (2.6 AMU ha^{-1}) than 1.1 AMU ha^{-1} in 2012.

Stocking rate may influence the available forage nutritional value, forcing ruminants to change diet selection and then modify the biodiversity in grassland. Mineral nutrients are crucial aspect of forage quality for herbivores, especially nitrogen. Nitrogen content of forage is usually enhanced by defoliation and this is depended on stocking rates (Baron *et al.*, 2002). Milchunas *et al.* (1995) reported that under medium stocking rate, grazing significantly increased percentage of nitrogen in forage. Optimizing quantity of nitrogen content can be best achieved with medium grazing rather than light or severe grazing.

There are many advisable reasons for higher herbage WSC concentration in grazed herbage, such as increased preference in sheep and cattle and improvement of animal intake (Lee *et al.*, 2002). A less severe grazing (leaving residual leaf) would result in faster recovery of rangeland swards, an important factor during cold season when feed is scarce. Increasing WSC content but decreasing NDF and ADF content has been proved as a critical method to improve nitrogen utilization of forages. Nutrients in forage with higher level of WSC content but lower NDF and ADF content may lead to higher dry matter digestibility. WSCs were significantly related to regrowth so high stocking rates eliminate too much water-soluble carbohydrate storage and inhibit its regrowth (Fulkerson and Donaghy, 2001). Plant community of the study area had higher WSC but lower NDF and ADF content under medium stocking rate so it means that pasture quality was improved in medium grazing treatment.

Consistent trends were apparent when the community forage quality data was plotted against functional group diversity (Fig. 1, 2). When comparisons were made across all functional group diversity, all functional group diversity indices were positively related to community N and WSC content (Fig. 1a, b; 2a, b) but negative relationship existed between all functional group diversity indices and NDF and ADF content of community (Fig. 1c, d; 2c, d).

Several plant functional groups have an assemblage with similar photosynthetic strategy or foliar nutrient content, possibly connected to biodiversity, which in turn influence the stability of rangeland environment. Exploitation of stocking rates on the effects of functional group diversity is not only beneficial for biodiversity targets but is also a means of maintaining individual livestock performance by enhancing nutritive value of forage. To some degree, use of functional group diversity may represent forage quality in this experiment, so that the results may be extrapolated more easily for management of ranch and optimizing with different grazing intensities. Several studies have concentrated on the impact of diversity on the functioning of ecosystem such as nutrient retention and net primary productivity but few studies have focused on the relationship between forage nutrient content and functional group diversity (Loreau *et al.*, 2001). The result of the present study supports the hypothesis that grazing may facilitate nutrition flow through animal-grassland system to some extent. So the change in functional group diversity of grassland under grazing may prove to be a possible basic indicator representing energy flow and forecasting forage quality.

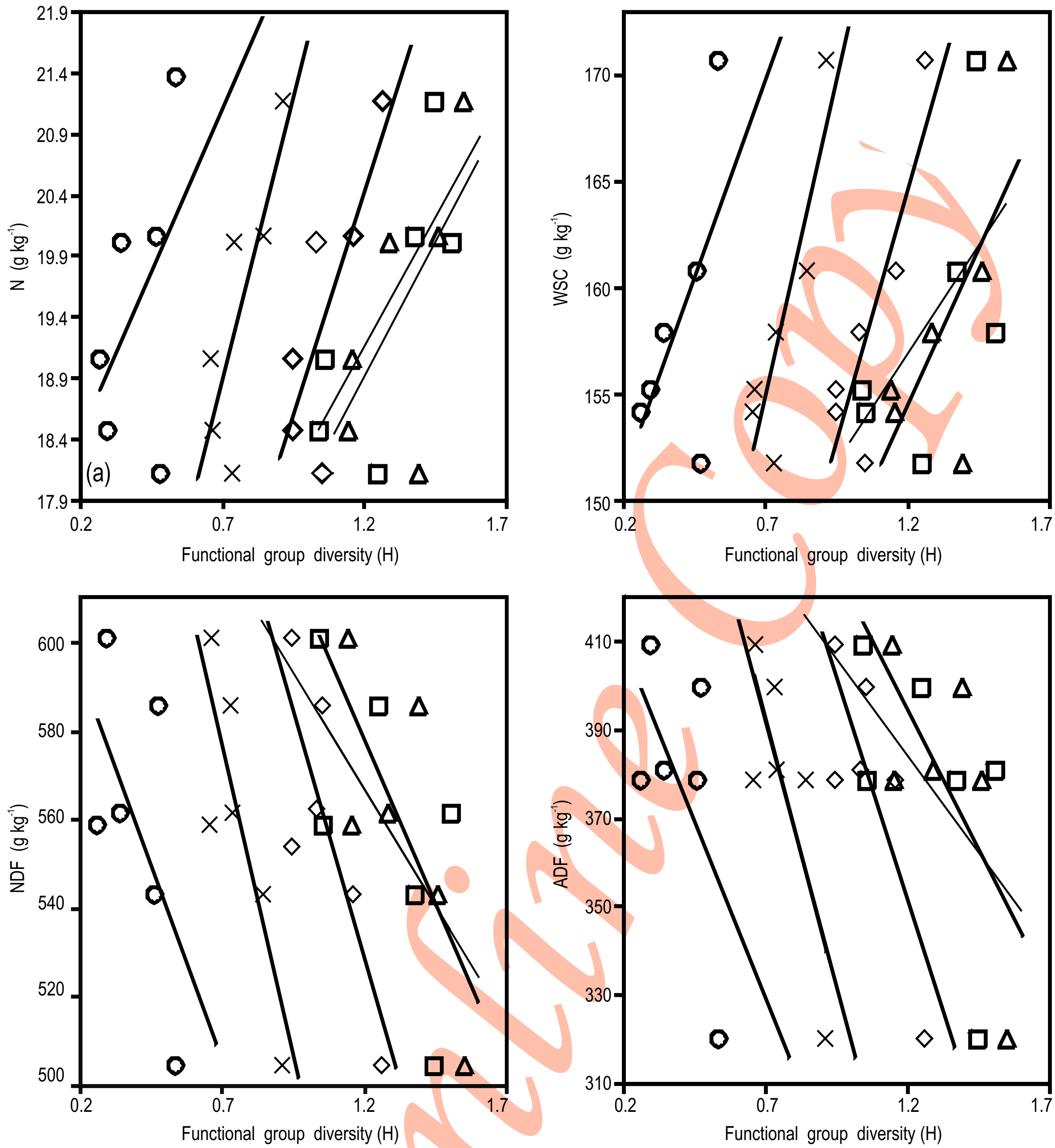

Fig. 1 : Relationship of N (a), WSC (b), NDF (c) and ADF (d) content with functional group diversity in 1999. ○ : life type diversity; ×: nitrogen fixation diversity; ◇: nutrition functional diversity; □: family compositional diversity; △: tillering type diversity

In conclusion, the present study confirmed that medium stocking rate had an impact of highest functional group diversity in Sunan alpine meadow. Grazing experiments showed that N and WSC peaked but NDF and ADF minimized at moderate grazing level. Heavy or light grazing did lead to decline in N and WSC of pasture. Thus, it is possible that continued high or very low stocking rates may potentially have a serious negative impact on rangeland environment. Stocking rates of 2.5 and 2.6 AMU ha^{-1} seemed to be sustainable for maintaining the health of Sunan grassland and to resolve the conflicts between grassland resources use and environmental conservation.

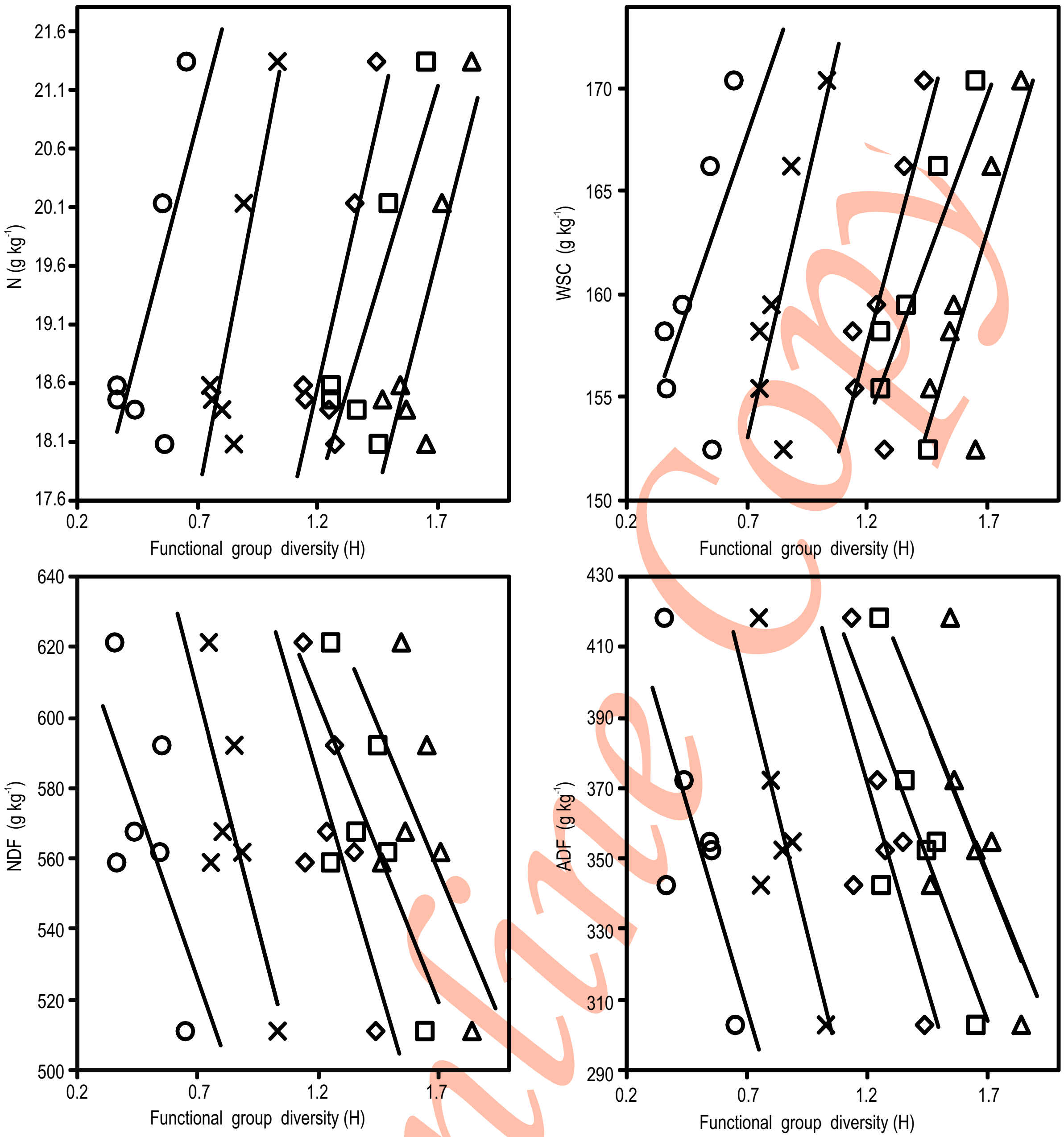

Fig. 2 : Relationship of N (a), WSC (b), NDF (c) and ADF (d) content with functional group diversity in 2012. ○: life type diversity; ×: nitrogen fixation diversity; ◇: nutrition functional diversity; □: family compositional diversity; △: tillering type diversity

Acknowledgments

This research was supported by the National Basic Research Program of China (2014CB138706), Program for Changjiang Scholars and Innovative Research Team in University (IRT13019) and National Natural Science Foundation of China (31172249).

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