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Effects of fertilization, burning, and grazing on plant community in the long-term fenced grasslands

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ABSTRACT

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Fencing is the common management practice to restore degraded grasslands. However, long-term fencing decreases grassland productivity and species diversity. The study was therefore conducted as a three-year (2011–2013) experiment with a randomized complete block in a grassland fenced for 20 years in the Loess Plateau of China, and the effects of fertilization, burning and grazing on aboveground biomass, species and functional group composition, species and some functional group diversity were analysed. Our results showed that the functional group of perennial bunchgrasses dominated the grassland regardless of management practices. However, burning altered species composition (i.e. the unpalatable species, *Artemisia sacrorum*) more significantly than fertilization or grazing, and surprisingly, nearly quadrupled the functional group of shrubs and semi-shrubs. Fertilization had a positive effect on the aboveground biomass (44.0%), while clearly reducing species diversity (21.9%). Grazing decreased aboveground biomass, but increased species diversity by 15.9%. This study indicated that fertilization influenced plant community through its impact on aboveground biomass, while burning changed plant community by altering dominant species. Thus, it was concluded that fertilizer could further improve community biomass while burning reduced the edibility of grass. Grazing could be carried out to enhance the biodiversity in the long-term fenced grasslands.

Keywords: management measures; community biomass; plant diversity; community structure; resource competition

Fencing is widely considered as the most common and effective way to restore grassland degradation throughout the world (Cheng et al. 2016). However, long-term fencing could inhibit grassland renewal and decrease species diversity and productivity (Jing et al. 2013, Cheng et al. 2014). Therefore, it is vital to take measures in long-term fenced grassland to optimize ecosystem functions.

Previous studies have shown that fertilization, grazing, and burning are common management practices affecting plant community (Alhamad et al. 2012, Veach et al. 2014). Although fertiliza-

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tion caused significant diversification of plant communities (Hejcman et al. 2007), it is generally accepted that fertilization increases productivity of grasslands but decreases species diversity (Chalcraft et al. 2008, Niu et al. 2014, Li et al. 2015). Several mechanisms involving competitive exclusion for resources, especially for light and soil water and nutrients, have been proposed to explain plant species loss (Borer et al. 2014, Li et al. 2015). Burning is often found to affect species richness positively, because the litter removal by burning enhances the availability of light for some competitive species (Alhamad et al. 2012). Although, very frequent burning can lead to dominance by a few species adapted to fire (Collins and Calabrese 2012, Scheiter et al. 2012). Grazing can affect grassland productivity and biodiversity via selective removal of certain species by grazers and the indirect impacts of greater light penetration and changes in soil resource availability and heterogeneity (Ritchie et al. 1998, Borer et al. 2014).

Taken as a whole, the effects of fertilization, burning or grazing on grassland ecosystems have been often initiated at different points in time, but less is known about how the impacts of management practices relate to each other, particularly in long-term fenced grasslands. Therefore, a three-year (2011–2013) experiment was conducted with a randomized complete block in a grassland fenced for 20 years on the Loess Plateau to analyse the effects of fertilization, burning and grazing on species and functional group composition, species and functional group diversity, and plant biomass. The object of this study was to identify managerial practices and how they affect plant community and to make management recommendations in the long-term fenced grasslands to optimize the economic and ecosystem services.

MATERIAL AND METHODS

Establishment of the sampling plots. The grasslands of the Yunwu Mountain National Natural Reserve, located on the Loess Plateau of China (106°21'–106°27'E, 36°10'–36°17'N), has been protected as a long-term monitoring site since 1982. The study region has a semiarid climate, with the mean annual temperature of 5°C and daily average maximum and minimum temperatures occurring in July (24°C) and January (–14°C), respectively. The mean annual precipitation was 425 mm, 60–75% of which falls from July to September. The annual evaporation ranges from 1330 mm to 1640 mm, with the frost-free period beginning in mid-April and ending in late September. The soil in the study area is a montane grey-cinnamon soil classified as a Calci-Orthic Aridisol according to the Chinese taxonomic system, which is equivalent to a HaplicCalcisol in the FAO/UNESCO system (Qiu et al. 2013).

Vegetative ecological characteristics and biomass reached their peak values approximately 20 years after fencing, then decreased with time of restoration (Jing et al. 2013). Therefore, we conducted our studies in grasslands that had been fenced for 20 years. The experimental design was a randomized complete block with three treatments (grazing, burning, and fertilization) and five replicates. These treatments were independent to each other. Plot size was 10 m × 10 m, with each plot separated by a 2 m walkway. The treatments were applied to the same plot areas for three successive years (2011, 2012, and 2013).

For the fertilized treatment, urea fertilizers were manually applied to the experimental plots at the level of 100 kg N/ha/year at the end of May in the early growing period every year, following Cheng et al. (1997) and Jia et al. (2013). Burning was carried out in early or late April each year before the start of growing season, depending on the time of snow melt. In order to simulate a natural wildfire, burning was allowed to take its natural course until it extinguished itself. Burning lasted on average twenty minutes per plot. Each plot was fenced with wire mesh and grazed in the middle ten days of June, July and August, respectively. Due to a small area, two sheep were driven to the plots for 30 min every day of grazing. Following previous studies (Chen et al. 2012, Jing et al. 2013), grazing in our study belonged to moderate grazing. All the treatments were carried out on the long-term fenced grasslands, so fenced grasslands could be used as the control treatment plots.

Aboveground vegetation investigation. Vegetation surveys were carried out in the early September each year when biomass reached its peak. Three 50 cm × 50 cm quadrats in each plot were randomly chosen each year to investigate plant communities, with a minimum distance of 2 m between quadrats. Thus fifteen quadrats were investigated for each treatment in each year. In each quadrat, species, height, coverage and

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Table 1. *P*-values of repeated analysis of variance for aboveground biomass (ABM), litter biomass, and species diversity using management practice, year, and all interactions as fixed-effects

Term	ABM	Litter biomass	Species diversity	SD of PB	SD of SS
Management practice (M)	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Year (Y)	0.283	0.976	0.100	0.727	0.175
M × Y	0.042	0.125	0.744	0.627	0.242

SD – species diversity; PB – perennial bunchgrasses; SS – shrubs and semi-shrubs

abundance for each species were investigated, using the methods shown in Jing et al. (2013) and Niu et al. (2014). Aboveground green parts were sorted and harvested by species. Community litter was also collected after removing the soil, gravel, and sundries. All the aboveground parts and litter samples were brought to dry at 65°C to a constant weight. Total aboveground biomass (g/m^2) was calculated by summing all dried biomass of harvested individuals within a quadrat. In order to discuss the functional group composition, species were classified primarily into perennial rhizome grass (PR); perennial bunchgrasses (PB); perennial forbs (PF); shrubs and semi-shrubs (SS), and annuals and biennials (AB) (Bai et al. 2004). Plant nomenclature and assignment to families both followed 'Flora of China'.

Index calculation and data analyses. Importance value (IV) was used to indicate dominant species and calculate the species diversity index:

$$IV = (RH + RC + RA + RF)/4$$

Where: RH – relative height; RC – relative coverage; RA – relative abundance; RF – relative frequency. Dominant species, as defined by the IV criterion, made up >60% of the importance value (Wang 2007). In addition, Shannon-Wiener index was chosen to describe species diversity as follows:

$$H' = -\sum_{i=1}^{S} P_i \ln P_i$$

Where: S – total species number of community, and P_i – relative aboveground biomass of species i.

Repeated measures ANOVA with SAS version 8.0 (SAS Institute Inc., USA) were performed to examine the effects of different management practices on plant community.

RESULTS AND DISCUSSION

Repeated measures ANOVA of aboveground and litter biomass using year, management practices and all interactions as fixed-factors, showed that year had no significant effects on aboveground and litter biomass while management practices had significant effects (Table 1). The average of three years demonstrated that fertilization and burning increased aboveground biomass by 44.0% and 22.3%, respectively, when compared to the fenced grasslands (Figure 1). Grazing decreased aboveground biomass by 32.4%, through the consumption of herbage by the livestock. Burning sharply reduced litter when compared to fenced grasslands; grazed grasslands were intermediate with about 1/3 as much litter as fenced grasslands (Figure 1).

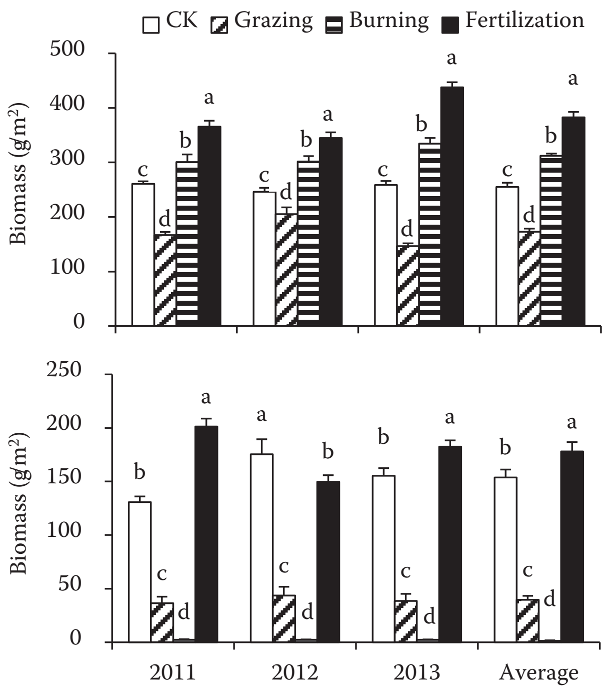

Figure 1. The aboveground biomass and litter biomass in the typical grasslands with different management practices. Different letters in a line mean a significant difference among management practice at P = 0.05. Error bars are the standard error of the mean

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Table 2. The important values of main species in the typical grasslands with different management practices. (The species in all grasslands < 5% important values were not shown)

Species	Functional groups	Important values (%)			
		CK	grazing	burning	fertilization
HetAlt	PF	13.49	2.89	4.01	0.26
StiBun	PB	9.84	9.57	12.99	14.69
AgrCri	PR	7.58	10.91	7.76	3.94
StiGra	PB	14.57	3.18	12.25	12.64
ArtGir	SS	2.62	4.17	8.22	5.5
MedRut	PR	7.05	5.35	2.91	8.37
PoaSub	PR	0	13.27	0	0.36
CarAri	PR	11.53	4.49	11.55	15.4
ArtSac	SS	6.07	8.86	15.12	7.55
PotAca	PF	1.74	10.6	0.06	0.41
PoaSph	PB	12.93	0	8.84	6.64

HetAlt – Heteropappus altaicus; *StiBun – Stipa bungeana*; *AgrCri – Agropyron cristatum*; *StiGra – Stipa grandis*; *ArtGir – Artemisia giraldii*; *MedRut – Medicago ruthenica*; *PoaSub – Poa subfastigiate*; *CarAri – Carex aridula*; *ArtSac – Artemisia sacrorum*; *PotAca – Potentilla acaulis*; *PoaSph – Poa sphondylodes.* PR –perennial rhizome grass; PB – perennial bunchgrasses; PF – perennial forbs; SS – shrubs and semi-shrubs

Management practices altered the species composition significantly, as shown by differences in the importance values of the dominant species (Table 2). Grazing modified plant community structure through selective herbivory, livestock trampling, and changes in litter quality. In our study, after being grazed, the dominant species were changed to *Poa subfastigiata*, *Agropyron cristatum*, and *Potentilla acaulis*. *Poa sphondylodes* disappeared from the grazed plots after three years. In burned grassland, *Artemisia sacrorum*, from the sub-shrub group, grew vigorously and became the dominant species. With fertilization, the importance values of *Carex aridula*, *Stipa bungeana* and *Stipa grandis* increased substantially and became dominant species while the growth of *Heteropappus altaicus* was reduced. In addition, functional group composition varied with year and management practice (Figure 2), although perennial bunchgrasses contributed the most in all grasslands and annuals and biennials were usually the least abundant. Due to the edibility of perennial bunchgrasses to herbivores, the functional group of perennial bunchgrasses was lower for grazed grasslands than the other treatments. The change in shrub dominance was one of the most dramatic effects of burning and became stronger as the experiment progressed, which was similar to the result of Veach et al. (2014) that shrub species could persist and still increased and expanded even in frequently burned areas. Rapid growth of shrub and semi-shrub species, especially the unpalatable shrub species (*Artemisia sacrorum*) (Table 2), also indicated that the forage production of the ecosystem was reduced after fire. What is yet unclear is whether this is a general result for grasslands, or it occurred because shrubs had been allowed to reach a fire resistant time over the 20 years of fencing.

Consistent with previous studies (Rajaniemi 2002, Gilliam 2006, Li et al. 2015), fertilization declined species diversity by 16.8%, compared to the control treatment (Figure 3a). However, perennial bunchgrasses (the dominant functional group) increased in diversity with fertilization (Figure 3b). This might reflect that perennial bunchgrasses have high maximum growth rates and more extensive and efficiency roots systems for nitrogen (N) uptake than shrubs and semi-shrubs (Wright et al. 2004), allowing them to capitalize on the added nitrogen and grow rapidly. Although fire could potentially make conditions more favourable for

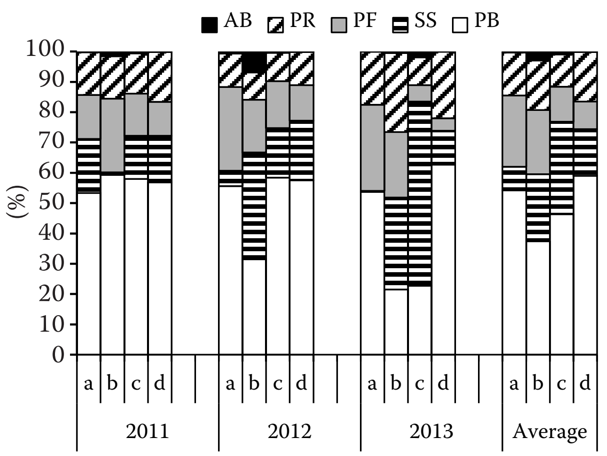

Figure 2. The biomass ratios of different functional groups in the typical grasslands with different management practices. PR – perennial rhizome grass; PB – perennial bunchgrasses; PF – perennial forbs; SS – shrubs and semi-shrubs; AB – annuals and biennials

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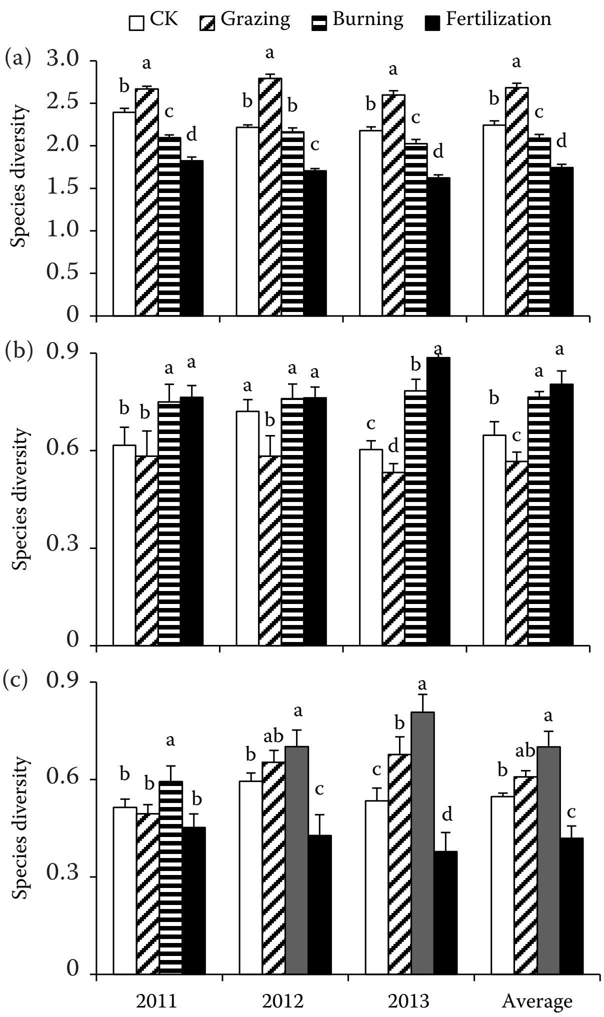

Figure 3. The species diversity of all the functional groups/PB/SS in the typical grasslands with different management practices. Different letters in a line mean a significant difference among management practices at $P = 0.05$. PB – perennial bunchgrasses; SS – shrubs and semi-shrubs

minor or less competitive species through the removal of accumulated litter and increased species diversity (Boughton et al. 2013), very frequent fire also reduced species diversity if just a few large grasses came to dominate the community (Collins and Calabrese 2012). Our study showed that burning decreased the species diversity by 7.4%; there are two possible explanations (Figure 3a). Firstly, fire probably reduced soil moisture (Busch and Smith 1993), which might hinder plant growth in semiarid grassland. Secondly, *Artemisia sacrorum*, as the dominant species in burned grasslands (Table 2), could be capable of secreting allelopathic compounds that inhibited the growth of other species (Wang et al. 2011) and of competing for light and perhaps soil resources better than other species (Ratajczak et al. 2012). With the increase of functional group of shrubs and semi-shrubs, the Shannon-Wiener diversity index of shrubs and semi-shrubs increased by 25.7% in burned grasslands (Figure 3c). In addition, grazing reduced resource competition, which provided more space for less competitive species and thus significantly increased species diversity by 15.9% (Figure 3a).

In conclusion, fertilization, burning, and grazing had diverse effects on plant community structure of grasslands. These comparisons reveal a series of trade-offs and some recommendations for meeting specific management goals. Fertilization increased aboveground biomass more than burning did, while burning improved the ratio of shrubs and semi-shrubs more significantly than fertilization. This could demonstrate different pathways how management practices alter biodiversity: fertilization influenced plant community structure through its impact on productivity, while burning changed plant community structure by altering dominant species. The significant increase of unpalatable *Artemisia sacrorum* and shrub and semi-shrub in burned grasslands indicated that burning might not be a suitable management practice taken to increase productivity of grasses and forage availability. Although removal of herbage via grazing naturally led to a reduction of aboveground biomass, grazing in the long-term fenced grasslands enhanced biodiversity. Thus, this study could support grassland managers in decisions to optimize the ecosystem function of long-term fenced grasslands.

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REFERENCES

Alhamad M.N., Alrababah M.A., Gharaibeh M.A. (2012): Impact of burning and fertilization on dry Mediterranean grassland productivity and diversity. Acta Oecologica, 40: 19–26.

Bai Y.F., Han X.G., Wu J.G., Chen Z.Z., Li L.H. (2004): Ecosystem stability and compensatory effects in the Inner Mongolia grassland. Nature, 431: 181–184.

doi: 10.17221/64/2017-PSE

Boughton E.H., Bohlen P.J., Steele C. (2013): Season of fire and nutrient enrichment affect plant community dynamics in subtropical semi-natural grasslands released from agriculture. Biological Conservation, 158: 239–247.

Borer E.T., Seabloom E.W., Gruner D.S., Harpole W.S., Hillebrand H., Lind E.M., Adler P.B., Alberti J., Anderson T.M., Bakker J.D., Biederman L., Blumenthal D., Brown C.S., Brudvig L.A., Buckley Y.M., Cadotte M., Chu C.J., Cleland E.E., Crawley M.J., Daleo P., Damschen E.I., Davies K.F., DeCrappeo N.M., Du G.Z., Firn J., Hautier Y., Heckmann R.W., Hector A., HilleRisLambers J., Iribarne O., Klein J.A., Knops J.M.H., La Pierre K.J., Leakey A.D.B., Li W., MacDougali A.S., McCulley R.L., Melbourne B.A., Mitchell C.E., Moore J.L., Mortensen B., O´Halloran L., Orrock J.L., Pascual J., Prober S.M., Pyke D.A., Risch A.C., Schuetz M., Smith M.D., Stevens C.J., Sullivan L.L., Williams R.J., Wragg P.D., Wright J.P., Yang L.H. (2014): Herbivores and nutrients control grassland plant diversity via light limitation. Nature, 508: 517–520.

Busch D.E., Smith S.D. (1993): Effects of fire on water and salinity relations of riparian woody taxa. Oecologia, 94: 186–194.

Chalcraft D.R., Cox S.B., Clark C., Cleland E.E., Suding K.N., Weiher E., Pennington D. (2008): Scale-dependent responses of plant biodiversity to nitrogen enrichment. Ecology, 89: 2165–2171.

Chen F.R., Cheng J.M., Liu W., Li Y., Ma Z.R., Wei L. (2012): Effects of different disturbances on soil physical and chemical properties in the typical grassland of Loess region. Journal of Soil and Water Conservation, 26: 105–110. (In Chinese)

Cheng J.M., Jia H.Y., Peng X.L. (1997): Biomass structure of fertilized grassland communities. Acta Pratacultural Science, 6: 22–27.

Cheng J.M., Jing Z.B., Jin J.W., Gao Y. (2014): Restoration and utilization mechanism of degraded grassland in the semi-arid region of Loess Plateau. Scientia Sinica Vitae, 44: 267–279. (In Chinese)

Cheng J.M., Jing G.H., Wei L., Jing Z.B. (2016): Long-term grazing exclusion effects on vegetation characteristics, soil properties and bacterial communities in the semi-arid grasslands of China. Ecological Engineering, 97: 170–178.

Collins S.L., Calabrese L.B. (2012): Effects of fire, grazing and topographic variation on vegetation structure in tallgrass prairie. Journal of Vegetation Science, 23: 563–575.

Gilliam F.S. (2006): Response of the herbaceous layer of forest ecosystems to excess nitrogen deposition. Journal of Ecology, 94: 1176–1191.

Hejcman M., Klaudisová M., Schellberg J., Honsová D. (2007): The Rengen Grassland Experiment: Plant species composition after 64 years of fertilizer application. Agriculture, Ecosystems and Environment, 122: 259–266.

Jia X.X., Shao M., Wei X.R. (2013): Soil CO_2 efflux in response to the addition of water and fertilizer in temperate semiarid grassland in northern China. Plant and Soil, 373: 125–141.

Jing Z.B., Cheng J.M., Chen A. (2013): Assessment of vegetative ecological characteristics and the succession process during three decades of grazing exclusion in a continental steppe grassland. Ecological Engineering, 57: 162–169.

Li W., Cheng J.-M., Yu K.-L., Epstein H.E., Du G.-Z. (2015): Niche and neutral processes together determine diversity Loss in response to fertilization in an alpine meadow community. PloS one 10, e0134560.

Niu K.C., Choler P., de Bello F., Mirotchnick N., Du G.Z., Sun S.C. (2014): Fertilization decreases species diversity but increases functional diversity: A three-year experiment in a Tibetan alpine meadow. Agriculture, Ecosystems and Environment, 182: 106–112.

Qiu L., Wei X., Zhang X., Cheng J. (2013): Ecosystem carbon and nitrogen accumulation after grazing exclusion in semiarid grassland. PloS one 8, e55433.

Rajaniemi T.K. (2002): Why does fertilization reduce plant species diversity? Testing three competition-based hypotheses. Journal of Ecology, 90: 316–324.

Ratajczak Z., Nippert J.B., Collins S.L. (2012): Woody encroachment decreases diversity across North American grasslands and savannas. Ecology, 93: 697–703.

Ritchie M.E., Tilman D., Knops J.M.H. (1998): Herbivore effects on plant and nitrogen dynamics in oak savanna. Ecology, 79: 165–177.

Scheiter S., Higgins S.I., Osborne C.P., Bradshaw C., Lunt D., Ripley B.S., Taylor L.L., Beerling D.J. (2012): Fire and fire-adapted vegetation promoted C4 expansion in the late Miocene. New Phytologist, 195: 653–666.

Veach A.M., Dodds W.K., Skibbe A. (2014): Fire and grazing influences on rates of riparian woody plant expansion along grassland streams. PloS one 10: e0129409.

Wang G.H. (2007): Leaf trait co-variation, response and effect in a chronosequence. Journal of Vegetation Science, 18: 563–570.

Wang H., Xie Y., Yang Y., Chuai J. (2011): Allelopathic effect of extracts from *Artemisia sacrorum* leaf and stem on four dominant plants of enclosed grassland on Yunwu Mountain. Acta Ecologica Sinica, 31: 6013–6021. (In Chinese)

Wright I.J., Reich P.B., Westoby M., Ackerly D.D., Baruch Z., Bongers F., Cavender-Bares J., Chapin T., Cornelissen J.H.C., Diemer M., Flexas J., Garnier E., Groom P.K., Gulias J., Hikosaka K., Lamont B.B., Lee T.L., Lee W., Lusk C., Midgley J.J., Navas M.-L., Niinemets Ü., Oleksyn J., Osada N., Poorter H., Poot P., Prior L., Pyankov V.I., Roumet C., Thomas S.C., Tjoelker M.G., Veneklaas E.J., Villar R. (2004): The worldwide leaf economics spectrum. Nature, 428: 821–827.

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