The Environmental Significance Of Stable Carbon Isotope Composition Of Modern Plant Leaves In The Northern Tibetan Plateau, China

Authors: Guangxiu Liu, Ming Li, and Lizhe An

Source: Arctic, Antarctic, and Alpine Research, 39(4) : 678-681

Published By: Institute of Arctic and Alpine Research (INSTAAR), University of Colorado

URL: https://doi.org/10.1657/1523-0430(07-505)[LIU-G]2.0.CO;2

Arctic, Antarctic, and Alpine Research, Vol. 39, No. 4, 2007, pp. 678–681

The Environmental Significance of Stable Carbon Isotope Composition of Modern Plant Leaves in the Northern Tibetan Plateau, China

*Guangxiu Liu**
Ming Li and*
Lizhe An†‡*

*Key Laboratory of Desert and Desertification, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China
†School of Life Sciences, Lanzhou University, Lanzhou 730000, China
‡Corresponding author: lizhean@lzu.edu.cn

Abstract

Foliar $\delta^{13}C$ values measured in 101 samples from 13 sites in northern Tibet averaged amplitude −26.9‰, and were higher than those of other mountain regions in the world. C_4 plants were found at 4161 m, higher than C_4 species have been found before. The foliar $\delta^{13}C$ values increased with altitude; however, the amplitude of increase was dependent on species. Furthermore, significantly higher $\delta^{13}C$ values were found in plants grown in the southern than the northern Tanggula Mountains, a difference ascribed to precipitation.

Introduction

Located at low latitude, the Tibetan Plateau has an average altitude of over 4000 m. It has been an important area for studying environment and evolution owing to its ecological fragility and climatic sensitivity (Li and Chen, 1998; Wang et al., 2003). The carbon isotope composition of leaves, shown by the value of $\delta^{13}C$, can reflect the physiological and ecological flexibility of the plants during their growth, and it has been recognized as a reliable way to estimate the long-term water-use efficiency of plants (Jiang, 1996). However, knowledge about the characteristics of stable carbon isotope compositions of plant leaves in Tibetan Plateau is limited.

Weather factors, such as temperature and especially precipitation and plant types vary on the two sides of the Tanggula Mountains (Yang et al., 2000, 2002). This study presents the distribution of foliar $\delta^{13}C$ values in the northern Tibetan Plateau, the relationship between foliar $\delta^{13}C$ values and altitude, and the difference in foliar $\delta^{13}C$ values on the northern and southern sides of the Tanggula Mountains. Our goal is to identify the main environmental factors limiting plant distribution or growth and provide some new data for further studies on ecosystem change in a changing environment.

Materials and Methods

Thirteen sites were chosen along the Qinghai-Xizang highway for sample collection. All the samples are leaves whose growth was not affected by overshadowing. By collecting 3 to 18 samples each site, a total of 101 samples were collected. The samples were identified at the School of Life Sciences, Lanzhou University. After the samples were taken back to the laboratory in envelopes, they were dried to a constant weight at 80°C in the laboratory and finely ground to No. 100 mesh. Cellulose was extracted from dry material according to the method of Leavitt (1993). The $\delta^{13}C$ values were determined following Qiang et al (2003), using a Finnigan MAT-252 mass spectrometer (Finnigan) supplied by the Cold Arid Region and Environment Engineering Institute, China Academy Science. Measurements were taken in triplicate and the mean was used. PDB was used as a standard and $\delta^{13}C$ values were calculated as:

$$\delta^{13}C_{PDB} = \left[\left({}^{13}C/{}^{12}C\right)_{sample} - \left({}^{13}C/{}^{12}C\right)_{standard}\right] \Big/ \left({}^{13}C/{}^{12}C\right)_{standard} \times 1000 \quad (1)$$

Results

FOLIAR $\delta^{13}C$ VALUES IN NORTHERN TIBET

The foliar $\delta^{13}C$ values of C_3 plants vary between −30.8‰ and −23.8‰, mainly between −26.0‰ and −27.0‰, with an average of −26.9‰ (Table 1, Fig. 1). This result is not only higher than that in northern China (Han et al., 2002) and eastern Tianshan Mountains (Xu et al., 2002), but is also higher than measured throughout the world (Korner et al., 1988) (Table 1). Additionally, the range of the foliar $\delta^{13}C$ values in the northern Tibet is lower than observed elsewhere.

It is generally accepted that the foliar $\delta^{13}C$ of C_3 plants is between −23‰ and −32‰, and that the foliar $\delta^{13}C$ of C_4 plants is between −6‰ and −19‰ (Han et al., 2002). Based on foliar $\delta^{13}C$ values of −13.8‰ and −13.6‰, respectively, we suggest that *Chenopodium album* L. and *Chenopodium aristatum* L. found at 4161 m altitude in Xidatan are C_4 plants.

EFFECTS OF ALTITUDE ON THE FOLIAR $\delta^{13}C$ AND DIFFERENCE OF FOLIAR $\delta^{13}C$ VALUES ACROSS THE TANGGULA MOUNTAINS

With increasing elevation, foliar $\delta^{13}C$ values increase (Fig. 2). However, the slope of the relationship between foliar $\delta^{13}C$ and elevations is species specific. *Saussurea nimborum* shows the maximum change in the $\delta^{13}C$ value, with a $\delta^{13}C$ increase of 3.2‰ per km increase in altitude, and *Leontopodium nanum* shows the lowest sensitivity, with a slope of 0.7‰ km^{-1}.

Foliar $\delta^{13}C$ values differed on the northern and southern Tanggula Mountain (Fig. 3): the values in the north are higher. It can be seen from Table 2 that both the average of the foliar $\delta^{13}C$ values and the $\delta^{13}C$ value of certain species in the Tuotuo River

1523-0430/07 $7.00

TABLE 1

Forb leaf $\delta^{13}C$ values in northern Tibetan Plateau and comparison with other regions.

Sites	Number of samples	Max value (‰)	Min value (‰)	Average value(‰)	Reference
Northern Tibetan Plateau	98	−23.8	−30.8	−26.9	This study
Eastern Tianshan Mt.	157	−22.9	−32.9	−28.3	Xu et al. (2002)
Northern China	210	−21.9	−32.0	−27.1	Han et al. (2002)
Worldwide	70	−22.7	−32.8	−27.2	Korner et al. (1988)

valley located north of the Tanggula Mountains are generally higher than values at Amdo to the south.

Discussion

The foliar $\delta^{13}C$ values in northern Tibetan Plateau are relatively high and cover a relatively narrow range, probably due to the high elevation (the average elevation of Tibetan Plateau is over 4000 m). Because of the elevation, it is difficult for the airflow from the sea to arrive at the top of the plateau, and consequently the precipitation there is relatively low and a large numbers of cold and desert ecosystems, arid grassland and semiarid grassland develop there. Research shows that foliar $\delta^{13}C$ value is a reliable index of water-use efficiency: the higher the foliar $\delta^{13}C$ value, the higher the water-use efficiency (Marshall and Zhang, 1994). Therefore, plants with high foliar $\delta^{13}C$ values have a stronger ability to acclimate themselves to drought. The narrow range of the foliar $\delta^{13}C$ values in northern Tibetan Plateau is probably related to the similar environmental conditions of the sampling sites with a cold and dry climate.

It is generally accepted that C_4 plants are rarely found over 3000 m in other regions of the world (Korner et al., 1988; Tieszen et al., 1979). In Ohio, U.S.A., the proportion of species and biomass of C_4 plants is 26% and 88 to 85% at low altitudes, such as 1400 m; when the altitude reaches 2650 m, all species are C_3. In Kenya, the transition zone between C_3 and C_4 plants is also rather abrupt and occurs between 2000 and 3000 m (Tieszen et al., 1979; Luo, 1985). In Tianshan Mountains, China, at approximately 2100 m, no C_4 plants are found. Even in select areas at high altitudes where a few C_4 grasses are found, these species disappear above 4000 m. However, when the altitude reaches 4161 m in Tibetan Plateau, C_4 species can still be found. In the future, it is necessary to further investigate the distribution of plants there.

In the present study, it is significant that altitude exerts influence on the foliar $\delta^{13}C$ values in northern Tibetan Plateau. The average slope of the seven species investigated is 1.1‰ km^{-1}, which is very close to the result of Korner et al. (1988) of 1.2‰ km^{-1}. The foliar $\delta^{13}C$ values of different species have different sensitivities to the changes of elevation, which is probably related to the adaptive strategies of plants to different environments. For example, some plants may acclimate with the environment by changing their morphologic structures, while others by changing their metabolism. It is reported that the leaf thickness increased with the increasing of elevation (Smith et al., 1984). The photosynthetic speed of *Korbresia humilis* increases with elevation. Both low stomatal conductance and high photosynthetic rate lead to high $\delta^{13}C$ values (Han et al., 1998).

There are many environmental factors influencing foliar $\delta^{13}C$ values, including temperature, precipitation, light intensity and relative humidity etc. The difference between the foliar $\delta^{13}C$ values in northern and southern Tanggula Mountain is perhaps an integrated response to these factors (Lin and Ke, 1995). From Table 2, the difference seems not to depend on the species, because *Stipa purpurea* and *Potentilla bifurca*, found on both sides of Tanggula Mountains, has higher foliar $\delta^{13}C$ values in southern Tanggula Mountains (Amdo) than the north (Tuotuo River). Since during sampling, shaded leaves were avoided and annual radiation time reaches above 2300 h, we believe that light is not important in interpreting the difference between the foliar $\delta^{13}C$ values in northern and southern Tanggula Mountains. Temperature, atmospheric pressure, and relative humidity were similar at the samplings sites, but precipitation and elevation are rather

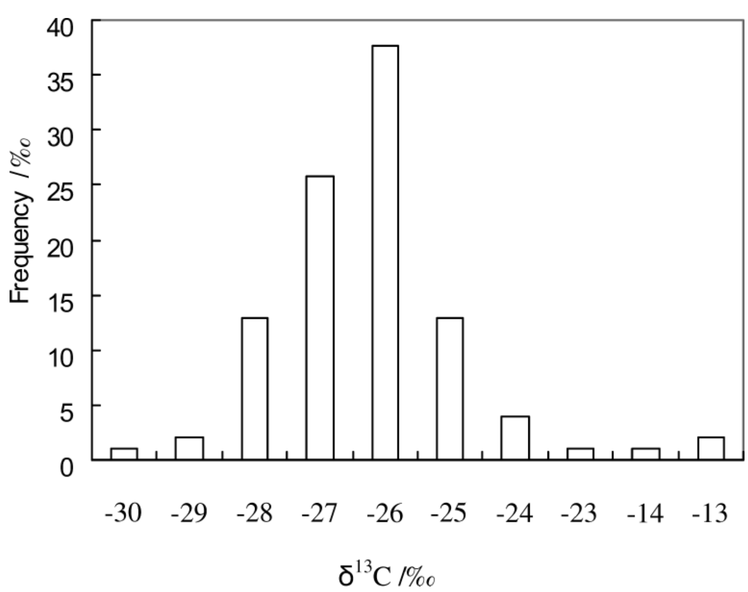

FIGURE 1. Frequency distribution map of foliar $\delta^{13}C$ in the northern Tibetan Plateau.

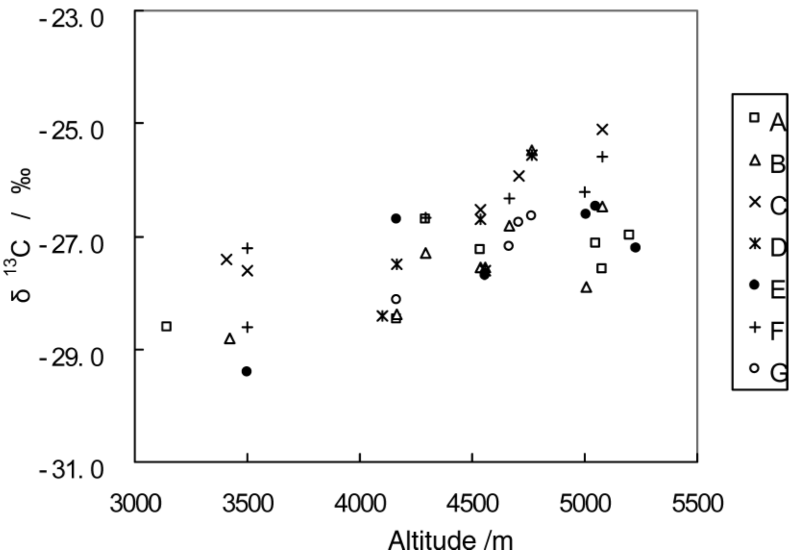

FIGURE 2. Effect of altitude on δ^{13}C values of different plant species. A: *Astragalus* sp. ($y = 0.032x - 41.25$, $R^2 = 0.71$); B: *Saussurea nimborum* ($y = 0.0013x - 33.388$, $R^2 = 0.45$); C: *Oxytropis sericopetala* ($y = 0.0024x - 38.11$, $R^2 = 0.84$); D: *Leontopodium nanum* ($y = 0.0007x - 30.11$, $R^2 = 0.46$); E: *Carex* spp. ($y = 0.0013x - 32.45$, $R^2 = 0.79$); F: *Potentilla bifurca* ($y = 0.0013x - 32.15$, $R^2 = 0.93$); G: *Kobresia humilis* ($y = 0.0013x - 33.18$, $R^2 = 0.58$).

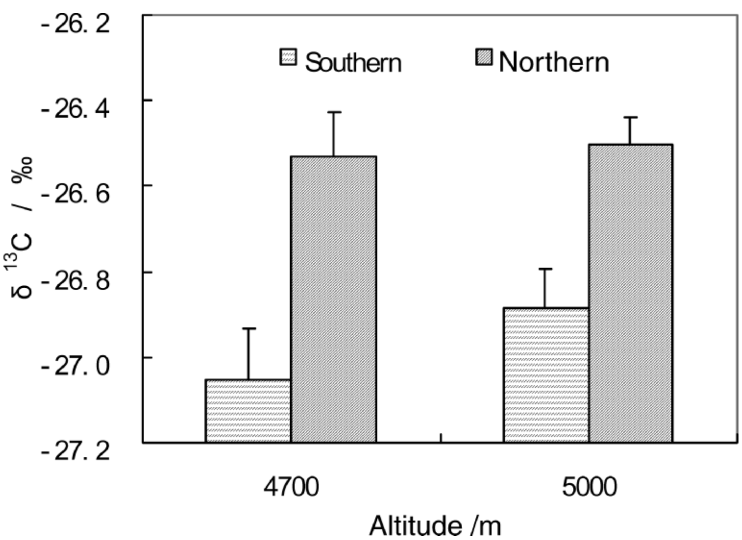

FIGURE 3. Difference of δ^{13}C values between northern and southern Tanggula Mountains.

different (Table 2). From the present result, the effect of altitude can be discounted, for difference in foliar δ^{13}C between Amdo and Tuotuo River shows the opposite trend expected for the altitude difference. Consequently, the difference of the foliar δ^{13}C values between the two regions is an effect of the precipitation. Precipitation is higher on the southern, windward side of the mountains than on the northern, leeward side (Wang et al., 2003). Plants close some stoma to reduce the evaporation when precipitation is insufficient or the air humidity and soil water decrease. When the stoma are closed, which causes a decline of the CO_2 density in the leaves, and the photosynthesis rate remains normal, the discrimination of $^{13}CO_2$ will decline and increase foliar δ^{13}C values (Farquhar et al., 1982).

The Tibetan Plateau is gradually warming and drying (Zheng et al., 2002). Therefore, to maintain a high water-use efficiency will be important for plants to survive in the future. The relatively high foliar δ^{13}C values on the Tibetan Plateau are probably a result of a long-term acclimatization of the plants. Similarly, the fact that the foliar δ^{13}C values to the north of the Tanggula Mountains are higher than those to the south probably reflects of the plant acclimatization strategies.

Acknowledgments

This research was supported by the Centurial Program of Chinese Academy of Sciences (Grant No. 2004401). Special

TABLE 2

Comparison of leaf δ^{13}C values between southern and northern Tanggula Mountains.

Place name	Number of samples	δ^{13}C value (‰)			T (°C)	P (mm)	Air pressure (Pa)	Relative humidity (%)	Altitude (m)
		Average	*Stipa purpurea*	*Potentilla bifurca*					
Amdo	8	−27.1 ± 1.2	−25.3	−25.9	7.89	242.2	577	72.8	4710
Tuotuo River	9	−26.3 ± 1.2	−24.4	−25.1	7.83	167.2	588	71.5	4533

thanks to editor Suzanne Anderson for helpful suggestions for improving of the manuscript.

References Cited

Farquhar, G. D., O'Leary, M. H., and Berry, J. A., 1982: On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. *Australian Journal of Plant Physiology*, 9: 121–137.

Han, F., Ben, G. Y., and Shi, S. B., 1998: Comparative study on the resistance of *Kobresia humilis* grown at different altitudes in Qinghai-Xizang Plateau. *Acta Ecologica Sinica*, 18(6): 654–660. (In Chinese with English abstract.)

Han, J. M., Wang, G. A., and Liu, T. S., 2002: Appearance of C4 plants and global changes. *Earth Science Frontiers*, 9(1): 233–243. (In Chinese with English abstract.)

Jiang, G. M., 1996: Application of stable carbon isotope technique in plant physiological ecology research. *Chinese Journal of Ecology*, 15(2): 49–54. (In Chinese with English abstract.)

Korner, C., Farquhar, G. D., and Roksandic, Z., 1988: A global survey of carbon isotope discrimination in plants from high altitude. *Oecologia*, 74: 623–632.

Luo, Y. H., 1985: The ecological significance in C_3, C_4 and CAM pathways. *Acta Ecologica Sinica*, 5(1): 15–27. (In Chinese with English abstract.)

Leavitt, S. W., and Danzer, S. R., 1993: Method for processing small wood samples to holocellulose for stable carbon isotope analysis. *Analytical Chemistry*, 65: 87–89.

Li, X. B., and Chen, J. F., 1998: Advances in study on plant carbon isotope discrimination and environment change. *Advance in Earth Sciences*, 13(3): 285–290. (In Chinese with English abstract.)

Lin, G.-H., and Ke, Y., 1995: Stable isotope techniques and global change research. *Li B. Lecture on Contemporary Ecology*. Beijing: Academy Publishing House, 161–188 (in Chinese with English abstract).

Marshall, J. D., and Zhang, J., 1994: Carbon isotope discrimination and water-use efficiency in native plants of the north-central Rockies. *Ecology*, 75(7): 1887–1895.

Qiang, W., Wang, X., and Chen, T., et al., 2003: Variations of stomatal density and carbon isotope values of *Picea crassifolia* at different altitudes in the Qilian Mountains. *Trees*, 17: 258–262. (In Chinese with English abstract.)

Smith, W. K., Young, D. R., Carter, G. A., Hadley, J. L., and McNaughton, G. M., 1984: Autumn stomatal closure in six conifer species of the Central Rocky Mountains. *Oecologica*, 63: 237–242.

Tieszen, L. L., Senyimba, M. M., Imbamba, S. K., and Troughton, J. M., 1979: The distribution of C_3 and C_4 grasses and carbon isotope discrimination along an altitudinal and moisture gradient in Kenya. *Oecologia*, 37: 337–350.

Wang, L., Lu, H. Y., and Wu, N. Q., et al., 2003: Altitudinal trends of stable carbon isotope composition for Poaceae in Qinghai-Xizang Plateau. *Quaternary Sciences*, 23(5): 573–579. (In Chinese with English abstract.)

Xu, S. J., Chen, T., and Feng, H. Y., et al., 2002: Environmental analysis of spatial changes of leaf $\delta^{13}C$ values in the upper reaches of Urumqi river, Xinjiang. *Progresses in Natural Sciences*, 12(6): 617–620. (In Chinese with English abstract.)

Yang, M. X., Yao, T. D., and Tian Lide., et al., 2000: Comparison of summer monsoon precipitation between northern and southern slope of Tanggula mountain over the Tibetan Plateau. *Quarterly Journal of Applied Meteorology*, 11(2): 199–204. (In Chinese with English abstract.)

Yang, M. X., Yao, T. D., He., and Yuanqing., et al., 2002: The water cycles between land surface and atmosphere in northern part of Tibetan Plateau. *Scientia Geographica Sinica*, 22(1): 29–33. (In Chinese with English abstract.)

Zheng, D., Lin, Z. Y., and Zhang, X. Q., 2002: Progress in studies of Tibetan plateau and global environmental change. *Earth Science Frontiers*, 9(1): 95–102. (In Chinese with English abstract.)

Ms accepted June 2007