Asian Agricultural Research 2014, 6(5): 69 – 73, 78

Study on the Characteristics of Soil Moisture of Artificial *Robinia pseudoacacia* Forest Land in Different Latitudinal Zones of Northern Shaanxi

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Abstract This article studies the soil moisture conditions of 30 years artificial *Robinia pseudoacacia* in the north of Shaanxi under different climate conditions in order to explore the relationship between soil moisture and impact factor of *Robinia pseudoacacia* in this area, and variation characteristics of soil moisture in the Loess Plateau region. The results show that soil moisture content decreases with increase of soil depth, and in 40 – 50 cm depth the jump point of moisture reduction appears significantly. Soil moisture was lower than the growth critical moisture in 5 samples to the north of Chunhua, and has different degrees of deficit. Soil moisture deficit degree was more than 50% in sandy loam and light loam soils such as Yulin, Shenmu and Suide. With the increasing of latitude, both of soil accumulative storage and net rainfall tends to decrease, but the relationship between them is significant correlation, indicating that that climate conditions are the major factors causing significant difference of soil moisture.

Key words *Robinia pseudoacacia*, Soil moisture, Soil water storage, The degree of moisture deficit

The northern Shaanxi is a typical gully region in the Loess Plateau, with serious soil erosion. According to the soil and water conservation statistics in 1979, the severely eroded areas and highly eroded areas in northern Shaanxi account for 20% and 29%, respectively[1]. The soil erosion not only undermines the local land resources and ecological environment, but also becomes the main reason for the high level of silt in Yellow River. From the 1960s, based on the soil erosion characteristics and local climate in the northern Shaanxi area, the soil and water conservation measures have been repeatedly implemented.

Due to the characteristics of strong adaptability, resilience[3], resistance to acid and alkali, fast growing and resistance to barrenness[4], *Robinia pseudoacacia*[2] becomes a pioneer tree species for soil and water conservation control[5]. The shelter forests with *Robinia pseudoacacia* as the dominant species bring certain ecological benefits while continuing to play the role of soil and water conservation.

In recent years, with the deepening of studies, some scholars have pointed out that since there are significant differences in the soil moisture utilization pattern between *Robinia pseudoacacia* and other artificial forests[13], and especially in the arid and semi-arid areas, the excessive use of soil water storage for *Robinia pseudoacacia* forests leads to the soil dry layer with low moisture in the understory layer[6], and it is difficult to recover.

The studies on the vegetation restoration in the Loess Plateau also prove that the soil physical and chemical properties has had a profound impact on the evolution and development of fragile ecosystems in the Loess Plateau[14], while biochemical reactions influencing the soil physical and chemical properties need mostly to be conducted in the aquatic environment[15 – 18], so the study on the soil moisture characteristics becomes the basis of researching the ecological environment for *Robinia pseudoacacia* forests in the Loess Plateau[21 – 23].

In this paper, with the 0 – 500 cm deep soil under 28 – 30 a *Robinia pseudoacacia* forests in the Shenmu, Yulin, Suide, Ansai, Yichuan and Chunhua as the object of study, we analyze the moisture and water storage of the soil of different depths, and explore the relationship between the soil moisture and soil depth of *Robinia pseudoacacia* forest land in different areas, in order to provide a basis for the further research of moisture use and ecological functions of *Robinia pseudoacacia* forests in the arid and semi-arid areas.

1 Overview of the study area

This study takes the soil under the *Robinia pseudoacacia* forests in different latitudinal zones of northern Shaanxi as the object. The study area includes Shenmu, Yulin, Suide, Ansai, Yichuan, and Chunhua, located at latitude 34°47′57.41″ – 38°50′32.71″ N, and longitude 108°34′35.03″ – 110°29′29.35″ E.

Shenmu, Yulin, Suide, Ansai, Yichuan and Chunhua are situated from north to south, spanning the grassland zone, grassland-forest zone and forest zone, respectively[4], where all the natural vegetation has been severely damaged. The 6 sample plots are in the gully region of Loess Plateau, featuring a temperate continental semi-arid climate.

Received: March 11, 2014 Accepted: May 4, 2014
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Except Chunhua, the annual evaporation is greater than the annual precipitation in the remaining 5 regions, with the minimum dryness of 0.9 and maximum dryness of 4.2, so they are typical arid regions.

The artificial forests are mainly composed of *Robinia pseudoacacia*, Simon poplar, Caragana korshinskii, and sea backthern. There are significant north-south differences in the soil composition: the soil in Shenmu and Yulin is aeolian sandy soil; the soil in Suide is sandy loam; the soil in Ansai is light loam; the soil in Yichuan is medium loam; the soil in Chunhua is heavy loam soil and clay soil. There are generally poor resistance to corrosion and serious soil erosion[7].

Table 1 The basic meteorological conditions of the study area

	Altitude//m	Precipitation//mm	Evaporation//mm	The annual average temperature//℃	Frost-free period//d	The annual average sunshine hours//h	Climatic zones
Shenmu	738 – 1 448	440.8	1 336.6	8.5	169	2 876	Grassland zone
Yulin	1 000 – 1 800	412.4	1 895.7	10.7	141	2 586	Grassland zone
Suide	608 – 1 287	486	2 061.9	9.7	165	2 615	Grassland zone
Ansai	997 – 1 731	500	1 000	8.9	165	2 379	Forest – grassland zone
Chunhua	630 – 1 808	577.2	520	9.8	183	2 373	Forest zone
Yichuan	388 – 1 710	561.9	1 576.4	9.9	167	2 436	Forest zone

2 Study methods

2.1 Selection of sample plots To understand the understory moisture status of *Robinia pseudoacacia* forests in the north of Shaanxi, through the historical data access and on – site investigation, inquiry and other ways, 6 sample points were selected from south to north according to the precipitation distribution characteristics of the Loess Plateau: Chunhua – Yichuan – Ansai – Suide – Yulin – Shenmu.

Each location selected the upper shady slope for the *Robinia pseudoacacia* forests with the growth years of 30 (28 in Shenmu) as the study area. The growth of *Robinia pseudoacacia* forests was in good condition for each study area. Two 20 m × 20 m sample plots were selected, with the spacing of 150 – 200 m and basically the same gradient.

Each sample plot selected two plants of *Robinia pseudoacacia*, with the trunk of *Robinia pseudoacacia* as the center. Two measurement points at the radial distance of 1 m were selected for sampling every 20 cm. The survey and determination were carried out from late August to early September 2008. In order to ensure the consistency of the soil conditions, the sampling selected the time period of seven consecutive days without rainfall prior to sampling.

2.2 Determination of soil moisture of the sample plots The soil moisture is determined using soil sampling method, with the sampling depth of 500 cm (400 cm in Yulin). The sampling is carried out every 20 cm, and each sample plot is repeated two times. In areas where conditions permit, the soil samples are promptly placed in the oven to be dried for 12 h under 105 ℃, so as to measure the soil moisture.

When there is no oven in the wild, the combustion method is used to measure the soil moisture. After using the portable electronic balance to weigh the wet weight, 95% alcohol is placed into a small aluminum box, and when the soil inside the box is fully infiltrated by the alcohol, the soil is burned to be loose, and then it is weighed to obtain dry weight.

In the laboratory, the drying and combustion methods are used to determine the soil moisture of the same sample, and the results show that there is a small difference in the soil moisture between these two methods, and there is no the measurement error due to the determination method.

2.3 Calculation formula

2.3.1 The degree of soil moisture deficit.

$$k = (\theta_a - \theta)/\theta_a$$

where k is the degree of soil moisture deficit; θ_a is the water content of inhibiting plant growth; θ is the soil moisture determined.

2.3.2 Soil water storage.

$$Q = d \cdot h \cdot c$$

where Q is the soil water storage (mm); d is the soil bulk density (g/cm^3); h is the soil thickness (mm); c is the soil moisture percentage.

3 Results and discussions

3.1 The profile characteristics of soil moisture Through the measuring and analysis of the soil water content in different areas, we can find the following characteristics. The soil moisture does not change significantly with the soil depth in Yulin and Shenmu, with the highest water content of 1.51% and lowest water content

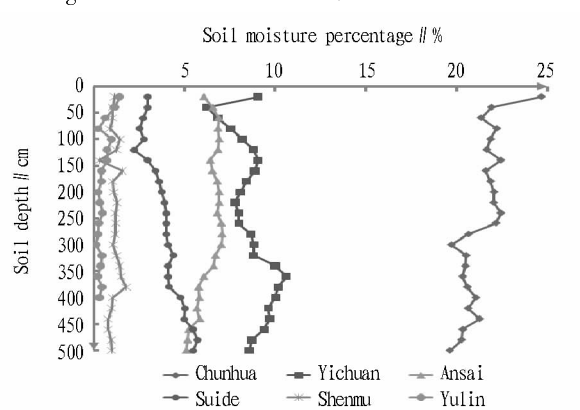

Fig.1 The soil profile characteristics of 30a artificial *Robinia pseudoacacia* forest land in different regions

of 0.4%. The soil moisture in the two areas is stabilized at 0.52% and 1.1%.

In Suide, the change in soil moisture shows an increasing trend with depth, and the gradient of change is very even. The profile characteristics of soil moisture in Ansai and Chunhua are prominent, showing a decreasing trend from top to bottom, and there are three representative layers. The sample plot of Chunhua is the most typical.

The moisture of 0 – 50 cm soil shows a rapid decline trend, and the soil moisture percentage falls from 24.66% to 21.33%, with an average moisture percentage of 22.63%, so this layer is the layer of active soil profile moisture cycle[15]; the moisture percentage of 50 – 250 cm soil is maintained at a relatively stable level, but it has decreased significantly compared to the 0 – 50 cm layer, with the highest moisture percentage of 22.42%, the lowest moisture percentage of 21.59%, and an average moisture percentage of 22.02%; the 250 – 500 cm soil and 50 – 250 cm soil share similar characteristics in terms of soil moisture percentage, and it is maintained at a stable level, with the highest moisture percentage of 21.26%, the lowest moisture percentage of 19.61%, and an average moisture percentage of 20.4%, but it is significantly lower than the moisture percentage of 50 – 250 cm soil.

The main reasons for these distribution characteristics include the following aspects.

Significantly affected by precipitation and evaporation, the moisture of 0 – 50 cm soil is high, but it declines quickly with the depth[11]. The roots of *Robinia pseudoacacia* forests are mainly distributed in the 50 – 250 cm soil layer[19], and the high water consumption characteristics of *Robinia pseudoacacia*[10] lead to the strong transpiration[20], so the soil moisture content of this layer is significantly lower than that of 0 – 50 cm soil layer.

The role of roots of *Robinia pseudoacacia* forests in the soil moisture makes the moisture content of this layer relatively stable, and there are no prominent fluctuations, with the characteristics of strong water consumption layer[15].

The rainfall in the Loess Plateau is concentrated in July to September, accounting for 60% to 80% of annual rainfall. During this period, the moisture of 250 – 500 cm soil layer can be complemented by the rainfall, but in the rest of the year, due to strong evaporation and transpiration, the rainfall is difficult to infiltrate and the moisture is difficult to be replenished, so the soil moisture content of this layer is seldom disturbed.

In addition, the plant roots are less distributed within this layer, and the moisture loss caused by the plant transpiration is also small, resulting in the low soil moisture content in this region.

The research results on the sample plot of Chunhua (34°53′43.7″ N; 108°35′21.5″ E) are strongly consistent with the research results by Ma Juanxia *et al*.[12] on the sample plot of Xiaoqiu Town in Tongchuan City (34°54′20.9″ N; E108°47′58.5″ E), indicating that there is universal regularity in the vertical distribution of soil moisture of *Robinia pseudoacacia* forest land in the same latitude.

The study of Yi Liang *et al*.[15] shows that in terms of the degree of soil moisture deficit of artificial forest land, the vegetation zones are sequenced as follows:

forest zone < forest – grassland zone < grassland zone.

The degree of deficit is gradually increased from non-deficit of forest zone to 61.52% of grassland zone, which is obviously consistent with the analysis results of this paper.

The degree of soil moisture deficit of different sample plots[8, 15] is as follows: Chunhua –70.02% (non-deficit), Yichuan 28.55%, Ansai 42.03%, Suide 58.65%, Shenmu 87.26%, and Yulin 93.81%.

Except Chunhua, the soil moisture content of *Robinia pseudoacacia* forest land in other five counties is lower than the water content of inhibiting plant growth[8, 9, 15], with medium and serious moisture deficit, so the growth of *Robinia pseudoacacia* forests is restricted by the moisture.

Robinia pseudoacacia is a tree species consuming a lot of water[2], and the excessive use of soil moisture during its growth period is one of the main factors making soil moisture content under forests much lower than the field moisture capacity.

Table 2 The degree of soil moisture deficit of artificial *Robinia pseudoacacia* forest land in different areas

	Regions	Soil moisture // %	Field moisture capacity // %	Water content of inhibiting plant growth // %	The degree of soil moisture deficit	Deficit status
Sandy loam zone	Yulin	0.52	14.00	8.40	93.81	Serious deficit
	Shenmu	1.07	14.00	8.40	87.26	Serious deficit
Light loam zone	Suide	3.92	15.80	9.48	58.65	Serious deficit
	Ansai	6.40	18.40	11.04	42.03	Medium deficit
Medium loam zone	Yichuan	8.66	20.20	12.12	28.55	Medium deficit
	Chunhua	21.32	20.90	12.54	–70.02	Non-deficit

* Note: The field moisture capacity data are from the study of Li Yushan[24], Wu Qinxiao, Yang Wenzhi[25], Han Shifeng, Huang Xu[26] *et al*.

Shenmu and Yulin are located in the edge of Mu Us Desert, and watershed topography is the sand-covered hills. Suide is in the grassland zone of Loess Plateau; the sample plot of Ansai is in the south of forest – grassland zone[4]; Yichuan is in the north of forest zone; Chunhua is in the south of forest zone.

The six regions are the soil erosions areas in the Loess Plateau, and the soil moisture of mature *Robinia pseudoacacia* forest land in the Loess Plateau is representative, as is shown in Fig. 2.

In terms of the moisture of 0 – 500 cm soil of 30a *Robinia pseudoacacia* forest land, the six regions are sequenced as follows:

Chunhua > Yichuan > Ansai > Suide > Shenmu > Yulin.

The rainfall decreases from south to north. There is serious deficit in the soil moisture of *Robinia pseudoacacia* forest land in the sample plots of Shenmu, Yulin and Suide, and the water stress

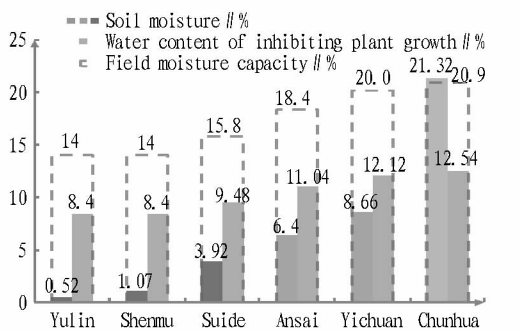

Fig. 2 The soil moisture, water content of inhibiting plant growth and field moisture capacity of *Robinia pseudoacacia* forest land in different regions

effect is obvious, easily leading to the phenomenon of "small – old trees"[2].

In Chunhua, the average soil profile moisture percentage is 21%, equivalent to the field moisture capacity, and the water is effective, so it is the region suitable for the growth of *Robinia pseudoacacia*.

Ansai and Yichuan are the forest – grassland ectone, and the soil moisture shows medium deficit, so these regions are the azonal habitat for *Robinia pseudoacacia*, and it is difficult to find vast stretches of *Robinia pseudoacacia* forests. The main reason for this phenomenon is that the precipitation can not meet the needs of long-term plant growth.

The average precipitation in the study area is only 498 mm, while the average evaporation reaches 1475 mm, much larger than the precipitation. So the soil moisture is in the unsaturated state, and the deep groundwater in the region makes the soil moisture lack timely replenishment.

In the loess area, the probability of occurrence of runoff and leakage is small, so the evaporation and transpiration play a leading role[24], and are the major factors affecting the soil moisture content.

There is a balance between precipitation and evaporation only in Chunhua, while the evaporation is much larger than the precipitation in other five regions. When there is vegetation, the total soil evaporation is equal to the sum of soil evaporation and plant transpiration, and when the precipitation is not sufficient for the evaporation, it is complemented by the water stored in the soil.

The water-consuming feature of *Robinia pseudoacacia* forests accelerates the rate of soil moisture loss, and this effect will constantly increase the moisture deficit of the deep soil, leading to the formation of dry layer.

3.2 Latitudinal characteristics of soil moisture The soil water storage and cumulative soil water storage of *Robinia pseudoacacia* forest land in different regions are compared (Fig. 3, 4). And the results indicate that in terms of the water storage of 0 – 500 cm soil, the regions are sequenced as follows:

Chunhua > Yichuan > Ansai > Suide > Shenmu > Yulin.

The average water storage of soil profile is 53.31 mm, 21.66 mm, 15.99 mm, 9.79 mm, 2.78 mm and 1.26 mm, respectively; the cumulative water storage of 0 – 500 cm soil is 1344 mm, 549 mm, 402 mm, 248 mm, 72 mm and 26 mm, respectively.

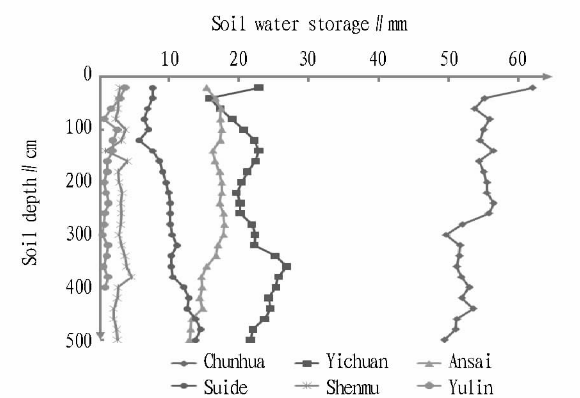

Fig. 3 The soil water storage of 30a *Robinia pseudoacacia* forest land in different regions

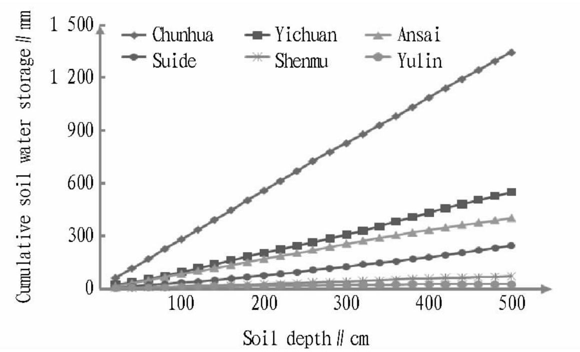

Fig. 4 The cumulative soil water storage of 30a *Robinia pseudoacacia* forest land in different regions

As can be seen from the figure of relationship between cumulative water storage and soil depth, the cumulative soil water storage in the sample plots is increased linearly, indicating that there are little changes in the water storage between different soil layers, with no significant differences, but there are significant differences in the cumulative water storage between different regions.

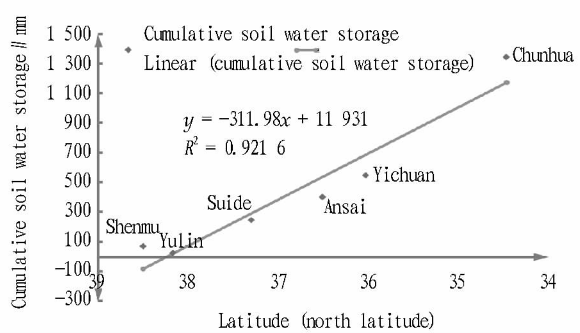

Fig. 5 The relationship between cumulative soil water storage and latitude of the study area

In order to study the relationship between cumulative water storage and latitude as well as the relationship between cumulative water storage and net precipitation, the least squares method is used to carry out the linear fitting of scatter diagrams (Fig. 5, 6).

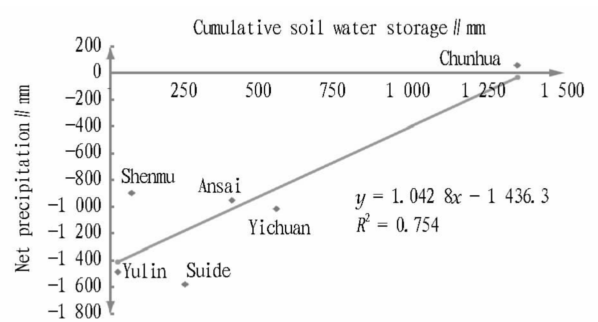

Fig. 6 The relationship between cumulative soil water storage and net precipitation

The R^2 value of fitted relationship between cumulative water storage and latitude is 0.9216, while the R^2 value of fitted relationship between cumulative water storage and net precipitation is 0.754, indicating that there is a significant correlation.

These results indicate that latitudinal characteristics are the main factor responsible for the differences in the soil water storage of *Robinia pseudoacacia* forest land between different regions.

With the increase in latitude, the rainfall is gradually reduced, and the soil moisture content and water storage are significantly reduced, indicating that there is a very close relationship between cumulative soil water storage and net precipitation.

4 Conclusions

(i) We measure the soil moisture of *Robinia pseudoacacia* forest land in different sample plots, and calculate the degree of soil moisture deficit based on the field moisture capacity. The results show that except Chunhua, there is moisture deficit in the other five regions, and it shows significant contradictions between supply and demand.

(ii) The soil moisture content in almost all depths shows the characteristics of Chunhua > Yichuan > Ansai > Suide > Shenmu > Yulin. It is consistent with the latitudinal changes of the 6 sample plots, fully indicating that there is a close relationship between soil moisture content and latitude.

(iii) Through the fitting of precipitation curve of different latitudinal zones and soil moisture curve of *Robinia pseudoacacia* forest land, it is found that there is a significant correlation between the cumulative soil water storage of *Robinia pseudoacacia* forest land and net precipitation, and both the precipitation and soil moisture content show a decreasing trend from south to north, indicating that the latitudinal characteristics are the dominant factor responsible for the significant differences in the soil moisture content.

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plants, and a total of 34 color-leafed plant varieties are introduced, such as *ulmus pumila cv. jinye*, *Prunus cerasifera*, *Physocarpus opulifolius var. luteus*, *Forsythia suspensa*, *Swida alba Opiz*, *Buddleja lindleyana Fortune*, *Iris tectorum*, *and Hemerocallis fulva*.

By the plant varieties, the color assortment and tree species combination are achieved, and by irregular planting methods, forest roads and water system construction, the best aesthetic effect is achieved (Fig. 8).

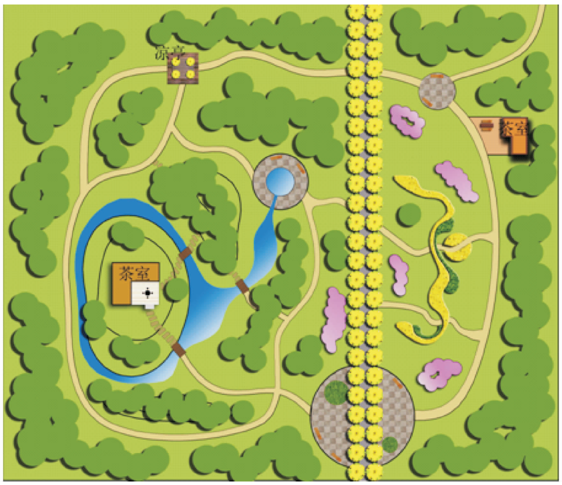

Fig. 8 Color-leafed plants garden plan

3.3 Dining area, fish pond and farm construction In the north of wine chateau for sightseeing, the supporting dining area, fish pond and farm are designed and constructed. The area of dining area is 500 m^2, and it can accommodate 150 people. The chess room and lounge are also designed within.

The designed area of fish pond is 100 m^2, and the water is 2 m deep. It can meet tourists' needs for fishing entertainment. The designed area of farm is 0.2 hm^2, and some animals are bred within, such as spotted deer, flying dragon, blue peacock, mallard ducks and pheasants.

4 Conclusions and discussions

In the design and construction of grape theme sightseeing garden, the variety selection, frame design, column erection and garden style design are carried out in accordance with the requirements of sightseeing, which helps to achieve the purpose of sightseeing and picking. The design and construction of wine making grape garden not only make us see the differences in the varieties for wine making and cultivation techniques, but also offer the raw materials for brewing high quality wine.

The design and construction of auxiliary theme grape garden landscape highlight the theme, beautify the environment, and make people see plants, animals and beauty, learn knowledge and taste the peasant food, thereby achieving the purpose of sightseeing, picking, appreciating the beautiful scenery, and enjoying palatable food.

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