Front. For. China 2009, 4(2): 159–164
DOI 10.1007/s11461-009-0035-1

RESEARCH ARTICLE

Xiaojuan ZHANG, Tianxing WEI, Libo JING, Na YIN, Yanhui LIU

Nutrient distribution and accumulation patterns of natural secondary forests in the Loess Plateau of Shanxi Province, northern China

Abstract We studied the biomass and its allocation in natural secondary forests, as well as the amounts, accumulation and distribution of nutrient elements (N, P, K, Ca and Mg) in sample plots established in the Loess Plateau in Shanxi Province, northern China. The results show that biomass in natural secondary forests amounted to 36.09 t/hm^2, of which the tree layer accounted for 46%, the shrub layer for 29%, the herb layer for 13% and the litter layer for 12%. The total storage of the five nutrient elements is 1089.82 kg/hm^2. Nutrient storage in the tree layer is the largest, at 41%. The sequence of storage of the elements varied among different layers and is given as follows: shrub layer 31.27%, herb layer 12.55% and litter layer 15.36%. The accumulation of nutrient elements in the tree layer, ordered from high to low, is: branches > roots > stems > bark > leaves. The total storage of the five nutrient elements in the soil is 634.97 t/hm^2, where the accumulation of the nutrients accounts for 95.32% (N), 99.64% (P), 99.91% (K), 99.84% (Ca) and 99.95% (Mg) of the total amounts. The accumulation coefficients of different organs in the tree layer are, from high to low: leaves > branches > roots > bark > stems. The accumulation coefficients in the different layers are listed as follows: shrub layer > tree layer > herb layer and for the elements as: N > P > Ca > K > Mg.

Keywords Loess Plateau, natural secondary forests, nutrient elements

Translated from *Journal of Beijing Forestry University*, 2008, 30(3): 57–62 [译自: 北京林业大学学报]

Xiaojuan ZHANG, Tianxing WEI (✉), Libo JING, Na YIN, Yanhui LIU
Key Laboratory of Soil and Water Conservation & Desertification Combating of Ministry of Education, School of Soil and Water Conservation, Beijing Forestry University, Beijing 100083, China
E-mail: weitx@bjfu.edu.cn

1 Introduction

Accumulation and distribution of nutrient elements in stands has long been the basis for studying material and energy flux of forest ecosystems. Nutrient cycling is an expression of the function of a forest ecosystem. Biological cycles of nutrient elements are closely related with carbon cycles in forest ecosystems, which benefit studies of restoration ecology, biodiversity, global change of carbon storage, etc. Since the 1970s, studies have ranged from nutrient accumulation, distribution and cycles of stands to the allocation of single trees based on nutrient elements in tree organs (Bazilevieh and Podin, 1966; Young, 1967; Tsutuumi et al., 1968; Ebermayer, 1976; Shen et al., 1985; Dan, 1986; Chen et al., 1997; Chen and Huang, 1997). In China, studies on biological productivity and nutrient elements of forest ecosystems mainly focus on plantations in southern and northeastern China (Chen and Lin, 1994). As well, a few studies have been conducted in northern China, such as in the hilly Loess Hilly Area where stands of *Pinus tabulaeformis* and *Robinia pseudoacacia* have been studied (Gao et al., 2002; Liu, 2002; Zhao et al., 2006). Carbon storage in plants has been the focus in recent years (Yu, 2003; Shi et al., 2004), but by and large, carbon storage has been estimated from biomass and by calculating coefficients of the amounts of carbon. Therefore, how to accurately calculate carbon storage of vegetation is the key to study the effect of vegetation restoration on the global carbon balance and carbon cycle (Watson et al., 2000). Studies on the function of the elements N, P, K, Ca and Mg in plants and their absorption and transformation in soils have been widely conducted. Given the relationships of these elements, the study results show that a rational concentration of each element could make nutrient uptake provide optimum effects (Li, 2007). Studies on minor elements in plants have also been carried out, including absorption and transformation, functions, and even heavy metal pollution, on the growth and quality of plants (You, 2005).

In the area of the Loess Plateau, original natural forests have been destroyed or diminished severely. Thus, the structure and functions of the original forest ecosystem have considerably changed. Secondary forests are now the main forest types in this area. Studies on nutrient element cycling in secondary forests are of theoretical and practical importance for the reforestation of natural forests.

2 Study area

The Caijiachuan watershed (36°16′N, 110°43′E) is located in Jixian County, Shanxi Province at the National Station of Forest Ecosystem Research. Elevation ranges from 1050 m to 1100 m. Average annual temperature is 10°C. Frost-free period can, on average, last 172 d. The annual precipitation is 579.1 mm, 828.9 mm fell in 1956, the maximum since records are kept and the minimum, 277.7 mm, occurred in 1997. Mean annual evaporation is 1729 mm. Soils are mainly carbonatite cinnamon soils. Canopy density of secondary forests in the study area is 0.7, with a density of 1655 tree/hm^2. The dominant species is *Populus davidiana*, diameter at breast height (DBH) 6.5 cm, height 7.5 m and, on average, 20 years old.

Forest cover is 72% in the Caijiachuan watershed (Zhang et al., 2005). Except for natural secondary forests, there are also *Pinus tabulaeformis* and *Robinia pseudoacacia* plantations. Natural vegetation include *Quercus wutaishancia*, *Ostryopsis davidiana*, *Lespedeza bicolor*, *Rose xanthina*, *Spiraea trilobata*, *Rose xanthina*, *Spiraea trilobata*, *Bothriochloa ischaemum*, *Agropyron cristatum*, *Artemisia capillaries*, *A. argyi* and *A. annua*. All of these stands, given their type, composition, structure, growth and site could represent forests in the area of the Loess Plateau.

3 Methods

3.1 Biomass measurement, collection and treatment of sample trees

In the Caijiachuan Watershed, based on an overall survey of natural secondary forests, sample plots of 20 m × 20 m were established and each tree tallied. In the tree layer, sample trees were selected by diameter classes. Biomass above ground was measured using a section method. Whole roots were dug out and taken back using bags. The biomass of roots was measured after washing and drying. Analytical methods were used to determine the individual organ biomass of single trees. Biomass of shrubs above and below ground was determined on five sample plots of 1 m × 1 m. For grasses, eight plots of 1 m × 1 m were established to measure biomass above and below ground. Five plots of 0.5 m × 0.5 m and one plot of 1 m ×1 m were established randomly to collect litter and measure its biomass. Elements in stems, branches, flowers, fruits and roots of trees and shrubs were measured in the laboratory.

3.2 Soil sample collection

In total, three soil profiles were dug. Soil bulk density of six layers, 0–10 cm, 10–20 cm, 20–40 cm, 40–60 cm, 60–80 cm and 80–100 cm, was measured by a ring cutting method. Amounts of 1 kg soil samples of each soil layer were taken back for chemical soil analysis.

3.3 Sample analysis

All vegetation samples were dried at 85°C in a drying oven, then ground, put in bottles and pasted with brand. Before the analyses, samples were dried at 105°C for 1 h, then dissolved using H_2SO_4-H_2O_2. N, P, K, Ca and Mg for testing.

4 Results and analysis

4.1 Biomass and its allocation in natural secondary forests

Due to low levels of sunshine in the Caijiachuan watershed, in western Shanxi Province, soil drought occurs. Natural secondary forests of *P. davidiana*, *Quercus wutaishancia*, *Betula* sp. and *Ostryopsis davidiana* were formed on these sites. The dominant species is *P. davidiana*. The total biomass was 36.09 t/hm^2, where the biomass of the tree layer accounted for 46.0%, that of the shrub layer for 29.0%, the grass layer 12.8% and the litter layer for 12.2%. Usually, in plantations, the biomass of the tree layer is more than 90%, but in the Loess Plateau, the shrub layer accounts for nearly 1/3 of the biomass. Shrubs grow vigorously in this area.

P. davidiana is dominant in the tree layer. The total biomass of *P. davidiana* was 16.26 t/hm^2, accounting for 97.9% of the total biomass of the tree layer. For *P. davidiana*, the above ground biomass was 12.98 t/hm^2, and 3.29 t/hm^2 below ground, accounting for 79.79% and 20.21%, respectively. In the above ground biomass of *P. davidiana*, stem biomass was 7.44 t/hm^2, 2.03 t/hm^2 for bark, 2.97 t/hm^2 for branches and 0.53 t/hm^2 for leaves, accounting for 45.8%, 12.5%, 18.3% and 0.03%, respectively. The order in terms of organ biomass is given as follows: stems > roots > branches > bark > leaves. The biomass of leaves was 16.2% of the root biomass. The biomass of *Q. wutaishancia* amounted to 0.35 t/hm^2 of which 81.3% was above ground. The order of each tree organ biomass was the same as for *P. davidiana*.

In the shrub layer, the total biomass was 10.46 t/hm^2, of which 49.2% was for branches, 47.2% for roots and 3.6% for leaves. In plantations, the percentage of the shrub layer biomass was relatively large. Thus, the shrub layer of the secondary forest played an important role in controlling soil erosion.

Grass accounted for 17.3% of the above ground biomass and 82.7% below ground. The below ground biomass is very important. Our results agree with those from Zhang and Liang (2002).

4.2 Contents of nutrient elements in natural secondary forests

The tree layer is the main body of natural secondary forests. It plays an important role in the material cycle of forest ecosystems. The allocation of nutrient elements varied in the different organs of the trees. From Table 1, it can be observed that in *P. davidiana* trees the amounts of the elements N, P and Mg were high in leaves, branches and roots, but low in stems. The amount of K was higher in bark than in branches and stems. In *Q. wutaishancia* trees, the elements N, P and Mg had the highest concentration in leaves and branches, next in bark and roots and lowest in stems. The order in terms of amount of K is given as follows: leaves > bark > branches > stems > roots; the concentration of Ca was the highest in bark. Amounts of N, P, K, Mg in leaves of *Q. wutaishancia* trees were significantly higher than in other organs, which agrees with the results from Huang and Gao (1997).

Biodiversity of shrubs and grasses depends on the structure and community habitat of the tree layer in forest ecosystems. However, amounts of nutrients in shrub and grass layers were higher than in the tree layer due to the their rapid growth. For the grass layer, the amounts of nutrient elements are listed as: Ca > N > K > Mg > P (Table 1).

4.3 Accumulation and allocation of nutrient elements in natural secondary forests

The accumulation of nutrient elements in natural secondary forests is the product of biomass and the amounts of nutrient elements in all organs of the trees. The accumulation of nutrients is also the result of interaction between forest communities and forest habitats. In our study of the natural secondary forests, *P. davidiana* and *Q. wutaishancia* were taken as representative species due to their predominance in the forest. The accumulation of nutrient elements in the tree layer was calculated from the multiplication of the amount of nutrient elements by the biomass ratio of each tree organ. In the shrub layer, *S. trilobata* was taken as a representative species. The accumulations of trees, shrubs, grasses and litter are shown in Table 2. From Table 2, it can be seen that the accumulation of the five nutrient elements in the forest was 1089.82 kg/hm^2 (not including soil layer). The tree layer is the most important and active sub-system in forest systems. The primary purpose of production in tree subsystems is to fix energy and accumulate nutrients. The

Table 1 Amounts of nutrient elements in different layers of natural secondary forests

layer	species	organ	nutrient elements /%				
			N	P	K	Ca	Mg
tree	*Q. wutaishancia*	stem	0.31	0.03	0.21	0.76	0.05
		bark	0.72	0.04	0.32	2.45	0.14
		branch	0.79	0.06	0.27	2.26	0.14
		leaf	1.76	0.26	0.99	1.52	0.26
		root	0.60	0.05	0.09	1.36	0.05
		average	0.83	0.09	0.37	1.67	0.13
	P. davidiana	stem	0.23	0.03	0.16	0.64	0.06
		bark	0.62	0.08	0.53	2.11	0.16
		branch	1.29	0.13	0.50	2.17	0.21
		leaf	1.54	0.10	1.21	2.12	0.39
		root	1.01	0.10	0.50	1.99	0.25
		average	0.94	0.09	0.58	1.81	0.22
shrub		leaf	1.23	0.07	1.36	1.91	0.34
		branch	0.56	0.04	0.24	1.24	0.06
		root	1.03	0.09	0.48	2.33	0.36
		average	0.94	0.07	0.69	1.83	0.26
grass		above ground	1.17	0.07	0.88	1.06	0.15
		below ground	0.60	0.04	0.29	1.82	0.14
		average	0.88	0.05	0.59	1.44	0.14

Table 2 Biomass and nutrient element accumulation in different layers of natural secondary forests

layer	organ	biomass /(t·hm^{-2})	accumulation of nutrient elements /(kg·hm^{-2})					
			N	P	K	Ca	Mg	sum
tree	stem	7.61	17.50	2.16	11.95	48.77	4.31	84.68
	bark	2.07	12.90	1.69	10.91	43.66	3.36	72.52
	branch	3.03	38.67	3.92	15.12	65.79	6.40	129.91
	leaf	0.56	8.64	0.60	6.67	11.68	2.17	29.76
	root	3.35	33.58	3.29	16.61	66.24	8.25	127.97
	sum	16.61	111.29	11.65	61.27	236.14	24.49	444.84
shrub	leaf	0.38	4.63	0.27	5.13	7.20	1.29	18.51
	branch	5.14	28.92	2.03	12.34	63.72	3.28	110.30
	root	4.94	51.05	4.57	23.54	114.98	17.90	212.04
	average	10.46	84.60	6.87	41.02	185.90	22.47	340.85
grass	above ground	0.80	9.27	0.54	7.02	8.42	1.16	26.41
	below ground	3.81	22.96	1.55	11.04	69.48	5.34	110.37
	average	4.60	32.23	2.08	18.04	77.90	6.51	136.78
litter	branch	1.04	7.43	0.22	0.64	22.61	0.62	31.51
	root	3.37	27.93	1.61	8.21	88.31	9.78	135.84
	sum	4.41	35.36	1.83	8.85	110.91	10.40	167.35
soil/cm	0–10		2120.10	1015.04	24452.70	46907.87	14708.27	89203.98
	10–20		442.31	963.10	22703.50	59814.33	16487.88	100411.12
	20–40		713.93	924.53	23711.25	58670.76	12799.75	96820.22
	40–60		1225.27	1061.25	25312.56	65913.72	23116.19	116629.00
	60–80		492.26	1108.37	26489.11	69953.86	22809.02	120852.63
	80–100		376.89	1156.96	21691.65	68580.90	28245.73	120052.13
	sum		5370.75	6229.26	144360.78	369841.44	118166.85	643969.08

accumulation of nutrient elements in the tree layer was 444.84 kg/hm^2, accounting for 40.82% of the total accumulation of forests and 31.27%, 12.55% and 15.36% for the shrub, grass and litter layers, respectively. The order of accumulation of nutrient elements was Ca > N > K > Mg > P. The amount of nutrient elements in stems was the lowest (Table 1), but the biomass of stems was the highest. Thus, relatively large amounts of nutrients are accumulated in stems. The amount of nutrient elements in leaves was the largest, but their accumulation the lowest. The order of accumulation of nutrients in trees was: branches > roots > stems > bark > leaves. Accumulation of Ca accounted for 53.08% in the tree layer and 54.54% in the shrub layer.

Soil fertility is a basic characteristic of soil properties and quality. It has a great effect on community succession. Soil fertility reflects the relationship of a forest community and its soil and determines forest succession. In our study area, soil fertility is relatively low. The total accumulation of the five nutrient elements in the soil was 634.97 t/hm^2. All together, the nutrient elements in the soil layer account for over 95% of the total accumulation in forests, where N accounts for 95.32%, P for 99.64%, K for 99.91%, Ca for 99.84% and Mg for 99.95%. The low N accumulation may be the key factor inhibiting plant growth.

4.4 Accumulation characteristics of nutrient elements in soil layer of natural secondary forests

Nutrient elements are mainly absorbed from the soil by roots and accumulated according to requirements of the trees (Gao et al., 2002). The relationship between amount of nutrient elements in plants and soils is the function of nutrient exchange between plants and soils. The amount of nutrient elements in plants depends on species and their organs and is closely related to the amount of available elements. Accumulation coefficients express the correlation of amounts of nutrient elements in plants and soils. An accumulation coefficient is determined from the element requirement of a plant, the status of elements and amounts in the soil, as well as the capacity of a plant to accumulate nutrients.

From Table 3, it can be seen that accumulation and accumulation coefficients of nutrient elements in different forest layers vary. The accumulation coefficients of N and P are the largest, which indicates that N and P are the elements most needed for plant growth. The accumulation coefficients of N, P and Mg in the tree layer are, ordered from high to low, as follows: leaves > branches > roots > bark > stems. The order of accumulation coefficients in the entire forest is: shrub layer > tree layer > grass

Table 3 Accumulation coefficients of soil nutrient elements in different organs and layers of natural secondary forests

layer	organ	accumulation coefficient /%				
		N	P	K	Ca	Mg
tree	stem	3.97	0.37	0.10	0.15	0.04
	bark	9.80	0.78	0.23	0.49	0.10
	branch	15.16	1.24	0.21	0.48	0.12
	leaf	24.11	2.31	0.61	0.39	0.22
	root	11.75	0.96	0.16	0.36	0.10
	sum	12.96	1.13	0.26	0.38	0.12
shrub	leaf	18.01	0.90	0.75	0.41	0.23
	branch	8.23	0.51	0.13	0.27	0.04
	root	15.12	1.19	0.26	0.50	0.25
	average	13.79	0.87	0.38	0.40	0.17
grass	above ground	17.07	0.87	0.49	0.23	0.10
	below ground	8.83	0.52	0.16	0.40	0.10
	average	12.95	0.69	0.32	0.31	0.10

layer and the distribution of elements is: N > P > Ca > K > Mg.

5 Conclusions and discussion

Our studies on biomass and its allocation, nutrient elements and their allocation and accumulation in natural secondary forests of the Loess Plateau show that the total biomass of the forest ecosystem is 36.087 t/hm^2, where the tree layer accounts for 46%, the shrub layer for 29%, the herb layer for 13% and the litter layer for 12%. The accumulation of nutrient elements in the tree layer, ordered from high to low is: branches > roots > stems > bark > leaves. Accumulation of the five nutrient elements in the forest was 1089.82 kg/hm^2 (not including the soil layer). The accumulation of nutrient elements in the tree layer was 444.84 kg/hm^2, accounting for 40.82% of the total accumulation in the forest and 31.27%, 12.55% and 15.36% for shrubs, grasses and the litter layer. The order of accumulation of nutrient elements is: Ca > N > K > Mg > P. The order of accumulation of nutrients in trees is: branches > roots > stems > bark > leaves. The total accumulation of these five nutrient elements in the soil is 634.97 t/hm^2. Each nutrient element in the soil layer accounted for over 95% of their total accumulation in the forest, i.e., N accounts for 95.32%, P for 99.64%, K for 99.91%, Ca for 99.84% and Mg for 99.95%. The soil layer is the main nutrient element storage pool in the area of the Loess Plateau, which agrees with the results from Zhang and Shangguan (2006). The accumulation coefficients of N, P and Mg in the tree layer are: leaves > branches > roots > bark > stems. The order of accumulation coefficients is: shrub layer > tree layer > grass layer and N > P > Ca > K > Mg. In general, the amount of Ca is quite high in the loess area, but in our study, the accumulation coefficient of Ca turned out to be rather modest. This could be caused by artificial cultivation methods in plantations, leading to a change in soil fertility. In general, the total biomass of natural secondary forests is low in the loess area due to drought. The growth of the shrub layer is vigorous, so intervention will benefit growth of the understory. Improvement of the shrub biomass will play an important role in nutrient cycling and water conservation of secondary forests in the Loess Plateau.

Acknowledgements This study was supported by the National Science & Technology Supporting Program of China (No. 2006BAD03A1206) and the National Stationary Station of Forest Ecosystem in Jixian County, Shanxi Province (No. 200702).

References

Chen C Y, Zhang J W (1988). Study on accumulation, distribution and circulation pattern of nutrient elements of mixed stands of *Cunninghamia lanceolata* and *Michelia macclurei* forest ecosystem. Chin J Ecol, 7 (4): 7–13 (in Chinese)

Chen F M, Lin X W (1994). Development of research on forest nutrient cycling related to recent issue of forest-environment. J Anhui Agricult Univ, 21(1): 67–70 (in Chinese)

Chen L Z, Huang J H (1997). Study on the Structure and Function of Forest in the Warm Zone. Beijing: Science Press, 265–271 (in Chinese)

Chen L Z, Huang J H, Yan C R (1997). Nutrient Cycling in Forest Ecosystem in China. Beijing: China Meteorological Press (in Chinese)

Bazilevieh N I, Podin L E (1966). The biological cycle of nitrogen and ash elements in plant communities of the tropical and subtropical zones. For Abstr, 27: 257–268

Dan B (1986). Forest Nutrient Management. New York: John Wiley & Sons

Ebermayer E (1976). Die Qesamte Lehre der Woldstreu mit Rucksicht

Aufdie Chemische Static des Woldbaues. Berlin: Julius Spriuger, 116

Gao J R, Zhang D S, Xiao B, Niu J Z (2002). Nutrient distribution and accumulation pattern of Chinese pine plantation ecosystems in the Loess Region. J Beijing For Univ, 24(1): 26–30 (in Chinese)

Huang J H, Gao X M (1997). A comparative study on species diversity in zonal forest communities. Acta Ecol Sin, 17(6): 611–618 (in Chinese)

Li J (2007). Research progress on potassium, calcium and magnesium nutrients in plants. Fujian Sci Technol Rice Wheat, 25(1): 39–43 (in Chinese)

Liu Z W (2002). Research method of litter decay rate in forest ecosystems. Acta Ecol Sin, 22(6): 954–956 (in Chinese)

Shen G F, Dong S R, Nie D P (1985). Studies on the nutrient cycling of *Pinus tabulaeformis* plantation I: Content and distribution of nutrient elements. J Beijing For Coll, 7(4): 1–14 (in Chinese)

Shi J, Liu J Y, Gao Z Q, Cui L L (2004). Research advances of the influence of afforestation on terrestrial carbon sink. Prog Geogr, 23 (2): 58–67 (in Chinese)

Tsutuumi T, Kawahara T, Shidei T (1968). The circulation of nutrients in forest ecosystems (I): On the amount of nutrients contained in the above-ground parts of single tree of stand. Jap For Soc, 150 (3): 66–74.

Young H E (1967). Symposium on primary productivity and mineral cycling in natural ecosystems. Orono, USA: University Maline Press

You X H, Nie L H (2005). Research progress in the plant heavy metal (Cu, Zn, Cd) pollution of forestry ecological system. J Fujian For Sci Technol, 32(3): 154–159 (in Chinese)

Yu G R (2003). Global Change and Carbon Cycle and Carbon Storage in Terrestrial Ecosystem. Beijing: China Meteorological Press, 44–77 (in Chinese)

Watson R T, Noble I, Bolin B, Ravindranath N H, Verardo D, Andrasko K (2000). Land-use Change and Forestry. Cambridge: Cambridge University Press

Zhang N, Liang Y M (2002). Studies on the below-ground above-ground biomass ratio of natural grassland in Loess Hilly Region. Acta Pratacult Sin, 11(2): 72–78 (in Chinese)

Zhang Z, Zhu J Z, Zhu Q K, Zhang Y Q, Li Y F (2005). Topographic variation pattern of landscape distribution in Caijiachuan watershed, the Loess Plateau of western Shanxi Province. J Beijing For Univ, 27 (2): 43–48 (in Chinese)

Zhang X B, Shangguan Z P (2006). Nutrient distributions and bio-cycle patterns in both natural and artificial *Pinus tabulaeformis* forests in Hilly Loess Regions. Acta Ecol Sin, 26(2): 373–382 (in Chinese)

Zhao H B, Liu G B, Hou X L (2006). Characteristics of nutrient cycling of different vegetation types in the Zhifanggou Watershed on the Loess Hilly Region. Acta Pratacult Sin, 15(3): 63–69 (in Chinese)