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Nutrient characteristics of throughfall and stemflow in the natural forest of *Pinus densata* in the Tibetan plateau

Características de los nutrientes a través del follaje y del tronco en el bosque natural de *Pinus densata* en la altiplanicie del Tibet

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Abstract. Precipitation, throughfall and stemflow were monitored and collected through the rainy season on a natural forest ecosystem of *Pinus densata* in the Gongbu Nature Reserve in Tibet. The concentrations of N, P, K, Na, Ca, Mg, Si, Mn, Fe, S, Zn and Cu were analyzed in the precipitation, throughfall and stemflow waters, Thereafter, and according to the amount of water of precipitation, throughfall and stemflow, the net input was calculated for each nutrient in the forest. The results showed that: (1) During the entire rainy season, the average concentration of different nutrients in the precipitation of the *Pinus densata* forest was ranked in the following order: N>K>Na>Ca>Mg>Si>P>Mn>Fe>S>Zn>Cu. The concentration of N 29.6145 mg/L, and that of Cu was only 0.1017 mg/L. (2) The average concentration of these nutrients in throughfall followed the order: N>Na>Ca>K>Mg>Si>P>Mn>Fe>S>Zn>Cu. The highest concentration was 11.2843 mg/L for N, and the lowest was only 0.0937 mg/L for Cu; the difference between the two was 120.4 times. (3) The order of N>K>Ca>Na>Mg>Zn>P>Si>Mn>Fe>Cu>S was found for the nutrient concentration in stemflow. The concentration of N (20.5096 mg/L) was 105.2 times higher than that of the lowest nutrient (S: 0.1949 mg/L). (4) As a whole, every nutrient was quite different on average for the stemflow, throughfall and precipitation. The concentration of Na, Ca, Mg and Zn followed ste mflow>throughfall>precipitation. During the entire rainy season, the net input (kg/hm^2) of nutrients in the *Pinus densata* forest was Na>S i>Ca>Mg>K>Zn>Fe>S>Cu>P>Mn>N, and the net input of N was negative.

Keywords: *Pinus densata*; Natural forest; Precipitation; Throughfall; Stemflow; Nutrient characteristics.

Resumen. La precipitación, la precipitación que atraviesa y corre por encima del follaje vegetal, y aquella que corre por las ramas y el tronco se juntaron durante la estación lluviosa en un ecosistema de bosque natural de *Pinus densata* en la reserva natural Gongbu en el Tibet. Las concentraciones de N, P, K, Na, Ca, Mg, Si, Mn, Fe, S, Zn y Cu se analizaron en la precipitación, la precipitación que atraviesa y corre por encima del follaje vegetal, y aquella que corre por las ramas y el tronco. Luego, y de acuerdo a la cantidad de estas tres clases de precipitación se calculó la entrada neta de cada nutriente en el bosque. Los resultados mostraron que: (1) Durante toda la estación lluviosa, la concentración promedio de los diferentes nutrientes en la precipitación en el bosque de *P. densata* siguió el siguiente orden: N>K>Na>Ca>Mg>Si>P>Mn>Fe>S>Zn>Cu. La concentración de N fue 29,61 mg/L y la de Cu de solo 0,10 mg/L; (2) La concentración promedio de estos nutrientes en la precipitación que atravesó el follaje y corrió sobre el mismo siguió el siguiente orden: N>Na>Ca>K>Mg>Si>P>Mn>Fe>S>Zn>Cu. La concentración más alta fue 11,28 mg/L para N, y la más baja de solo 0,09 mg/L para Cu; la diferencia entre el N y el Cu fue de 120,4 veces; (3) El orden de N>K>Ca>Na>Mg>Zn>P>Si>Mn>Fe>Cu>S fue obtenido en la precipitación que corrió por ramas y tronco. La concentración de N (20,51 mg/L) fue 105,2 veces más alta que aquella del nutriente (S) en menor concentración (0,19 mg/L). (4) En general, cada nutriente fue en promedio bastante diferente en los tres tipos de precipitación. Las concentraciones de Na, Ca, Mg y Zn siguieron el orden de agua que corrió por ramas y tronco > agua que atravesó y corrió por encima del follaje de *Pirus densata* > agua de precipitación natural. Durante toda la estación de crecimiento, la entrada neta de nutrientes (kg/hm^2) en el bosque de *P. densata* fue Na>Si>Ca>Mg>K>Zn>Fe>S>Cu>S>P>Mn>N; la entrada neta de N fue negativa.

Palabras clave: *Pinus densata*; Bosque natural; Precipitación; Precipitación que atraviesa y corre por encima del follaje vegetal; Precipitación que corre por las ramas y el tronco; Características de nutrientes.

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INTRODUCTION

The relationship and interactive processes of forest and water are not only a key issue of concern today but also one of the core problems in the research field of forest ecology (Hou & Wei, 2001; Aboal et al., 2002; Dezzeo & Chacón, 2006; Levia et al., 2010). For forest ecosystems, precipitation is the main form of nutrient input. Nutrient input is not only of great significance for the development and succession of forest communities, but also an important part of the forest ecosystem biochemical cycles (Potter & Swank, 1991; Balestrini & Tagliaferri, 2001; Levia, 2003; Rodrigo et al., 2003; Iida et al., 2005). Precipitation is partly intercepted by the canopy when it passes through it, but most of the precipitation into the forest flows along the branches and trunks, and forms the stemflow. Precipitation which directly runs through the canopy forest is in the form of throughfall. In recent years, some research has been reported on nutrient content and input dynamic of throughfall and stemflow on forest ecosystems. They have been greatly concerned and made some achievements. There are a multiplicity of conclusions because of differences in the study time, space and forest species (Huang et al., 2000; Hou & Wei, 2001; Liu & Sheu, 2003; Tian & Xiang, 2003; Xiaojun et al., 2003; Gong, 2005; Laclau et al., 2005; Kang, 2006; Sheng et al., 2008;). These studies enriched the research field. At the same time, they provided scientific background information for analyzing and managing nutrients on forest ecosystems.

Pinus densata is a sun tree, mainly growing at 2600-3500 m.a.s.l. in the mountains, terraces and gorges either as a pure forest or mixed with *Picea likiangensis* var. *linzhiensis* in Tibet. At present, many studies have been carried out on *Pinus densata*, including fruit characteristics, introduction and afforestation (Zeng & Wang, 2006; Mao et al., 2007; Fei-Fei et al., 2008; Lu & Pan, 2008; Pu et al., 2008), but the forest hydrology has not been reported. The *Pinus densata* forest plays an important role in regulating water balance and conserving soil and water in the Brahmaputra middle course area in Tibet. Therefore, precipitation, throughfall and stemflow coming from the *Pinus densata* forest on the Gongbu Nature Reserve in Tibet were studied in this paper. The chemical properties of its water, including the size and rule of nutrient inputs were analyzed. The results laid the foundation for further studying hydrological processes, the water conservation function of forest ecosystems, as well as on the evaluation of the Tibetan plateau as an ecological security barrier.

MATERIALS AND METHODS

Study area. The study site (29° 39' 82' N, 94° 20' 52' E) locates at the Gongbu Nature Reserve in Tibet. The Reserve includes 18 townships situated at the south margin of the Qinghai-Tibet plateau. Its area is 21626.38 km^2, and its center is the confluence belt of the Brahmaputra and the Niyang River. The reserve belongs to a semi-humid monsoon climatic region, within a temperate zone. The dry and wet season are clearly demarcated. Mean annual temperature is more than 7 °C. The frostless period is above 150 days. Annual precipitation is from 500 to 700 mm, 75% of it falling from June to September, while relative humidity is 50-75%. The soil is from brown to dark brown. The wild vascular plants in the Reserve are 1106 species. They belong to 417 genera and 101 families. There are 2 families, 6 genera and 9 species of gymnosperms and 79 families, 308 genera and 1024 species of angiosperms. Ferns reach 20 families, 31 genera and 73 species. A high percent of the total number of genera and species are endemic. The tree layer of the vegetation at the study site is *Pinus densata*, which is natural and not destructive. Their average stem diameter is 29.3 cm. The average height is 15.5 m. The canopy density is 0.7 and the density is 572 plants/hm^2. The shrub layer is mainly composed of *Quercus aquifolioides*, *Salix oritrepha*, *Cotoneaster obscurus*, *Potetilla fuuticosa* var. *albicans*, *Lonicera lanceolata*, *Rubus hypargyrus* var. *niveus*, *Beris uymbtllliflora*, *Spiraea myrtilloedes*, etc.; its coverage is about 30%. The herb layer mainly includes *Arundinella yunnanensis*, *Hypericum hookerianum*, *Eremopogon delavayi*, *Lris decora*, *Polygonatum cirrhifolium*, *Anemone rivularis*, and *Poa* sp. The herbaceous coverage is approximately 40%.

This work was conducted based on the Forestry Standards "Observation Methodology for Long-term Forest Ecosystem Research" of the People's Republic of China. Based on the overall investigation for the vegetation in the study area, a standard plot of 50 m × 50 m was set in the experimental field of the *Pinus densata* forest. Throughfall and stemflow were monitored and sampled in the plot, as well as the precipitation near the plot.

Water sampling. Groove-type collectors (length: 200 cm, width: 30 cm, depth: 20 cm), made of PVC material, were immersed continuously during 24 hours in 3% hydrochloric, and thereafter washed over 3 times in distilled water. Other apparatus were managed in the same way. Five such collectors were installed randomly in the plot to receive the tree throughfall in a way that the influence of herbaceous and shrub by vegetation was avoided. The distance between the collectors and the ground was no less than 30 cm, and a low-angle was kept from the horizontal. A small mouth was opened in the lower end of the collector to connect it with a 5L plastic bucket. Litter was cleaned up from the collectors before raining to alleviate its effects on the results. The amount of throughfall was the mean of five collectors; nutrient content was determined in the mixed sample. Three rain gauges were put in a forest gap near the plot to monitor and collect precipitation, and determine its nutrient content. According to the diameter distribution of *Pinus densata* in the plot, stemflow was monitored by using five standard trees. The specific methods were as follows: (1) cutting the plastic pipe whose diameter was 2 cm, fixing the pipe on the stema circle from up to spiral down in the 2 m height with a small nail; (2) sealing the interface between the tree and the pipe, connecting the end of the pipe to a 5L plastic bucket to collect the stemflow; (3) determining nutrient content in the sample; (4) observing the precipitation, throughfall and stemflow after each rainfall; (5) collecting the water samples to the determine nutrient content three times every mouth.

Sampling analysis. Concentrations and contents of twelve nutrient elements (N, P, K, Na, Ca, Mg, Si, Mn, Fe, S, Zn, Cu) were measured in the water samples. Measuring methods were as follows: N: Micro-kjeldahl method; P: Molybdenum-antimony anti-spectrophotometric method; K: Flame spectrophotography; S: barium sulfate turbidity; Na, Ca, Mg, Si, Mn, Fe, Zn, Cu: Atomic absorption Spectrometry. The net input of every element in the *Pinus densata* natural forest was calculated by the equation "net input = throughfall + stemflow - precipitation". Data processing and drafting were conducted by Excel 2010 and SPSS19.0.

RESULTS

Nutrient characteristics of precipitation. There was a great variation on each nutrient content in precipitation even in the same area at different periods. Also, there was a remarkable difference on nutrient concentrations each month. The change of every nutrient concentration in precipitation was very obvious at different months of the whole rainy season in the *Pinus densata* natural forest (Fig. 1), and Phosphorus had the greatest change in concentration, the maximum (6.7836 mg/L) was 8.1030 times the minimum (0.8375 mg/L) values. The ratio of the maximum and minimum was 7.4500 for N; the change was the least for S, where the ratio was only 1.4277. In the 12 nutrients, the maximum value (N: 55.7796 mg/L) was 1562.4538 times the minimum one (Cu: 0.0375 mg/L).The ratio order between the maximum and minimum contents of the same nutrient was P>N>Mn>Si>Mg>Cu>Fe>Ca>Zn>K>Na>S. The maximum N concentration appeared in September, while it was in June for S, Si, Fe and Zn, and July for Mn, Mg, Cu, Na, Ca and K. The minimum concentration value of Si occurred in July; N, P, K and Ca elements showed minimum concentrations in June, and Na, S, Mg, Zn, Fe, Cu and Mn showed them in September (Fig. 1).

The average concentration of each element was also very different in the entire rainy season: it was the largest for N (29.6145 mg/L) and the least for Cu (0.1017 mg/L); their ratio was 291.1234. The sequence of the mean concentration for each nutrient was N>K>Na>Ca>Mg>Si>P>Mn>Fe>S>Zn>Cu, and the concentrations of Fe, S, Zn and Cu were less than 0.5000 mg/L (Fig. 1).

Nutrient characteristics of throughfall. Throughfall landed directly to the surface of the forest land when precipitation passed through the canopy. The eluting, leaching and absorbing during rainwater and canopy surface implied a change in the nutrient concentration of throughfall (Fig. 2). This shows that each nutrient concentration in the throughfall of the *Pinus densata* natural forest changed greatly in different months. The concentration of Ca was the biggest change; the maximum value was 30.1952 times the minimum value. The lowest change was

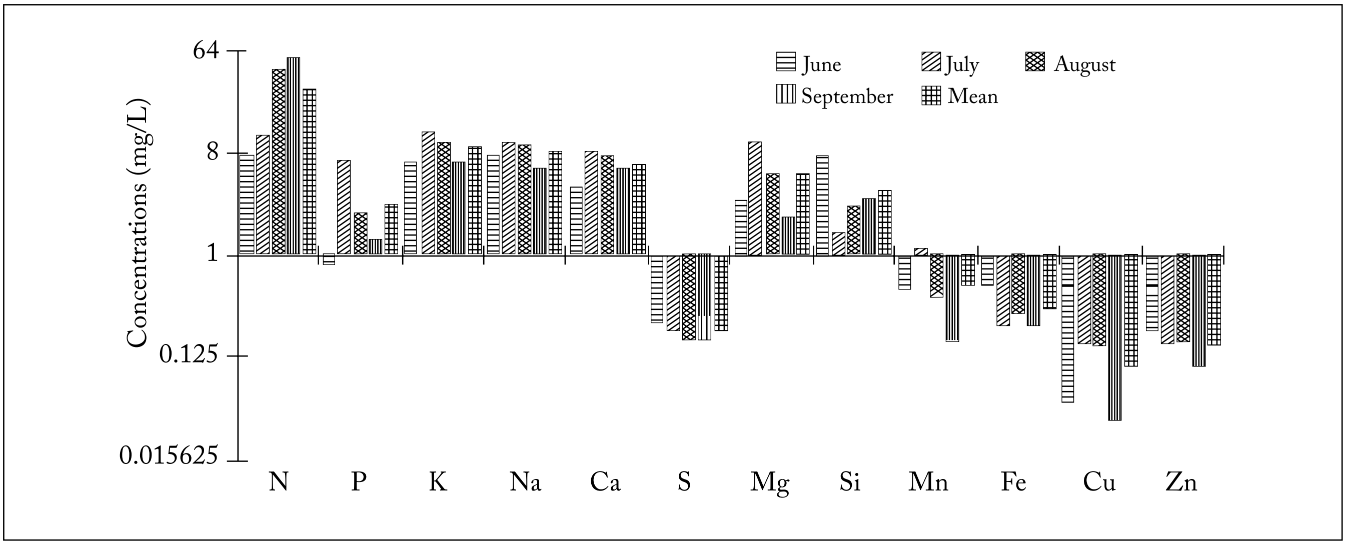

Fig. 1. The nutrient concentrations of the precipitation in the *Pinus densata* natural forest.
Fig. 1. Concentración de nutrients en la precipitación en un bosque natural de *Pinus densata*.

for the concentration of S, and its ratio was only 1.3453. The highest concentration (21.9803 mg/L) was for N, while the lowest (0.0253 mg/L) was for Cu; their ratio was 868.7866. The largest concentration values for S, Fe, Zn and Si were in June; the largest values for N, P, K, Na, Ca and Mg were in August, and the greatest Mn concentration was in July. The minimum concentration values of N, P, K, Na, Ca, Mg and Cu happened in June, those of S, Si and Mn occurred in September, and those of Fe and Zn appeared in July. The ratio between the maximum and minimum contents of the same element was Ca>Na>K>Mg>P>Cu>Zn>N>Mn>Fe>Si>S in the throughfall.

The N concentration was the greatest (11.2843 mg/L) among all average nutrient concentrations in the entire rainy season, while the Cu one was the lowest (0.0937 mg/L); the difference between the two was 120.4298 times. The concentration sequence of each element was N>Na>Ca>K>Mg>Si >P>Mn>Fe>S>Zn>Cu, and Fe, Mn, Zn, Cu, and S were less than 0.5000 mg/L.

Compared with precipitation, each nutrient concentration of the throughfall changed in different months of the rainy season. The concentration of many nutrients was increased, such that of S and Zn in June; N, Na and Si in July; P, K, Na, Ca, S, Mg, Si, Mn and Zn in August, and Na, Ca, S, Mg, Si, Fe, Cu and Zn in September. The increasing ranges were different: the maximum amplitude was 252.1008% while the minimum was only 0.4725%. The other nutrient concentrations showed a negative growth: the declining extent was 1.7210%-90.0288%. Regarding the mean concentration in the rainy season, Na, Ca, S, Mg, Si and Zn were reduced in the range of 5.8400% to 49.5100% in the throughfall; the other nutrients were obviously increased in the range of 7.8889% to 61.8962%.

Nutrient characteristics of stemflow. Each nutrient concentration in the stemflow of the *Pinus densata* natural forest showed differences in each month, and differences were lower than those of throughfall based on Figures 2 and 3. Phosphorus showed the greatest change; the maximum change was 11.6320 times that of the minimum. The lowest change was for S, and the ratio was only 1.5063. The peak concentration was 27.1144 mg/L for N, while the least concentration was for S (0.1479 mg/L), and their ratio was 183.3293 (Fig. 3). The peak concentrations of K, Na, Ca, S, Mn, Fe, Zn and Mg were in June, while those of N, P and Si occurred in July, and that of Cu in August. The valley concentrations of N, P and Cu occurred in June, while those of Ca and Zn in July, Mn in August, and K, Na, S, Mg, Si and Fe in September (Fig. 3). The order of P>N>Mn>Si>Mg>Cu>Fe>Ca>Zn>K>Na>S was for the ratio between the maximum and minimum concentrations within the same nutrient.

Regarding the mean concentration in the rainy season, the maximum concentration (20.5096 mg/L) was for N and the minimum (0.1949 mg/L) for S. Their difference was 105.2314 times. The mean concentration sequence was N>K>Ca>Na> Mg>Zn>P>Si>Mn>Fe>Cu>S. The concentrations of Mn, Fe, Cu and S were relatively low, and their values were 0.4162, 0.2952, 0.2430 and 0.1949 mg/L, respectively.

Compared with precipitation, the concentration of each nutrient on stemflow was different in every month. The concentrations of P, K, Cu and Zn increased clearly in all months; that of N increased in June and July, while those of Na, Ca and Mg increased in June, August and September, Mn in June and September, Fe in August, Si and S in July. While the maximum increase rate was 6012.6336% for Zn in September, the mini-

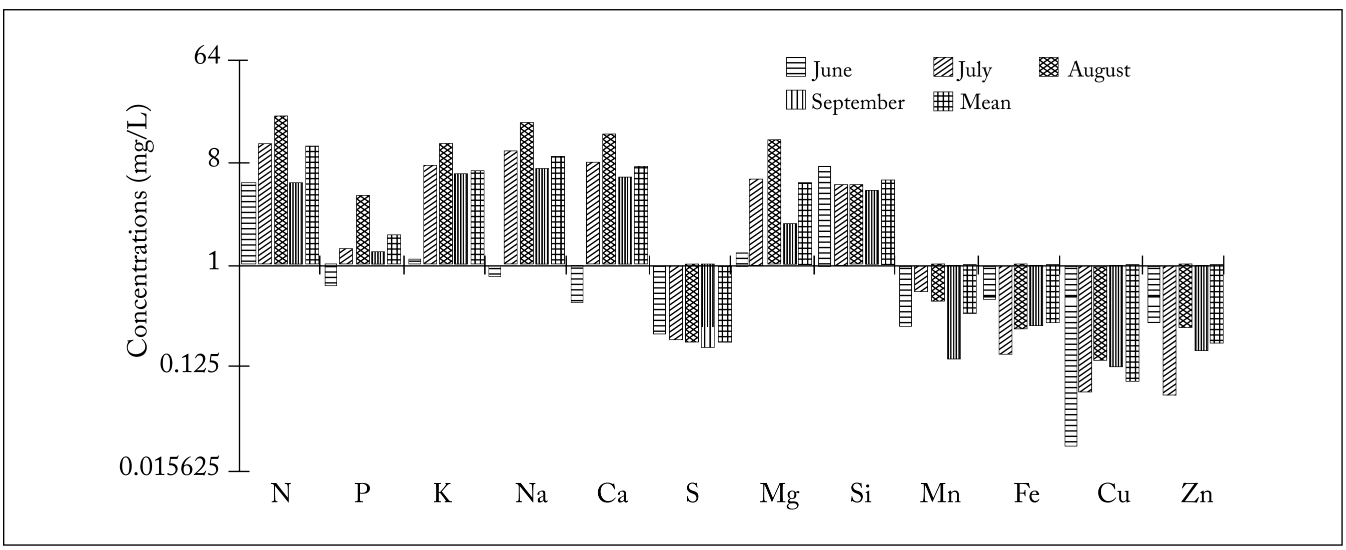

Fig. 2. The nutrient concentrations of the throughfall in the *Pinus densata* natural forest.
Fig. 2. Concentración de nutrients obtenida bajo el follaje de un bosque natural de *Pinus densata*.

mum was only 3.4873% for S in July. Other nutrients showed all negative values in other months. The maximum reduction rate was 63.9501% for N in September, and the minimum was merely 5.3190% for S in August. Regarding the mean concentration in the rainy season, N, S, Si, Mn and Fe decreased in extent from 5.0190% to 30.7448%; at the same time, other nutrients increased in the order of Zn>Cu>Mg>P>Ca>K>Na.

Compared with throughfall, concentrations of N, P, Cu and Zn all increased in stemflow in every month, but Si showed a decrease in every month. Other nutrients either increased or decreased in different months. In the entire rainy season, the average concentrations of S, Si and F decreased, while that of the other nutrients increased.

Nutrient input characteristics of forest. The monitoring results showed that the stemflow accounted for 1.32% of the precipitation, and throughfall was 73.11% of it in the forest ecosystem of *Pinus densata*. The net input was calculated by the equation "net input = throughfall + stemflow - precipitation" (Table 1). The data showed the input from different water sources was different. The input of nutrient elements in the precipitation followed the decreasing tendency of N>K>Na>Ca>Mg>Si>P>Mn>Fe>S>Zn>Cu; the total amount was 153.6934 kg/hm^2. The greatest contribution to this total amount was from N with 69.0504 kg/hm^2. Cu contributed only 0.2732 kg/hm^2 to this total. The nutrient input in the throughfall was in the order of N>Na>Ca>K>Mg>Si>P>Mn>Fe>S>Zn>Cu; the total input was 164.8615 kg/hm^2, where N was 38.4717 kg/hm^2, and Cu was 0.3195 kg/hm^2. In the stemflow, the order was N>K>Ca>Na>Mg>Zn>P>Si>Mn>Fe>Cu>S; the total input was 4.8353 kg/hm^2; 1.2625 kg/hm^2 from this input was N; S was 0.1020 kg/hm^2. The net input of nutrients in the rainy season was as follows: Na>Si>Ca>Mg>K>Zn>Fe>S>Cu>P>Mn>N, and that of N was negative (-29.3162 kg/hm^2).

DISCUSSION

We found that the mean concentration for every nutrient in the precipitation, throughfall and stemflow was different in each month. This phenomenon could be explained by a function relation between the atmospheric rainfall and the tree surface; the relation included elution and adsorption etc. (Potter & Swank, 1991). Nutrient enrichment occurred in the throughfall and stemflow when elution was more than adsorption. In addition, the nutrient input was affected by other factors such as rainfall, rainfall intensity, rainfall continuity, rain angle, crown size, branch shape, branch angle, bark, species composition, stand density and canopy structure, and the nutrient content of atmospheric rainfall (Elewijck, 1989; Hanchi & Rapp, 1997; Marin et al., 2000; Park & Cameron, 2008; Cattan et al., 2009). Sampling methods and scale are future studies.

The average concentration of each nutrient was very different in the precipitation. The maximum value was 29.6145 mg/L for N; the minimum was only 0.1017 mg/L for Cu, being the former 291.1234 times greater than the latter. The content sequence in the precipitation was N>K>Na>Ca>Mg>Si>P>Mn>Fe>S>Zn>Cu. Among them, Mn, Fe, S, Zn and Cu were less than 1.00 mg/L.

In the throughfall, the maximum concentration was 11.2843 mg/L for N, the minimum was 0.0937 mg/L for Cu,

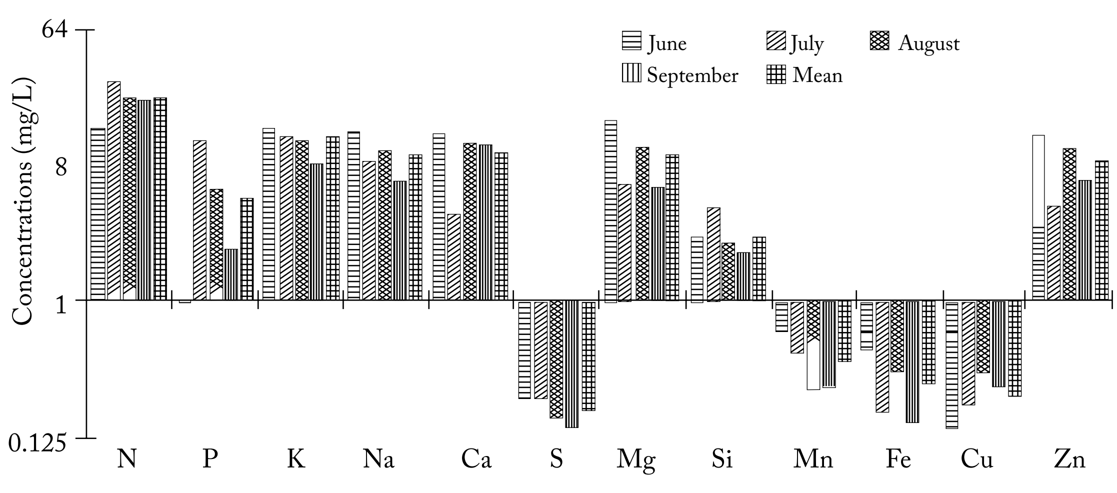

Fig. 3. The nutrient concentrations of the stemflow in the *Pinus densata* natural forest.
Fig. 3. Concentración de nutrientes en el agua de precipitación luego que la misma ha recorrido las ramas y el tronco en un bosque natural de *Pinus densata*.

Table 1. Nutrient input (kg/hm²) in the *Pinus densata* natural forest during the rainy season.
Tabla 1. Entrada de nutrients (kg/hm²) en un bosque natural de *Pinus densata* durante la estación lluviosa.

Item	N	P	K	Na	Ca	S	Mg	Si	Mn	Fe	Cu	Zn
Precipitation	69.0504	6.5709	20.5110	18.9813	14.7752	0.4785	11.9441	8.6971	1.2818	0.7807	0.2372	0.3853
Throughfall	38.4717	6.3042	22.8622	30.3746	24.5884	0.7405	19.1747	19.0127	1.2629	1.0444	0.3195	0.7056
Stemflow	1.2625	0.3134	0.7208	0.5900	0.5978	0.0120	0.5856	0.1748	0.0256	0.0182	0.0150	0.5197
Net input	-29.3162	0.0467	3.0720	11.9833	10.4109	0.2741	7.8162	10.4904	0.0067	0.2819	0.0972	0.8401

the ratio of the two was 120.4298. The order for each nutrient content was N>Na>Ca>K>Mg>Si>P>Mn>Fe>S>Cu>Zn. The average concentrations of Na, Ca, S, Mg, Si and Zn in throughfall were from 5.84% to 49.51%, lower than those in precipitation. The concentration of the other nutrients in the throughfall increased from 7.8889% to 61.8962% with respect to values in precipitation.

In the stemflow, while N had the maximum concentration (20.5096 mg/L), S had the minimum concentration (0.1949 mg/L); their ratio was 105.2314. The average concentration ranked in the order of N>K>Ca>Na>Mg>Zn>P>Si>Mn>Fe>Cu>S. Compared with precipitation, the concentrations of N, S, Si, Mn and Fe were all reduced in stemflow in a ratio from 5.0190% to 30.7448%. The other nutrients were increased in the order of Zn>Cu>Mg>P>Ca>K>Na. However, except for S, Si and Fe, all other nutrients increased in the stemflow compared with the throughfall.

Every nutrient was obviously different on average in the stemflow, throughfall and precipitation. The order for N and Mn were precipitation>stemflow>throughfall. Nutrients such as P, K and Cu followed the order of stemflow>precipitation>throughfall. Sodium, Na, Ca, Mg and Zn were stemflow>throughfall>precipitation, while S and Si were throughfall>precipitation>stemflow. Finally, Fe was precipitation>throughfall>stemflow.

The net input sequence of nutrients from the three water sources was Na>Si>Ca>Mg>K>Zn>Fe>S>Cu>P>Mn>N in the study *Pinus densata* forest. The net input of N was negative.

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REFERENCES

Aboal, J.R., M.S. Jiménez, D. Morales & J.M. Hernández (2002). Net below canopy fluxes in Canarian laurel forest canopies. *Journal of Hydrology* 264: 201-212.

Balestrini, R. & A. Tagliaferri (2001). Atmospheric deposition and canopy exchange processes in alpine forest ecosystems (northern Italy). *Atmospheric Environment* 35: 6421-6433.

Cattan, P., S.M. Ruy, Y.M. Cabidoche, A. Findeling, P. Desbois & J.B. Charlier (2009). Effect on runoff of rainfall redistribution by the impluvium-shaped canopy of banana cultivated on an Andosol with a high infiltration rate. *Journal of Hydrology* 368: 251-261.

Dezzeo, N. & N. Chacón (2006). Nutrient fluxes in incident rainfall, throughfall, and stemflow in adjacent primary and secondary forests of the Gran Sabana, Southern Venezuela. *Forest Ecology & Management* 234: 218-226.

Elewijck, L.V. (1989). Influence of leaf and branch slope on Stemflow amount. *Catena* 16: 525-533.

Fei-Fei, H.E., L.I. Yong-Mei & L.I. Cui-Ping (2008). On *Pinus densata* seedling substrates of ecological forest in westnorth Yunnan. *Journal of Hunan Agricultural University* 34: 631-634.

Gong, H. (2005). Nutrient Characteristics of Throughfall and Stemflow in Three Forests at the Subalpine of Western Sichuan. *Scientia Silvae Sinicae* 41: 14-20.

Hanchi, A. & M. Rapp (1997). Stemflow determination in forest stands. *Forest Ecology & Management* 97: 231-235.

Hou, B.F. & H. Wei (2001). Estimation of dry deposition and canopy exchange in Chinese fir plantations. *Forest Ecology & Management* 105: 153-166.

Huang, J.H., L.I. Hai-Tao, X.G. Han & L.Z. Chen (2000). Nutrient characteristics of stemflow and throughfall in two coniferous forest ecosystems. *Acta Phytoecologica Sinica*.

Iida, S.I., T. Tanaka & M. Sugita (2005). Change of interception process due to the succession from Japanese red pine to evergreen oak. *Journal of Hydrology* 315: 154-166.

Kang, W. (2006). Effects of Canopy Interception on Water and Nutrient Cycling in the Chinese Fir Plantation Ecosystem. *Scientia Silvae Sinicae* 42: 1-5.

Laclau, J.P., J. Ranger, P. Deleporte, Y. Nouvellon, L. Saintandre, S. Marlet & J.P. Bouillet (2005). Nutrient cycling in a clonal stand of *Eucalyptus* and an adjacent savanna ecosystem in Congo. 3. Input-output budgets and consequences for the sustainability of the plantations. *Forest Ecology & Management* 210: 375-391.

Levia, D.F. (2003). Winter stemflow leaching of nutrient-ions from deciduous canopy trees in relation to meteorological conditions. *Agricultural & Forest Meteorology* 117: 39-51.

Levia, D.F., J.T.V.S. Ii, S.M. Mage & P.W. Kelley-Hauske (2010). Temporal variability of stemflow volume in a beech-yellow poplar forest in relation to tree species and size. *Journal of Hydrology* 380: 112-120.

Liu, C.P. & B.H. Sheu (2003). Dissolved organic carbon in precipitation, throughfall, soil solution, and stream water at the Guandaushi subtropical forest in Taiwan. Progress in Biophysics & Molecular Biology 172: 315-325.

Lu, S.H. & Z.H. Pan (2008). Distribution Pattern of *Pinus densata* Population in the Southeast Tibet. *Journal of Northeast Forestry University* 36: 22-24.

Mao, J.F., L.I. Yue, Y.J. Liu & H. Liu (2007). Cone and seed characteristics of *Pinus densata* and their adaptive fitness implications. *Journal of Plant Ecology* 31: 291-299.

Marin, C.T., W. Bouten & J. Sevink (2000). Gross rainfall and its partitioning into throughfall, stemflow and evaporation of intercepted water in four forest ecosystems in western Amazonia. *Journal of Hydrology* 237: 40-57.

Park, A. & J.L. Cameron (2008). The influence of canopy traits on throughfall and stemflow in five tropical trees growing in a Panamanian plantation. *Forest Ecology & Management* 255: 1915-1925.

Potter, C.S. & W.T. Swank (1991). Atmospheric deposition and foliar leaching in a regenerating Southern Appalachian forest canopy. *Journal of Ecology* 79: 97-115.

Pu, W., L. Wang & X. Shao (2008). Reconstruction of summer temperature variation from maximum density of alpine pine during 1917–2002 for west Sichuan Plateau, China. *Journal of Geographical Sciences* 18: 201-210.

Rodrigo, A., A. Àvila & F. Rodà (2003). The chemistry of precipitation, throughfall and stemflow in two holm oak (*Quercus ilex* L.) forests under a contrasted pollution environment in NE Spain. *Science of the Total Environment* 305: 195-205.

Sheng, H.C., T.J. Cai, D.G. Zhu, L.I. Hua & W.U. Xiu-Juan (2008). Nutrient Characteristics of Through-all and Stem-flow in Virgin Forest of Pinus koraiensis. *Journal of Soil & Water Conservation* 22: 47-51.

Tian, D.L. & W.H. Xiang (2003). Nutrient characteristics in hydrological processes of Chinese fir plantation ecosystem. *Acta Ecologica Sinica* 23: 1369-1376.

Xiaojun, Y.U., S. Wang, S. Deng & X. Zhang (2003). Nutrient characteristics of stemflow and throughfall in evergreen broad-leaved forest and *Cunninghamia lanceolata* plantation forest. *Chinese Journal of Ecology* 22: 7-11.

Zeng, Q.Y. & X.R. Wang (2006). Divergence in structure and function of tau class glutathione transferase from *Pinus tabulaeformis*, *P. yunnanensis* and *P. densata*. *Biochemical Systematics & Ecology* 34: 678-690.