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麻竹山地笋用林水文过程及养分动态

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摘要：在福建省南靖国有林场的小山城工区设置试验地，进行了麻竹林生态系统水文特征和养分动态研究。实验表明：在一定降雨量级范围内，林冠截留量随着降水量的增加而增加，且较小雨量级时增加较快，较大雨量级时增加较慢，并趋于一定值；林冠截留量与一次性降雨量的关系可以用 Richards 函数较好地拟合。由于雨季降雨量大，林冠截留、穿透水和茎流量都具有明显的季节性，穿透水和茎流量明显多于旱季，林冠截留率则明显小于旱季。全年林冠截留、穿透水和竹秆茎流量分别是 283.10、1720.45 和 99.09 mm。年均林冠截留率、穿透率和竹秆茎流率分别为 13.47%，81.82%和 4.71%。在养分动态方面，在实验地分别实施全翻、带翻及扩穴（即按农户常规土壤管理，每年 3 月扩穴，不深翻）3 种不同的土壤垦复措施，结果显示全翻垦复措施地表径流的 N，P，K 的流失量最大，其中又以中 K 的流失量最大（3.84 kg/hm²），N，P，K 的年流失量大小顺序为全翻＞带翻＞扩穴。就林地养分利用率而言，带翻是 3 种措施中最高的为 21.22%，其次为全翻为 20.46%，最小为扩穴 19.61%，且 N、P 和 K 的年盈余量也是 3 种措施中最少的，分别为 783.18 kg/hm²，120.68kg/hm² 和 184.50kg/hm²，所以带翻的经营方式，在带来最好的经济效益的同时，不至于显著提高水土流失，是值得推广的一种麻竹林经营方式。

关键词：麻竹；生态系统；水文；养分动态

Hydrological process and nutrient dynamics in mountainous bamboo-shoot-oriented *Dendrocalamus latiflorus* stand

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Abstract: The study on hydrological process and nutrient dynamics of *Dendrocalamus latiflorus* stand ecosystem was conducted in Nanjing National Forest Farm, Fujian Province. The results were presented in this paper. Within certain rainfall range, the canopy interception increased quickly with increasing rainfall during light rainfall events, but slightly during heavy rainfall events, and then tended to a fixed value. The relationship between canopy interception and precipitation was well simulated by the Richards Function. The canopy interception, through fall and stemflow exhibited significant seasonal dynamics, due to plentiful rainfall in wet season, the through fall and stemflow were much higher than those in dry season, while the canopy interception rate was much lower. The annual canopy interception amount, through fall and stemflow were 283.10 mm, 1720.45 mm, and 99.09 mm, respectively; and the annual average rate of canopy interception, through fall and stemflow were 13.47%, 81.82% and 4.71%, respectively. As to nutrient dynamics, 3 different ways of reclamation, overall ploughing, strip ploughing and ditch ploughing (regular management by farmers, only ditching around root zone in every March), were applied to the stands. The results showed that the annual loss of N, P, and K in surface runoff was the highest in over ploughed stand with K loss being the greatest among the three elements, 3.84 kg/hm², followed by strip ploughed stand and ditch ploughed stand. Concerning the nutrient utility efficiency of the stand, the highest of 21.22% occurred in strip ploughed stand, followed by overall ploughed stand of 20.46%, and ditch ploughed stand of 19.61%. Moreover, the annual surplus of N, P and K in

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strip ploughed stand were 783.18 kg/hm^2, 120.68 kg/hm^2, and 184.50 kg/hm^2, respectively, also being the lowest among three stands. In general, strip ploughing was worthy of being popularized in this region because it gained the highest economical profit without causing significantly increased soil erosion.

Key words: *Dendrocalamus latiflorus*; ecosystem; hydrological process; nutrient dynamic

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Forest hydrological effects play a very important role in forest ecological effects. As a key medium for nutrient cycle, water is the most active component in ecosystem, which can strongly influence nutrient cycle. Being an important active factor in hydrological cycle, forest functions best in water conservation and can significantly improve the conditions of water resource. Forest hydrological effect is not only an important subject of Forest Ecology and Forest Hydrology, but also a component of water resource study. Runoff is a main form of water movement and an element in water balance and nutrient cycle, which varies with multiple factors, such as precipitation, underlying surface and human disturbance. Surface runoff, the redistribution of through fall on the ground, is influenced by water potential and ground conditions. The nutrient content in surface runoff is related to surface runoff amount, forest site, management practices and stand growth[1~6].

Because of its high economic value, broad use, easy cultivation, fast growth and strong adaptability, *Dendrocalamus latiflorus becomes* an important planting bamboo species in tropics, south subtropics, and middle subtropics. In practice, it produces high economic, social and ecological benefit. Fujian lies in the middle and south subtropics with abundant water and heat resources. In the southeast of Fujian, an optimum place for the growth of *Dendrocalamus latiflorus*, such bamboo stands spread at an astonishing rate. However, knowledge of its cultivation in mountain still remains at perceptual level, and its biological and ecological characteristics has not been fully recognized. For the purpose of determining the feasibility and suitable way of soil preparation in *Dendrocalamus latiflorus* forest, three manipulations of overall ploughing, strip ploughing and ditch ploughing (regular management by farmers, only ditching around root zone in every March) were carried out in *Dendrocalamus latiflorus* stand to sutdy the physical and chemical properties of soil, soil erosion, and nutrient budgets in the ecosystem. Meanwhile, the hydrologic process and nutrient dynamic, such as the stemflow, through fall, canopy interception, water conserving capacity, and nutrient distribution and cycle in forest ecosystem, were also studied. The final objective is to develop a model for managing *Dendrocalamus latiflorus* forest to gain the best economic profits and better water and soil conservation in the southern subtropical area of China, and to provide a scientific basis for management of bamboo-shoot-oriented forest and protective forest.

1　Natural conditions of experimental stands

The e xperimental stands were established in Xiaoshancheng working district, Nanjing National Forest Farm, Nanjin, the southeast part of Fujian Province, with a latitude of 24°26 N ～24°59 N, a longitude of 117°20 E and an elevation of 280 m. Lying in the hilly region of the southern Fujian, the study area has a monsoon climate of South subtropics, humid all year around, warm in winter and cool in summer. Light, heat and water resources are very abundant. The annual average temperature is 21℃. The active accumulated temperature (higher than 10℃) is 5323.1～7512.7℃, and lasts 273～341d, with a short frost period. Annual precipitaion is between 1587.5 mm and 1879.6 mm, and mainly distributed in the period from March through August.. So Apr. 2001～May 2001 belongs to wet season in this paper. The soil is mountainous red soil derived from sandstone parent material, deep and acid with a pH of 4.57. The main major undergrowth is dominated by *Dicranopter dichotoma*, *Miscanthus floridulus*, *Rhodomyrtus tomentosa* and *Pteridophyta*. In gerneral, the southeastern part of Fujian Province is an optimum region for *Dendrocalamus latiflorus*, and the experimental site is suitable for the growth of *Dendrocalamus latiflorus* bamboo. The stand features of the experimental site are listed in Table 1.

Table 1　The stand features of the experimental stands

Treatments	Stand density (clump/hm^2)	Diameter (cm)	Height (m)	*LAI*	Biomass (t/hm^2)	Canopy density
Overall ploughing	400	6.52	14.8	4.8	38.59	0.70
Strip ploughing	400	6.84	15.2	5.5	41.73	0.75
Ditch ploughing	400	5.49	13.6	4.4	32.27	0.60

2 Research methods

2.1 Runoff plot

2.1.1 Experimental design

Experimental stands were established by transplantation of *Dendrocalamus latiflorus* in 1996. The planting density was 400 tree/hm^2, with a distance of 5 m between rows and lines. During the seedling stage, fertilization and weed clearing were carried out in spring once a year. At the end of May 2000, three ways of site preparation were overall ploughing together with thoroughly hoeing, strip ploughing at interval of 1 m, and ditch ploughing. After that, all the stands were managed by the same practices, fertilized 3 times a year, in middle March with Ca-Mg-P compound fertilizer of 4.7kg, peanut cake fertilizer of 6 kg, urea 1.1 kg, and 1000 mg/L hormone of 15 ml per clump, early June with urea of 2.1kg and KCL of 1kg per clump and late July with urea of 1.1kg per clump). Weed clearing and ditching around root zone were also done in March.

2.1.2 Establishment of runoff plot

Three runoff plots were built on a slope with a gradient of 21° in each stands. The runoff plot was 20 m long along the slope with a width of 5 m. To avoid leaking, drains were dug at upper sides and along the slope of the plot, and a water-collecting trough in inverse trapezoid shape was built at the bottom. Next to the trough was a main water-collecting pool, 1m in length, 1m in width and 1m in depth, with 9 diffluent holes set in the front side and 1 diffluent hole in the left side. A diffluent pool was built at the left of the main pool to collect water spilled from the main pool[7]. And the surface runoff amount was calculated by use of the following equation.

$$Q = 1 + 10X$$

Where Q is runoff amount, X is runoff amount collected in the diffluent pool (Unit: m^3).

2.2 Hydrological characteristics and nutrient dynamic

2.2.1 Measurement of surface runoff amount and analysis of N, P, K content in surface runoff

The runoff amount was measured and sampled after every rainfall event. The water samples were condensed to analyze the total N, total P and total K by regular soil analysis method[8~10].

2.2.2 Measurement of precipitation

The measurement of every rainfall and the collection of water sample were referred to the reference[11].

2.2.3 Measurement of through fall

Two sample clumps were selected, and 12 standard rain-gauges were placed on the ground by Grid Method in canopy projective area of each clump. Measurement of through fall was referred to the reference[12].

2.2.4 Measurement of stemflow

According to the reference[12], the stands were grouped with ages and diameter classes, and 1 sample tree was selected in each group. Finally, the amount of stemflow was calculated by weighted average method.

2.2.5 Canopy interception calculation

Canopy interception was calculated by the Water Balance Formula:

$$I = P - P_t - P_s$$

Where I is canopy interception, P is precipitation, P_t is through fall and P_s is stemflow.

3 Results and analysis

3.1 Nutrient dynamic of differently treated stands

3.1.1 N content of surface runoff

The duration of high N content in surface runoff around the year was from June to August 2000 and from March to May 2001, respectively, possible resulting from the fertilization of urea in middle March, early June and late July. Fertilization significantly enhanced N content in surface runoff of that month, and prolonged the effect to the next month.

N content in surface runoff in overall ploughed stand was higher than both strip ploughed and ditch ploughed stands in the year except Sep. 2000 and Mar. 2001. In overall ploughed stand, the nutrient retention capacity of soil declined because soil surface was loosen and deprived of the shelter of vegetation and litter, so available nutrient could be easily released from soil surface runoff. Comparatively, nutrients were lost at a low rate in ditch ploughed stand, and the N content in surface runoff peaked in Sep. 2000, because quite a part of the fertilizer remained in soil during the early and fast-growing period of shooting.

The highest value of N content in surface runoff occurred in June in overall ploughed stand, and in August both in strip ploughed stand and ditch ploughed stand (see figure 1).

In overall ploughed stand, the annual N output in surface runoff was 2.9930 kg/hm^2, the highest among 3 stands, 9.16 times as high as that in strip ploughed stand and 20.77 times as high as in ditch ploughed stand. The N output peaked in Aug 2000 in strip and ditch ploughed stand, but in Jun 2000 in overall ploughed stand, which reached as high as 2.0470 kg, 68.39% of its total annual amount (see table 1). Both the nutrient content and nutrient output in surface runoff in overall ploughed stand peaked earlier than in the other two stands. In conclusion, the overall ploughed stand had the highest rate and quantity for nutrient loss.

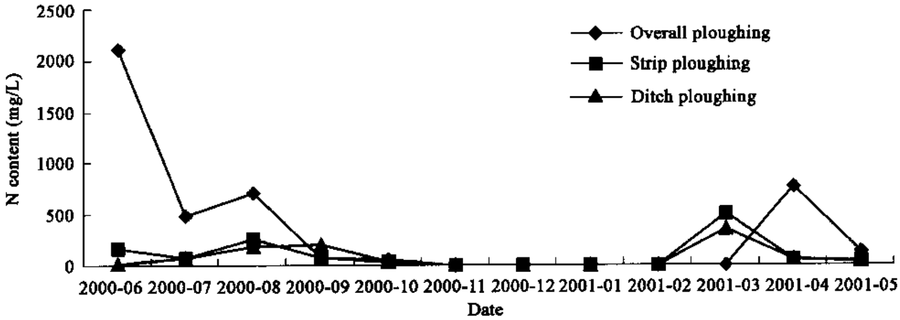

Fig. 1　Monthly dynamic of N content in surface runoff in different stands

3.1.2　P content in surface runoff

In contrast to N content, P content in surface runoff in overall ploughed and strip ploughed stand increased up to a peak, and then declined rapidly to a low level during annual wet season. However, the P content pattern in ditch ploughed stand appeared gear-form, with three peaks occurring in Jun 2000, Aug. 2000 and Mar. 2001, respectively (see fig. 1).

Among 3 different stands, the annual P output in surface runoff in overall ploughed stand was also the highest, 0.0343 kg/hm^2. The annual P output was 0.0206 kg/hm^2 in strip ploughed stand, and 0.0140 kg/hm^2 in ditch ploughed stand (see table 2). The P content peaked in Jun 2000 in overall ploughed and strip ploughed stands, and in Aug. 2000 in ditch ploughed stand. Generally, ditch ploughed stand had lower P loss than overall ploughed and strip ploughed stand.

Table 2　Monthly dynamic of N output in surface runoff in different stands (kg/hm^2)

Month	Overall ploughing	Strip ploughing	Ditch ploughing	Average
2000-06	2.0470	0.1068	0.0074	0.7204
2000-07	0.1061	0.0100	0.0086	0.0416
2000-08	0.6727	0.1650	0.0757	0.3045
2000-09	0.0286	0.0171	0.0282	0.0246
2000-10	0.0076	0.0076	0.0082	0.0078
2000-11	0.0000	0.0000	0.0000	0.0000
2000-12	0.0000	0.0000	0.0000	0.0000
2001-01	0.0000	0.0000	0.0000	0.0000
2001-02	0.0000	0.0000	0.0000	0.0000
2001-03	0.0000	0.0041	0.0039	0.0026
2001-04	0.1073	0.0079	0.0082	0.0411
2001-05	0.0237	0.0084	0.0039	0.0120
Sum of a year	2.9930	0.3269	0.1441	1.1546

Note: Owing to local dry season from Oct. 2000 to Mar. 2001, there was nearly no surface runoff, and the corresponding values in table 1, 2 and 3 were all zero or negligible

3.1.3　K content in surface runoff

Compared with N and P content, K content in surface runoff had a fairly similar monthly dynamics for all three stands. The content and output of K in surface runoff both reached maximum in Aug. 2000. K fertilizer, which was applied to the stand in late July, was easily leached by rainfall. The annual loss of K in overall ploughed stand was the highest, 3.8364 kg/hm^2 (see table 3), 21.81% and 106.7% higher than that of strip ploughed and ditch ploughed stand, respectively.

As Table 4 suggested, the highest annual nutrient (N, P, and K) loss occurred in overall ploughed stand, 6.863 kg/hm^2, followed by strip ploughed and ditch ploughed stand. Under the influences of fertilization and human activities, nutrient content in surface runoff was much higher in June and Aug. 2000 than any other month. Among the 3 elements, annual average loss of K was the greatest, averaged 2.9474 kg/hm^2 for the three stands, occupying 71.45% of the annual loss of total N, P and K, while P only occupying 0.56%.

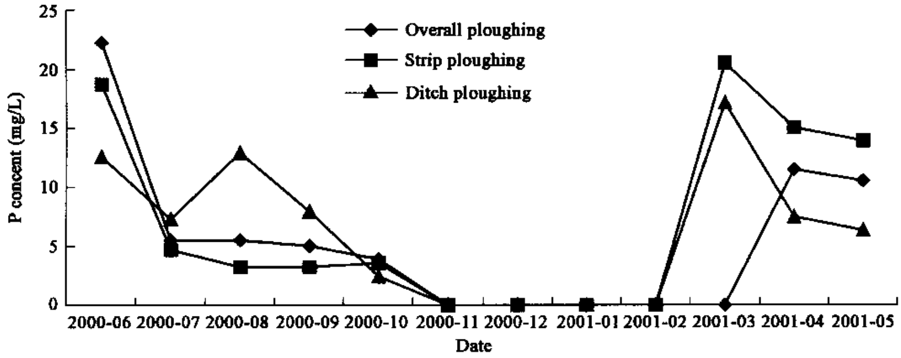

Fig. 2 Monthly dynamic of P content in surface runoff in different stands

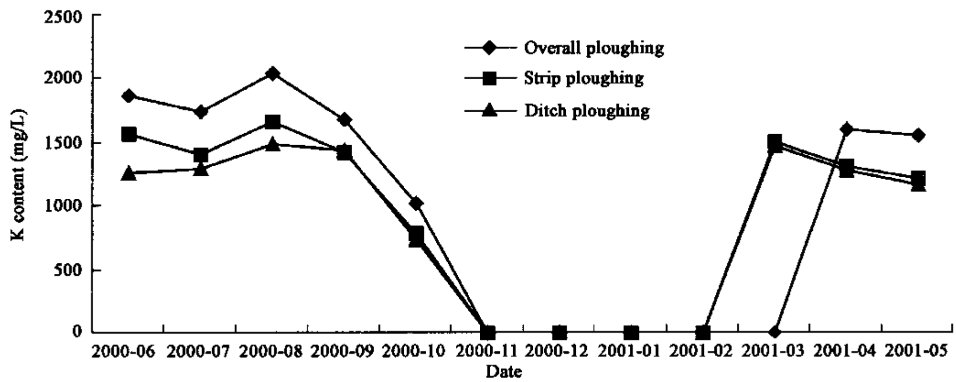

Fig. 3 Monthly dynamic of K content in surface runoff in different stands

Table 3 Monthly dynamic of P output in surface runoff in different stands (kg/hm^2)

Year Month	Overall ploughing	Strip ploughing	Ditch ploughing	Average
2000-06	0.0216	0.0117	0.0046	0.0216
2000-07	0.0012	0.0006	0.0008	0.0012
2000-08	0.0053	0.0021	0.0052	0.0053
2000-09	0.0021	0.0008	0.0011	0.0021
2000-10	0.0006	0.0006	0.0005	0.0006
2000-11	0.0000	0.0000	0.0000	0.0000
2000-12	0.0000	0.0000	0.0000	0.0000
2001-01	0.0000	0.0000	0.0000	0.0000
2001-02	0.0000	0.0000	0.0000	0.0000
2001-03	0.0000	0.0002	0.0002	0.0000
2001-04	0.0016	0.0020	0.0010	0.0016
2001-05	0.0019	0.0026	0.0006	0.0019
Sum of a year	0.0343	0.0206	0.0140	0.0343

Table 4 Monthly dynamic of K output in surface runoff in different stands (kg/hm^2)

Year Month	Overall ploughing	Strip ploughing	Ditch ploughing	Average
2000-06	1.1702	0.9752	0.4607	0.8687
2000-07	0.2427	0.1970	0.1413	0.1937
2000-08	1.3306	1.0806	0.5892	1.0001
2000-09	0.4192	0.3541	0.1997	0.3243
2000-10	0.1739	0.1322	0.1623	0.1561
2000-11	0.0000	0.0000	0.0000	0.0000
2000-12	0.0000	0.0000	0.0000	0.0000
2001-01	0.0000	0.0000	0.0000	0.0000
2001-02	0.0000	0.0000	0.0000	0.0000
2001-03	0.0000	0.0120	0.0162	0.0094
2001-04	0.2141	0.1753	0.1721	0.1872
2001-05	0.2856	0.2234	0.1145	0.2078
Sum of a year	3.8364	3.1497	1.8560	2.9474

For determining the differences between 3 ways of site preparation and seasonal dynamics of nutrient output in surface runoff, Non-interaction Double-factor Variance Analysis were performed, and the F test value of nutrient output for different reclamation stands were 1.91(N), 1.42(P) and 4.29(K), respectively, with $F_{0.05}(2,22) = 3.44$. As it indicated, the differences between the three rehabilitated stands were insignificant in N and P output in surface runoff, but significant in K. Moreover, the mean difference for K output was 0.165 kg/hm^2, between overall ploughed and ditch ploughed stand, 0.057

kg/hm² between overall ploughed and strip ploughed stand, and 0.108 between strip ploughed and ditch ploughed stand, with $w_{0.05}(3.22) = 0.145$. In other words, difference was significant between overall ploughed and ditch ploughed stand, but insignificant between strip ploughed and ditch ploughed stand and between overall ploughed and strip ploughed stand.

3.1.4 Comparison of nutrient output and input in the three bamboo ecosystems

Generally, precipitation and fertilization were two important ways of the nutrient input into the bamboo forest ecosystem, whereas the nutrient output includes soil erosion and harvesting of bamboo shoot and bamboo wood. Because the annual litter fall was mostly left in the stands, it could be negligible when calculating the nutrient surplus and loss of the ecosystem. Furthermore, the nutrients carried away by seepage flow was also not taken into account due to the limitations of the experiment design.

The annual surplus and loss of nutrient in *Dendrocalamus latiflorus* ecosystem was estimated by using the equation:

Annual nutrient budget＝Annual input－Annual output.

Table 5　Monthly dynamic of N, P, and K output in surface runoff in different stands (kg/hm²)

Year-Month	Overall ploughing	Strip ploughing	Ditch ploughing	Average
2000-06	3.2388	1.0937	0.4727	1.6017
2000-07	0.3500	0.2076	0.1507	0.2361
2000-08	2.0086	1.2477	0.6701	1.3088
2000-09	0.4499	0.3720	0.2290	0.3503
2000-10	0.1821	0.1405	0.1710	0.1645
2000-11	0.0000	0.0000	0.0000	0.0000
2000-12	0.0000	0.0000	0.0000	0.0000
2001-01	0.0000	0.0000	0.0000	0.0000
2001-02	0.0000	0.0000	0.0000	0.0000
2001-03	0.0000	0.0162	0.0203	0.0121
2001-04	0.3230	0.1852	0.1813	0.2298
2001-05	0.3112	0.2344	0.1190	0.2215
Sum of a year	6.8637	3.4971	2.0141	4.1250

As suggested in table 5, the nutrient input was the same in the 3 reclaimed stands, with the annual input of N, P and K being 951.85 kg/hm², 152.23 kg/hm², and 281.90 kg/hm², respectively. However, the nutrient output was different among the 3 stands. The nutrient output was the highest in strip ploughed stand, followed by overall ploughing and ditch ploughing. The annual output of N, P and K removed altogether by harvesting of bamboo shoot and stems, and by surface runoff was estimated to be 168.67 kg/hm², 31.55 kg/hm², and 97.41 kg/hm², respectively.

The nutrient budget in bamboo forest ecosystems was positive in every reclaimed stand, with the highest one occurring in overall ploughed stand, and the lowest in strip ploughed stand. You Z D(2003) also drew out the similar conclusions that annual surface runoff and sediment losses were the highest in overall ploughing, which reached to 30.37mm and 234.45 kg/hm², respectively[13]. Nutrient loss shows negative relationship with stand density. In the stand with a density of 825 clump/hm², the annual nutrient loss of surface runoff were 0.309 kg/(hm²·a) for N, 0.057 kg/(hm²·a) for P and 1.781 kg/(hm²·a) for K respectively[14]. Compared with Xie's conclusions, the ways of reclamation, as well as the stand density, were important factors that influenced the nutrient loss. As it revealed, quite a part of the fertilizer applied in experiment plot was unavailable and caused waste to some extent. As to nutrient utility efficiency, the highest one occurred in strip ploughed stand, 21.22%, followed by overall ploughed and ditch ploughed stand (see table 5). The reason may be that strip ploughing could not only loosen the soil to release more available nutrient, but also improve the physical and chemical properties, the nutrient holding capacity and the fertility of the soils.

Table 6　Comparison of annual nutrient output and input in the three bamboo ecosystems (kg/hm²)

Item		Overall ploughing				Strip ploughing				Ditch ploughing			
		N	P	K	Total	N	P	K	Total	N	P	K	Total
Input	Rainfall	0.65	0.25	15.10	16.00	0.65	0.25	15.10	16.00	0.65	0.25	15.10	16.00
	Fertilization	951.20	151.98	266.80	1369.98	951.20	151.98	266.80	1369.98	951.20	151.98	266.80	1369.98
	Subtotal	951.85	152.23	281.90	1385.98	951.85	152.23	281.90	1385.98	951.85	152.23	281.90	1385.98
Output	Shoot	95.35	24.40	82.99	202.74	100.34	25.68	87.34	213.36	89.85	22.99	78.20	191.04
	Stem	68.00	5.85	6.92	80.76	68.00	5.85	6.92	80.76	68.00	5.85	6.92	80.76
	Surface runoff	2.99	0.03	3.84	6.86	0.33	0.02	3.15	3.50	0.14	0.01	1.86	2.01
	Subtotal	166.34	30.28	93.75	290.37	168.67	31.55	97.41	297.62	157.99	28.85	86.98	273.82
Nutrient budget		+785.51	+121.94	+188.16	+1095.6	+783.18	+120.68	+184.50	+1088.36	+793.86	+123.37	+194.93	+1112.16
Nutrient utilizing rate		17.16	19.87	31.89	20.46	17.69	20.71	33.44	21.22	16.58	18.95	30.19	19.61

Note: ①The nutrient output of bamboo stem was calculated by nutrient amount in stem of one 1y-old and 2 y-old bamboo per clump, 400 clumps per hectare; ②Nutrient utilizing rate = nutrient output through shoot and stem / nutrient input of the system

3.2 Rainfall Redistribution by canopy

3.2.1 Rainfall redistribution by canopy in different rainfall classes

(1) Canopy interception Forests can effectively regulate the behaviors of rainfall. Firstly, it can intercept rainfall by canopy, buffering the kinetic energy of raindrop, and protecting soil from the striking of raindrops. The canopy interception consists of two parts, one part is the rainfall intercepted and held by canopy after rainfall event terminates, the other is the intercepted rainfall evaporating during the rainfall process. Generally, canopy interception is a complex process, depending on rainfall parameters (rainfall amount and intensity), canopy characteristics (crown density, branch and leave quantity and distribution, and the humidity of canopy), microclimate, and so on. According to researches on canopy interception of *Pinus tabulate* plantation in Loess Plateau[15], both rainfall intensity and rainfall duration are key factors affecting canopy interception. The more intense and the longer the rainfall event lasts, the lower the interception rate, because heavier rainfall has stronger penetrating ability, and continuous rainfall can saturate the canopy and make canopy interception reach and keep stable at a maximum level, then no changes occurred even if the precipitation increased further.

Within certain range of precipitation amount, canopy interception increased with increased precipitation, faster in low rainfall class than in high rainfall class, and tended to a fixed value. That was because the canopy interception is composed of two parts: canopy storage capacity and evaporation of intercepted rainfall during rainfall event. For a given forest stand, the later part only makes up a relatively small proportion in the total interception, the former is the main part and will reach a saturated point. After reaching the point, further rainfall produces nearly no more canopy interception. The same conclusions were obtained in a study on the interception of *Phyllostachys heterocycla* cv. *pubescens* canopy by Cao Q G[16].

Canopy interception rate changed in the reverse trend as interception amount changed. As the precipitation increased, the canopy interception rate continuously decreased, more quickly in high precipitation class than in low precipitation class. For instance, the interception rate dropped from 100% to 25.36% when the precipitation only increased from 0 to 20 mm (see table 6 and fig. 4).

Table 7 Rainfall redistributions by canopy in different rainfall classes

Rainfall class (mm)	Rainfall (mm)	Through fall		Stemflow		Interception	
		(mm)	(%)	(mm)	(%)	(mm)	(%)
<5	44.40	13.52	30.45	0.00	0.00	30.88	69.55
5～10	42.86	21.38	49.89	0.15	0.35	21.33	49.76
10～20	107.11	76.88	71.77	2.99	2.79	27.24	25.43
20～30	103.67	81.23	78.35	3.84	3.70	18.61	17.95
30～40	218.16	176.64	80.97	9.48	4.35	32.04	14.69
40～60	335.53	277.14	82.60	16.36	4.88	42.02	12.52
60～80	269.05	224.64	83.49	13.64	5.07	30.78	11.44
80～100	273.56	232.48	84.98	14.48	5.29	26.61	9.73
100～150	384.23	332.30	86.49	20.73	5.40	31.19	8.12
>150.1	324.20	284.25	87.68	17.42	5.37	22.54	6.95
Annual rainfall	2102.77	1720.45	81.82	99.09	4.71	283.23	13.47

According to the data of 48 rainfall events collected from field survey, the relationship between canopy interception and precipitation was simulated. Richards's function exhibited it better fitness. The equation was as following:

$$I = 21.5107 \times (1 - e^{-0.0010P})^{0.3934}$$

Where I was canopy interception, P was precipitation, both in mm.

As the result shown, the correlative index reached 0.9452, and the regression effect was extremely significant ($|t| = 18.3092 > t_{0.01}(46) = 2.704$).

(2) Stemflow Stemflow comes from two parts: the saturation of canopy interception and the rainfall that directly dropped in bamboo stem. The water flows down along the stem in gravitation after the stem bark has been saturated and forms stemflow. Stemflow can partly protect the soil from erosion by raindrop, and increase the amount of water and nutrient around root zone. It plays an important role in soil conservation and plant growth[16]. The amount of stemflow is closely related to the roughness and thickness of bark, the rainfall characteristics and the canopy structure.

As showed in Table 6, when the precipitation class was below 5 mm, there was no stemflow. Subsequently, with precipitation increase, the bamboo stemflow rate steadily increased and eventually reached the maximum, 5.40% (see table 6). The stemflow rate increased with the increasing rainfall, elevating faster in low rainfall class than in high rainfall class (see fig. 4).

(3) Through fall Through fall consists of two parts, one part is rainfall that dropped straightly to the ground through canopy gap, the other part is raindrops derived from canopy interception. Rainfall characteristic is the leading factor influencing through fall. The absolute through fall amount and through fall rare increased with increased amount, intensity and duration of

rainfall. Roughly, with the increasing precipitation, the through fall increased in linear, sharply at low precipitation class, and moderately at high precipitation class (see fig. 4). As shown in table 6, the though-fall rate jumped from zero to 71.77% when rainfall class rose from zero to 10～20 mm. However, the through fall only increased from 78.35% to 87.68% with an increase of only 9.33% when the precipitation rose from 20～30 mm to 150～200 mm.

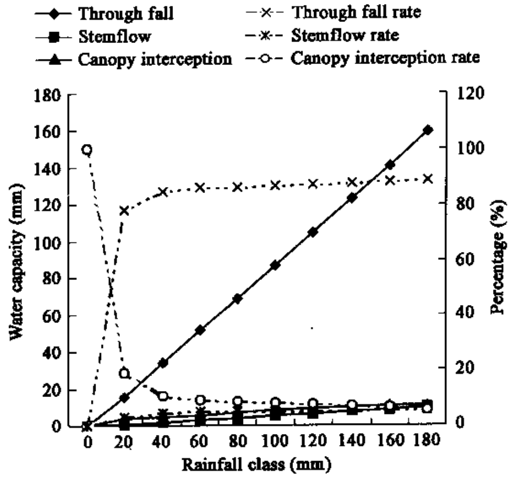

Fig. 4　Rainfall redistribution by canopy in different precipitation classes

3.2.2　Monthly dynamic of rainfall redistribution by canopy

(1) Monthly dynamic of canopy interception　The canopy interception exhibited significant seasonal pattern. In dry season, the interception amount was low but the interception rate was relatively high due to limited rainfall and mostly light rainfall events occurred. However, in wet season, the rainfall and interception were both relatively higher while the interception rate was very low.

In wet season, monthly canopy interception was ranged between 16.86mm and 47.23mm, totally 203.29mm, and the monthly interception rate was in the range of 9.82% to 16.09%. In dry season, the values were 10.42～28.26mm for monthly interception amount, and 22.40%～48.78% for monthly interception rate. The average interception rate in dry season was 2.94 times as high as that in wet season (see table 7). The difference between dry season and wet season was caused by precipitation amount and some other factors. Firstly, in wet season, the frequency of heavy rain events was relatively higher in wet season, greater raindrop showing stronger penetrability. Secondly, low evaporation and high canopy humidity kept the interception rate at a low level due to the short interval between rainfall events. The annual canopy interception was 283.10 mm, making 13.47% of annual precipitation. In Fenyi County, Jiangxi Province, the annual interception rate by *Phyllostachys heterocycla* cv. *pubescens* stands was 11.1%[17].

(2) Monthly dynamic of stemflow　As suggested in figure 5, bamboo stemflow also significantly changed in season. In wet season, water storage by canopy was high because branches and leaves were kept moist, so stemflow was relatively higher. The total bamboo stemflow was 92.56 mm in wet season, occupying 93.41% of the total annual amount (see table 7). In contrast, in dry season, bamboo stem was relatively dry due to the limited rainfall amount. The plant itself absorbed most of the raindrops falling on it, so the stemflow amount became relatively low. Because the stem of *Dendrocalamus latiflorus* was fairly smooth and hard, stemflow could be easily produced. The annual stemflow of the stand was 99.09mm, and the annual stemflow rate was 4.71%. In *Phyllostachys heterocycla* cv. *pubescens* stand in Fenyi county, Jiangxi Province, the annual stemflow rate was 4.4%[17].

Table 8　Monthly dynamic of rainfall redistribution by canopy

Month	Rainfall (mm)	Through fall (mm)	Through fall (%)	Stemflow (mm)	Stemflow (%)	Interception (mm)	Interception (%)
2000-06	481.15	408.97	85.00	24.94	5.18	47.23	9.82
2000-07	256.83	216.75	84.39	12.88	5.02	27.20	10.59
2000-08	455.46	385.84	84.71	23.09	5.07	46.53	10.22
2000-09	155.99	131.14	84.07	8.00	5.13	16.86	10.81
2000-10	151.10	126.54	83.74	7.68	5.08	16.89	11.18
2000-11	34.77	22.44	64.54	1.00	2.89	11.32	32.57
2000-12	56.53	39.57	70.00	1.55	2.74	15.41	27.27
2001-01	64.31	47.88	74.45	2.02	3.14	14.41	22.40
2001-02	21.44	10.80	50.36	0.19	0.86	10.46	48.78
2001-03	77.98	47.87	61.38	1.77	2.27	28.34	36.34
2001-04	184.65	146.97	79.60	7.97	4.32	29.70	16.09
2001-05	162.55	135.68	83.47	7.99	4.92	18.88	11.61
Wet season	1847.74	1551.89	83.99	92.56	5.01	203.29	11.00
Dry season	255.03	168.56	66.09	6.53	2.56	79.94	31.35
Sum of the year	2102.77	1720.45	81.82	99.09	4.71	283.23	13.47

(3) Monthly dynamics of through fall　The monthly dynamic of through fall revealed significant seasonal variation similar to the rainfall. In wet season, heavy rain events were more frequent and mostly with storm, so the raindrops have high kinetic energy and strong penetrability. As a result, the atmospheric humidity, canopy humidity, through fall and through fall rate were high, and the total amount of through fall was 1551.89mm in wet season, 9.21 times as much as that in dry season (see table 7).

4 Conclusion

This paper studied the hydrologic characteristics and nutrient dynamic of shoot-oriented *Dendrocalamus latiflorus* stands, including the surface runoff and nutrient loss in three reclaimed stands and the redistribution of rainfall by canopy. The main results were as following:

(1) The highest annual loss of element N, P and K occurred in the overall ploughed stand, followed by strip ploughed and ditch ploughed stand. The differences of annual N and P loss were insignificant among the 3 stands. The differences of annual K loss were significant in 3 stands, but insignificant between strip ploughed stand and ditch ploughed stand. Owing to influence from fertilization and surface runoff, the nutrient content in surface runoff was obviously higher in June and August 2000 than the other months.

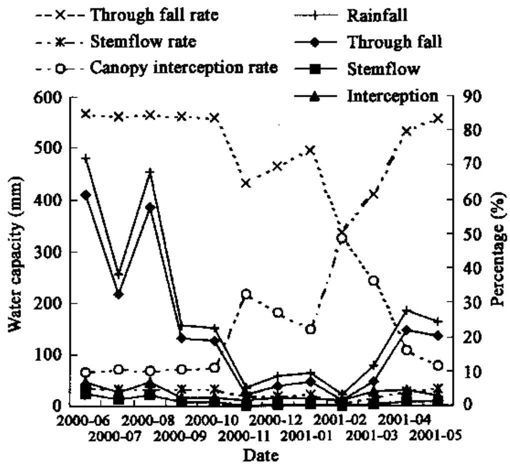

Fig. 5 Monthly dynamics of rainfall redistribution by canopy

(2) Through rainfall and fertilization in *Dendrocalamus latiflorus* ecosystem, the annual input of N, P and K were 951.85 kg/hm^2, 152.23 kg/hm^2, and 281.90 kg/hm^2, respectively, totaling 1385.98 kg/hm^2. Nutrient (N, P, and K) loss removed altogether by harvesting of carried away through bamboo shoot and bamboo wood, and by surface runoff were 168.67 kg/hm^2, 31.55 kg/hm^2, and 97.41 kg/hm^2, respectively. Among the stands, both nutrient output and nutrient utility efficiency were the highest in strip ploughed stand, while the nutrient surplus of the system was the lowest.

(3) The canopy interception, through fall, and stemflow varied with precipitation, but not in the same trends When precipitation increased, the canopy intercept rate decreased, while the through fall rate and bamboo stemflow rate increased.

(4) In the bamboo stand, the annual canopy interception, through fall and stemflow were 283.102 mm, 1720.45 mm and 99.09 mm, respectively, and the corresponding annual average rates were 13.47%, 81.82%, and 4.71%, respectively. They all exhibited clear seasonal patterns, with larger amount in wet season than in dry season.

(5) There was surplus annual N, P and K in *Dendrocalamus latiflorus* ecosystem in the three rehabilitated stands. Strip ploughing could loosen soil to improve the spread and nutrient absorbance of plant root. As a result, the nutrient loss amount and loss rate were both quite low, and the nutrient utility efficiency was the highest in strip ploughed stand. Thus the annual budget of N, P and K in strip ploughed stand, which were 783.18 kg/hm^2, 120.68 kg/hm^2, and 184.50 kg/hm^2, respectively, were the lowest among the three stands, and the corresponding nutrient utility efficiencies were 17.69%, 20.71% and 33.44%, respectively. Accordingly, the current fertilization applied in bamboo stand was too much or in an inefficient way. Excess nutrients would be carried away from the site into rivers and lakes by surface runoff or underground flow, leading to water eutrophication. Proper quantity and fertilization method should be used to avoid such problems.

(6) The nutrient dynamic in soil and plant, the nutrient released in soil and the nutrient demand by vegetation are not involved in this study, we couldn't provide infomation for the proportions, methods, and time of fertilization, which needs further study.

As stated above, overall ploughing improved the physical and chemical soil properties, but evidently aggravated soil erosion, and gained less bamboo shoot than strip ploughing. As to ditch ploughing, the capacity of soil and water reservation was quite strong, but the bamboo shoot yields and consequently the economic profits was the lowest among the 3 stands. However, strip ploughed stand gained the highest bamboo shoot yields and economic profit, and the differences in nutrient loss was insignificant between strip ploughed and ditch ploughed stand. In a word, strip ploughing gained the highest economical profit without causing significant soil erosion, and was a relatively optimal management method for *Dendrocalamus latiflorus* stand, worthy of being widely popularizing in this region.

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