

ISSN 1000-0933  
CN 11-2031/Q

# 生态学报

## Acta Ecologica Sinica



第32卷 第4期 Vol.32 No.4 2012

中国生态学学会  
中国科学院生态环境研究中心  
科学出版社

主办  
出版



中国科学院科学出版基金资助出版

# 生态学报 (SHENTAI XUEBAO)

第32卷 第4期 2012年2月 (半月刊)

## 目 次

围垦对南江东滩湿地大型底栖动物的影响.....	马长安,徐霖林,田伟,等 (1007)
基于 ArcView-WOE 的下辽河平原地下水生态系统健康评价 .....	孙才志,杨磊 (1016)
京郊典型集约化“农田-畜牧”生产系统氮素流动特征 .....	侯勇,高志岭,马文奇,等 (1028)
不同辐射条件下苹果叶片净光合速率模拟.....	高照全,冯社章,张显川,等 (1037)
藏北高原典型植被样区物候变化及其对气候变化的响应.....	宋春桥,游松财,柯灵红,等 (1045)
祁连山中段林草交错带土壤水热特征及其对气象要素的响应 .....	唐振兴,何志斌,刘鹤 (1056)
祁连山青海云杉林冠生态水文效应及其影响因素.....	田风霞,赵传燕,冯兆东,等 (1066)
呼伦贝尔沙地樟子松年轮生长对气候变化的响应.....	尚建勋,时忠杰,高吉喜,等 (1077)
结合激光雷达分析上海地区一次连续浮尘天气过程.....	马井会,顾松强,陈敏,等 (1085)
福建中部近海浮游动物数量分布与水团变化的关系 .....	田丰歌,徐兆礼 (1097)
香港巨牡蛎和长牡蛎幼虫及稚贝的表型性状.....	张跃环,王昭萍,闫喜武,等 (1105)
东海原甲藻与中肋骨条藻的种间竞争特征.....	李慧,王江涛 (1115)
起始生物量比对3种海洋微藻种间竞争的影响.....	魏杰,赵文,杨为东,等 (1124)
不同磷条件下塔玛亚历山大藻氮的生态幅.....	文世勇,宋璐璐,龙华,等 (1133)
秦岭天然次生油松林冠层降雨再分配特征及延滞效应.....	陈书军,陈存根,邹伯才,等 (1142)
伊犁河谷北坡垂直分布格局及其与环境的关系——一种特殊的双峰分布格局.....	田中平,庄丽,李建贵 (1151)
濒危种四合木与其近缘种霸王水分关系参数和光合特性的比较.....	石松利,王迎春,周红兵,等 (1163)
干旱胁迫下黄土高原4种乡土禾草抗氧化特性 .....	单长卷,韩蕊莲,梁宗锁 (1174)
施加角担子菌B6对连作西瓜土壤微环境和西瓜生长的影响 .....	肖逸,王兴祥,王宏伟,等 (1185)
内蒙古典型草原区芨芨草群落适生生境.....	张翼飞,王炜,梁存柱,等 (1193)
盐渍化灌区土壤盐分的时空变异特征及其与地下水埋深的关系.....	管孝艳,王少丽,高占义,等 (1202)
黄土高原水蚀风蚀交错区坡地土壤剖面饱和导水率空间异质性.....	刘春利,胡伟,贾宏福,等 (1211)
松嫩平原玉米带农田土壤氮密度时空格局.....	张春华,王宗明,居为民,等 (1220)
小麦冬性强弱评价体系的建立.....	王鹏,张春庆,陈化榜,等 (1230)
唐家河自然保护区高山姬鼠和中华姬鼠夏季生境选择的比较.....	黎运喜,张泽钧,孙宜然,等 (1241)
西花蓟马在6种蔬菜寄主上的实验种群生命表 .....	曹宇,郅军锐,孔译贤 (1249)
同位素富集-稀释法研究食性转变对鱼类不同组织N同位素转化率的影响 .....	曾庆飞,谷孝鸿,毛志刚,等 (1257)
基于生态网络分析的南京主城区重要生态斑块识别.....	许文雯,孙翔,朱晓东,等 (1264)
珠三角城市绿地CO <sub>2</sub> 通量的季节特征 .....	孙春健,王春林,申双和,等 (1273)
污染场地地下水渗流场模拟与评价——以柘城县为例 .....	吴以中,朱沁园,刘宁,等 (1283)
<b>专论与综述</b>	
湿地退化研究进展 .....	韩大勇,杨永兴,杨杨,等 (1293)
绿洲农田氮素积累与淋溶研究述评 .....	杨荣,苏永中,王雪峰 (1308)
<b>问题讨论</b>	
抗辐射菌 <i>Deinococcus radiodurans</i> 的多样性 .....	屠振力,方俐晶,王家刚 (1318)
平茬措施对柠条生理特征及土壤水分的影响 .....	杨永胜,卜崇峰,高国雄 (1327)
<b>研究简报</b>	
祁连山典型灌丛降雨截留特征 .....	刘章文,陈仁升,宋耀选,等 (1337)
野生鸭儿芹种子休眠特性及破除方法 .....	喻梅,周守标,吴晓艳,等 (1347)
期刊基本参数:CN 11-2031/Q * 1981 * m * 16 * 348 * zh * P * ¥ 70.00 * 1510 * 36 * 2012-02	



封面图说: 遗鸥群飞来——遗鸥意即“遗落之鸥”(几乎是最后才被发现的新鸥种,因此得名)。1931年,瑞典动物学家隆伯格撰文记述在中国额济纳采到了标本。1987年,中国的鸟类学家在鄂尔多斯的桃力庙获得了一对遗鸥的标本。1990年春夏之交,发现了湖心各岛上大量的遗鸥种群。近年来的每年夏季,大约全球90%以上的遗鸥都会到陕西省神木县境内的沙漠淡水湖-红碱淖上聚集。遗鸥——国家一级重点保护、CITES附录一物种。

彩图提供: 陈建伟教授 国家林业局 E-mail: cites.chenjw@163.com

DOI: 10.5846/stxb201012211822

刘章文, 陈仁升, 宋耀选, 韩春坛. 祁连山典型灌丛降雨截留特征. 生态学报, 2012, 32(4): 1337-1346.

Liu Z W, Chen R S, Song Y X, Han C T. Characteristics of rainfall interception for four typical shrubs in Qilian Mountain. Acta Ecologica Sinica, 2012, 32(4): 1337-1346.

## 祁连山典型灌丛降雨截留特征

刘章文<sup>1,2,3</sup>, 陈仁升<sup>1,2,\*</sup>, 宋耀选<sup>1,2</sup>, 韩春坛<sup>1,2</sup>

(1. 中国科学院寒区旱区环境与工程研究所黑河上游生态-水文试验研究站, 兰州 730000;

2. 中国科学院内陆河流域生态水文重点实验室, 兰州 730000; 3. 中国科学院研究生院, 北京 100049)

**摘要:** 基于2010年6月至10月的野外试验数据, 研究了祁连山金露梅、高山柳、沙棘和鬼箭锦鸡儿灌丛降雨截留特征, 分析了降雨量和雨强对灌丛降雨截留过程的影响。结果表明: 试验期间共降雨298.6 mm, 在降雨量<2.1 mm时, 降雨被全部截留, 实际发生穿透和茎流的降雨为283.1 mm; 金露梅灌丛穿透雨量、茎流量和截留量分别为175.8 mm(62.0%)、9.5 mm(3.4%)和62.0 mm(34.6%), 高山柳为179.8 mm(63.5%)、9.1 mm(3.2%)和63.5 mm(33.3%), 沙棘分别为148.1 mm(52.3%)、22.5 mm(8.0%)和52.3 mm(39.7%), 鬼箭锦鸡儿分别为170.4 mm(60.2%)、11.8 mm(4.2%)和60.2 mm(35.6%); 灌丛穿透雨量、茎流量和截留量均与降雨量呈显著线性正相关( $P<0.001$ ); 穿透率、茎流率和截留率与降雨量呈指数函数关系( $P<0.05$ ); 平均雨强与截留率关系以指数函数拟合最好( $P<0.05$ )。在降雨性质相同的情况下, 植被形态特征是影响灌丛降雨截留的重要因素。

**关键词:** 截留; 茎流; 灌丛; 祁连山

## Characteristics of rainfall interception for four typical shrubs in Qilian Mountain

LIU Zhangwen<sup>1,2,3</sup>, CHEN Rensheng<sup>1,2,\*</sup>, SONG Yaoxuan<sup>1,2</sup>, HAN Chunshan<sup>1,2</sup>

1 Heihe Upstream Watershed Ecology-Hydrology Experimental Research Station, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China

2 Key Laboratory of Ecohydrology of Inland River Basin, Chinese Academy of Sciences, Lanzhou 730000, China

3 Graduate University of Chinese Academy of Sciences, Beijing 100049, China

**Abstract:** Rainfall intercepting by vegetation plays an important role affecting the water balance at local and catchment scale due to the control that vegetation canopy exert by modifying both evaporation and the redistribution of incident rainfall. Qilian Mountain is source regions of Heihe River, Shiyang River and Shule River inland river basin. In consideration of widespread shrubs which account for 68% of the whole forest area of Qilian Mountain, the research on rainfall interception process of shrubs for understanding the impact of rainfall characteristics on alpine shrubs and revealing the mechanism of hydrologic cycle and water resources with the impact of the shrub canopy, especially in the mountainous regions of an inland river basin, is very important and necessary. This paper took the four typical alpine shrubs *Potentilla fruticosa*, *Salix cupularis*, *Hippophae rhamnoides*, and *Caragana jubata* in Qilian Mountain as test objects, based on the field experimental data from June to October 2010, characteristics of rainfall interception and rainfall redistribution of four typical alpine shrubs in Qilian Mountain was investigated by permanent plot method, and impact of rainfall characteristics on rainfall redistribution of shrubs was analyzed by statistical method. The results indicated that the gross rainfall was 298.6 mm during the experimental period. Rainfall was intercepted entirely by shrubs when rainfall is less than 2.1 mm, gross rainfall

**基金项目:** 国家自然科学基金项目(91025011, 40771045); 国家自然科学基础人才培养基金冰川学冻土学特殊学科点资助(J0930003/J0109)

**收稿日期:** 2010-12-21; **修订日期:** 2011-05-23

\* 通讯作者 Corresponding author. E-mail: crs2008@lzb.ac.cn.

which observed throughfall and stemflow was 283.1 mm. The amount of throughfall of *P. fruticosa*, *S. cupularis*, *H. rhamnoides* and *C. jubata* was 175.8 mm, 179.8 mm, 148.1 mm, and 170.4 mm. Throughfall percentages of *P. fruticosa*, *S. cupularis*, *H. rhamnoides* and *C. jubata* was 62.0%, 63.5%, 52.3%, and 60.2%, respectively. Stemflow was 9.5 mm, 9.1 mm, 22.5 mm, and 11.8 mm for *P. fruticosa*, *S. cupularis*, *H. rhamnoides*, and *C. jubata*, and averaged 3.4%, 3.2%, 8.0%, and 4.2% of the gross rainfall, respectively. Interception was 62.0 mm, 63.5 mm, 52.3 mm, and 60.2 mm for *P. fruticosa*, *S. cupularis*, *H. rhamnoides*, and *C. jubata*, and accounted for 34.6%, 33.3%, 39.7%, and 35.6% of the gross rainfall, respectively. The amount of thoughfall, stemflow and interception of *P. fruticosa*, *S. cupularis*, *H. rhamnoides* and *C. jubata* increased in a significant positive linear correlation with increasing rainfall depth ( $P<0.001$ ). The relationship of throughfall percentage, stemflow percentage and interception percentage of shrubs with rainfall could be fitted with exponential curve ( $P<0.05$ ). Throughfall percentage and stemflow percentage showed an increase trend with the increasing rainfall, while interception percentage decreased with the increasing rainfall depth. Moreover, interception percentage of shrubs decreased in exponential function correlation with increasing rain intensity ( $P<0.05$ ). Interception percentage decreased with increasing rainfall intensity, when the rainfall intensity is less than 4 mm/h, the interception percentage was significantly decreased, and then the trend is becoming stable values with increasing rainfall intensity. Interception characteristics of each shrubs was different with others when rainfall characteristics were similar during the experimental period. According to field plot observation, the height, branch angle, canopy morphology and crown projection area all affected canopy interception process of alpine shrubs in Qilian Mountain. In order to analyze intercept capability per leaf area of shrubs, some morphology characteristics parameters, such as leaf area index (LAI), freedom throughfall coefficient, biomass, canopy hold water ability, should be measurement in the next experiment.

**Key Words:** interception; stemflow; shrubs; Qilian Mountain

植被对降雨的截留和再分配过程作为土壤-植被-大气系统水分循环的重要环节,在森林生态系统水文循环和水量平衡中具有重要作用,一直是生态水文学研究的热点问题<sup>[1-4]</sup>。植被冠层截留的相关研究主要集中在热带雨林<sup>[5-6]</sup>、北方针叶林<sup>[7-10]</sup>、萨瓦纳草地<sup>[11-12]</sup>和温带森林<sup>[13]</sup>,对灌丛研究少且集中于干旱半干旱区<sup>[14-20]</sup>,而对于高山区湿性灌丛的冠层截留研究极少。车克钧等<sup>[21]</sup>对祁连山水源涵养林研究结果表明,灌丛的截留率为50%(夏季为68.3%),聂雪花<sup>[22]</sup>研究得到祁连山排露沟流域灌丛截留率变化范围为6.98%—22.45%,常学向等<sup>[23]</sup>研究了祁连山森林对降雨的截留率,得出灌丛的平均截留率高达66.5%(仅7—8月)。上述祁连山灌丛的研究结果相差很大,且均忽略了茎流的观测,单独以降雨量减去穿透雨量来估算的截留量存在较大误差,有必要对高山区湿性灌丛的降雨截留过程进行深入研究。

祁连山灌丛面积约 $4.13\times10^5\text{hm}^2$ ,约占祁连山区林业用地面积的68%,其有效涵蓄水量在 $3\times10^8\text{m}^3$ 以上,与云杉林相比是更大的一座“绿色水库”<sup>[24]</sup>。鉴于以前对湿性灌丛的研究均在祁连山中段走廊南山北坡的浅山区,因此选取祁连山中段深山区托勒南山北坡典型湿性灌丛为研究对象,通过对灌丛穿透雨、茎流和降雨截留的观测,研究灌丛冠层降雨的再分配特征及其与降雨过程的关系,为进一步认识祁连山湿性灌丛的生态水文功能提供一些观测数据和经验参数。

## 1 材料与方法

### 1.1 研究区概况

试验布设在黑河源区中国科学院寒区旱区环境与工程研究所黑河祁连站马粪沟试验流域,地理位置为 $38.2^\circ\text{N}$ , $99.9^\circ\text{E}$ ,流域面积 $23.1\text{ km}^2$ ,海拔2960—4820 m。流域内主要乔木树种为青海云杉(*Picea crassifolia*)和祁连圆柏(*Sabina przewalskii*),灌丛主要有鬼箭锦鸡儿(*Caragana jubata*)、金露梅(*Potentilla fruticosa*)、银露梅(*Potentilla glabra*)、高山柳(*Salix cupularis*)、沙棘(*Hippophae rhamnoides*)等,草本主要有珠芽蓼(*Polygonum viviparum*)、狼毒(*Stellera chamaejasme*)、披碱草(*Elymus dahuricus*)等。土壤主要为山地森林

灰褐土、山地栗钙土、草甸土、亚高山灌丛草甸土和高山寒漠土等5个类型。

## 1.2 试验方法

经过野外调查,选取具有代表性的金露梅、高山柳、沙棘、鬼箭锦鸡儿灌丛,在流域内海拔3 203—3 370 m分别设置大小为10 m×10 m的标准样地。

根据水量平衡原理,灌丛对降雨的再分配过程可分为3个部分,截留量,茎流量和穿透雨量:

$$IC = P - SF - TF \quad (1)$$

式中,P为林外降雨量;TF为穿透雨量;SF为茎流量;IC为截留量。

穿透雨使用直径为15 cm,高度10 cm的圆形铁制容器测量。由于金露梅和鬼箭锦鸡儿灌丛不能进行单株观测,因此对样地冠层郁闭度进行测定后,每个样地放置9个接水器,使得不同郁闭冠层下均有接水器。这种方法可以更好的收集灌丛下不同部位的穿透雨。由于草本植被少且观测难度大,忽略了灌丛下草本的截留作用。

每种灌丛选取4株(高度、基径均不同)进行茎流观测。茎流采用标准枝法,即对所选灌丛的每一枝进行基径测量,取得基径平均值后,选择与基径平均值相当的枝干作为标准枝(每株灌丛选4枝且其与地面的角度不同)来测定茎流。由于灌丛形态特征,所以常规观测方法并不适合<sup>[25-26]</sup>。因此本研究在灌丛所有枝下茎干上,使用塑料管,中间剖开,用塑料胶布粘好并固定,然后用该塑料管直接接入茎流收集瓶,瓶口粗细和塑料管一致,避免降雨和穿透雨进入收集瓶,经人工试验可以实现准确的收集茎流。每个收集瓶实测水量除以该标准枝投影面积得到该枝茎流量,标准枝上的茎流量乘以整个灌丛的枝数即可得到整个灌丛的茎流量。

观测时段为2010年6月1日至10月31日。林外降雨使用DSJ2型虹吸式自记雨量计,同时用人工气象站降雨进行过校正。为减少测定过程中蒸发造成的误差,在雨后及时测量穿透雨量和茎流量,如夜间降雨,第2天清晨取样。

## 1.3 数据处理

剔除因茎流收集瓶满导致降雨溢出的数据,采用Microsoft Excel 2003软件和origin8.0对数据进行处理和绘图。文中所用的误差限均为标准偏差。

## 2 结果

### 2.1 降雨特征

试验期间共观测到降雨55次,总降雨量298.6 mm,次最大降雨发生于2010年7月8日,降雨历时10 h,降雨量23.5 mm,最小降雨发生于2010年9月22日,降雨历时0.5 h,降雨量为0.3 mm。为便于分析,将降雨从雨量上分为6个等级(表1)。其中,34.5%的降雨事件<2 mm,60.0%的降雨事件<5 mm,83.6%降雨事件<10 mm,降雨事件>10 mm仅占16.4%,大降雨事件较少。观测期间平均雨强3.4 mm/h,最小雨强0.4 mm/h,最大雨强16.5 mm/h,各雨量级对应的平均雨强见表1。

表1 试验期间研究区降雨特征

Table 1 Rainfall characteristics in study area during the experimental period

雨量级 Rainfall class /mm	降雨次数 Rainfall frequency	降雨次数比例 Frequency percentage /%	降雨量 Rainfall /mm	降雨量比例 Rainfall percentage /%	降雨强度 Rainfall intensity /(mm/h)
< 2	19	34.5	15.4	5.2	0.7(0.4)
2—5	14	25.5	45.0	15.1	1.9(0.9)
5—10	13	23.6	91.5	30.6	1.7(1.0)
10—15	4	7.3	52.0	17.4	11.2(16.6)
15—20	3	5.5	51.0	17.1	6.9(8.3)
> 20	2	3.6	43.7	14.6	1.9(0.6)

括号内数值为标准差

观测的降雨事件中,<2.1 mm的降雨次数占总降雨次数的34.5%,而其降雨量仅占总降雨量的5.1%,所

观测的4种灌丛均没有观测到茎流和穿透雨,降雨全部都被灌丛所截留。实际发生穿透雨和茎流的降雨共计35次,总降雨量为283.1 mm。

## 2.2 穿透雨变化

试验期间,各样地灌丛降雨截留特征见表2。穿透雨量以高山柳灌丛最高,依次为金露梅灌丛、鬼箭锦鸡儿灌丛,沙棘灌丛最小,穿透率也为同样的趋势。单次最大穿透雨量出现在2010年7月8日,降雨历时10 h,降雨量23.5 mm,穿透雨量金露梅、沙棘、高山柳和鬼箭锦鸡儿分别为17.6、15.8、15.2 mm和14.2 mm,对应穿透率(穿透雨量占降雨量的百分比,TF%)为74.9%、67.4%、64.7%和60.4%。

表2 试验期间灌丛截留特征

Table 2 Characteristics of interception for *P. fruticosa*, *S. cupularis*, *H. rhamnoides* and *C. jubata*

灌丛 shrub	穿透雨量 Throughfall/mm	穿透率 Throughfall percentage/%	茎流量 Stemflow/mm	茎流率 Stemflow percentage /%	截留量 Interception/mm	截留率 Interception percentage/%
金露梅 <i>P. fruticosa</i>	175.8(2.2)	62.0(18.3)	9.5(0.7)	3.4(1.2)	98.0(1.5)	34.6(18.0)
高山柳 <i>S. cupularis</i>	179.8(2.4)	63.5(16.9)	9.1(0.3)	3.2(1.3)	94.2(1.6)	33.3(18.9)
沙棘 <i>H. rhamnoides</i>	148.1(1.5)	52.3(15.0)	22.5(1.2)	8.0(4.1)	112.5(2.5)	39.7(19.7)
鬼箭锦鸡儿 <i>C. jubata</i>	170.4(2.6)	60.2(18.5)	11.8(0.8)	4.2(1.7)	100.9(1.7)	35.6(19.4)

括号内数值为标准差

4种灌丛穿透雨量与降雨量之间均呈显著的线性正相关关系(图1,  $P<0.001$ )。对4种灌丛穿透率(TF%)与降雨量( $P$ )之间的关系进行回归,比较后得出指数函数具有较好的拟合性,穿透率随着降雨量的增加而逐渐增大,最后趋于稳定值(图2,  $P<0.05$ )。

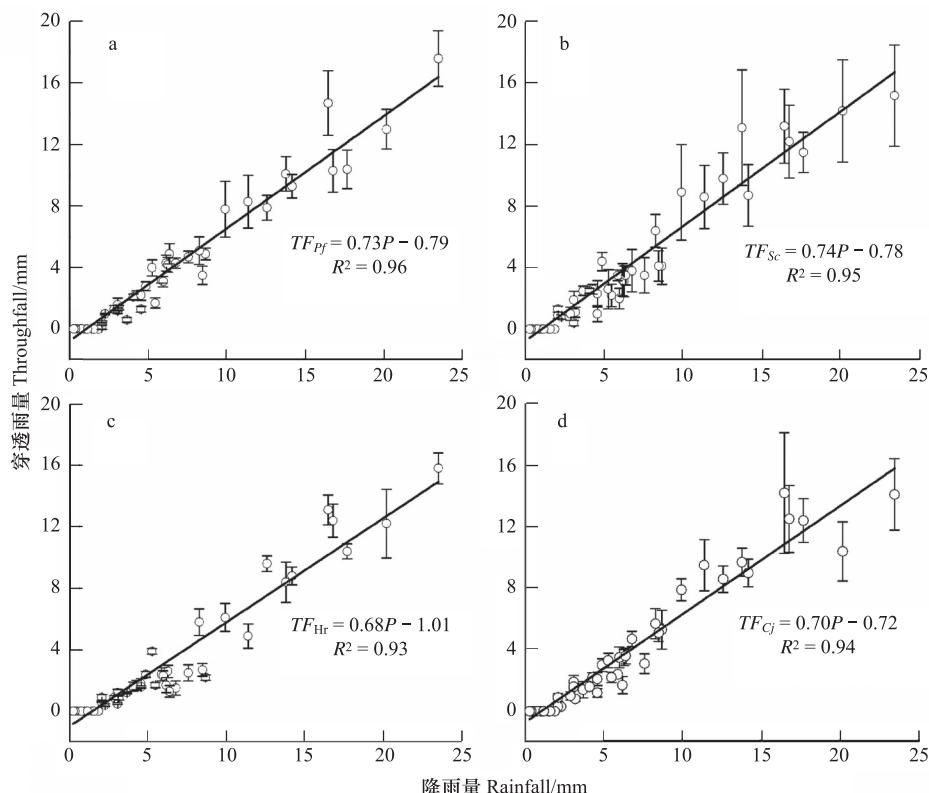


图1 灌丛穿透雨量与降雨量之间的关系

Fig. 1 Relationship between throughfall and rainfall

(a) 金露梅 *P. fruticosa*; (b) 高山柳 *S. cupularis*; (c) 沙棘 *H. rhamnoides*; (d) 鬼箭锦鸡儿 *C. jubata*; 下同

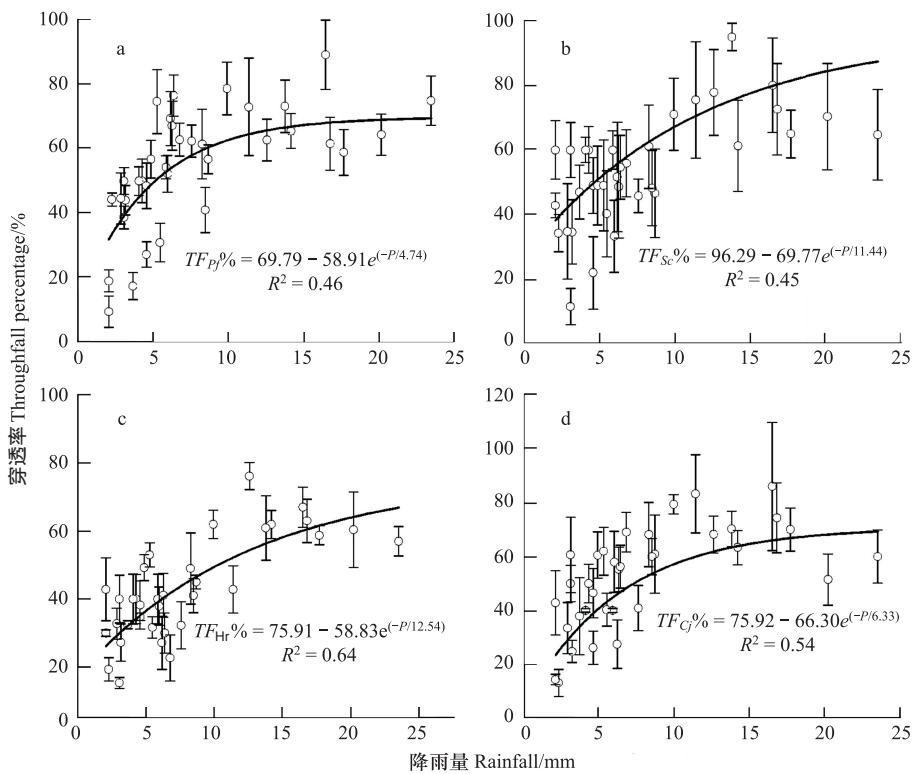


图2 灌丛穿透率与降雨量之间的关系

Fig. 2 Relationship between throughfall percentage and rainfall

### 2.3 茎流变化

试验期间金露梅灌丛茎流量和茎流率(茎流量占降雨量的百分比, $SF\%$ )见表2。茎流量相差较大,以沙棘灌丛最高,依次为鬼箭锦鸡儿灌丛,金露梅灌丛,高山柳灌丛最小,茎流率也表现出同样特征,分别为3.4%,3.2%,8.0%,4.2%。金露梅和高山柳单次最大茎流出现在2010年7月8日(降雨历时10 h,降雨量23.5 mm),分别为0.87 mm(3.7%)和1.1 mm(4.7%),沙棘和鬼箭锦鸡儿单次最大茎流出现在2010年8月19日(降雨历时12 h,降雨量20.2 mm),分别为2.3 mm(11.3%)和1.5 mm(7.2%)。

4种灌丛的茎流量( $SF$ )随降雨量( $P$ )的变化关系见图3。4种灌丛茎流量与次降雨量之间均呈显著的正相关关系( $P<0.001$ ),茎流量随着降雨量的增加而增加。

### 2.4 截留变化

利用试验测定的穿透雨和茎流数据,利用式(1)计算灌丛截留量。各灌丛截留特征见表2。试验期间,截留量最大的是沙棘灌丛,依次为鬼箭锦鸡儿灌丛,金露梅灌丛和高山柳灌丛,截留率依次为39.7%,35.6%,34.6%,33.3%。单次最大截留量鬼箭锦鸡儿为8.4 mm,高山柳为7.2 mm(2010年7月8日),金露梅为6.6 mm(2010年8月19日),沙棘6.5 mm(2010年6月23日,降雨历时8 h,降雨量17.7 mm)。

4种灌丛降雨量( $P$ )与截留量( $IC$ )之间为显著线性正相关关系( $P<0.05$ ),而截留率(截留量占降水量的百分比, $IC\%$ )与降雨量的关系则能被指数函数很好的拟合(图5, $P<0.05$ )。可以看出,降雨量大小对截留率影响较大,截留率随降雨量增加而减小,雨量较小时,大部分降雨被灌层所截留,而当灌丛叶片、枝干表面水分达到饱和状态时,截留率就会达到一个稳定值,不会随着降雨量的增加而增加。4种灌丛达到稳定截留率所对应的降雨量相差较大,金露梅灌丛为6 mm,高山柳灌丛为10 mm,沙棘灌丛为14 mm,鬼箭锦鸡儿灌丛为7 mm。

### 2.5 截留率与降雨强度的关系

对灌丛截留率( $IC\%$ )与降雨期间平均雨强( $I$ )的关系进一步分析,降雨强度和4种灌丛的截留率关系见图6( $P<0.05$ ),4种灌丛的截留率均为雨强的指数函数。在雨强<4 mm/h时,灌丛截留率随着雨强的增加呈

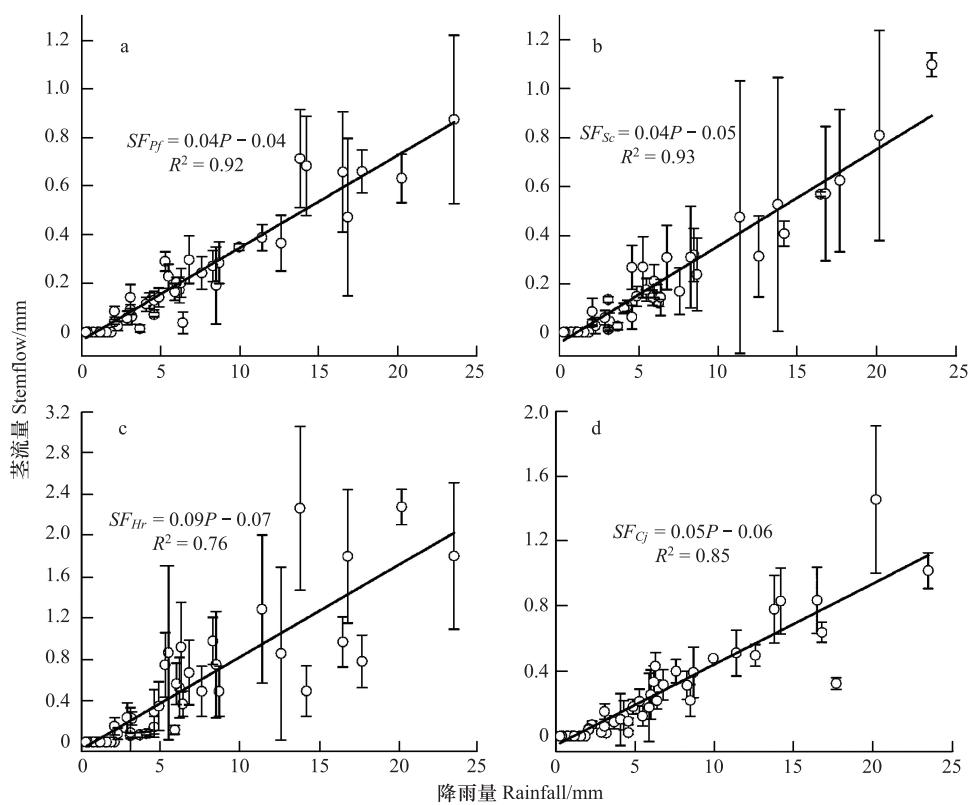


图3 灌丛茎流量与降雨量之间的关系

Fig. 3 Relationship between stemflow and rainfall

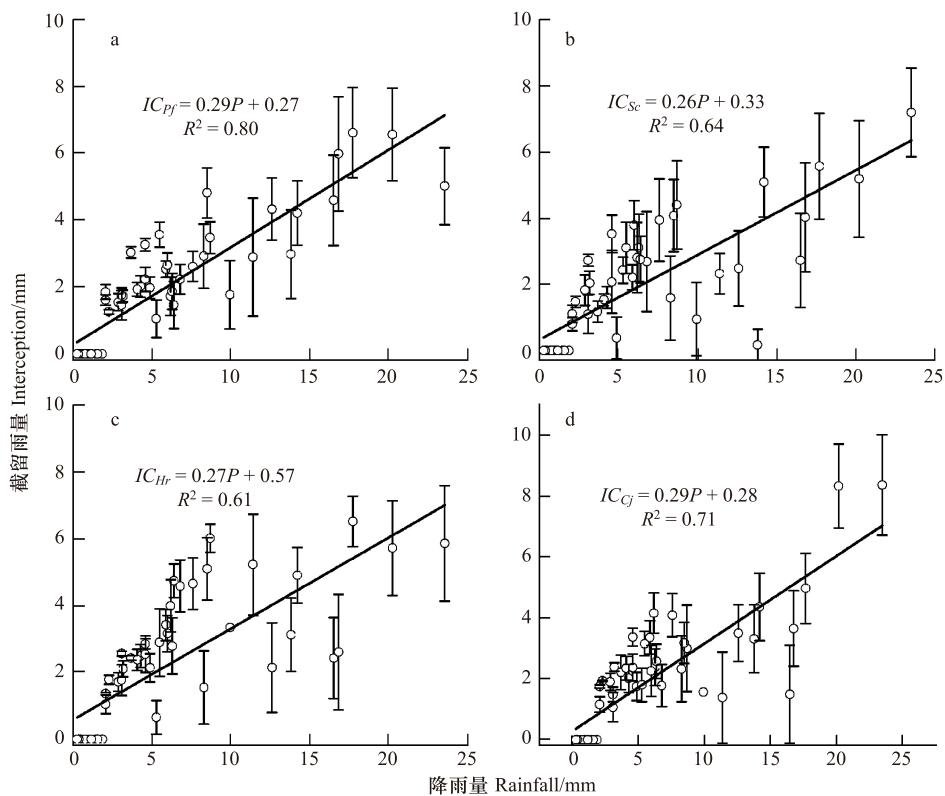


图4 灌丛截留量与降雨量之间的关系

Fig. 4 Relationships between interception and rainfall

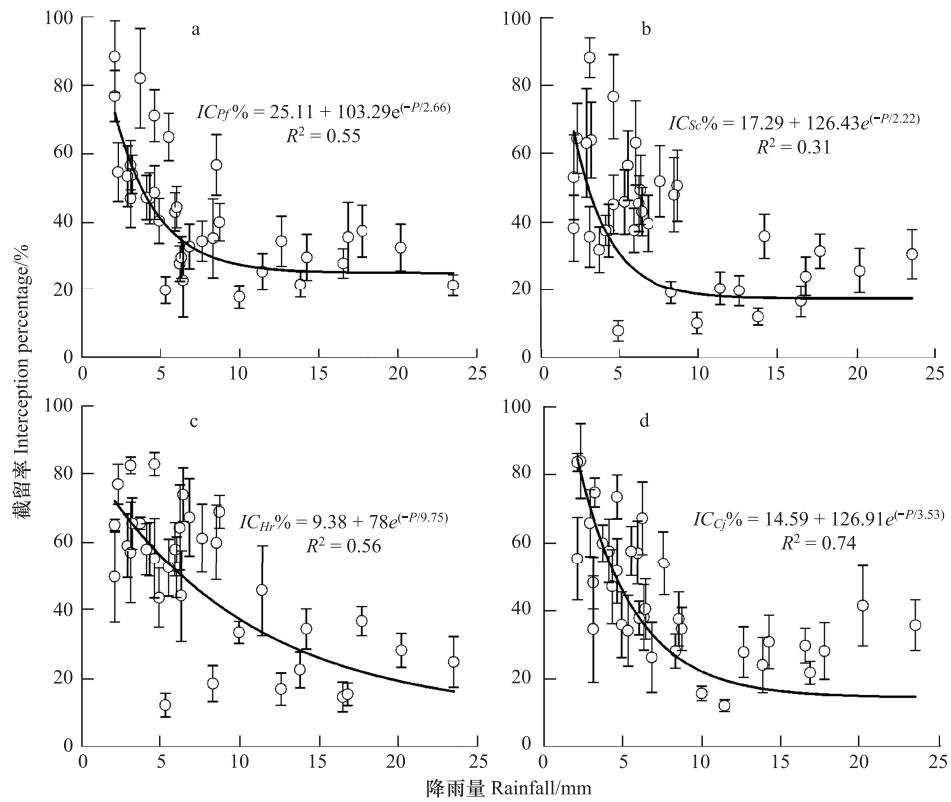


图5 灌丛截留率与降雨量之间的关系

Fig. 5 Relationships between interception percentage and rainfall

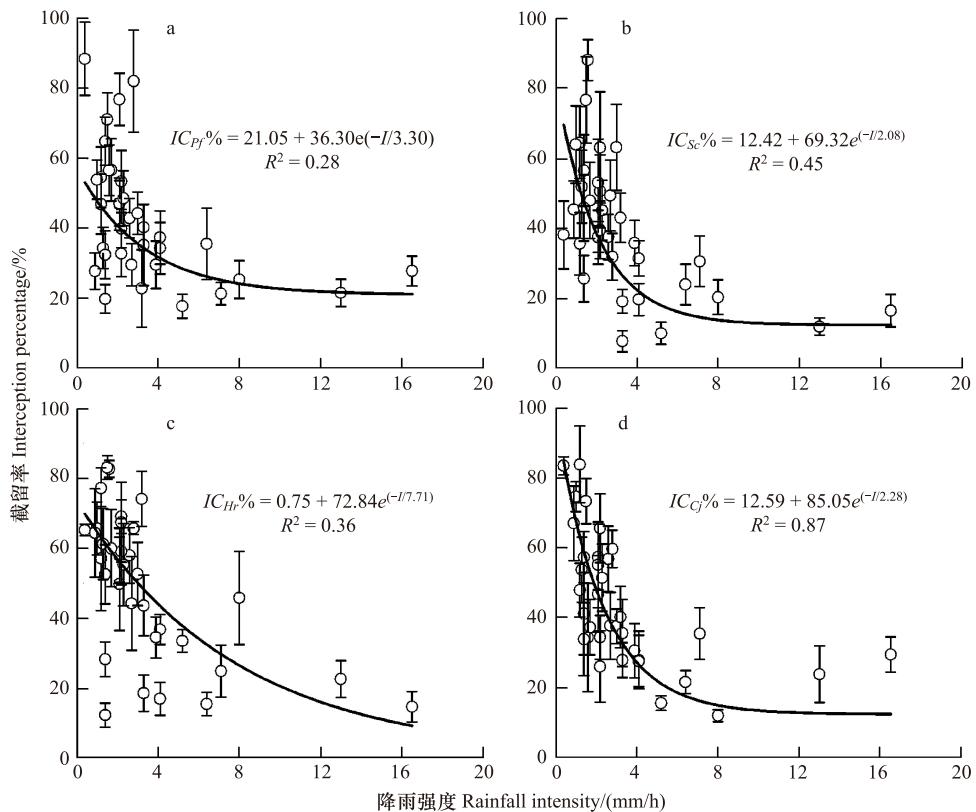


图6 灌丛截留率与雨强之间的关系

Fig. 6 Relationships between interception percentage and rainfall intensity

减小趋势,当雨强>4 mm/h后,截留率减小趋势变缓并且趋于稳定。

### 3 讨论

本研究的降雨截留结果与 Owens MK<sup>[27]</sup>得出的刺柏(*Juniperus formosana*)灌丛研究结果(40%)相近,相比于聂雪花<sup>[22]</sup>得出祁连山排露沟流域金露梅截留率(10.4%)和鬼箭锦鸡儿截留率(16.8%),以及干旱半干旱区的结果(17%—26%)<sup>[14-20,28-30]</sup>,截留量偏大,而与常学向等<sup>[23]</sup>,车克钧等<sup>[21]</sup>结果相比则偏低。原因之一是降雨特征的差异性,本研究区位于祁连山深山区,降雨量高于上述干旱半干旱区,与祁连山水源涵养林相比,降雨特征也有差异<sup>[22]</sup>。此外,不同灌丛结构方面的差异也会对截留产生很大的影响<sup>[29]</sup>。影响单株植物冠层截留能力的主要因子是平均叶角、散射系数与透射系数,对群落截留过程起决定作用的群落学指标将是株高、叶面积指数与植被盖度<sup>[19]</sup>。在降雨特征相同的情况下,4种灌丛达到稳定截留率所对应的降雨量相差较大,说明植被特征是本区影响截留的重要因素。

4种灌丛的降雨截留量、穿透雨量、茎流量与降雨量之间均呈显著正相关关系,这与杨志鹏等<sup>[18]</sup>、李衍青等<sup>[29]</sup>、王新平等<sup>[20]</sup>的结论一致。指数函数可以较好地描述灌丛截留率、穿透率随降雨量的变化。穿透率先是随着降雨量增加而增加,达到一定雨量后,穿透率趋于稳定值。比较来看,金露梅和鬼箭锦鸡儿灌丛更为明显,当降水量分别大于7 mm和6 mm的时候,金露梅和鬼箭锦鸡儿灌丛穿透率基本不变,高山柳和沙棘灌丛则没有很明显的拐点。截留率则是随着降雨量增加而减小,4种灌丛达到稳定截留率所对应的降雨量相差较大,这与灌丛形态特征有很大的关系<sup>[19]</sup>。

金露梅、高山柳、沙棘和鬼箭锦鸡儿灌丛茎流分别为3.4%、3.2%、8.0%、4.2%。这与杨志鹏等<sup>[18]</sup>、Carlyle-Moses等<sup>[1]</sup>、Owens MK<sup>[27]</sup>得出的一些灌丛的茎流的结论相近。影响茎流的因素很多,主要有气象因素(雨量,雨强等)和冠层特征(冠层结构,枝叶倾角,树皮光滑度等)<sup>[15,25]</sup>。试验观测发现在次降雨量最小值(2010年9月26日,降雨历时1h,降雨量2.1 mm)和雨强最小值(2010年7月12日,雨强0.7 mm/h)的条件下均产生了茎流,但数量极小,说明灌丛产生茎流的临界降雨量较小。据野外实际调查,金露梅和高山柳的茎干较为光滑,分枝多且比较细小,有利于在雨量和雨强很小的情况下容易形成茎流,但是茎流随着降雨量增加而很快减小,故茎流量较小。鬼箭锦鸡儿灌丛枝干比较粗糙,刺状枝比较密集,灌丛投影面积小但是叶面积指数大,降雨量比较小时,不易产生茎流,但是当降雨量较大时,茎流也会随之增加,所以茎流量较大。所选沙棘灌丛郁闭度高,其株高、冠幅、茎干长度、地径也远大于其他3种灌丛,因此茎流量最大。就叶片大小而言,高山柳最大,但是其茎流量却比较低,说明叶片对茎流形成影响并不显著,而植株形态的大小对茎流影响较大,这与 Martinez-Meza<sup>[29]</sup>等的结论一致。

雨强也是影响灌丛截留率的重要因素。腾格里沙漠柠条(*Caragana korshinskii*)和油蒿(*Artemisia ordosica*)截留率与雨强呈幂函数,雨强>1.0 mm/h时,截留率达到稳定<sup>[19]</sup>,毛乌素沙地沙柳(*Salix psammophila*)灌丛截留量则与最大10min雨强呈线性正相关<sup>[18]</sup>。本研究中灌丛截留率是雨强的指数函数,截留率随着雨强的增加而减小,当雨强小于4.0 mm/h时,截留率呈显著下降趋势,随着雨强的增加,截留率则逐渐趋于稳定值,这也解释了次降雨过程中,灌丛单次截留量最大时,其相对应截留率并不是最低的现象。

本研究对于植被冠层结构特征和灌丛生长特征未进行全部测量,对于灌丛冠层特征对截留的影响,还不能进行系统定量的分析。在后续的试验中,应该测定植被形态特征,如:叶面积指数(LAI)、自由透雨系数、生物量、冠层持水能力等,从而分析灌丛单位叶面积截留能力。

### References:

- [1] Muzylo A, Llorens P, Valente F, Keizer J J, Domingo F, Gash J H C. A review of rainfall interception modelling. *Journal of Hydrology*, 2009, 370:191-206.
- [2] Wang L X, Zhang Z Q. Advances in the study of ecohydrological effects from vegetation changes. *World Forestry Research*, 1998, (6): 14-23.
- [3] Wang Y H, Yu P T, Xu D Y, Zhao M S. A preliminary study on transformation of rainfall interception models and parameter's variation. *Journal of Beijing Forestry University*, 1998, 26(6): 25-30.

- [ 4 ] Crockford R H, Richardson D P. Partitioning of rainfall into throughfall, stemflow, and interception: effect of forest type, ground cover and climate: Linking hydrology and ecology. *Hydrological Processes*, 2000, 14(16/17) : 2903-2920.
- [ 5 ] Schellekens J, Scatena F N, Bruijnzeel L A, Wickel A J. Modelling rainfall interception by a low land tropical rain forest in northeastern Puerto Rico. *Journal of Hydrology*, 1999, 225(3/4) : 168-184.
- [ 6 ] Wang X, Zhang Y P, Liu W J. Modeling canopy rainfall interception of a tropical seasonal rainforest in Xishuangbanna, Southwest China. *Acta Ecologica Sinica*, 2006, 26(3) : 722-729.
- [ 7 ] Taniguchi M, Tsujimura M, Tanaka T. Significance of stemflow in groundwater recharge. 1: Evaluation of the stemflow contribution to recharge using a mass balance approach. *Hydrological Processes*, 1996, 10(1) : 71-80.
- [ 8 ] Tanaka T, Taniguchi M, Tsujimura M. Significance of stemflow in groundwater recharge 2: A cylindrical infiltration model for evaluating the stemflow contribution to groundwater recharge. *Hydrological Processes*, 1996, 10(1) : 81-88.
- [ 9 ] Schroth G, Silva L F, Wolf M A, Geraldus T W, Zech W. Distribution of throughfall and stemflow in multistrata agroforestry, perennial monoculture, fallow and primary forest in central Amazonia, Brazil. *Hydrological Processes*, 1999, 13(10) : 1423-1436.
- [ 10 ] Price A G, Dunham K, Carleton T, Band L. Variability of water fluxes through the black spruce (*Picea mariana*) canopy and feather moss (*Pleurozium schreberi*) carpet in the boreal forest of northern Manitoba. *Journal of Hydrology*, 1997, 196(1/4) : 310-323.
- [ 11 ] Carlyle-Moses D E. Throughfall, stemflow and canopy interception loss fluxes in a semi-arid Sierra Madre Oriental matorral community. *Journal of Arid Environments*, 2004, 58(2) : 180-201.
- [ 12 ] Crockford R H, Richardson D P. Partitioning of rainfall in a eucalypt forest and pine plantation in southeastern Australia: iii. Determination of the canopy storage capacity of a dry sclerophyll eucalypt forest. *Hydrological Processes*, 1990, 4(2) : 157-167.
- [ 13 ] Soulsby C, Reynolds B. The chemistry of throughfall, stemflow and soil water beneath oak woodland and moorland vegetation in upland Wales. *Journal of Chemical Ecology*, 1994, 9(2) : 115-134.
- [ 14 ] Llorens P, Domingo F. Rainfall partitioning by vegetation under Mediterranean conditions. A review of studies in Europe. *Journal of Hydrology*, 2007, 335(1/2) : 37-54.
- [ 15 ] Levia D F Jr., Frost E E. A review and evaluation of stemflow literature in the hydrologic and biogeochemical cycles of forested and agricultural ecosystems. *Journal of Hydrology*, 2003, 274(1/4) : 1-29.
- [ 16 ] Martinez-Meza E, Whitford W G. Stemflow, throughfall and channelization of stemflow by roots in three Chihuahuan desert shrubs. *Journal of Arid Environments*, 1996, 32(3) : 271-287.
- [ 17 ] Huo Z, Shao M A. Characteristics of rainfall and crown interception of shrub in wind-water erosion interleaving region of Loess Plateau. *Agricultural Research in the Arid Areas*, 2005, 23(5) : 88-92.
- [ 18 ] Yang Z P, Li X Y, Sun Y L, Liu L Y, Zhang X Y, Ma Y J. Characteristics of rainfall interception and stemflow for *Salix psammophila* in Maowusu sandland, Northwest China. *Advance in Water Science*. 2008, 19(5) : 693-698.
- [ 19 ] Wang X P, Kang E S, Zhang J G, Li X R. Comparison of interception loss in shrubby and sub-shrubby communities in the Tengger desert of northwest China. *Journal of Glaciology and Geocryology*, 2004, 26(1) : 89-94.
- [ 20 ] Li Y Q, Zhang T H, Zhao X Y, Liu X P, Tong X Z, Yun J Y. Rainfall interception and stemflow for *Caragana microphylla* in Horqin Sandy Land, northern China. *Acta Pratacultrae Sinica*, 2010, 19(5) : 267-272.
- [ 21 ] Che K J, Fu H E, He H Y, Zhang H, Zhang X L, Qu K L, Miao W. Studies on the effects of water conservation forest in the Qilian Mountain. *Scientia Silvae Sinicae*, 1992, 28(6) : 544-548.
- [ 22 ] Nie X H. Study on Water Conservation Function of Shrub in Qilian Mountain. Lanzhou: Gansu Agricultural University, 2009.
- [ 23 ] Chang X X, Zhao A F, Wang J Y, Chang Z Q, Jin B W. Precipitation characteristic and interception of forest in Qilian Mountain. *Plateau Meteorology*, 2002, 21(3) : 274-280.
- [ 24 ] Wang X F. The importance of shrub in Qilian Mountain and its protection and development countermeasures. *Journal of Gansu Forestry Science and Technology*, 2005, 30(2) : 32-35.
- [ 25 ] Zhou Z F, Zhang G C, Liu X, Bo J Y, Li X L. Review on research methods of stemflow. *Journal of Soil and Water Conservation*, 2004, 18(3) : 137-140.
- [ 26 ] Belmonte Serrato F, Romero Diaz A. A simple technique for measuring rainfall interception by small shrub: interception flow collection box. *Hydrological Processes*, 1998, 12(3) : 471-481.
- [ 27 ] Owens M K, Lyons R K, Alejandro C L. Rainfall partitioning within semiarid *Juniper* communities: Effects of event size and canopy cover. *Hydrological Processes*, 2006, 20(15) : 3179-3189.
- [ 28 ] Návar J, Bryan R B. Interception loss and rainfall redistribution by three semi-arid growing shrubs in northeastern Mexico. *Journal of Hydrology*, 1990, 115(1/4) : 51-63.

- [29] Martinez-Meza E. Stemflow, Throughfall, and Root Water Channelization by Three Arid Land Shrubs in Southern New Mexico. Las Cruces: New Mexico State University, 1994.
- [30] Slatyer R O. Measurement of precipitation, interception by an arid plant community (*Acacia aneura* F. Muell.). *Arid Zone Research*, 1965, 25: 181-192.

**参考文献:**

- [2] 王礼先, 张志强. 森林植被变化的水文生态效应研究进展. *世界林业研究*, 1998, (6): 14-23.
- [3] 王彦辉, 于澎涛, 徐德应, 赵茂盛. 林冠截留降雨模型转化和参数规律的初步研究. *北京林业大学学报*, 1998, 20(6): 25-30.
- [6] 王馨, 张一平, 刘文杰. Gash 模型在热带季节雨林林冠截留研究中的应用. *生态学报*, 2006, 26(3): 722-729.
- [17] 霍竹, 邵明安. 黄土高原水蚀风蚀交错带降水及灌木林冠截留特性研究. *干旱地区农业研究*, 2005, 23(5): 88-92.
- [18] 杨志鹏, 李小雁, 孙永亮, 刘连友, 张晓影, 马育军. 毛乌素沙地沙柳灌丛降雨截留与树干茎流特征. *水科学进展*, 2008, 19(5): 693-698.
- [19] 王新平, 康尔泗, 张景光, 李新荣. 荒漠地区主要固沙灌木的降水截留特征. *冰川冻土*, 2004, 26(1): 89-941.
- [20] 李衍青, 张铜会, 赵学勇, 刘新平, 童勋章, 云建英. 科尔沁沙地小叶锦鸡儿灌丛降雨截留特征研究. *草业学报*, 2010, 19(5): 267-272.
- [21] 车克钧, 傅辉恩, 贺红元, 张虎, 张学龙, 阎克林, 苗旺. 祁连山水源涵养林效益的研究. *林业科学*, 1992, 28(6): 544-548.
- [22] 聂雪花. 祁连山灌木林水源涵养功能的研究. 兰州: 甘肃农业大学, 2009.
- [23] 常学向, 赵爱芬, 王金叶, 常宗强, 金博文. 祁连山林区大气降水特征与森林对降水的截留作用. *高原气象*, 2002, 21(3): 274-280.
- [24] 王学福. 灌木林在祁连山区的作用及其发展策略研究. *甘肃林业科技*, 2005, 30(2): 32-35.
- [25] 周择福, 张光灿, 刘霞, 薄金燕, 李小磊. 树干茎流研究方法及其评述. *水土保持学报*, 2004, 18(3): 137-140.

# ACTA ECOLOGICA SINICA Vol. 32, No. 4 February, 2012 (Semimonthly)

## CONTENTS

The influence of a reclamation project on the macrobenthos of an East Nanhui tidal flat .....	MA Chang'an, XU Linlin, TIAN Wei, et al (1007)
Ecological health assessment of groundwater in the lower Liaohe River Plain using an ArcView-WOE technique .....	SUN Caizhi, YANG Lei (1016)
Nitrogen flows in intensive “crop-livestock” production systems typically for the peri-urban area of Beijing .....	HOU Yong, GAO Zhiling, MA Wenqi, et al (1028)
The simulation of leaf net photosynthetic rates in different radiation in apple canopy .....	GAO Zhaoquan, FENG Shezhang, ZHANG Xianchuan, et al (1037)
Phenological variation of typical vegetation types in northern Tibet and its response to climate changes .....	SONG Chunqiao, YOU Songcai, KE Linghong, et al (1045)
Soil moisture and temperature characteristics of forest-grassland ecotone in middle Qilian Mountains and the responses to meteorological factors .....	TANG Zhenxing, HE Zhibin, LIU Hu (1056)
Eco-hydrological effects of Qinghai spruce ( <i>Picea crassifolia</i> ) canopy and its influence factors in the Qilian Mountains .....	TIAN Fengxia, ZHAO Chuanyan, FENG Zhaodong, et al (1066)
Response of tree-ring width of <i>Pinus sylvestris</i> var. <i>mongolica</i> to climate change in Hulunbuir sand land, China .....	SHANG Jianxun, SHI Zhongjie, GAO Jixi, et al (1077)
Analysis of a dust case using lidar in Shanghai .....	MA Jinghui, GU Songqiang, CHEN Min, et al (1085)
Relating the distribution of zooplankton abundance in the coastal waters of central Fujian Province to the seasonal variation of water masses .....	TIAN Fengge, XU Zhaoli (1097)
Phenotypic traits of both larvae and juvenile <i>Crasstrea hongkongensis</i> and <i>C. gigas</i> .....	ZHANG Yuehuan, WANG Zhaoping, YAN Xiwu, et al (1105)
Inter-specific competition between <i>Prorocentrum donghaiense</i> and <i>Skeletonema costatum</i> .....	LI Hui, WANG Jiangtao (1115)
Effects of initial biomass ratio on the interspecific competition outcome between three marine microalgae species .....	WEI Jie, ZHAO Wen, YANG Weidong, et al (1124)
On the ecological amplitude of nitrate of <i>Alexandrium tamarensis</i> at different initial phosphate concentrations in laboratory cultures .....	WEN Shiyong, SONG Lili, LONG Hua, et al (1133)
Time lag effects and rainfall redistribution traits of the canopy of natural secondary <i>Pinus tabulaeformis</i> on precipitation in the Qinling Mountains, China .....	CHEN Shujun, CHEN Cungen, ZOU Bocai, et al (1142)
The vertical distribution of vegetation patterns and its relationship with environment factors at the northern slope of Ili River Valley: a bimodal distribution pattern .....	TIAN Zhongping, ZHUANG Li, LI Jiangui (1151)
Comparative analysis of water related parameters and photosynthetic characteristics in the endangered plant <i>Tetraena mongolica</i> Maxim. and the closely related <i>Zygophyllum xanthoxylon</i> (Bunge) Maxim. ....	SHI Songli, WANG Yingchun, ZHOU Hongbing, et al (1163)
Antioxidant properties of four native grasses in Loess Plateau under drought stress .....	SHAN Changjuan, HAN Ruilan, LIANG Zongsuo (1174)
The effects of the addition of <i>Ceratobasidium stevensii</i> B6 and its growth on the soil microflora at a continuously cropped water-melon ( <i>Citrullus lanatus</i> ) site in China .....	XIAO Yi, WANG Xingxiang, WANG Hongwei, et al (1185)
Suitable habitat for the <i>Achnatherum splendens</i> community in typical steppe region of Inner Mongolia .....	ZHANG Yifei, WANG Wei, LIANG Cunzhu, et al (1193)
Spatio-temporal variability of soil salinity and its relationship with the depth to groundwater in salinization irrigation district .....	GUAN Xiaoyan, WANG Shaoli, GAO Zhanyi, et al (1202)
Spatial heterogeneity of soil saturated hydraulic conductivity on a slope of the wind-water erosion crisscross region on the Loess Plateau .....	LIU Chunli, HU Wei, JIA Hongfu, et al (1211)
Spatial and temporal variations of total nitrogen density in agricultural soils of the Songnen Plain Maize Belt .....	ZHANG Chunhua, WANG Zongming, JU Weimin, et al (1220)
The evaluation system of strength of winterness in wheat .....	WANG Peng, ZHANG Chunqing, CHEN Huabang, et al (1230)
A comparison of summer habitats selected by sympatric <i>Apodemus chevrieri</i> and <i>Apodemus draco</i> in Tiangjiahe Nature Reserve, China .....	LI Yunxi, ZHANG Zejun, SUN Yiran, et al (1241)
Life tables for experimental populations of <i>Frankliniella occidentalis</i> on 6 vegetable host plants .....	CAO Yu, ZHI Junrui, KONG Yixian (1249)
Effect of diet switch on turnover rates of tissue nitrogen stable isotopes in fish based on the enrichment-dilution approach .....	ZENG Qingfei, GU Xiaohong, MAO Zhigang, et al (1257)
Recognition of important ecological nodes based on ecological networks analysis: A case study of urban district of Nanjing .....	XU Wenwen, SUN Xiang, ZHU Xiaodong, et al (1264)
Seasonal characteristics of CO <sub>2</sub> fluxes above urban green space in the Pearl River Delta, China .....	SUN Chunjian, WANG Chunlin, SHEN Shuanghe, et al (1273)
Simulation and evaluation of groundwater seepage in contaminated sites: case study of Tuocheng County .....	WU Yizhong, ZHU Qinyuan, LIU Ning, LU Genfa, DAI Mingzhoet al (1283)
<b>Review and Monograph</b>	
Recent advances in wetland degradation research .....	HAN Dayong, YANG Yongxing, YANG Yang, LI Ke (1293)
A review concerning nitrogen accumulation and leaching in agro-ecosystems of oasis .....	YANG Rong, SU Yongzhong, WANG Xuefeng (1308)
<b>Discussion</b>	
The diversity of the radio-resistant bacteria <i>Deinococcus radiodurans</i> .....	TU Zhenli, FANG Lijing, WANG Jiagang (1318)
Effect of pruning measure on physiology character and soil waters of <i>Caragana korshinskii</i> .....	YANG Yongsheng, BU Chongfeng, GAO Guoxiong (1327)
<b>Scientific Note</b>	
Characteristics of rainfall interception for four typical shrubs in Qilian Mountain .....	LIU Zhangwen, CHEN Rensheng, SONG Yaoxuan, et al (1337)
Dormancy break approaches and property of dormant seeds of wild <i>Cryptotaenia japonica</i> .....	YU Mei, ZHOU Shoubiao, WU Xiaoyan, et al (1347)

# 《生态学报》2012 年征订启事

《生态学报》是中国生态学学会主办的自然科学高级学术期刊,创刊于 1981 年。主要报道生态学研究原始创新性科研成果,特别欢迎能反映现代生态学发展方向的优秀综述性文章;研究简报;生态学新理论、新方法、新技术介绍;新书评介和学术、科研动态及开放实验室介绍等。

《生态学报》为半月刊,大 16 开本,280 页,国内定价 70 元/册,全年定价 1680 元。

国内邮发代号:82-7 国外邮发代号:M670 标准刊号:ISSN 1000-0933 CN 11-2031/Q

全国各地邮局均可订阅,也可直接与编辑部联系购买。欢迎广大科技工作者、科研单位、高等院校、图书馆等订阅。

通讯地址:100085 北京海淀区双清路 18 号 电 话:(010)62941099; 62843362

E-mail: shengtaixuebao@rcees.ac.cn 网 址: www.ecologica.cn

编辑部主任 孔红梅

执行编辑 刘天星 段 靖

## 生态学报

(SHENGTAI XUEBAO)

(半月刊 1981 年 3 月创刊)

第 32 卷 第 4 期 (2012 年 2 月)

## ACTA ECOLOGICA SINICA

(Semimonthly, Started in 1981)

Vol. 32 No. 4 2012

编 辑 《生态学报》编辑部  
地址:北京海淀区双清路 18 号  
邮政编码:100085  
电话:(010)62941099  
www.ecologica.cn  
shengtaixuebao@rcees.ac.cn

主 编 冯宗炜  
主 管 中国科学技术协会  
主 办 中国生态学学会  
中国科学院生态环境研究中心  
地址:北京海淀区双清路 18 号  
邮政编码:100085

出 版 科 学 出 版 社  
地址:北京东黄城根北街 16 号  
邮政编码:1000717

印 刷 北京北林印刷厂  
行 销 科 学 出 版 社  
地址:东黄城根北街 16 号  
邮政编码:100717  
电话:(010)64034563

订 购 国外发行  
E-mail:journal@cspg.net  
全国各地邮局  
中国国际图书贸易总公司  
地址:北京 399 信箱  
邮政编码:100044

广告经营  
许 可 证  
京海工商广字第 8013 号

Edited by Editorial board of  
ACTA ECOLOGICA SINICA  
Add:18, Shuangqing Street, Haidian, Beijing 100085, China  
Tel:(010)62941099  
www.ecologica.cn  
Shengtaixuebao@rcees.ac.cn

Editor-in-chief FENG Zong-Wei  
Supervised by China Association for Science and Technology  
Sponsored by Ecological Society of China  
Research Center for Eco-environmental Sciences, CAS  
Add:18, Shuangqing Street, Haidian, Beijing 100085, China

Published by Science Press  
Add:16 Donghuangchenggen North Street,  
Beijing 100717, China

Printed by Beijing Bei Lin Printing House,  
Beijing 100083, China

Distributed by Science Press  
Add:16 Donghuangchenggen North  
Street, Beijing 100717, China  
Tel:(010)64034563  
E-mail:journal@cspg.net

Domestic All Local Post Offices in China  
Foreign China International Book Trading  
Corporation  
Add:P. O. Box 399 Beijing 100044, China

ISSN 1000-0933  
9 771000093125  
0 4 >