Edge effect of intercepted fog water by forest canopy at a rubber plantation in Xishuangbanna, Southwest China

LIU Wen-Jie1, 2, 3, *, ZHANG Yi-Ping1, LI Hong-Mei1, LIU Yu-Hong1, DUAN Wen-Ping1


Abstract: Xishuangbanna is located at the northern edge of the distribution of tropical forest in Southeast Asia, and it has a very high frequency of radiation fog, especially during the dry season (November~April). Radiation fog events in this site are generally associated with low wind speeds and region-wide air mass stagnation resulting from strong nighttime radiative cooling. Intercepted fog water by forest canopy from both the windward edge and leeward edge to the interior of the forest and related microclimatic factors were measured during November 2001 and October 2002 at a rubber (Hevea brasiliensis) plantation in Xishuangbanna, Southwest China. The object of the study is to determine whether the windward edge and leeward edge of forest floor receives greater deposition of fog water than the interior of the forest. Bottle-funnel collectors were used to determine daily amount of intercepted fog water during fog-only events along windward and leeward transects in the rubber plantation. Related microclimatic variables including air temperature, relative humidity, wind speed, wind direction, and rainfall were also recorded by a meteorological observation system (MAOS-1) mounted on a 31 m meteorological tower in the study stand. The number of fog days was extremely higher inside the rubber plantation, with 172 days per year. The fog frequency was up to 76.7% in the foggy season (November~February). During the study period, an absolute amount of annual intercepted fog water in the rubber plantation was up to 16.2 mm. Annual intercepted fog water varied dramatically and...
increased exponentially from the windward and leeward edge to the interior of the forest. Intercepted fog water at the edge of the forest was on average 1.5 to 2.5 times, and up to 9 times greater than that in the interior of the forest. The intercepted fog water “stable-distance”, i.e. the point at which the fog water interception is generally no change within the forest edge farther, was found to be 25 m for the windward edge and 15 m for the leeward edge. We also found that the intercepted fog water at the edge was positively correlated with average wind speed during 0:00~10:00 of the day (P<0.01), demonstrating that high wind speed resulted to further extension of the edge effect and lower spatial heterogeneity. Our intercepted fog water data were compared to other studies, which showed similar result. Although our data are not extensive enough to allow broad generalizations, they provide further evidence that the amount of intercepted fog water from the forest canopy to the forest floor in edge zones can be very different from that in the forest interiors. In regions of high winds and significant intercepted fog water, the edge effect is likely to be even greater than we have shown here. We attribute this difference to the mechanism of fog formation in different sites. The fog in montane forest close to coasts with high wind is mainly caused by the cooling effect of rising air plus long-wave radiation loss. However, the fog in Xishuangbanna, which is far from the coast, is mainly a result of long-wave radiation at relatively low altitude. Meanwhile, it is reasonable to believe that converting multi-layer tropical rain forest with single-layer rubber plantation will reduce intercepted fog water in adjacent tropical rain forest. Furthermore, the method used to collect fog drip water is also different from other studies that could contribute to the relatively low value reported in this study. As the data obtained from canopy drip are net inputs to the forest floor, the estimate is considered to be conservative compared to fog water via impaction by fog gauges. We could further hypothesize that the edge of the rubber plantations would generally intercept less fog drip than that of the tropical rain forest during the dry season. The edge effect phenomenon we have described could have important effects on many ecological processes, biodiversity and forest regeneration. These results also demonstrate the importance of understanding the impacts of climate factors, and have important implications for ecologists and hydrologists interested in fog-inundated ecosystems and the plants that inhabit them.

Key words: intercepted fog water; forest canopy; edge effect; rubber plantation; Xishuangbanna

...
(11~2月)、(3~4月)、(5~10月)、(11月~次年2月) [18]。平均0.7 m/s。相对湿度86%。
日均1400~1500 mm。83%~87%。13%~17%。

2.1

(Hevea brasiliensis)、(Baccaurea rambil)、(Raoulia comitoria)。

2.2

MAOS-1型自动气象观测站

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1 Monthly average fog events and frequency in different season at rubber plantation during November 2001 and October 2002

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.1

3.2

3.2.1

3.2.2

* (11 ~ 2月) Foggay season (November ~ February);
* (3~4月) Hot-dry season (March~April);
* (5~10月) Rainy season (March~October)
与日平均风速的关系

如图所示，二者呈现显著的正相关。即大的风速与多的林缘截留雾水相对应。

表2 人工橡胶林迎风面和背风面林缘处的年雾水截留量

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Distance from edge (m)</th>
<th>Interior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windward edge</td>
<td>0</td>
<td>31.6</td>
</tr>
<tr>
<td>Leeward edge</td>
<td>0</td>
<td>20.2</td>
</tr>
</tbody>
</table>

图1 年雾水截留量与年平均风速的关系（2001-11～2002-10）

图2 年平均风速与年雾水截留量的关系（2002年）
人工橡胶林迎风面林缘处的相对雾水截留由林缘至林内的距离变化

图1!人工橡胶林迎风面林缘处的相对雾水截留由林缘至林内的距离变化

平均风速

误差线表示标准离差

图2表明，风速大时雾水截留的边缘效应向林内越深入且空间变异性减小。相对于迎风面林缘处的雾水截留而言，大的风速将削弱林内和林缘雾水截留量的差别，从而导致更多的雾水进入森林。

在人工橡胶林收集的雾水实际上包括了露水。根据本文作者的研究，雾是在露形成后空气湿度接近饱和时才出现。有雾必有露，但有露并不一定有雾形成。仅有露形成的天气里林冠叶片被浸湿，但没有形成由叶片滴落的露水。因此，本文的林冠截留雾水实际上是在叶片被露水浸湿后林冠进一步对雾的机械拦截作用所致。

与Weathers [14, 16], Hasselrot [22] Potts [22]等观测方法相比，本研究采用的大口径漏斗承接滴落的雾水显然更具有代表性。因为大口径漏斗无疑削弱了短距离滴落雾水的空间差异，从而较真实的呈现出截留雾水的边缘效应。

而使用较小口径的漏斗承接雾水，漏斗的摆放位置将极大的影响观测数据的代表性，因为林冠截留雾水的关键滴落位置点会极大的干扰漏斗位置的代表性。因此，GT0;U16//5等建议在使用小口径收集装置收集林冠滴落水时采用移动观测方法更具有说服力。

在研究林缘附近的截留雾水时，无疑各观测点林冠处的风速是必须考虑的重要环境因子，但受观测条件的限制仅参考了林内观测铁塔上林冠处的风速。显然，风速大时林缘处的林冠对风的削弱也将增强，从而可能导致更多的雾水被林缘截获。因此，林缘附近截流的雾水与各测点风速叶面积指数等因子的关系有待进一步研究。

虽然没有测定林缘处雾水截留导致的化学元素和大气污染物干沉降的输入，但Weathers [14, 16], Hasselrot [22] Potts [22]等的观测数据表明，林缘处沉降的雾水内的化学元素和大气污染物明显高于林内，其沉降速率平均可达林内的N倍。林缘处呈现与雾水截留量相似的空间变异性。

许多学者的研究还表明，林缘的存在还影响了众多生态过程，可导致林缘许多生物学特性的改变，如林缘附近凋落物分解加快，先锋植物成分的增多，植物对水的需求量增多等，对生物多样性和森林更新也具有非常深远的影响。

林缘截获和浓集更多的水分、养分和大气污染物可能是一种普遍现象，且风速大的地区这种截获和浓集将会更大。对本地区而言，人工橡胶林内的年雾水截留量远低于本地区热带雨林内的相应值，因而热带雨林林缘处的雾水截留量可能更多。这也说明热带雨林的水分循环利用和涵养水源功效是人工橡胶林无法比拟的。

在研究林缘附近的截留雾水时，无疑各观测点林冠处的风速是必须考虑的重要环境因子，但受观测条件的限制仅参考了林内观测铁塔上林冠处的风速。显然，风速大时林缘处的林冠对风的削弱也将增强，从而可能导致更多的雾水被林缘截获。因此，林缘附近截流的雾水与各测点风速叶面积指数等因子的关系有待进一步研究。

虽然没有测定林缘处雾水截留导致的化学元素和大气污染物干沉降的输入，但Weathers [14, 16], Hasselrot [22] Potts [22]等的观测数据表明，林缘处沉降的雾水内的化学元素和大气污染物明显高于林内，其沉降速率平均可达林内的N倍。林缘处呈现与雾水截留量相似的空间变异性。

许多学者的研究还表明，林缘的存在还影响了众多生态过程，可导致林缘许多生物学特性的改变，如林缘附近凋落物分解加快，先锋植物成分的增多，植物对水的需求量增多等，对生物多样性和森林更新也具有非常深远的影响。

林缘截获和浓集更多的水分、养分和大气污染物可能是一种普遍现象，且风速大的地区这种截获和浓集将会更大。对本地区而言，人工橡胶林内的年雾水截留量远低于本地区热带雨林内的相应值，因而热带雨林林缘处的雾水截留量可能更多。这也说明热带雨林的水分循环利用和涵养水源功效是人工橡胶林无法比拟的。

人工橡胶林内的年雾水截留量远低于本地区热带雨林内的相应值，因而热带雨林林缘处的雾水截留量可能更多。这也说明热带雨林的水分循环利用和涵养水源功效是人工橡胶林无法比拟的。

林缘处的雾水截留量与日平均风速呈显著的正相关关系。风速大则雾水截留的边缘效应向林内越深入且空间变异性减小。相对于迎风面林缘处的雾水截留而言，大的风速将削弱林内和林缘雾水截留量的差别，从而导致更多的雾水进入森林。

结论

西双版纳热带人工橡胶林内的雾日数及雾日频率呈现明显的季节变化。全年雾日数可达%(#7G其中雾季7=的雾日数及雾日频率最多。高7=月均雾日数可达#!7"[JV[O&P由橡胶林林缘至林内年雾水截留量在迎风面和背风面均呈现出指数形式急剧减小。二者均是在林缘最边行外测的林冠下达到最大，分别为N%V%44和#NV!44P迎风面和背风面林缘处的雾水截留量分别是林内雾水截留量的#VF和%VF倍。迎风面的雾水截留率在林内约#F4处趋于稳定，而背风面在林内约%F4处趋于稳定。林缘处的雾水截留量与日平均风速呈显著的正相关关系。风速大，则雾水截留的边缘效应向林内越深入且空间变异性减小。相对于迎风面林缘处的雾水截留而言，大的风速将削弱林内和林缘雾水截留量的差别，从而导致更多的雾水进入森林。

本文的林冠截留雾水实际上是在叶片被露水浸湿后林冠进一步对雾的机械拦截作用所致。与Weathers [14, 16], Hasselrot [22] Potts [22]等的观测方法相比，本研究采用的大口径漏斗承接滴落的雾水显然更具有代表性。因为大口径漏斗无疑削弱了短距离滴落雾水的空间差异，从而较真实的呈现出截留雾水的边缘效应。而使用较小口径的漏斗承接雾水，漏斗的摆放位置将极大的影响观测数据的代表性，因为林冠截留雾水的关键滴落位置点会极大的干扰漏斗位置的代表性。因此，GT0;U16//5等建议在使用小口径收集装置收集林冠滴落水时采用移动观测方法更具有说服力。


Lovett G M. Rates and mechanisms of cloud water deposition to a subalpine balsam fir forest. *Atmospheric Environment*, 1984, 18: 381～371.


