Effects of Chinese-fir mixing with N-fixing and non-N fixing tree species on forestland quality and forest-floor solution chemistry


Abstract: Chinese fir (Cunningharia lanceolata) is a type of subtropical fast-growing conifer tree, widely distributed in South China, and its plantation area in China is more than $7 \times 10^4$ hm$^2$, accounting for 24% of total area of planted forest in China. In recent decades, the system of successive plantation of Chinese fir is widely used in the southern China for an anticipated high economic return. However, recent studies have documented that the practice of this system led to dramatic decreases in soil fertility and forest environment as well as in productivity. Compared with the first plantation generation of Chinese-fir, soil organic C, N, P, K and forest productivity, respectively, decrease 12.0%, 18.8%, 16.7%, 10.2% and 12.5% for the second rotation, 18.5%, 31.2%, 27.5%, 25.4% and 45.5% for the third rotation. Therefore, in recent years, increasing concern about the sustainable productivity of Chinese fir plantation forest has emphasized the need to seek a way to control the forestland degradation effectively and maintain soil quality.

Some forest ecologists and managers recognize the ecological role performed by broadleaf trees growing in mixtures with conifers, and a great deal of studies on mixtures effects have been conducted, particularly on mixture species of temperate and boreal forest, but these research results were not completely consistent each other. Maybe the mixtures effects depend in large...
part on specific site conditions, the interactions among species in mixtures and biological characteristics of species, etc.. Although some researchers also studied the effects of mixtures of Chinese fir and broadleaf tree species on soil fertility, forest environment and tree growth status, little information is available about systematic studies in mid-subtropical region on different forest management models such as mixtures of Chinese-fir and broadleaf trees (including N-fixing and non-N-fixing tree species), effects on soil quality, in particular on soil microbiological and biological properties. Similarly, reports about effects of different forest management models on forest-floor solution chemistry are also very scarce.

The experimental site was situated at Huiting Experimental Station of Forest Ecology, Chinese Academy of Sciences, Hunan Province (N 26°40′~27°09′ latitude and E 109°26′~110°08′ longitude). It locates at the transition zone from the Yunnan-Guizhou plateau to the low mountains and hills of southern bank of Yangtz River at an altitude of 300~1100 m above mean sea level and at the same time, it is also a member of the Chinese Ecosystem Research Network (CERN), sponsored by the Chinese Academy of Sciences (CAS). This region has a humid mid-subtropical monsoon climate with a mean annual precipitation of 1200~1400 mm, most of the rain falling between April and August, and a mean temperature of 16.5 °C with a mean minimum of 4.9 °C in January and a mean maximum of 26.6 °C in July. The soil of the experimental field is red-yellow soil.

After a clear-cutting of the first generation Chinese-fir planted forest (Cunninghamia lanceolata) in autumn of 1989, three different forest management models, viz. mixture of Chinese-fir and N-fixing alder (Alnus cremastogyne) (MCA), mixture of Chinese-fir and non-N-fixing Kalopanax septemlobus (MCK) and pure Chinese-fir stand (PCS), were established in spring of 1990. The effects of these three planted forest stands on soil characteristics were evaluated by measuring physico-chemical, microbiological, biochemical parameters and soil solution chemistry. Both MCA and MCK exerted a favourable effect on soil fertility maintenance, the improvement being greater under MCA. The concentrations of the mainly atmospherically derived ions in soil solutions, including SO$_4^{2-}$, Cl$^-$, Na$^+$ and Mg$^{2+}$, were significantly higher under the conifer (PCS) than under the mixtures (MCA and MCK). Whereas the concentrations of ions that mainly controlled by within system processes such as K$^+$, NO$_3^-$ and NH$_4^+$ varied small among the management models. The concentrations of H$^+$ and Al$^{3+}$ were highest under PCS. SO$_4^{2-}$ was the dominant anion and Ca$^{2+}$ the main cation in soil solutions. In addition, the observed evidence from this study also suggests that, total organic C (TOC), cation exchange capacity (CEC) and microbial biomass-C ($C_{mic}$) can be used as indicators of soil quality in planted forest ecosystem under subtropical region.

**Key words:** Chinese fir; N-fixing tree species; non-N-fixing tree species; soil quality; soil solution chemistry
803

1989

1990

3

3

2000

872

12

2003

6

3

10

4

0~10 cm

0.4

0.1

0.05

0.02

<0.002 mm

Table 1 Soil particle size distribution (%)

<table>
<thead>
<tr>
<th>Stand composition</th>
<th>2.0~1.0 mm</th>
<th>1.0~0.5 mm</th>
<th>0.5~0.25 mm</th>
<th>0.25~0.05 mm</th>
<th>0.05~0.02 mm</th>
<th>0.02~0.002 mm</th>
<th>&lt;0.002 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCS</td>
<td>0.68 b</td>
<td>0.95 a</td>
<td>0.74 b</td>
<td>2.80 b</td>
<td>5.40 a</td>
<td>42.60 a</td>
<td>46.83 a</td>
</tr>
<tr>
<td>MCA</td>
<td>0.80 a</td>
<td>0.83 a</td>
<td>0.79 b</td>
<td>3.69 a</td>
<td>5.32 a</td>
<td>42.95 a</td>
<td>45.62 a</td>
</tr>
<tr>
<td>MCK</td>
<td>0.90 a</td>
<td>0.92 a</td>
<td>1.05 a</td>
<td>3.48 a</td>
<td>5.90 a</td>
<td>41.54 a</td>
<td>46.21 a</td>
</tr>
</tbody>
</table>

Values in the same columns that do not contain the same letters are significantly different at the 5% level. *

Table 2 Soil bulk density, porosity and hydrological properties

<table>
<thead>
<tr>
<th>Stand composition</th>
<th>Bulk density (g/cm³)</th>
<th>Total porosity (%)</th>
<th>Non-capillary porosity (%)</th>
<th>Capillary porosity (%)</th>
<th>Porosity ratio</th>
<th>Capillary moisture content (%)</th>
<th>Natural moisture content (%)</th>
<th>Soil thickness (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCS</td>
<td>1.26 a</td>
<td>52.82 a</td>
<td>4.06 b</td>
<td>48.76 a</td>
<td>0.083 b</td>
<td>51.74 a</td>
<td>29.38 a</td>
<td>77 a</td>
</tr>
<tr>
<td>MCA</td>
<td>1.14 a</td>
<td>56.51 a</td>
<td>7.33 a</td>
<td>49.18 a</td>
<td>0.15 a</td>
<td>55.26 a</td>
<td>32.80 a</td>
<td>92 a</td>
</tr>
<tr>
<td>MCK</td>
<td>1.22 a</td>
<td>54.13 a</td>
<td>6.37 a</td>
<td>47.76 a</td>
<td>0.13 a</td>
<td>53.54 a</td>
<td>30.76 a</td>
<td>86 a</td>
</tr>
</tbody>
</table>

Values in the same columns that do not contain the same letters are significantly different at the 5% level.
2.2

2.2.1 pH

2.2.2

2.3

2.3.1

<table>
<thead>
<tr>
<th>Stand composition</th>
<th>TOC (g/kg)</th>
<th>Total N (g/kg)</th>
<th>C/N</th>
<th>Total P (g/kg)</th>
<th>Available P (mg/kg)</th>
<th>Total K (mg/kg)</th>
<th>Available K (mg/kg)</th>
<th>Hydrolyzable N (mg/kg)</th>
<th>CEC (cmol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCS</td>
<td>13.21 a</td>
<td>1.24 b</td>
<td>10.65 a</td>
<td>0.075 a</td>
<td>1.08 b</td>
<td>13.31 a</td>
<td>56.13 b</td>
<td>64.95 c</td>
<td>11.19 a</td>
</tr>
<tr>
<td>MCA</td>
<td>16.17 a</td>
<td>1.53 a</td>
<td>10.57 a</td>
<td>0.12 a</td>
<td>1.55 a</td>
<td>15.54 a</td>
<td>84.62 a</td>
<td>122.34 a</td>
<td>13.33 a</td>
</tr>
<tr>
<td>MCK</td>
<td>14.66 a</td>
<td>1.38 ab</td>
<td>10.62 a</td>
<td>0.086 a</td>
<td>1.23 a</td>
<td>13.87 a</td>
<td>103.07 a</td>
<td>87.89 b</td>
<td>12.47 a</td>
</tr>
</tbody>
</table>

Values in the same columns that do not contain the same letters are significantly different at the 5% level.

3

3.1

<table>
<thead>
<tr>
<th>Item</th>
<th>PCS</th>
<th>MCA</th>
<th>MCK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Litterfall mass (kg/(hm²•a))</td>
<td>1790.8</td>
<td>3591.7</td>
<td>2559.7</td>
</tr>
<tr>
<td>Leaf</td>
<td>1140.2</td>
<td>1398.5</td>
<td>1030.0</td>
</tr>
<tr>
<td>Non-leaf</td>
<td>3111.0</td>
<td>4990.2</td>
<td>3589.7</td>
</tr>
<tr>
<td>Total</td>
<td>928.90</td>
<td>1716.19</td>
<td>1175.88</td>
</tr>
<tr>
<td>Nutrient accumulation from leaf litterfall (kg/(hm²•a))</td>
<td>23.85</td>
<td>68.11</td>
<td>31.18</td>
</tr>
<tr>
<td>C</td>
<td>1.79</td>
<td>4.15</td>
<td>3.67</td>
</tr>
<tr>
<td>K</td>
<td>7.69</td>
<td>15.75</td>
<td>13.29</td>
</tr>
</tbody>
</table>

4

4.1

<table>
<thead>
<tr>
<th>Item</th>
<th>PCS</th>
<th>MCA</th>
<th>MCK</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>61.51%</td>
<td>28.17%</td>
<td>61.51%</td>
</tr>
<tr>
<td>Exchangeable acid (mmol/kg)</td>
<td>54.21 a</td>
<td>46.08 a</td>
<td>8.13 a</td>
</tr>
<tr>
<td>Exchangeable H (mmol/kg)</td>
<td>34.08 b</td>
<td>28.40 b</td>
<td>5.68 b</td>
</tr>
<tr>
<td>Exchangeable Al (mmol/kg)</td>
<td>40.79 b</td>
<td>34.37 b</td>
<td>6.42 b</td>
</tr>
</tbody>
</table>

Values in the same columns that do not contain the same letters are significantly different at the 5% level.
统内往往表现出一个较低的值，物生物活性的一个较敏感的指标。壤含有较多的易为生物降解的有机质。其它理化性质中，性关中。表中同一栏数据带不同字母的表示达到了显著水平。表

### Microbial biomass-C and basal respiration

<table>
<thead>
<tr>
<th>Stand composition</th>
<th>Microbial biomass C (mg/kg DWS⁻¹)</th>
<th>TOC</th>
<th>(Cmic + Cwet) Microbial quotient</th>
<th>basal respiration (mg CO₂C/(g DWS⁻¹ * d))</th>
<th>(gCO₂) Metabolic quotient</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCS</td>
<td>252 b</td>
<td>13.21 a</td>
<td>1.91 b</td>
<td>9.5 b</td>
<td>1.57 a</td>
</tr>
<tr>
<td>MCA</td>
<td>407 a</td>
<td>16.17 a</td>
<td>2.52 a</td>
<td>13.9 a</td>
<td>1.42 a</td>
</tr>
<tr>
<td>MCK</td>
<td>323 a</td>
<td>14.66 a</td>
<td>2.09 ab</td>
<td>11.4 ab</td>
<td>1.47 a</td>
</tr>
</tbody>
</table>

### Enzyme activities of soils

<table>
<thead>
<tr>
<th>Stand composition</th>
<th>DH (µg TPF/g DWS • 24h)</th>
<th>UK (µmol NH₃/g DWS • h)</th>
<th>PR (µmol NH₄⁺/g DWS • h)</th>
<th>CA (µmol KMnO₄/g DWS • h)</th>
<th>AP (µg P-nitrophenol/g DWS • h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCS</td>
<td>111.4 b</td>
<td>0.37 b</td>
<td>0.87 b</td>
<td>3.17 b</td>
<td>57.7 b</td>
</tr>
<tr>
<td>MCA</td>
<td>186.9 a</td>
<td>0.61 a</td>
<td>1.36 a</td>
<td>7.60 a</td>
<td>101.6 a</td>
</tr>
<tr>
<td>MCK</td>
<td>134.3 b</td>
<td>0.49 a</td>
<td>1.18 a</td>
<td>5.79 a</td>
<td>88.2 a</td>
</tr>
</tbody>
</table>

Values in the same columns that do not contain the same letters are significantly different at the 5% level. * DWS Dry weight soil.

### 6  土壤有机质物理化学性质

<table>
<thead>
<tr>
<th>Stand composition</th>
<th>TOC</th>
<th>Humified organic C</th>
<th>Humic acids C</th>
<th>Fulvic acids C</th>
<th>HAC/FAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCS</td>
<td>6.21 a</td>
<td>1.59 b</td>
<td>4.62 b</td>
<td>0.34 a</td>
<td></td>
</tr>
<tr>
<td>MCA</td>
<td>8.84 a</td>
<td>2.55 a</td>
<td>6.29 a</td>
<td>0.41 a</td>
<td></td>
</tr>
<tr>
<td>MCK</td>
<td>7.12 a</td>
<td>1.91 b</td>
<td>5.21 ab</td>
<td>0.37 a</td>
<td></td>
</tr>
</tbody>
</table>

Values in the same columns that do not contain the same letters are significantly different at the 5% level.
应增加构和特性有关

可以看出方面因整个欧洲

显著高于本研究地相应离子浓度

比值常用作森林土壤酸化的一个指示指标

这与众多研究工作者结果基本一致

这与众多研究工作者结果基本一致

经穿透雨作用沉降到系统内部的量也相

同样高于本研究地相应离子浓度

比值常用作森林土壤酸化的一个指示指标

这与众多研究工作者结果基本一致

经穿透雨作用沉降到系统内部的量也相
### Table 13  Correlation coefficient between ions

<table>
<thead>
<tr>
<th>Item</th>
<th>SO\textsuperscript{2−}</th>
<th>NO\textsubscript{3}−</th>
<th>NO\textsubscript{2}−</th>
<th>F\textsuperscript{−}</th>
<th>Cl\textsuperscript{−}</th>
<th>H\textsuperscript{+}</th>
<th>NH\textsubscript{4}\textsuperscript{+}</th>
<th>K\textsuperscript{+}</th>
<th>Na\textsuperscript{+}</th>
<th>Ca\textsuperscript{2+}</th>
<th>Mg\textsuperscript{2+}</th>
<th>Al\textsuperscript{3+}</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO\textsuperscript{2−}</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO\textsubscript{3}−</td>
<td>0.375*</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO\textsubscript{2}−</td>
<td>0.232</td>
<td>0.381*</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F\textsuperscript{−}</td>
<td>0.317</td>
<td>0.295</td>
<td>0.175</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl\textsuperscript{−}</td>
<td>0.614*</td>
<td>0.362*</td>
<td>0.204</td>
<td>0.436**</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H\textsuperscript{+}</td>
<td>0.175</td>
<td>0.414*</td>
<td>0.213</td>
<td>0.079</td>
<td>0.283</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH\textsubscript{4}\textsuperscript{+}</td>
<td>0.144</td>
<td>0.131</td>
<td>0.129</td>
<td>0.107</td>
<td>0.109</td>
<td>−0.257</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K\textsuperscript{+}</td>
<td>0.596*</td>
<td>0.447*</td>
<td>0.087</td>
<td>0.105</td>
<td>0.569**</td>
<td>0.024</td>
<td>0.071</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na\textsuperscript{+}</td>
<td>0.332*</td>
<td>0.209</td>
<td>0.046</td>
<td>0.074</td>
<td>0.577**</td>
<td>0.019</td>
<td>0.026</td>
<td>0.362*</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca\textsuperscript{2+}</td>
<td>0.647*</td>
<td>0.516**</td>
<td>0.102</td>
<td>0.082</td>
<td>0.308</td>
<td>0.033</td>
<td>0.108</td>
<td>0.587**</td>
<td>0.543**</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg\textsuperscript{2+}</td>
<td>0.571*</td>
<td>0.391*</td>
<td>0.061</td>
<td>0.050</td>
<td>0.281</td>
<td>0.153</td>
<td>0.225</td>
<td>0.491**</td>
<td>0.376*</td>
<td>0.613**</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Al\textsuperscript{3+}</td>
<td>0.114</td>
<td>0.087</td>
<td>0.035</td>
<td>0.044</td>
<td>0.143</td>
<td>0.558*</td>
<td>0.071</td>
<td>0.026</td>
<td>0.035</td>
<td>0.079</td>
<td>0.169</td>
<td>1.000</td>
</tr>
</tbody>
</table>

*P < 0.05, * * P < 0.01, n = 35

### References:


